Mississippi Valley Division,
Regional Planning and Environment Division South

Hatchie-Loosahatchie Mississippi River Ecosystem Restoration Study

Appendix 5 – Ecological Models

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

Section 1

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

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 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 ft 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 A5-1). In other words, areas with elevations ≤ 214 ft 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.

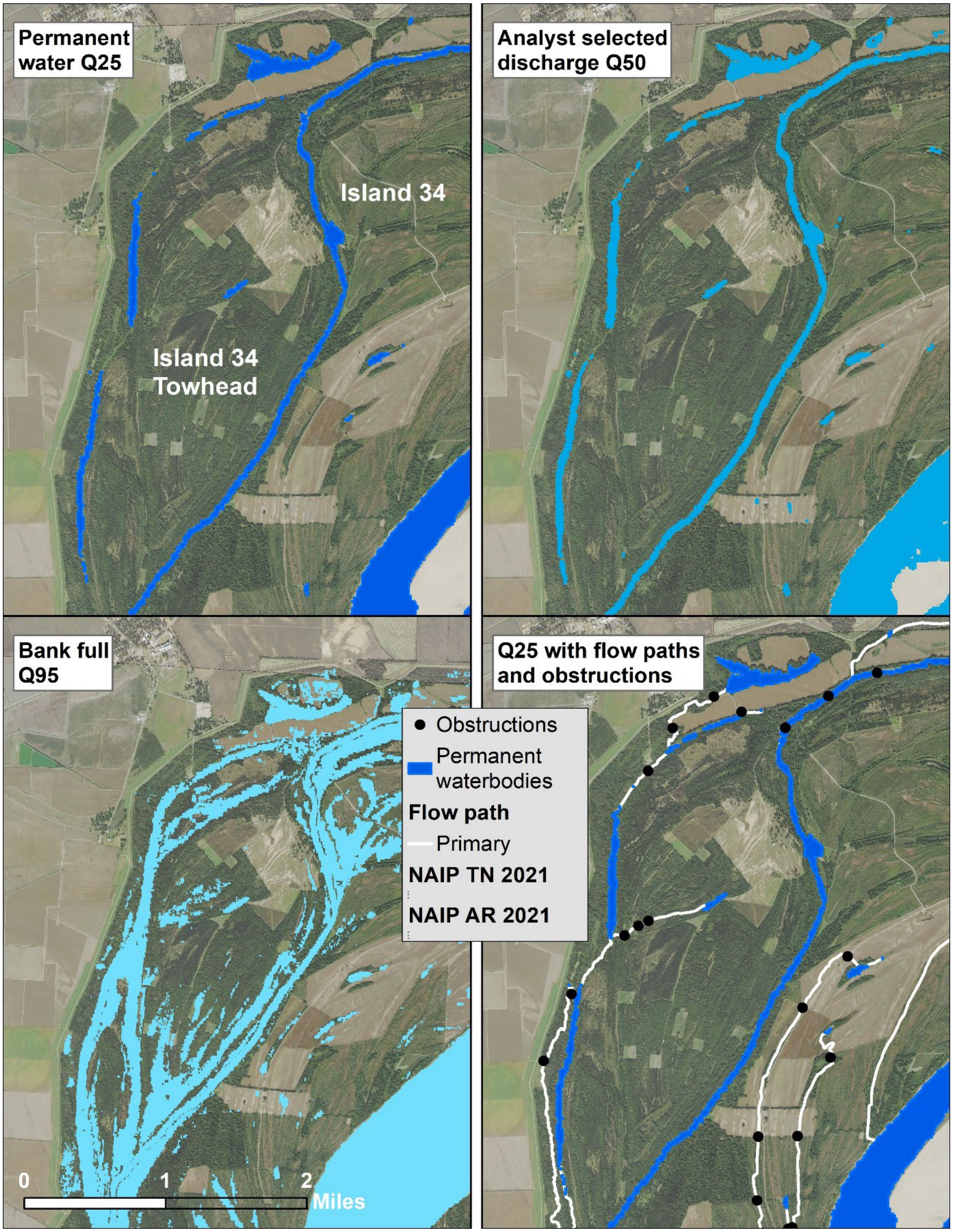

Figure A5- 1. Illustration of the various waterbody classifications using satellite imagery taken at or below a known discharge.

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.

<u>Analyst selected discharge (Q50)</u>**:** 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 A5-1). This discharge is near the average stage at Memphis of 14.1 ft. or 585 kcfs. Waterbodies classified with this method could have a bed elevations of ≤ 14.1 ft. and thus be dry up to 50% of the year. This method was discarded.

<u>Q25 (selected method):</u> 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 A5-1). 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 A5- 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**
	Flow (cfs)
5 (Q95)	1,149,000
10	987,000
15	878,000
20	797,194
25	719,000
30	653,000
35	602,000
40	554,000
55	428,000
60	396,000
65	362,000
70	334,000
75 (Q25)	301,430
80	272,000
85	244,825
90	219,000

45	511,000	95	189,000
50 (Q50)	466,000		

Waterbody file editing and attribution

Once waterbodies were identified from the Sentinnel2 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 2); in part to assist the 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.

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 ft could be inundated and thus have no ground elevation.

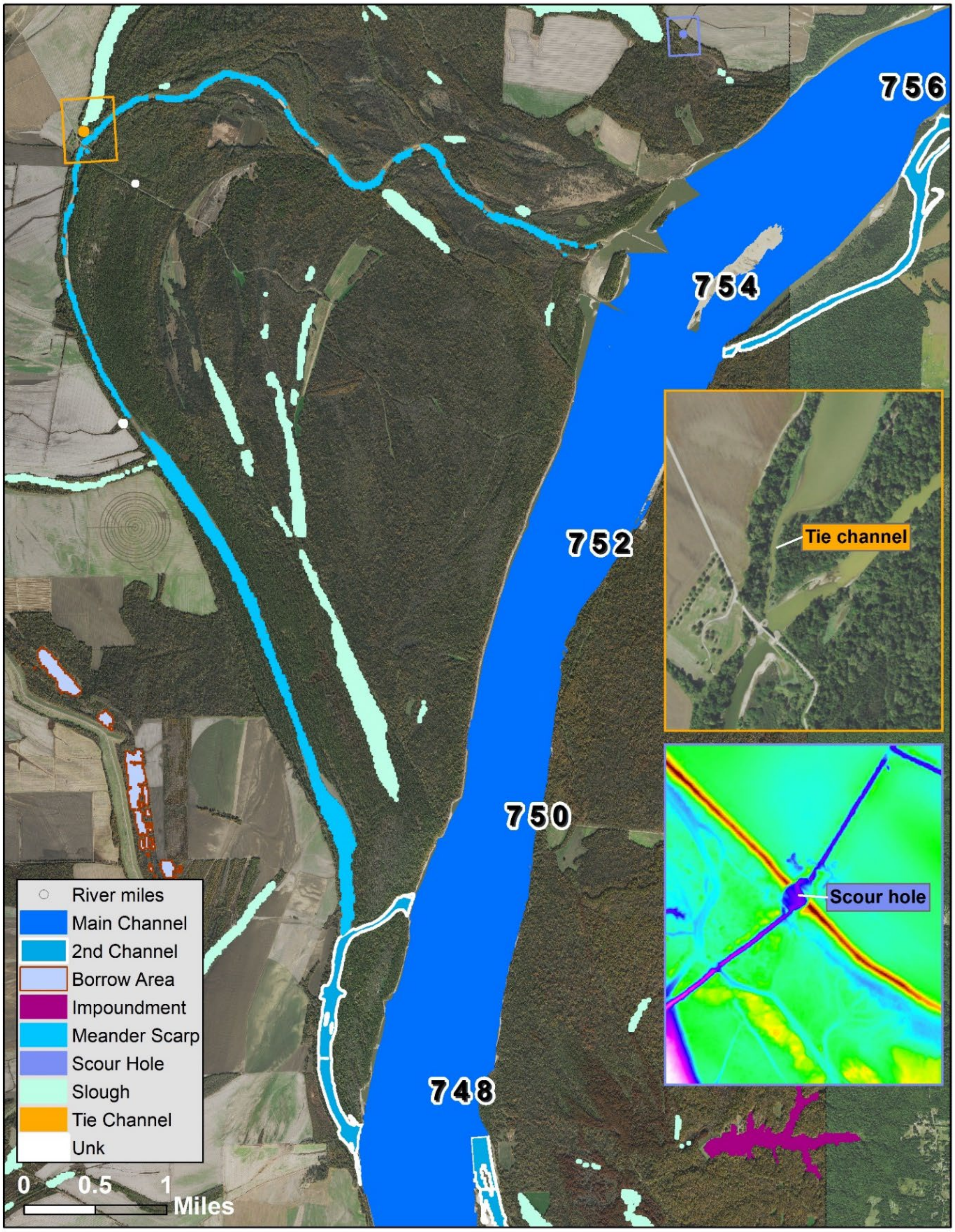

Figure A5- 2. Waterbody types found around Brandywine Chute (a meander scarp) within the Hatchie to Loosahatchie project area.

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 thru 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 A5-2.

Table A5- 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.

<u>Without Project Elevation</u>: 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 A5-3). See Appendix A1: Island 35 management measure I35_2, I35_5c, and I35_12a for examples where connection frequency was used.

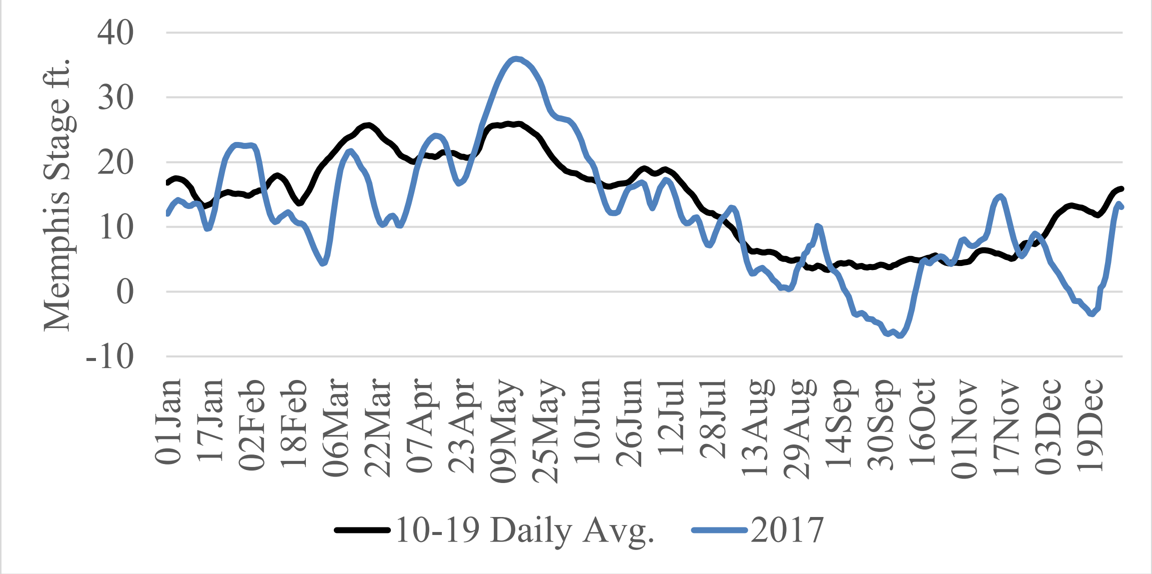

Figure A5- 3. Memphis gage daily 8:00 am stage for 2017 compared to the daily stage averaged from 2010 to 2019. The 2010-to-19-time frame was chosen to reduce effects of the changing stage discharge relationship occurring near Memphis.

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 of 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.

<u>Waterbody enhancement</u>**:** 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 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.

Aquatic channel enhancement: 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 which 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.

Water management: 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, 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 ft 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.

2.2 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 HSI 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:

$$\text{Bidirectional} \qquad \frac{(21.86+1.438x)}{150\,\text{max CPUE}}$$

$$\text{Isolation} \qquad \frac{(19.29-0.183x)}{25\ \text{max CPUE}}$$

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.

Unidirectional model: 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.

$$\text{Unidirectional} \qquad \frac{(23.288-0.78x)}{27\ \text{max richness}}$$

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:

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

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 ft when other information was not available. The environmental design for borrow areas recommends 75% of the borrow area be 5 ft or greater. Thus, engineering planned for depth increases of 5 ft making the maximum with project depth 8 ft.

%Area > 5ft: The percent of the waterbody that is greater than 5 ft 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 ft was 23 NTU. This value was used for the without project value. Since there were no borrow areas with an average 8 ft 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 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.

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

Table A5- 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.

2.3 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 channel (thalweg to bank within the complex boundary that the waterbody connects to) were evaluated as supplemental acreage (Figure A5-4).

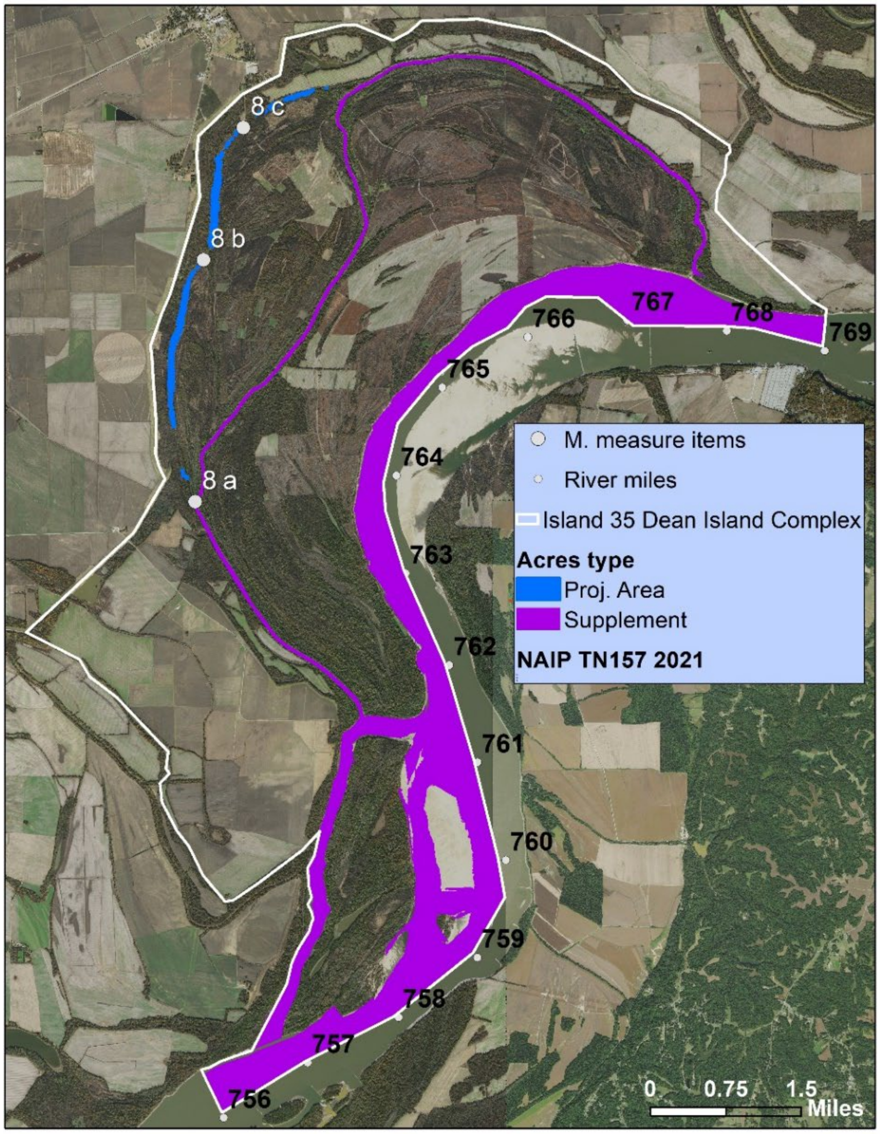

Figure A5- 4. Example of project area and supplemental acreage of waterbodies representing Island 35 Dean Island Management Measures 8_a evaluated with the Bidirectional Model.

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 A5-5). 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).

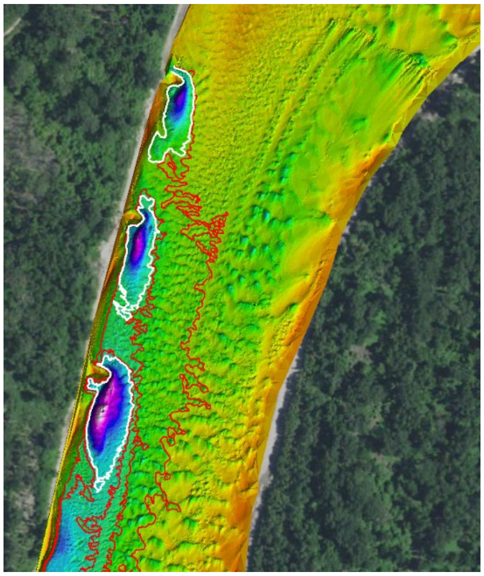

Figure A5- 5. The area of effect of hardpoints shown by the white contour line. The white contour encompassed the change in bathymetry above and below the hardpoint while the next contour (red, 1 ft greater) expanded beyond the hardpoint's effect.

<u>Floodplain plant communities</u>**:** 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 A5-6). In these cases, forest/scrub/shrub was digitized from 2021 NAIP imagery.

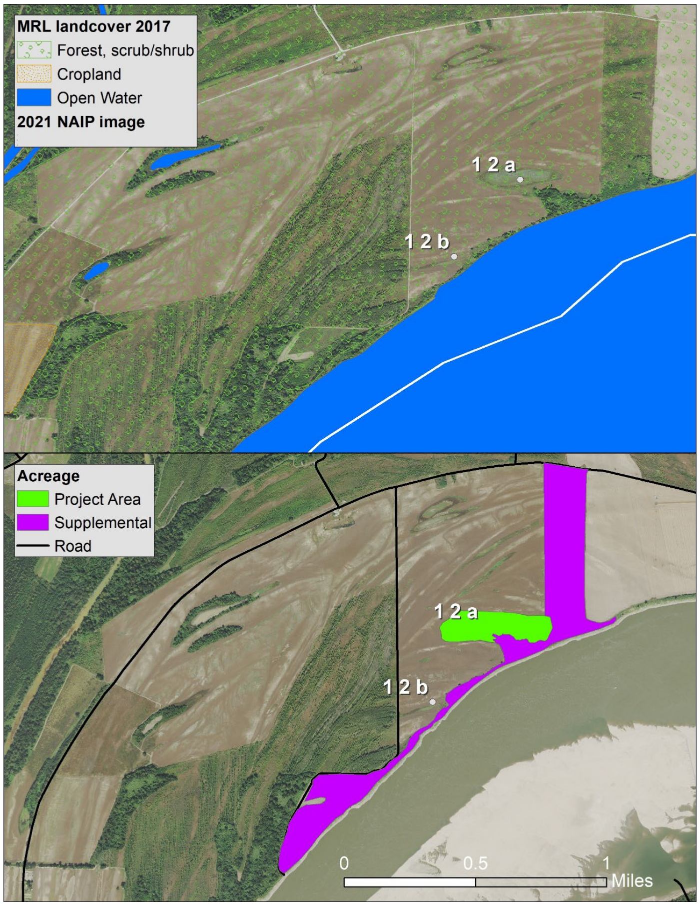

Figure A5- 6. Example of project area and supplemental forest acreage for Island 35 Dean Island Management Measures 12a and 12b evaluated with the HGM model.

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.

2.4 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.

Bidirectional, Isolation and Unidirectional target years: 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. The majority of 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) (Figure #). This study also found that when the river is at higher discharge, the water surface elevation has not changed (Figure A5-7). 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.

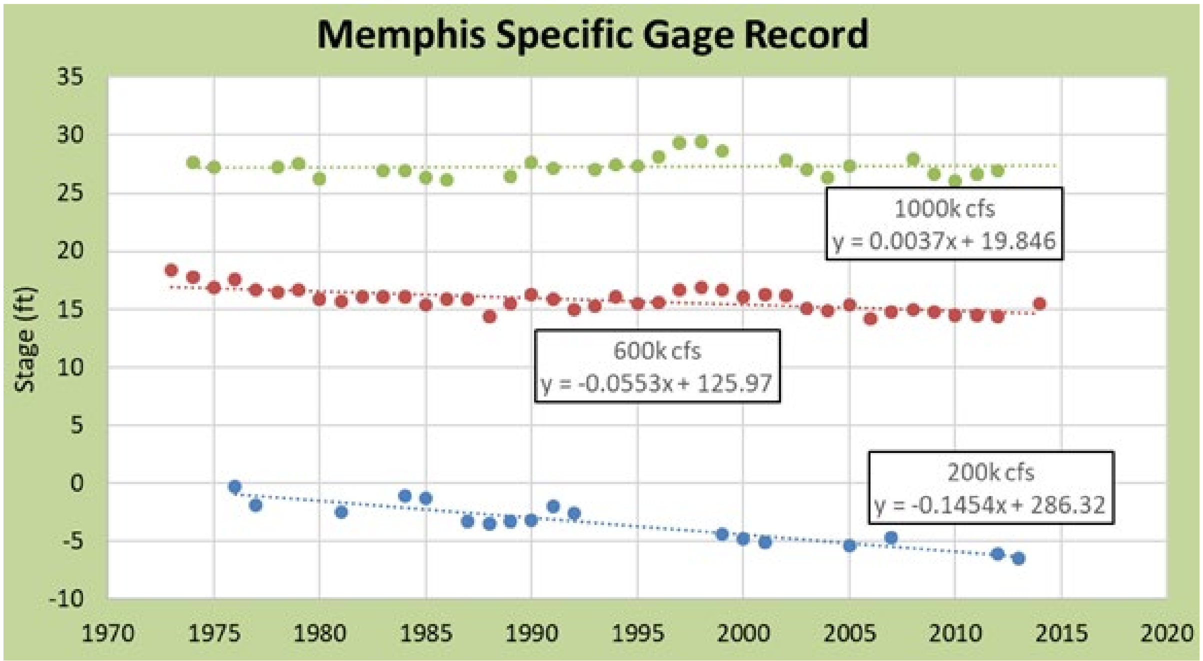

Figure A5- 7. The stage (a way of measuring the Lower Mississippi River water surface elevation) at the Memphis gage when the river is carrying a set amount of water (discharge). Stages at low and moderate discharge are decreasing while high discharge shows no change.

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 A5-4). 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 A5-4). 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 A5- 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.

<u>Eddy, Substrate, and Wood Trap model target years</u>: 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 determine 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 A5-8). 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 A5-3).

A minimum of 16 years is required to fully realize the ecological benefits of downed woody debris and snags (Figure A5-9). 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 A5-3).

A minimum of 8 years is required to fully realize the ecological benefits of leaf litter on the forest floor (Figure A5-10). The occurrence of leaf litter is expressed in two functions: detain precipitation and export organic matter (Table A5-3). 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 A5-11). Vertical plant strata are expressed in four functions: detain floodwater, cycle nutrients, export organic matter, and provide habitat for fish and wildlife (Table A5-3).

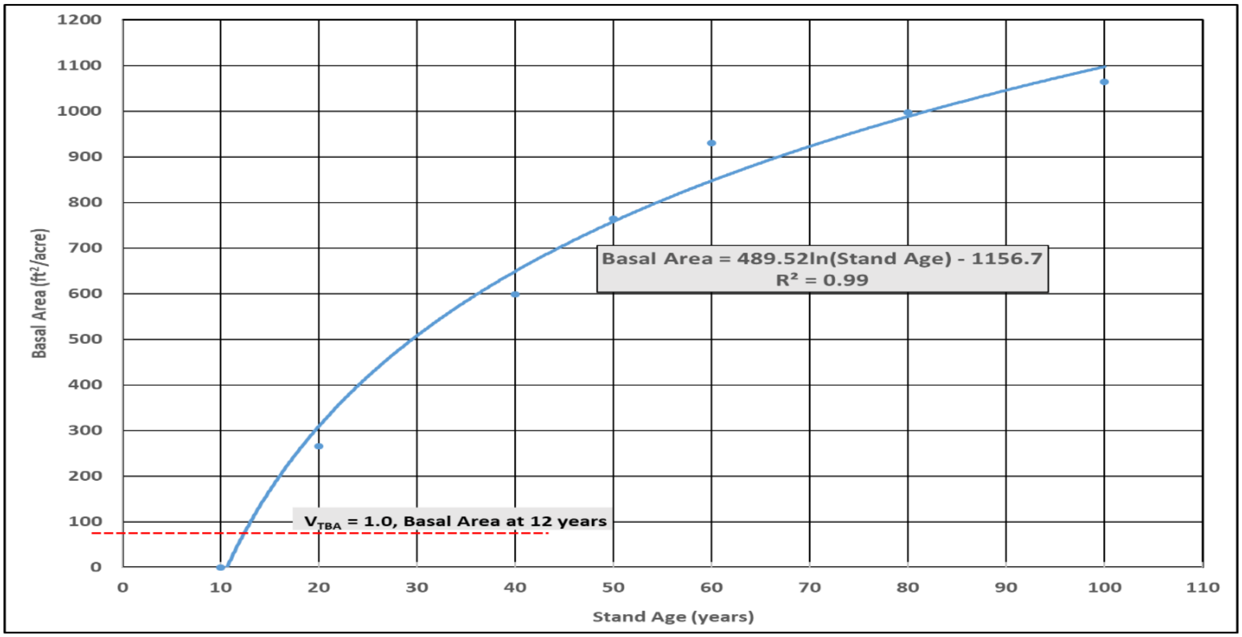

Figure A5- 8. Recovery trajectory for restored forested wetlands depicted by tree basal area per acre.

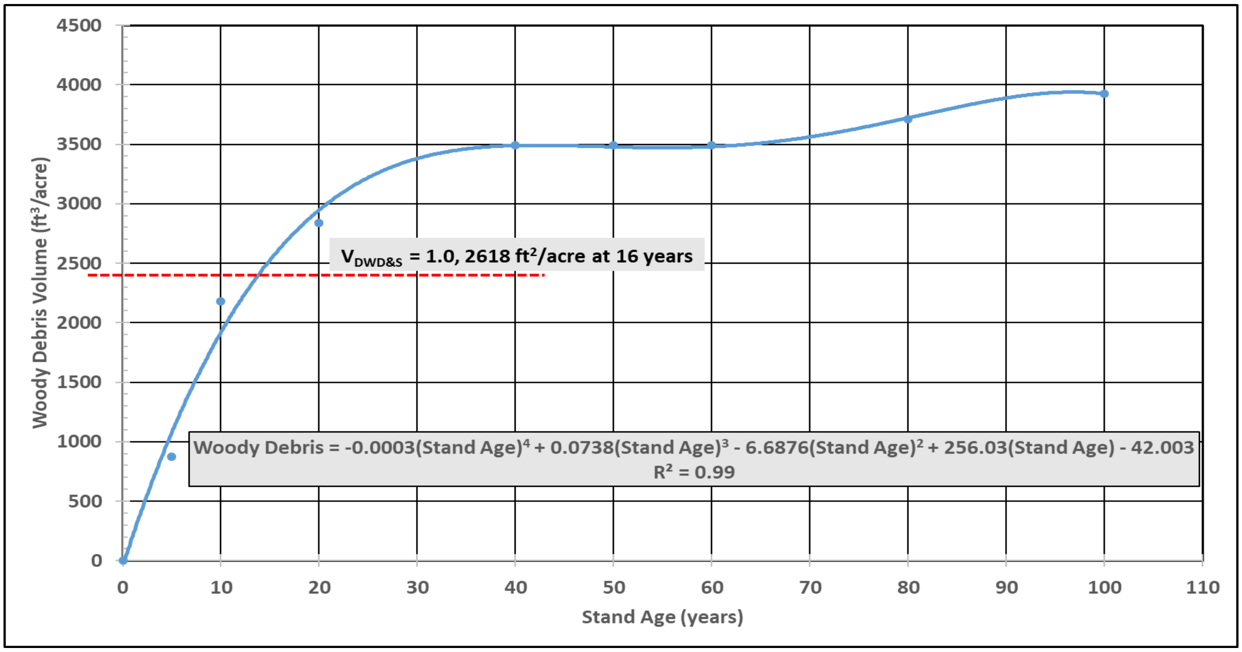

Figure A5- 9. Recovery trajectory for restored forested wetlands depicted by woody debris volume.

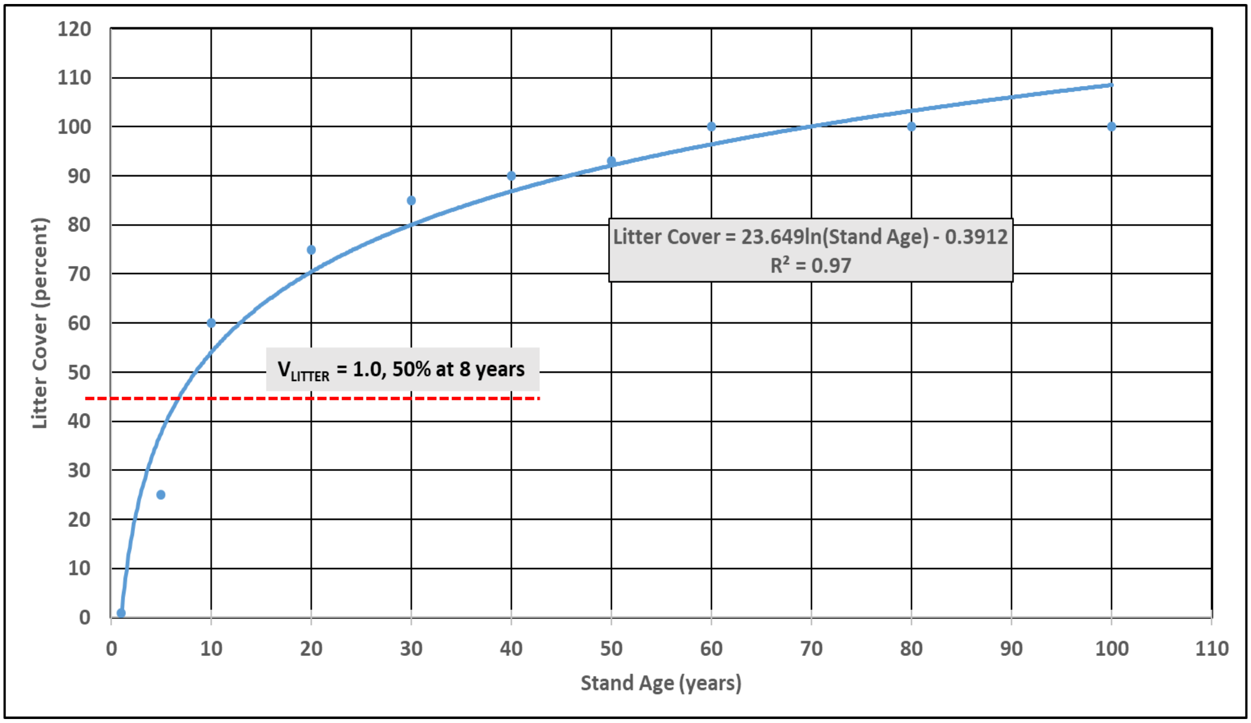

Figure A5- 10. Recovery trajectory for restored forested wetlands depicted by litter coverage.

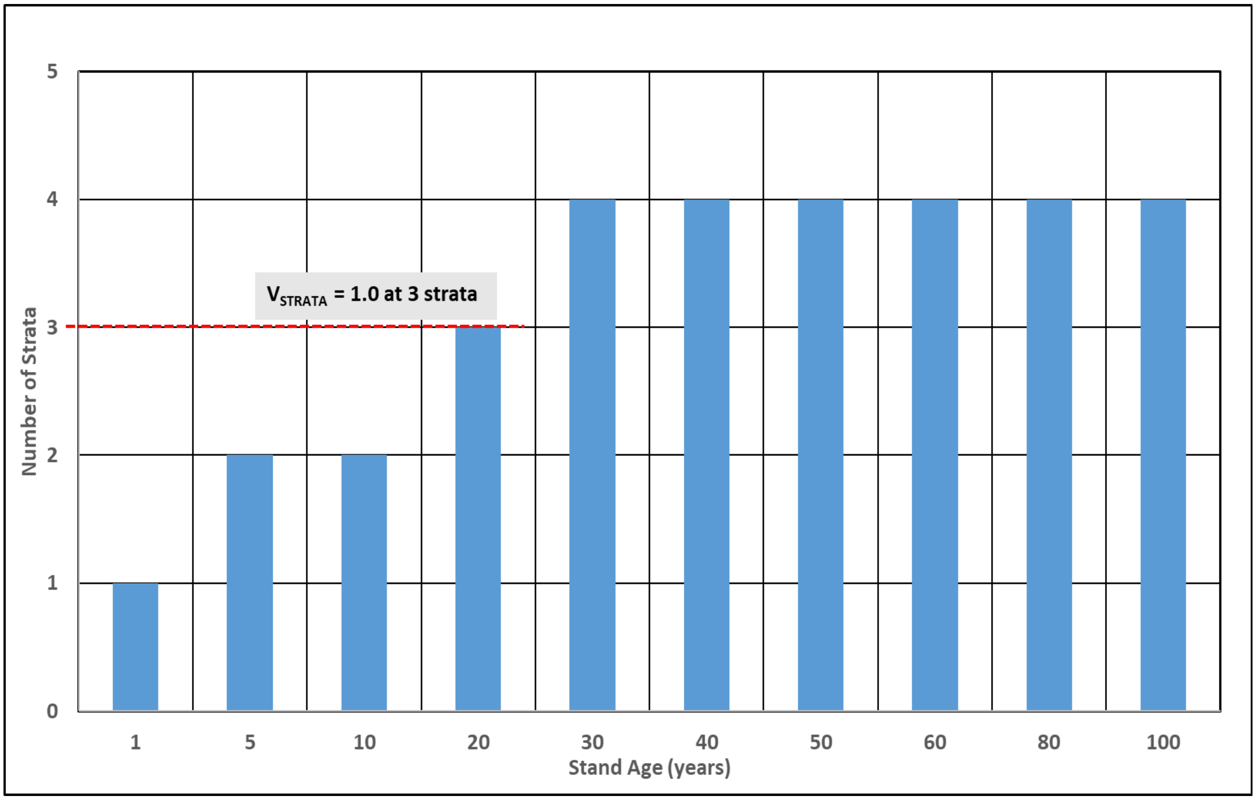

Figure A5- 11. Recovery trajectory for forest vertical strata.

2.5 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 Average annual habitat units 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 A5-5).

Table A5- 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 A5-6).

Table A5- 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 ft and project measures proposed to decrease the elevation to -2 to -7 ft. The large acreage of these measures combined with modest improvements in HSI resulted in AAHUs ranging from 23 – 275 (Table A5-7).

Table A5- 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 A5-8).

Table A5- 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 A5-9).

Table A5- 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 A5-10).

Table A5- 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	With	Net AAHU
			HSI		
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 11). The HGM evaluation provided a particularly compelling opportunity to visualize the temporal response for each complex (Figures A5-12-16). In general, the following conclusions can be made:

- Approximately ten 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 A5- 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

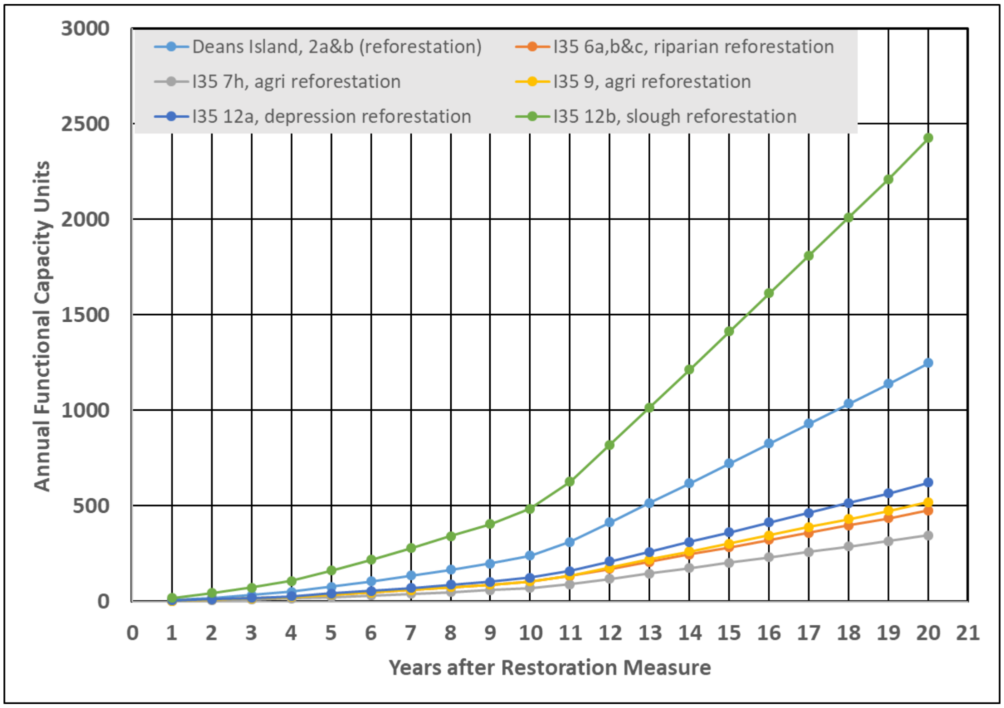

Figure A5- 12. Average functional capacity units over 20-year period following restoration actions on Deans Island and Island 35.

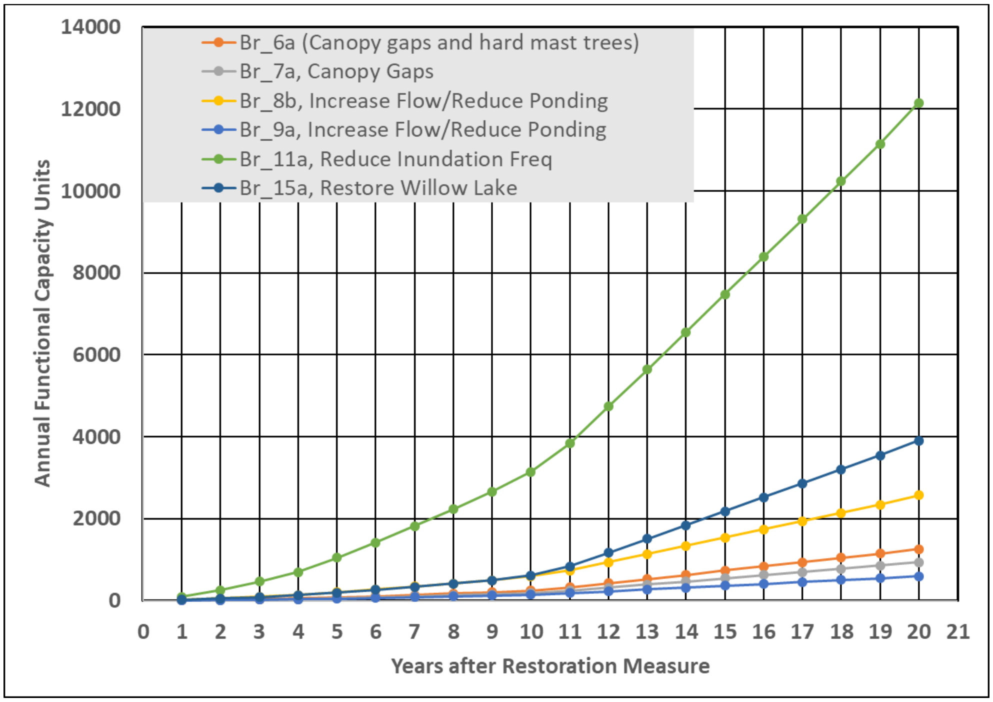

Figure A5- 13. Average functional capacity units over 20-year period following restoration actions on Brandywine Island (Br).

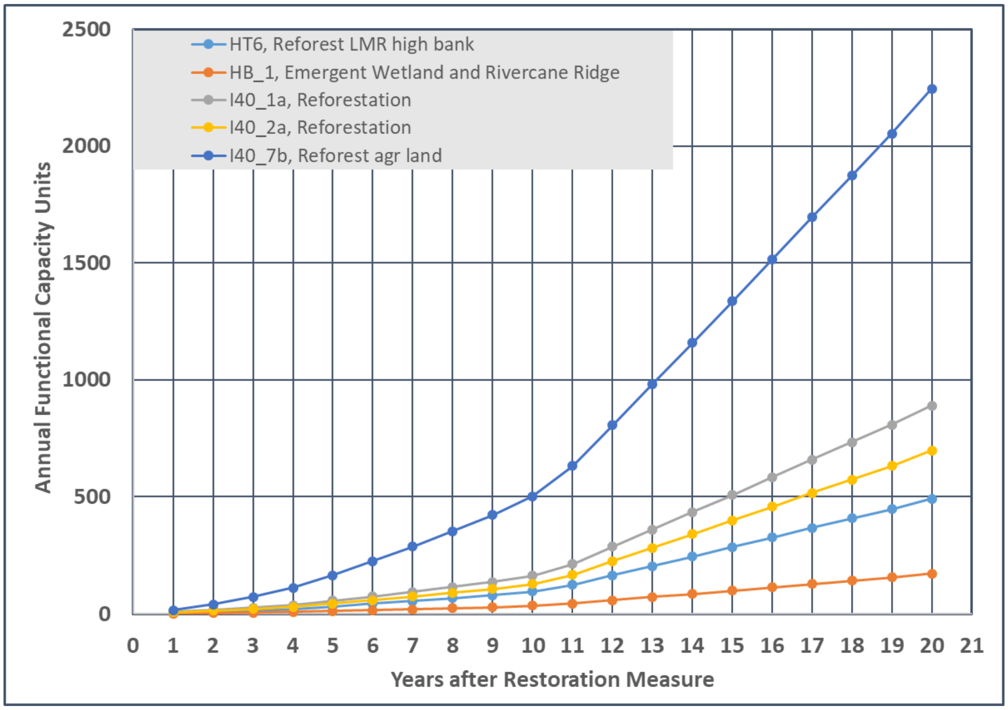

Figure A5- 14. Average functional capacity units over 20-year period following restoration actions on Hatchie-Townhead (HT), Hopefield Point (HB), and Island 40 (I40).

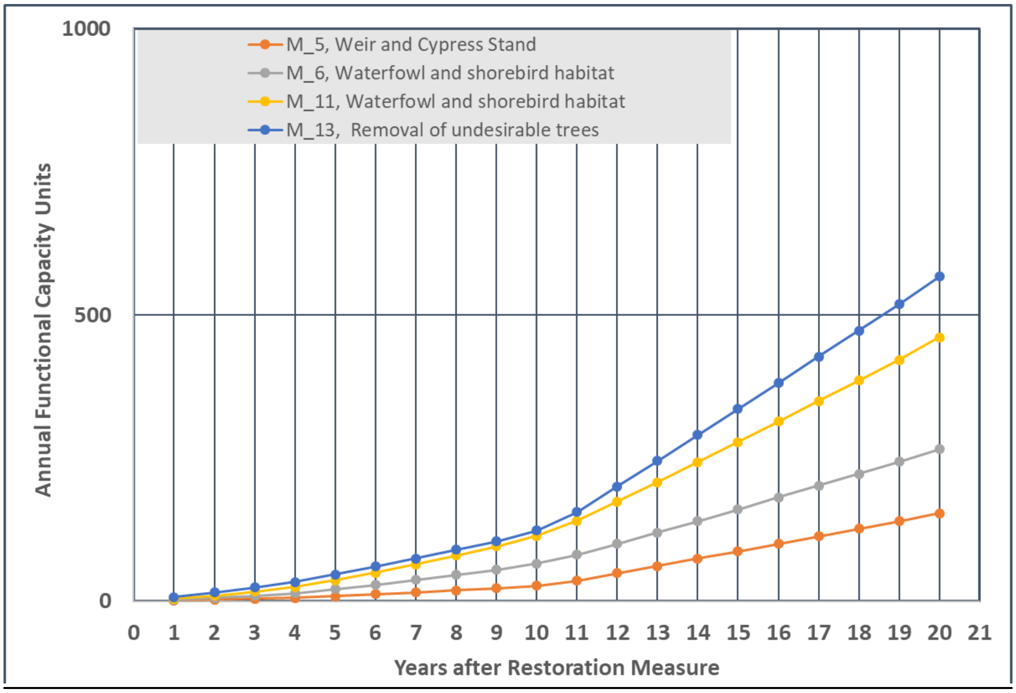

Figure A5- 15. Average functional capacity units over 20-year period following restoration actions on Meeman-Shelby (M).

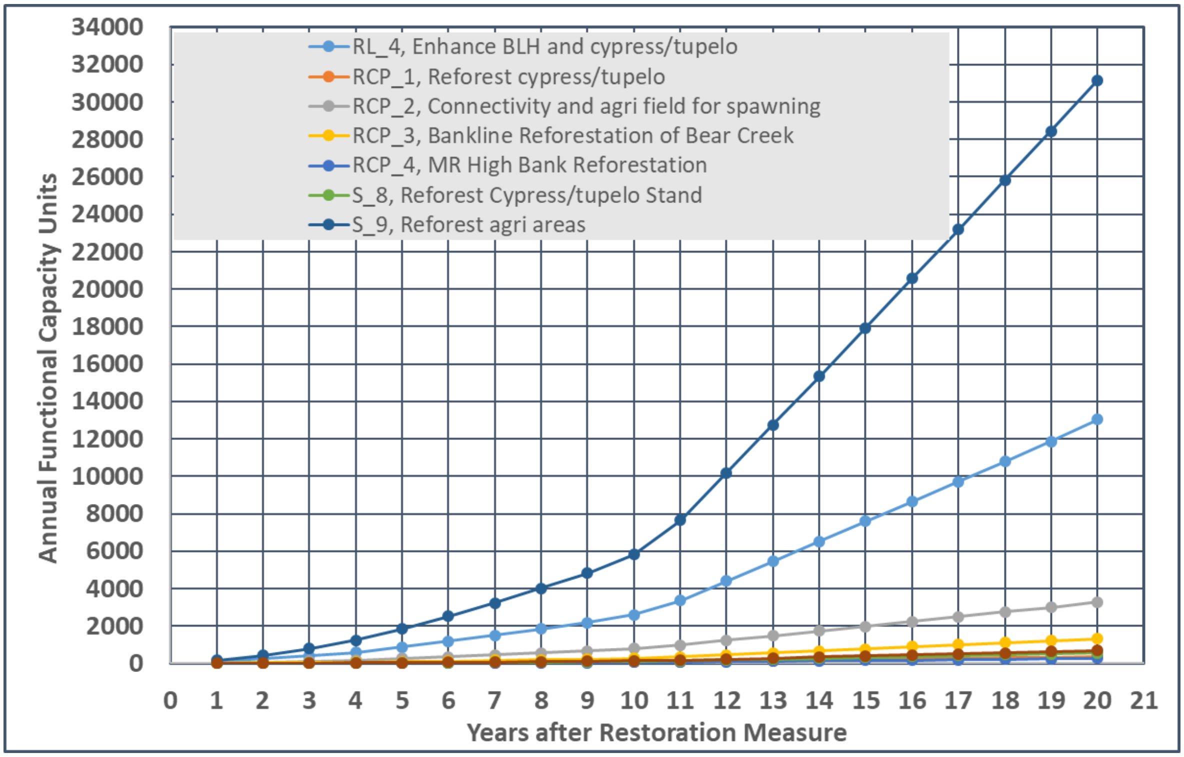

Figure A5- 16. Average functional capacity units over 20-year period following restoration actions on Redman Point (RL), Richardson Cedar Point (RCP) and Sunrise Towhead (S).

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List of Acronyms and Abbreviations

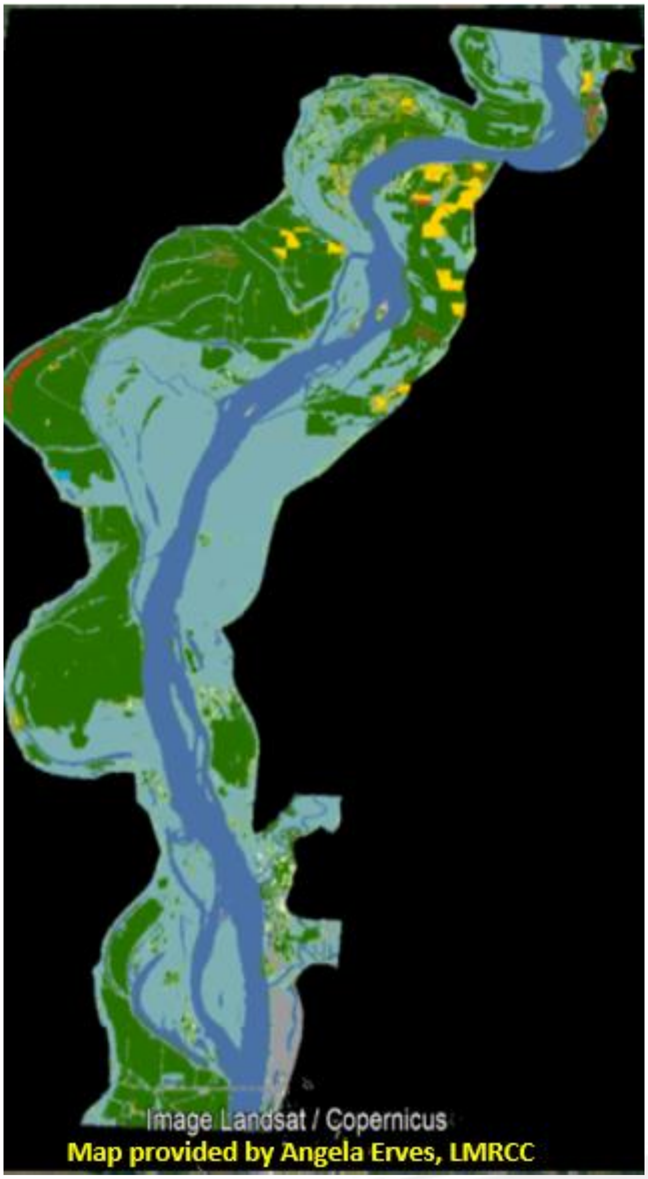
3DEP	3D elevation program
AAFCU	Average Annual Functional Capacity Unit
AAHU	Average Annual Habitat Unit
BLH	Bottomland Hardwood
CPUE	Catch Per Unit Effort
ERDC	Engineer Research and Development Center
ESA	Endangered Species Act
ECO-PCX	Ecosystem Planning Center of Expertise
FCU	Functional Capacity Unit
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

US Army Corps of Engineers®

Lower Mississippi River Resource Assessment – Library of Aquatic Habitat Models

by ERDC Fish and Invertebrate Ecology Team

MRG&P Tech Report January 2023



Map provided by Angela Erves, LMRCC

MRG&P
Mississippi River
Geomorphology &
Potamology Program

Lower Mississippi River Resource Assessment - Library of Aquatic Habitat Models

Contents

List of Figures

List of Tables

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Abstract

Lower Mississippi River Resource Assessment – Library of Habitat Models

Six ecosystem models were developed to evaluate restoration measures for the Lower Mississippi River Resource Assessment that considered connectivity between river and floodplain, substrate quality in riverine habitats, and targeted species of special interest including Paddlefish and wetland fish assemblages. A total of 84 restoration measures in the Hatchie to Loosahatchie reach were identified by the Project Delivery Team that required different modeling requirements. Field data collected by the Engineer Research and Development Center Environmental Laboratory (ERDC-EL) in the Lower Mississippi River (LMR) and floodplain were evaluated to identify ecological guilds of fish and aquatic invertebrates representative of different habitats, are important ecological indicators, and abundance and species diversity are correlated to predictable habitat variables characterizing riverine and floodplain habitat in the LMR. Regression and frequency bar chart models were developed statistically from this database to predict a biotic response as a function of restoring habitat quality. Six models were categorized based on their application to either riverine (unidirectional flow) or floodplain (bidirectional flow) environments. Outputs were normalized as a Habitat Suitability Index to a 0 to 1 scale and equations were used in spreadsheets to calculate and annualize Habitat Units.

Section 1 – Introduction

1.1 Project Background

The Lower Mississippi River Resource Assessment (LMRRA) is a congressionally authorized study for identifying information needs required for managing the Lower Mississippi River (LMR). This includes assessments of information needed for river-related management, natural resource habitat needs, and recreation and access. Within the LMR, eight conservation reaches were initially identified and funding for the assessment of Conservation Reach 2 (Hatchie-Loosahatchie Reach, River Mile 775-736) was approved in 2021. The goal of the assessment is to identify cost-effective habitat restoration projects that have value to the nation and will benefit fish and wildlife, water and air quality, local and regional economies and stakeholders (LMRRA 2015).

Aquatic impacts have occurred over the years as the LMR was developed for year-round navigation and flood risk reduction under the Mississippi River and Tributaries Project (MR&T). Construction of levees reduced the connected floodplain by over 80%. Placement of rip-rap and ACM along banks for stabilization prevented meandering so no new oxbow lakes, and fewer secondary channels and other waterbodies are being created (Guntren et al 2016). Stabilization measures and de-snagging reduced the contribution of woody debris, a major aquatic habitat, to the aquatic system. Construction of over 800 dikes has impacted the littoral and channel borders by increasing sedimentation. Despite the loss of aquatic area and bathymetric diversity, the un-impounded LMR remains resilient because the system retains a dynamic hydrograph with a predictable pattern of strong connection to a relatively substantial floodplain mosaic of natural habitat types (Ochs et al 2022). The goals of the LMRRA focus on conserving and restoring these natural habitat types. This document describes the models used to evaluate ecological benefits of restoration measures identified by the Project Delivery Team (PDT).

1.2 Restoration Objectives

Species-habitat models were developed to evaluate restoration benefits of both riverine and floodplain habitats to address two primary objectives of the LMRRA project. The first objective is to restore ecological structure and function to the mosaic of habitats along the Mississippi River by improving the quantity and/or quality of diverse riverine habitats such as gravel bars, secondary channels, meander scarps, bathymetric diversity such as eddies, and reestablishment of large woody debris. These habitats support critical life history requirements of priority species including obligate riverine fishes such as the federally endangered Pallid Sturgeon and aquatic invertebrates that support the biodiversity of the ecosystem. The second objective addressed by the models is to increase quality and quantity of the diverse mosaic of floodplain waterbodies including but not limited to oxbow lakes, sloughs, crevasses, and borrow pits and optimize and manage their aquatic connectivity with the Mississippi River to support species that require access to floodplain habitat to complete life history requirements.

1.3 Ecological Setting

1.3.1 Hydraulic Connectivity

Waterbodies within the active floodplain experience a variety of flow and connectivity regimes. 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). Hydrologic connectivity and flow between the active floodplain (i.e., batture) and river has major implications for biodiversity patterns (Ward et al. 1999) and was the basis for developing different types of models. Ward and Stanford (1995) adopted terminology for the French Rhône based on attributes of connectivity, successional trajectory, and community structure (Figure 1). The LMR may reflect this pattern of decreasing connectivity with distance from the main channel. In close proximity to the main channel, secondary channels are generally connected at the upstream and downstream end and experience unidirectional flow (eupotamal). Whereas waterbodies on the edges of the active floodplain are more isolated connecting only during extreme high-water events (paleopotamal). Other waterbodies, like oxbow lakes have a low elevation nearly year-round connection at the downstream end and a high elevation connection at the upper end (parapotomal). Remnant lakes or sloughs less frequently connect to the river on either end (pleisopotamal) through smaller connecting channels, ditches, or overland. Encompassed within the terminology, is the shifting nature of connectivity and flow. Eupotamal waterbodies, such as secondary channels, infrequently become disconnected at one end (transition from unidirectional to bidirectional flow) and very rarely disconnect entirely to become an isolated waterbody. Paleopotamal waterbodies rarely connect at one end (bidirectional flow) and only experience flow thru (unidirectional flow) during batture inundating floods.

Batture width in the LMR, traversing up to almost 15 miles at some locations, creates a heterogeneous floodplain supporting over a 100 species of fish (Baker et al. 1991). Baker et al (1991) further divides the fish assemblage in the Lower Mississippi River into a swiftwater guild occupying mostly flow-thru habitats, and a slackwater guild requiring floodplain habitats to complete one or more of their life cycles (e.g. spawning, rearing, growth). The unregulated flow of the LMR maintains a natural flood-pulse hydrograph periodically connecting oxbow lakes, sloughs, forested lands, and other aquatic habitats in the batture to the channel (Junk et al. 1989). Resident fish living in batture waterbodies and seasonal migrants from the channel receive food and nutrients from the river water contributing to increased somatic growth and survival. The ebb and flow of floodwater in the batture benefits many other groups of animals contributing to its high biodiversity.

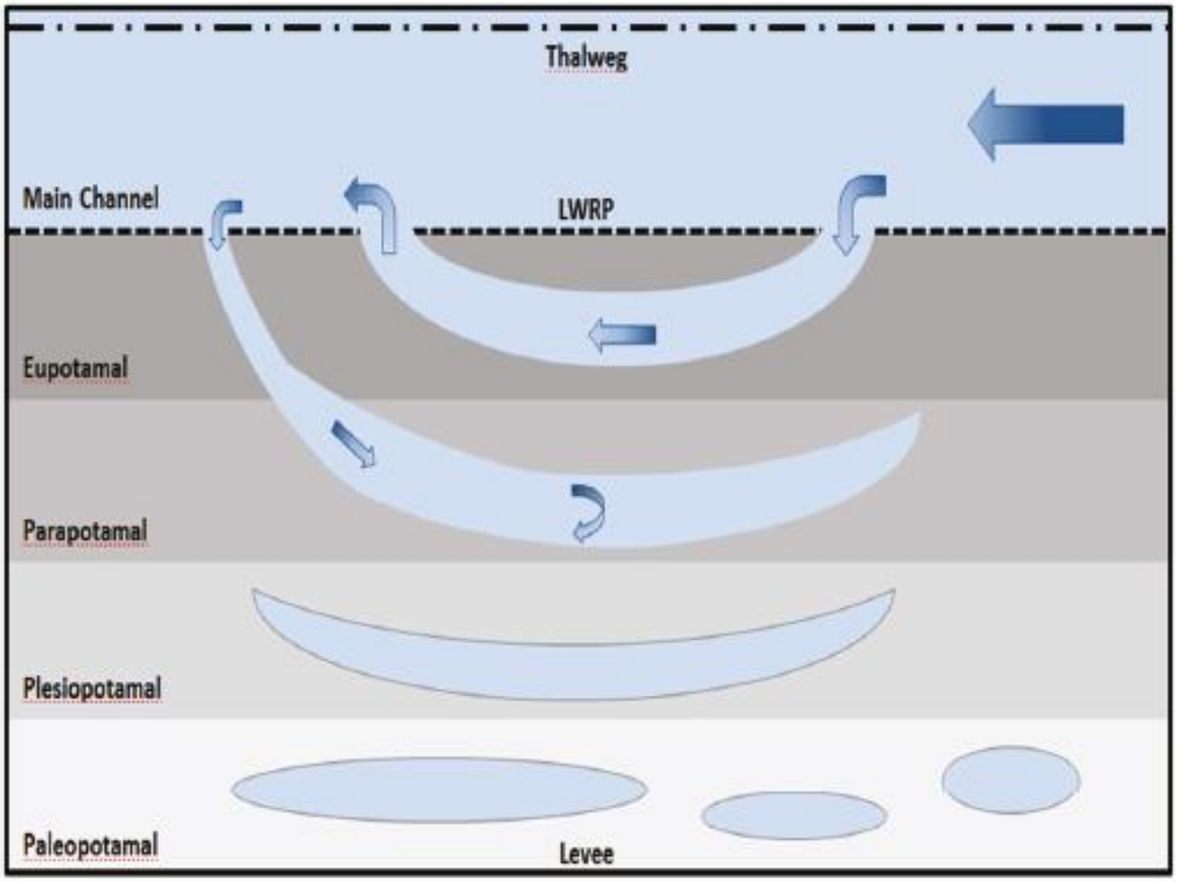


Figure 1. Typology of connectivity between river and floodplain based on Ward et al. 1999, and adapted from Biedenharn et al. (2018).

1.3.2 Ecological Guilds

The high number of fish species present in the Lower Mississippi River (>100 species) represent different functional guilds (Table 1). Ecological guilds adapted from the guilds developed for the Navigation Predictive Analysis Technique NAVPAT (Maynord et al. 2005) and Baker et al. (1991) were considered during model development. Guilds were arranged by preferred spawning substrates (vertical axis), velocity preference of juveniles and adults (horizontal axis), and tolerance ranking (generalists/invasive). Reproductive strategy of fishes was included for species that release floating eggs (i.e., pelagic spawners) and those that deposit demersal and often adhesive eggs over sand, gravel, and vegetation. These modes of reproduction can be influenced by navigation traffic through scour and shoreline dewatering. Another category included species that hide their eggs in crevices. Habitat preference was delineated according to swiftwater, slackwater, and wetland/backwater inhabitants. Those species that tolerate a wide range of habitat conditions with no well-defined preference were placed into the "Generalist" guild. This arrangement resulted in 14 functional guild cells that represented the broad range of reproductive requirements and habitat preferences of the fish assemblage in large navigable rivers. A guild approach is used in several models.

Table 1. Species guilds for fishes of the lower Mississippi River and Ohio River Basins. Guilds were arranged by preferred spawning substrates (vertical axis), velocity preference of juveniles and adults (horizontal axis), and tolerance ranking (generalists/invasive). Boldfaced species are endangered, threatened, or vulnerable according to Warren et al. (2000). Species are arranged in phylogenic and alphabetic order within a guild cell. Adapted from Maynord et al. 2005 and Baker et al. 1991. [1] –Catadromous.

	GENERALIST/INVASIVE	**SLACKWATER**	**SWIFTWATER**	**WETLAND/BACKWATER**
PELAGIC	Gizzard shad, *Dorosoma cepedianum* Grass carp, *Ctenopharyngodon idella* Silver carp, *Hypophthalmichthys molitrix* Bighead carp, *Hypophthalmichthys nobilis* Western mosquitofish, *Gambusia affinis*	Threadfin shad , *D. petenense* Miss. silvery minnow, *Hybognathus nuchalis* Plains minnow, *H. placitus*	Goldeye, *Hiodon alosoides* Mooneye, *Hiodon. tergisus* American eel, *Anguilla rostrata*[1] **Alabama shad, *Alosa alabamae*** Skipjack herring, *A. chrysochloris* Emerald shiner, *N. atherinoides* River shiner, *N. blennius* Mimic shiner, *N. volucellus* Silverband shiner, *N. shumardi* Channel shiner, *N. wickliffi* Freshwater drum, *Aplodinotus grunniens*	
VEGETATION	Common carp, *Cyprinus carpio* Golden shiner, *Notemigonus crysoleucas*	Shortnose gar, *L. platostomus* **Alligator gar, *L. spatula*** Inland silverside, *Menidia beryllina* Bigmouth buffalo, *I. cyprinellus*	Longnose gar, *L. osseus* Smallmouth buffalo, *Ictiobus bubalus* Black buffalo, *I. niger*	Spotted gar, *Lepisosteus oculatus* Bowfin, *Amia calva* Brook silverside, *Labidesthes sicculus* Grass pickeral, *Esox americanus* Chain pickerel, *E. niger* Taillight shiner, *Notropis maculatus* Weed shiner, *N. texanus* Golden topminnow, *Fundulus chrysotus* Blackspotted topminnow, *F. olivaceus* Starhead topminnow, *F. dispar* Blackstripe topminnow, *F. notatus*
CREVICE	Channel catfish, *Ictalurus punctatus* Red shiner, *Cyprinella lutrensis* Bullhead minnow, *Pimephales vigilax*		Stonecat, *Noturus flavus* Freckled madtom, *N. nocturnus* Blue catfish, *Ictalurus furcatus* Flathead catfish, *Pylodictis olivaris* Whitetail shiner, *Cyprinella galactura* Blacktail shiner, *C. venusta* Steelcolor shiner, *C. whipplei*	Pugnose minnow, *Opsopoeodus emiliae* Pirate perch, *Aphredoderus sayanus*

	GENERALIST/INVASIVE	SLACKWATER	SWIFTWATER	WETLAND/BACKWATER
SAND & GRAVEL	Green sunfish, *Lepomis cyanellus* Orangespotted sunfish, *L. humilus* Bluegill, *L. macrochirus*	Spotted sucker, *Minytrema melanops* Ribbon shiner, *Lythrurus fumeus* Redfin shiner, *L. umbratilis* Weed shiner, *N. texanus* Bullhead minnow, *Pimephales notatus* Redear, *L. microlophus* Largemouth bass, *Micropterus salmoides* White crappie, *Pomoxis annularis* Black crappie, *Pomoxis nigromaculatus*	Chestnut lamprey, *Ichthyomyzon castaneus* **Paddlefish, *Polyodon spathula*** **Pallid sturgeon, *Scaphirhynchus albus*** Shovelnose sturgeon, *S. platorynchus* River carpsucker, *Carpiodes carpio* Quillback, *Carpiodes cyprinus* Highfin carpsucker, *C. velifer* **Blue sucker, *Cycleptus elongatus*** Northern hog sucker, *Hypentelium nigricans* Golden redhorse, *Moxostoma erythrurum* Shorthead redhorse, *Moxostoma macrolepidotum* Rainbow smelt, *Osmerus mordax* Central stoneroller, *Campostoma anomalum* Gravel chub, *Erimystax x-punctatus* Speckled chub, *Macrhybopsis aestivalis* **Sturgeon chub, *M. gelida*** **Sicklefin chub, *M. meeki*** Silver chub, *Macrhybopsis storeriana* Pallid shiner, *Notropis amnis* Ghost shiner, *N. buchanani* Spottail shiner, *N. hudsonius* Sabine shiner, *N. sabinae* **Flathead chub, *Platygobio gracilis*** White bass, *Morone chrysops* Yellow bass, *M. mississippiensis* Longear, *L. megalotis* Spotted bass, *Micropterus punctulatus* Smallmouth bass, *Micropterus dolomieu* **Western sand darter, *Ammocrypta clara*** Scaly sand darter, *A. vivax* Mud darter, *Etheostoma asprigene* Harlequin darter, *E. histrio* Speckled darter, *E. stigmaeum* Logperch, *Percina caprodes* Blackside darter, *P. maculata* Dusky darter, *P. sciera* River darter, *P. shumardi* Saddleback darter, *P. vigil* Sauger, *Stizostedion canadense*	Flier, *Centrarchus macropterus* Banded pygmy sunfish, *Elassoma zonatum* Warmouth, *Lepomis gulosus* Redspotted sunfish, *L. miniatus* Bantam sunfish, *L. symmetricus* Bluntnose darter, *Etheostoma chlorosomum* Slough darter, *E. gracile* Cypress darter, *E. proeliare*

Section 2 – Model Development Process

2.1 Approach

USACE civil works policy ER 1105-2-100 requires that ecosystem restoration projects quantify benefits for use in incremental cost analyses, and EC 1105-2-407 requires certification of planning models by the appropriate Planning Center of Expertise (PCX). For the LMRRA project, the Habitat Evaluation Procedure was used to calculate Habitat Units by multiplying a Habitat Suitability Index (model output) by acres of habitat area influenced (USFWS 1980). Habitat Units were then used in the incremental cost analysis to forecast environmental benefits (i.e., eco-lift), screen alternatives, and select cost-effective restoration measures.

2.2 Restoration Measures

The Hatchie to Loosahatchie reach extends from approximately river miles 735 - 774 and includes Mississippi, and Crittenden Co., AR, and Tipton and Shelby Co., TN. Over a 2-3 month period, the Project Delivery Team (PDT) identified 84 restoration measures in the 39-mile reach of the LMR that addressed the goals and objectives of the LMRRA project. Categories of measures that could not be evaluated with existing certified models included:

- Meander scarp (chutes) plug removal.
- Restore channels connecting floodplain waterbodies to Mississippi River main channel.
- Optimize/maintain isolation of rarely connected floodplain waterbodies.
- Bridge modification to increase connectivity in meander scarps.
- Installation of Wood Traps.
- Construction of hardpoints to create eddies.
- Notching dikes in secondary channels and meander scarps.
- Install river training structures to expose/prevent fine deposition on gravel bars.

2.3 Model Categories

The diversity of restoration measures required multiple habitat models that target different groups or guilds of aquatic species in the river-floodplain environment and generally follows the habitat classification by Baker et al. (1991). Statistical models were developed from long-term databases at ERDC to predict eco-lift resulting from the various measures. A one-model-fits-all approach was not feasible since the measures influenced both channel and floodplain habitats with different types of connectivity influencing different guilds of aquatic organisms. Thus, models were developed for the guild or other functional groups that are most representative of the particular habitat and are important ecological indicators. Models were developed from several decades of field data that quantifies both species abundance and habitat utilization parameters from various LMR studies. The advantage of using this data is it can be analyzed by any third party for transparency and it predicts a biological endpoint that can monitored in the future.

Models were categorized based on their application to either riverine (unidirectional flow) or floodplain (bidirectional flow) environments (Figure 2). The type of connection and flow influences biogeochemical and ecological patterns (Leibowitz et al. 2018). With bidirectional flow, both the floodplain waterbody and river interact through mutual transport of waterborne materials, whereas unidirectional flow does not. Models were further categorized according to the habitat or target species of interest. Models for unidirectional habitats considered the elevation when mainstem river water flowed through secondary channels and meander scarps, substrate type emphasizing wood and gravel for aquatic invertebrate diversity, and bathymetric and flow diversity created by eddies benefitting obligate riverine species. Models for bidirectional habitats considered connection frequency of floodplain habitats with the mainstem river and targets two different guilds of fishes. High connection frequency benefits a large, diverse guild of slackwater fishes that reside mostly in larger floodplain waterbodies (Baker et al. 1991), while low connectivity promotes wetland fish assemblages that have declined in the Lower Mississippi River Valley (Hoover and Killgore 1998).

2.4 Model Outputs

All model equations represent a Habitat Suitability Index (HSI) value scaled to 0 to 1 that can predict eco-lift for the type of restoration measures identified through the interagency process. The dependent response variables in all models were the relative abundance of a species or guild, or taxonomic richness of an aquatic assemblage, and the format of the models was either regression equations or frequency bar charts of discrete categorical variables from field data collected by ERDC. Outputs were standardized to a 0 to 1 HSI rating. The explanatory or independent habitat variables directly influenced by the restoration measure were calculated as presented in the accompanying excel model calculator workbook. This document describes the database used to develop the ecological models including the type of statistical method used, results for each model, and assumptions. The accompanying excel workbook (LMRRA AAHU Calculator) contains the instructions, data entry and calculation functions to calculate Habitat Units (HU) and Average Annualized Habitat Units (AAHU) once acres and target years are known. Annualization and application to the planning process can proceed by the user. The LMRRA Hatchie-Loosahatchie Reach Feasibility Study Appendix 1 Habitat Benefits Analysis provides an example of model application. Models were developed to be applicable to the LMR and active floodplain (batture) from the mouth of the Ohio River to Baton Rouge, LA (EC 1105-2-412, PB 2013-02).

2.5 List of Models

The six models and the habitats they represent are listed below and in Table 2. Detailed description of each model are provided in the subsequent sections.

1. LMR Unidirectional Channel Connectivity Model (Unidirectional) – eupotamal (flow-thru, connected on both ends) typical for secondary channels and meander scarps (chutes).
2. LMR Waterbody Bidirectional Connectivity Model (Bidirectional) - plesiopotamal, parapotamal (connected on one end), and eupotamal waterbody backwater connections. For example, oxbow lakes with tie channels.
3. LMR Floodplain Waterbody Wetland Isolation Model (Isolation) – decrease connection to plesiopotamal/paleopotamal floodplain waterbodies for backwater assemblages.
4. LMR Aquatic Invertebrate Substrate Model (Substrate) – scouring sand over gravel bars, diversifying riverine substrates.
5. LMR Wood Traps Model– adding wood to secondary channels for invertebrate colonization and structural diversity.
6. LMR River Training Structure Eddy Model (Eddy) – constructing hard points or other structures creating eddies.

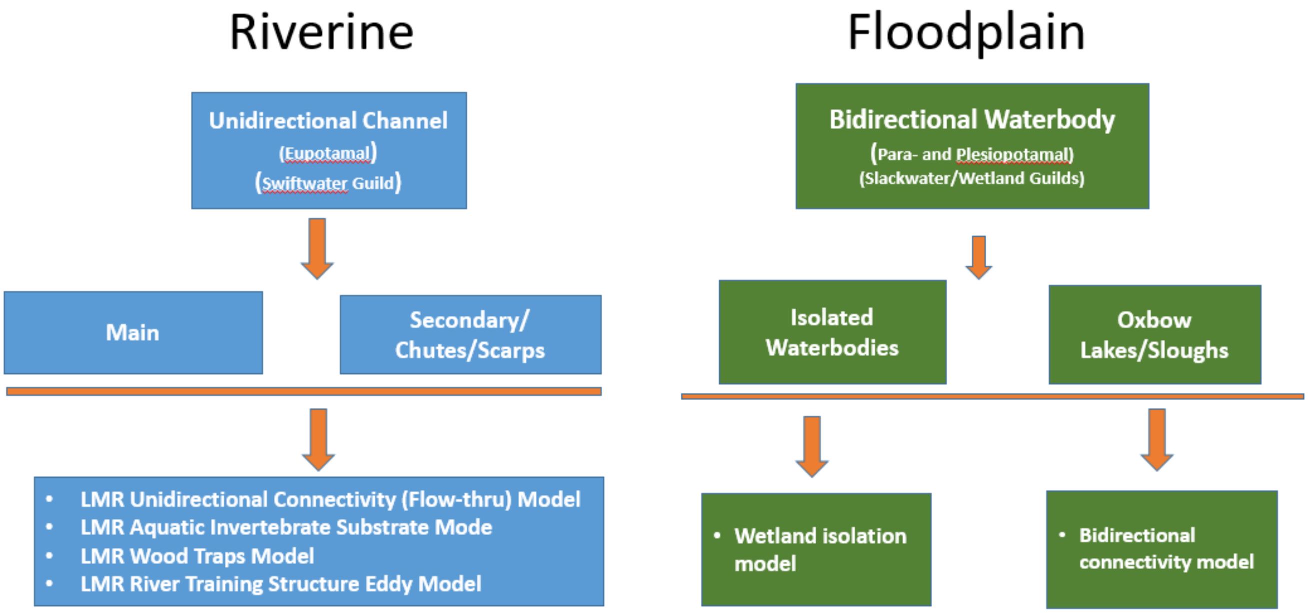


Figure 2. Conceptual diagram of model applicability in riverine and floodplain habitats in the Lower Mississippi River. Six models were developed to quantify ecological benefits of LMRRA restoration measures.

Table 2. List of aquatic habitat models developed for the LMRRA project to quantify habitat benefits of different restoration measures.

Model Name	Model Type	Independent Variable (s)	Dependent Variable	Project Type
LMR Unidirectional Channel Connectivity Model (Unidirectional)	Empirical – regression	Flow thru stage (ft Low Water Reference Plane) when main channel water begins flowing through secondary channel	Benthic aquatic invertebrates - number of taxa (richness)	Riverine - Decrease elevation to increase amount of time main channel water flows through eupotamal secondary channels and meander scarps.
LMR Waterbody Bidirectional Connectivity Model (Bidirectional)	Empirical – regression	2000-2015 cumulative connection frequency. Cumulative percent of days river exceeds blockage over 15-year period.	Slackwater fish guild - Inland Silverside as a representative species	Floodplain - Increase frequency of floodplain waterbody connection to the river. Model applies to all bidirectional connection types and includes oxbow lakes, sloughs, secondary channels and meander scarps.
LMR Floodplain Waterbody Wetland Isolation Model (Isolation)	Empirical - regression	2000-2015 cumulative connection frequency. Cumulative percent of days river exceeds blockage over 15-year period.	Wetland Fish Guild	Floodplain - Decrease frequency of floodplain waterbody connections to the river to promote longer periods of isolation. Model applies to all bidirectional connection types including borrow areas and backwater sloughs.
LMR Aquatic Invertebrate Substrate Model (Substrate)	Empirical - Categorical	Substrate type	Aquatic invertebrate taxonomic richness	Riverine - Scouring sand off or restoring gravel bars.
LMR Wood Traps Model	Empirical - Categorical	Addition of wood	Aquatic invertebrate taxonomic richness	Riverine - Installing wood traps in secondary channels.
LMR River Training Structure Eddy Model (Eddy)	Empirical - Categorical	Formation of eddies with river training structures	Species richness, Paddlefish, Blue Catfish, Freshwater Drum. Represents large-bodied benthic riverine fish guild of the LMR	Riverine - Construction of hardpoints or other river training structures that form eddies, which are defined as a hydrodynamic condition where river flow converges or diverges due to the influence of river training structures creating eddies, scour holes, and bank scallops.

Section 3 – Database Description

Three different databases were used to develop models, all funded by Mississippi Valley Division's Mississippi River Geomorphology and Potamology Program (MRG&P) and Lower Mississippi River Environmental Studies (LMRES): 1) multi-decadal trawling data for Pallid Sturgeon and other obligate riverine benthic fish species, 2) Island 63 ecohydrology fish data collected from 2014 – 2016 using multiple gear types including seines, and 3) aquatic invertebrate data collected with a benthic sled and colonization baskets beginning in 2014. Each gear type and collecting methods are described below.

3.1 Benthic Fish Studies - Trawling

A Missouri-type otter trawl similar to that described by Herzog and Barko (2005) was used to sample benthic fish in main and secondary channels of the LMR. The foot rope of the trawl was 3.3 m wide and fitted with a tickler chain to maintain bottom contact. The trawl was fitted with 0.3 x 0.6 m otter boards to keep it open while towed along the bottom. When in operation, the gape size was assumed to be 3 m wide and 1m tall. The trawl had two mesh sizes. The exterior mesh was 3.8 cm stretch to retain small fishes, and the interior mesh was 5.1cm stretch. The length of the trawl warps (i.e., tow line) were about three times the water depth to ensure that the trawl mouth maintained contact with the bottom at a proper opening.

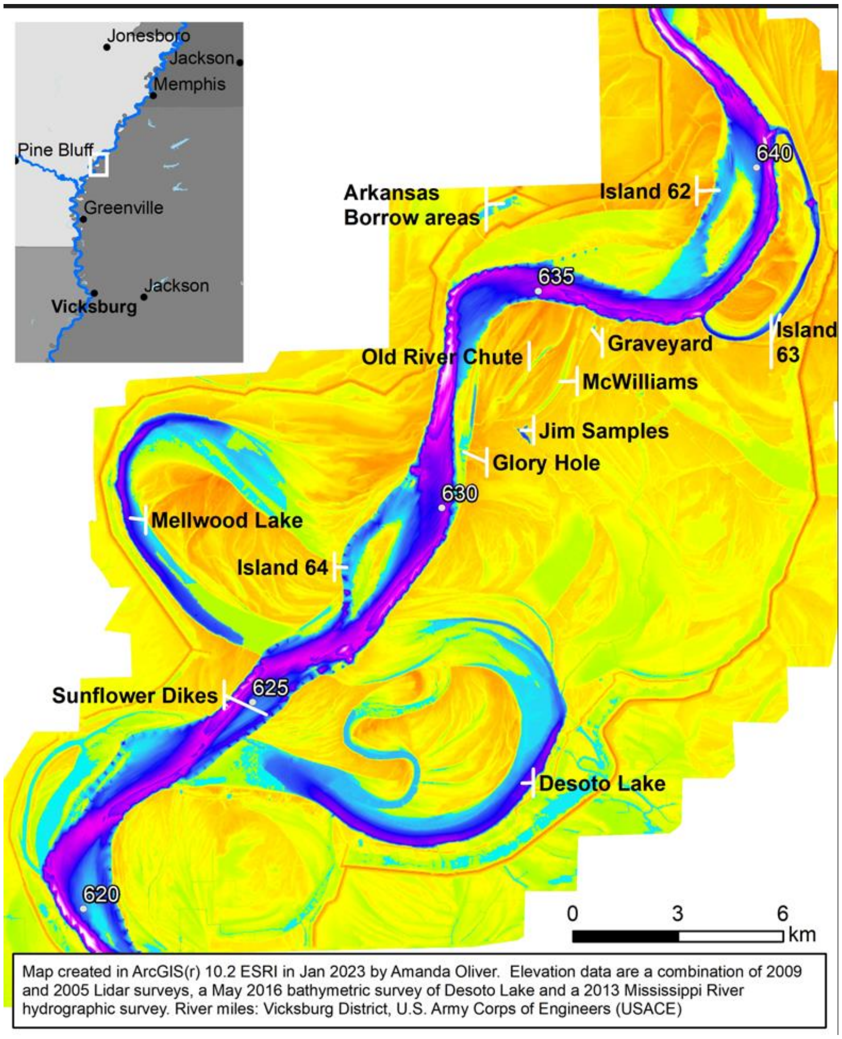
The trawl was deployed from the bow while the boat was backing downstream. This approach provided a margin of safety and greater maneuverability in case the trawl became entangled on underwater objects. When the trawl did become entangled, a trailer boat grabbed the cod end float and backed upstream until the trawl was lifted off the underwater obstruction. The distance traveled, average speed and depth range were recorded during each trawling event. All fish captured were identified to species, enumerated and total length (fork length for sturgeon, eye to fork length for Paddlefish) was measured. At each sampling location, water depth, surface water velocity, substrate type, and effort were recorded. Water quality (temperature, dissolved oxygen, conductivity, pH, turbidity) was measured at each sampling reach.

3.2 Island 63 Ecohydrology Study - Seining

A 3-year ecohydrologic assessment was undertaken to evaluate the linkages between waterbody connectivity and other physical processes to biodiversity. A 22-mile (River Mile 620 – 642) segment of river, including Island 63, was selected as a representative reach based upon the availability of long-term gage data, presence of numerous discrete water bodies arrayed along a gradient of connectivity, and site accessibility. We evaluated the quantity and quality of aquatic habitats in this section of the LMR floodplain by relating biota within water bodies to the manner and timing of connection with the river.

Twelve waterbodies within the Island 63 reach representing a hydrologic connectivity gradient were grouped by type: eupotamal, parapotamal, plesiopotamal (Ward and Stanford 1995). Each type exhibits a different stage of hydrologic succession and each is characterized by a distinctive biotic community (Baker et al. 1991; Ward and Stanford 1995). These waterbodies were sampled seasonally (Figure 3):

- Eupotamal secondary channel – Islands 62, 63, and 64, and Sunflower sandbars (unidirectional flow stage dependent, sometimes bidirectional or isolated at low stages)
- Parapotamal waterbodies - DeSoto and Mellwood oxbow lakes, Glory Hole (frequent bidirectional flow, typically lower elevation connection on downstream end sometimes via a tie channel, infrequent unidirectional flow during floods)
- Plesiopotamal waterbodies - Old River Chute, McWilliams Lake, Jim Samples Lake, Graveyard Bluehole, Arkansas borrow areas (less frequent bidirectional flow through channels with culverts, rare unidirectional flow during large floods)



Map created in ArcGIS(r) 10.2 ESRI in Jan 2023 by Amanda Oliver. Elevation data are a combination of 2009 and 2005 Lidar surveys, a May 2016 bathymetric survey of Desoto Lake and a 2013 Mississippi River hydrographic survey. River miles: Vicksburg District, U.S. Army Corps of Engineers (USACE)

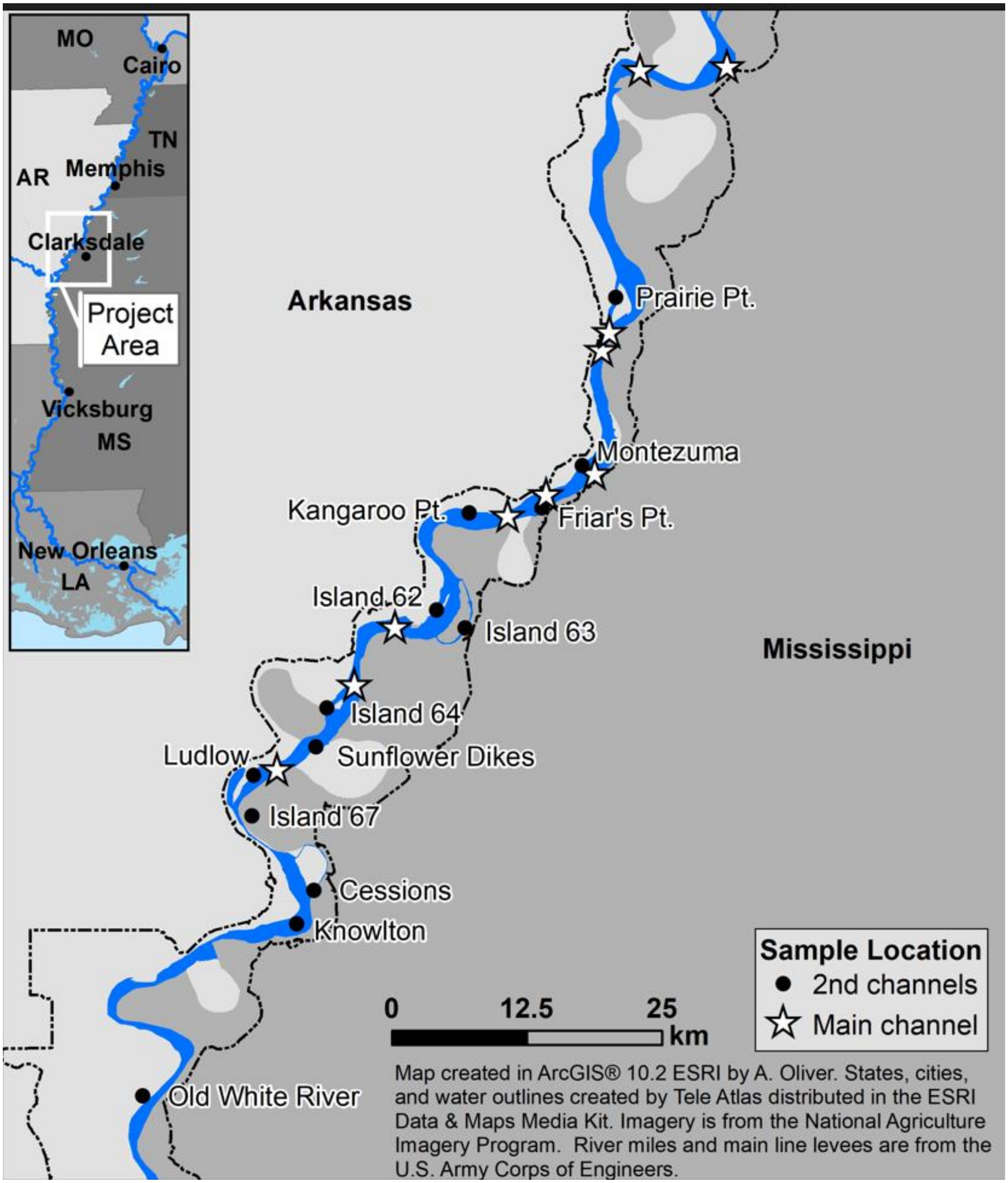
Figure 3. Sampling locations for the Island 63 ecohydrology study in the Lower Mississippi river conducted fall 2014 – summer 2016.

Fishes were collected during the fall, winter, spring, and summer fall 2014 – summer 2016 using multiple gear types. Seining data were used to characterize the fish assemblage over the gradient of connections for model development. A 2.4 m x 3.0 m seine constructed of 5 mm square mesh was used to collect fish. A single effort consisted of 10 hauls stratified among all apparent microhabitats in a predefined reach within each waterbody. Reach data were pooled into a single composite waterbody sample and CPUE was calculated as number of individuals per species or guild.

3.3 Aquatic Invertebrate Collection Methods

Invertebrate samples were collected actively and passively using a benthic sled and colonization baskets, respectively. Samples were collected within a 50-mile reach of the LMR, within the Helena, AR, and Clarksdale, MS, regions, from 2014-2020 (Figure 4). To account for different collection methodologies between sampled substrates, data were transformed to presence/absence. Species richness was used as the diversity measure.

> Benthic Sled - A benthic sled described by Harrison et al. (2018) was used to sample benthic macroinvertebrates in main and secondary channels. Briefly, a benthic dredge fitted with 500-µm mesh netting, was deployed from the bow of the boat, and allowed to drop to the river bottom, where it was then pulled approximately 50-m downstream. Upon retrieval, to standardize results between hauls, 8-L of the retrieved substrate sample was processed. Sediments were washed on-board using a water hose and elutriated to separate living organisms from inorganic particles. Samples were placed in bags with ethanol and returned to the laboratory for sorting, identification, and enumeration. Substrates were classified according to average particle size.
>
> Colonization Baskets - To characterize invertebrate colonization of rough/vertical substrates in the LMR, 72 cylindrical baskets measuring 30 cm x 22 cm were filled with native and artificial substrates (including leaf packs, gravel, wood, rip rap, ACM). Six baskets were attached to 12 lollipop buoys and deployed into LMR secondary channels. Each buoy was fitted with each substrate and basket position on the buoy was randomized. Three buoys were retrieved every 3-6 weeks during an 8-month period to capture seasonal diversity in invertebrate use. Upon buoy retrieval, baskets were carefully removed, placed in buckets of ethanol, and returned to the laboratory for washing, picking, identification, and enumeration.



Map created in ArcGIS® 10.2 ESRI by A. Oliver. States, cities, and water outlines created by Tele Atlas distributed in the ESRI Data & Maps Media Kit. Imagery is from the National Agriculture Imagery Program. River miles and main line levees are from the U.S. Army Corps of Engineers.

Figure 4. Main and secondary channel aquatic invertebrate sampling sites for the unidirectional benthic sled studies.

Section 4 – Model Descriptions

4.1 LMR Unidirectional Channel Connectivity Model

Applicability: The Unidirectional Model is a regression equation that predicts benthic macroinvertebrate taxonomic richness as a function of decreasing flow-thru frequency based on Harrison et al. (2017). Benthic macroinvertebrate fauna are considered indicators of biological response to alterations to flow. Harrison et al. (2017) focused on the effects of flow alterations due to closure dikes within naturally occurring secondary channels of the LMR.

Data Sources: Data were collected in 2014-15 as part of a secondary channel research work unit. The following description is adapted from Harrison et al. (2017): Nine secondary channels along a 58-mile reach of the Lower Mississippi River (river mile 610 – 668), spanning a gradient of flow frequency, were chosen for analysis of benthic macroinvertebrate community structure during June 2014. Flow frequency was quantified as the river stage at which main channel water began flowing through each secondary channel (Oliver et al. 2016 & 2023). Elevation was determined for the highest obstruction within the channel: low spot in the controlling dike, dike notch, or sediment deposit (Harrison et al. 2017). To make the model applicable throughout the LMR, these elevations were converted to stage in 2007 low water reference plane. Thus, samples with high river stage values represent channels with infrequent flow, while channels with low values flow more frequently and for longer duration. All invertebrate samples included in this model were collected during high water conditions where all secondary channels were connected to the mainstem river, resulting in flow through the secondary channel.

Methods: Collections of benthic macroinvertebrates are summarized based on Harrison et al. (2017). Six benthic samples were taken at each secondary channel site using a benthic sled described by Harrison et al. (2018). The main channel was also sampled in two locations in June 2014 as a control (i.e., always lotic). The benthic sled was deployed, allowed to briefly rest on substrate, pulled until full (<50 m), and retrieved using a windlass. In the laboratory, macroinvertebrates from each sample were isolated, counted, and identified to genus-level when possible. Data were compiled and analyzed using Microsoft Excel. Taxonomic richness refers to counts of individual taxa in each sample. Linear regression was used to predict taxonomic richness as a function of flow thru stage. The coefficients (y-intercept and slope) of the linear regression equation were used in a Habitat Suitability Index (HSI) model standardized from 0 to 1.0 by dividing the predicted value by the maximum observed taxonomic richness.

Results: Based on Harrison et al. (2017), combined taxonomic richness for each secondary channel was negatively correlated with flow thru stage ($R^2 = 0.66$, $p < 0.001$) (Figure 5). The difference in richness between the least and most frequently flowing benthic sites was 15 species. Additionally, although every secondary channel transitioned to lentic conditions at least once during the previous year, channels with longer flow duration supported more species-rich communities. A Habitat Suitability Index (HSI) value was calculated for secondary channels by dividing the maximum taxonomic richness measured during the study (27 taxa) into the calculated richness for a given flow thru stage with the mainstem using the following equation:

$HSI = 23.288 - 0.78x / 27_{max\ richness}$

where x = flow thru stage in feet low water reference plane (LWRP) when main channel water begins flowing through secondary channel.

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 obstruction elevation 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.

To convert elevation to LWRP:

- Determine the rivermile of the obstruction that river water must flow over by drawing a line perpendicular from the rivermile to the obstruction.
- Determine the LWRP value for that rivermile
- Subtract the 0 LWRP elevation value from the obstruction’s elevation

A Habitat Suitability Index graph was developed indicating that any stage below -4.75 ft LWRP will by default result in a HSI=1.0 (Figure 6).

Assumptions/Limitations: The unidirectional model was developed specifically for secondary or meander scarp channels of the LMR with unidirectional flow within the Mississippi River Alluvial Plain Level 3 ecoregion. The model assumes that benthic macroinvertebrate richness during the spring represents a legacy of flow and indicates more frequent flow results in higher taxonomic richness. Therefore, frequency of mainstem flow through secondary channels is considered a limiting factor on resilience of benthic macroinvertebrates assemblages.

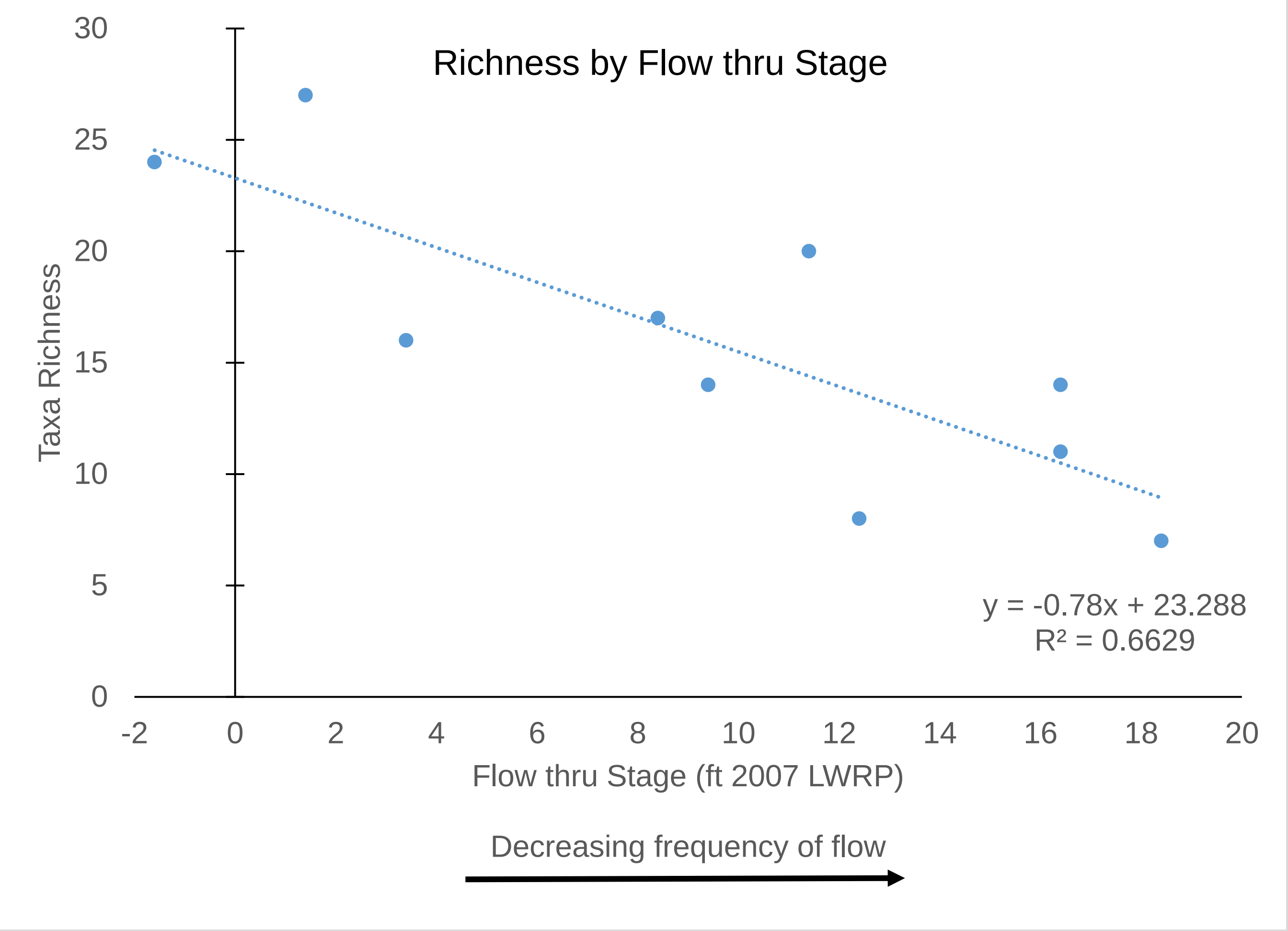


Figure 5. Linear regression (R^2=0.66) of combined aquatic macroinvertebrate species richness counts plotted against flow thru stage (2007 LWRP ft) for each secondary channel. Each combined species richness count is based on six benthic sled samples taken within a particular site. Main channel represents always flowing conditions (0 ft.); data for spring (early June) based on Harrison et al. (2017).

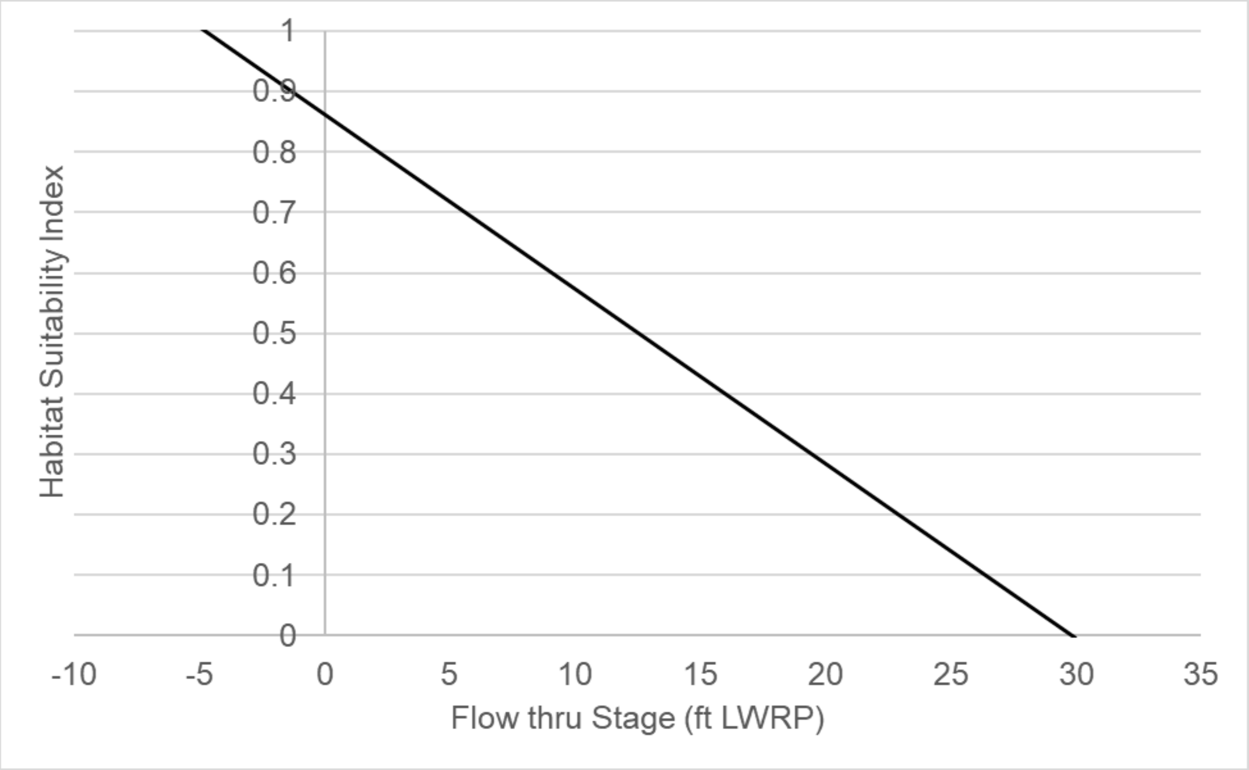


Figure 6. Habitat Suitability Index graph for aquatic macroinvertebrate species richness as a function of Lower Mississippi River flow thru stage (07 LWRP ft) for secondary channels based on the following equation: HSI = 23.288 - 0.78x / 27(max richness), where x = flow thru stage, feet low water reference plane. Any stage below -4.75 ft LWRP will by default result in a HSI=1.0.

4.2 LMR Waterbody Bidirectional Connectivity Model

Applicability: The Bidirectional Model is a regression equation that predicts changes in the relative abundance of Inland Silversides (*Menidia beryllina*) and Brook Silversides (*Labidesthes sicculus*) as a function of increasing connection frequency to the LMR mainstem. Waterbodies include but are not limited to secondary channels, oxbow lakes, scour holes, crevasses, sloughs, and borrow areas. Silversides represent the slackwater guild of fishes inhabiting floodplain waterbodies in the LMR that predominantly connect bidirectionally as river stage fluctuates.

Data Sources: Silversides and other slackwater, limnophilic fish species were collected as part of the Island 63 ecohydrology study from fall 2014 to summer 2016. A variety of connectivity metrics were calculated for this study because the connectivity metric with the strongest relationship to species presence/absence/richness is unknown. Connectivity metrics investigated included: cumulative connection frequencies (2000-2015, 2011 peak flood to sample date, past year, past six months, past 3 months), days since connection, connection stage, and number of days connected during last connection event calculated based on the methods of Oliver et al. (2016 & 2023).

Methods: The Analysis of Similarity (ANOSIM) option in the Primer software package was used to statistically compare similarity of species groups between unidirectional (eupotamal) and bidirectional (para and plesiopotamal) waterbodies (Clarke 1993). The SIMPER (similarity percentages – species composition) procedure, also available in Primer, was used to identify the slackwater floodplain guild by calculating similarity percentages on the abundance values to determine which species contribute to the similarity pattern depicted within groups (i.e., typifying species) as well as those species that contribute to the dissimilarity between groups (i.e., discriminating species) (Clarke & Gorley 2001).

Catch-per-unit-effort (CPUE) was calculated as relative abundance of silversides per 10 seine hauls, the relationships between silverside abundance and the various connectivity metrics investigated, and a predictive equation was calculated using quantile regression. 2000-2015 cumulative connection frequency had the strongest relationship to species abundance and was therefore used in the quantile regression. Species abundance-habitat relationships are typically skewed with zero-inflated count data, contains outliers, and do not meet the assumptions of normality required for linear regression (Terrell et al. 1996; Vaz et al 2008). Quantile regression is a non-parametric method of modeling response variables when assumptions of ordinary least squares regression are not met. It estimates multiple rates of change (slopes) from the minimum to maximum response, providing a more complete picture of the relationships between variables missed by other regression methods (Cade and Noon 2003). The 0.95 regression quantile was considered in model development, which represents the upper bounds of species–environment relationships and thus estimates how the environment is limiting the distribution of a species (Vaz et al. 2008). Using diagnostic options in SAS 9.4 (SAS 2013), an equation to predict silverside abundance as a function of connection frequency was calculated using quantile regression with the sparsity method providing confidence limits. The coefficients (y-intercept and slope) of the quantile regression were used in a Habitat Suitability Index (HSI) model standardized from 0 to 1.0.

Results: Analysis of Similarity (ANOSIM) between unidirectional and bidirectional habitat types indicated species groups were significantly different from each other (Global R=0.77, p=0.001). Average similarity (SIMPER) between the two types based on fourth-root transformed abundance values was 35.1% with Bluegill, Western Mosquitofish, Inland Silverside, and Orangespotted Sunfish contributed the most to similarity within sites (i.e., typifying species) (63.7%) with 5 additional species, including Brook Silverside, contributing the remaining balance. These procedures resulted in nine species of fish representing the ichthyofauna that typified bidirectional floodplain waterbodies (Table 3) and are representative of the slackwater fish species guild (Table 1). Of these species, Inland and Brook Silverside combined abundance had one of the highest Spearman correlation coefficients with 2000 – 2015 cumulative connection frequency and was therefore used in quantile regression as the dependent variable to represent the slackwater guild. Silversides are readily captured in these waterbodies, increasing monitoring capabilities, and they have a documented preference to backwater or floodplain waterbodies.

A total of 172 silversides were collected at 54 sampling events with a mean (±1SD) number of 48.1 ± 62.5 ranging from 1 to 278 individuals. Collections were made in waterbodies ranging in 2015 cumulative connection frequency from 6 to 22 and 76 to 100%. The 95% quantile of abundance was used to calculate model coefficients along with the 95% confidence limits around the median (Figure 7), and model parameters were significant (Table 3). A Habitat Suitability Index (HSI) value was calculated by dividing the maximum CPUE measured during the ecohydrology study (150 individuals per ten seine hauls) into the calculated abundance for a given connection frequency using the following equation and shown in Figure 8:

$HSI = 21.86 + 1.438x / 150 \text{ max CPUE}$

where x = 2000-2015 cumulative connection frequency, percentage of days from 2000 to 2015 that the adjacent main channel water surface elevation exceeded the measure’s elevation.

The measure’s elevation is the elevation of the channel blockage. With project elevation is the new elevation proposed by the PDT, or if blockage removal is proposed, then elevation is the predominant channel bed elevation outside of the blockage area. The main channel water surface elevation was calculated using the nearest upstream and downstream gage and the equation for slope (Oliver et al. 2023). To determine distance for the slope equation, gage river mile and the obstruction’s river mile were used. The obstruction’s river mile was determined by drawing a perpendicular line between the LMR river mile and the point where the bidirectional channel connected to a unidirectional channel. Thus, all obstructions along a bidirectional channel have the same river mile.

Assumptions/Limitations: The bidirectional model was developed specifically for batture waterbodies of the LMR in the Mississippi River Alluvial Plain Level 3 ecoregion. Some waterbodies have an obvious connection to the mainstem (e.g., tie channel of an oxbow lake), while others are connected through sloughs, ditches, and manmade channels. However, the bidirectionality of connection is the primary factor for applying this model. The model assumes that 2000-2015 cumulative connection frequency, the 15 years immediately prior to ecohydrology sampling, represents one of the key ecological drivers in silverside abundance. It also assumes a species-connectivity relationship for midrange connectivity not present within the Island 63 ecohydrology dataset. There may be midrange connectivity waterbodies present elsewhere in the LMR that could supplement model data or these waterbodies may be scarce due to natural or anthropogenic effects on connectivity. Quantile regression models are used to estimate the effects of limiting factors when ecological responses are highly variable. They are robust to outlying data points, and they represent the concept of limiting factors (Dunham et al. 2002; Cade et al. 1999). Habitat variables other than connectivity influence species abundance and richness in bidirectional waterbodies, such as water quality, depth, and velocity, but connectivity is assumed to be the primary limiting factor on the resilience of slackwater fishes of the LMR.

Table 3. Results of SIMPER Primer Analysis of Island 63 Ecohydrology study using seining data to identify fish species representing the slackwater guild. Abundance is fourth-root transformed prior to SIMPER Analysis. Variables include average abundance, average similarity, similarity standard deviation, and percent contribution. This guild accounts for 35% of the average similarity of fish species in floodplain waterbodies with bidirectional connections to the mainstem LMR.

Species	Common Name	Avg Abund.	Avg Similarity	Similarity SD	Contrib%	Cum.%
Lepomis macrochirus	Bluegill	1.99	9.17	1.43	26.1	26.1
Gambusia affinis	Mosquitofish	1.9	7.29	1.03	20.75	46.85
Menidia beryllina	Inland Silverside	1.59	5.32	0.91	15.13	61.98
Lepomis humilis	Orangespotted Sunfish	1.33	4	0.87	11.37	73.35
Opsopoeodus emiliae	Pugnose Minnow	0.84	1.51	0.47	4.31	77.65
Labidesthes sicculus	Brook Silverside	0.83	1.48	0.42	4.22	81.87
Micropterus salmoides	Largemouth Bass	0.77	1.31	0.43	3.74	85.61
Lepomis miniatus	Redspotted Sunfish	0.63	1.3	0.47	3.71	89.32
Lepomis gulosus	Warmouth	0.39	0.58	0.3	1.64	90.97

Table 4. Parameter estimates for the bidirectional connectivity model (n=172, p<0.001). The model represents the 95% quantile regression of Silverside CPUE as a function of connection frequency over a 15-year period prior to sampling.

Parameter	DF	Estimate	Standard Error	95% Confidence Limits		t Value	Pr > |t|
Intercept	1	31.34	9.36	12.85	49.82	3.35	0.001
2000-2015 cumulative connection frequency	1	1.16	0.28	0.60	1.71	4.09	<.0001

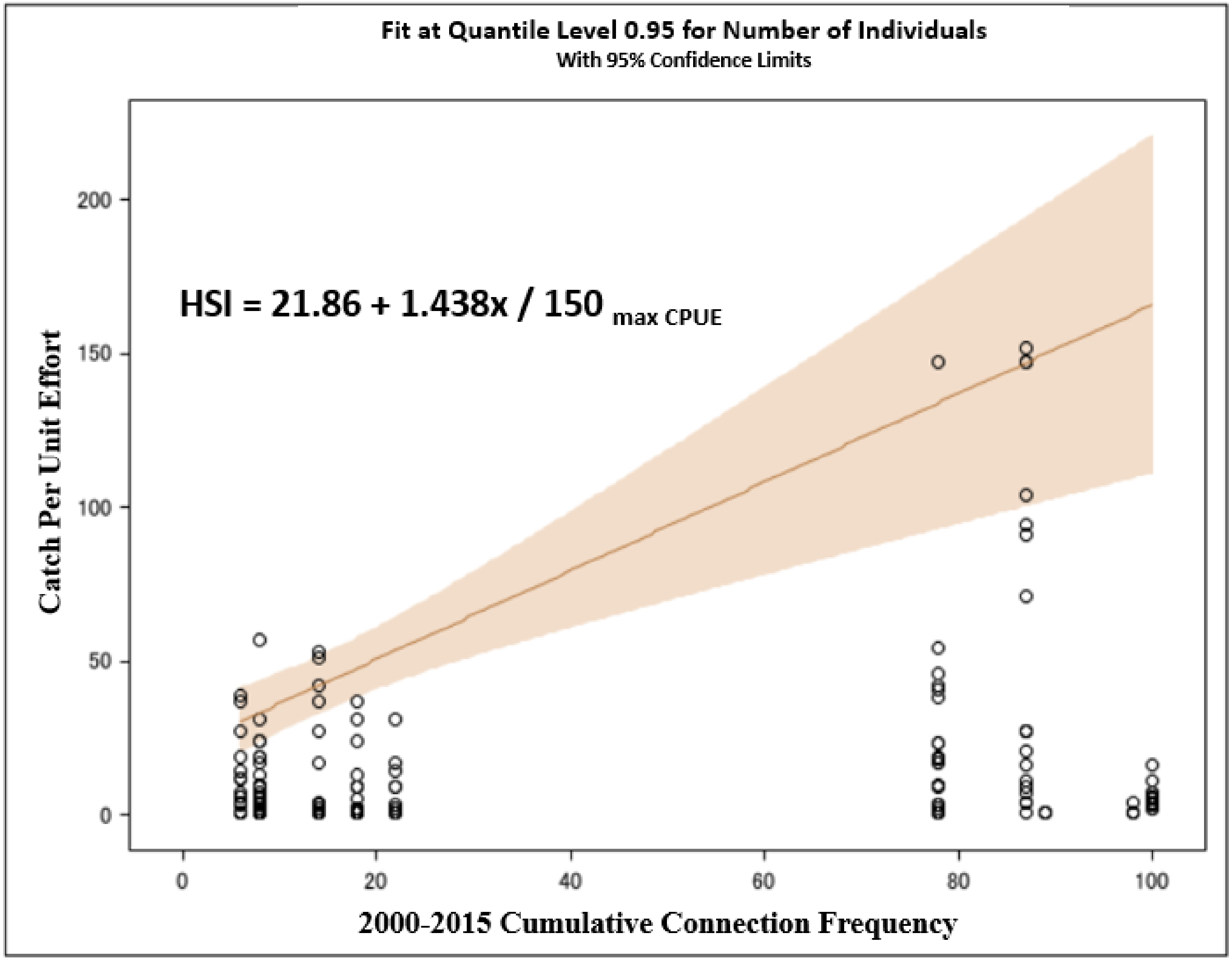


Figure 7. Quantile regression model of silverside abundance (CPUE seining) as function of the 2000-2015 cumulative connection frequency of bidirectional floodplain waterbodies with the main channel. A Habitat Suitability Index value was calculated by dividing the predicted value by the maximum observed abundance.

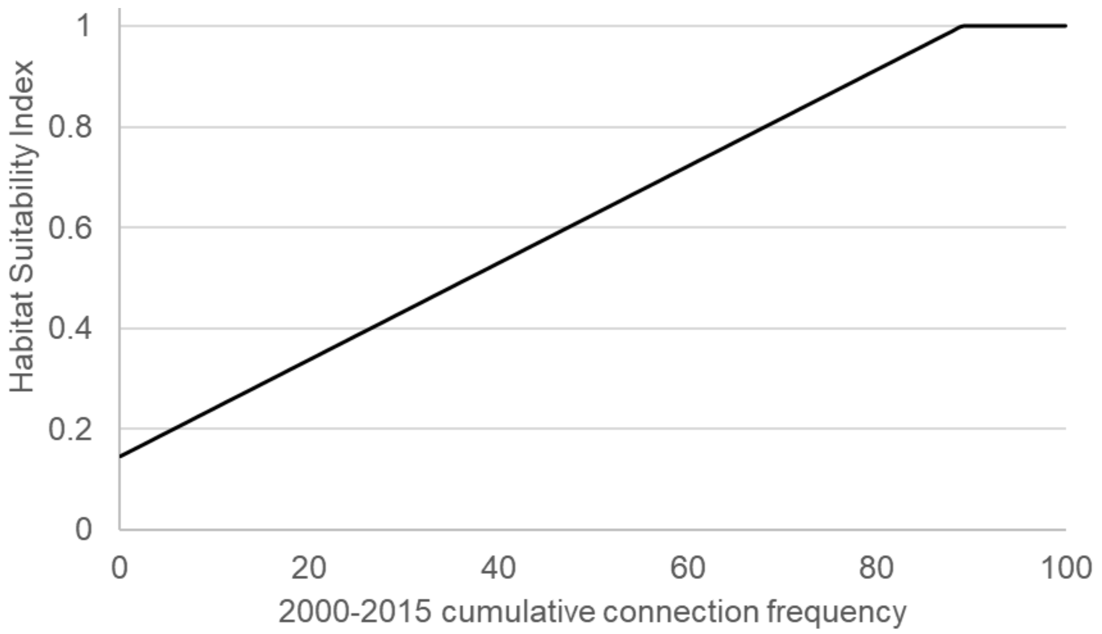


Figure 8. Habitat suitability Index graph of Silverside abundance as a function of the 2000-2015 cumulative connection frequency of bidirectional floodplain waterbodies with the main channel.

4.3 LMR Floodplain Waterbody Wetland Isolation Model

Applicability: The Isolation Model is a regression equation that predicts the relative abundance of wetland fishes (i.e., backwater fish guild) as a function of decreasing frequency of waterbody connection to the LMR mainstem. Wetland fishes characteristically prefer more isolated, non-flowing floodplain waterbodies. Waterbodies targeted for this model are typically smaller than oxbow lakes, most are plesiopotamal, and are ideally forested including cypress-tupelo swamps. Precipitation and possibly groundwater may be the primary source of water until large floods inundate the entire batture.

Data Sources: The wetland fish guild was developed from the summer 2015 and 2016 Island 63 ecohydrology study collections. Because the bidirectional model development identified a strong relationship between 2000-2015 cumulative connection frequency and abundance, this variable was also used for the Isolation Model. This connection frequency was calculated from stage data from 2000 to 2015 based on the methods of Oliver et al. (2016 & 2023).

Methods: Fish species representing the wetland guild were selected based on three criteria: non-rheophilic or tends to avoid flow, mostly intolerant to habitat and water quality changes, and noted to prefer wetland habitats infrequently connected to rivers as documented in the literature and based on collective field experiences. Catch-per-unit-effort (CPUE) was calculated as relative abundance of the wetland guild per 10 seine hauls and a predictive equation was calculated using quantile regression using the same methods described in the bidirectional model. The coefficients (y-intercept and slope) of the quantile regression were used in a Habitat Suitability Index (HSI) model standardized from 0 to 1.0.

Results: Eleven species of fishes in the Island 63 study area were selected to represent the wetland guild (Table 5), but they also are representative of a greater number of wetland/backwater species in the LMR (Table 1). A total of 326 individuals were collected during 18 sampling events in summers of 2015 and 2016 with a mean (±1SD) CPUE of 6.3 ± 9.9. The 2000-2015 cumulative connection frequency ranged from 6 to 22 and 76 to 100%. The 95% quantile of wetland guild abundance was used to calculate model coefficients along with the 95% confidence limits around the median (Figure 9), producing a statistically significant model (Table 6). A Habitat Suitability Index (HSI) value was calculated by dividing the maximum CPUE measured during the ecohydrology study (25 individuals per ten seine hauls) into the calculated abundance for a given connection frequency using the following equation and shown in Figure 10:

$HSI = 19.29 - 0.183x / 25 \max_{CPUE}$

where x = 2000-2015 cumulative connection frequency, percentage of days from 2000 to 2015 that the adjacent main channel water surface elevation exceeded the measure's elevation (see Bidirectional model for further details).

Assumptions/Limitations: The wetland isolation model was developed specifically for batture waterbodies of the LMR in the Mississippi River Alluvial Plain Level 3 ecoregion. Connections with the mainstem are predominantly bidirectional. Using quantile regression, the model assumes that reduced connectivity of a waterbody to the mainstem promotes longer periods of isolation that benefit wetland, backwater fish species. It also assumes a species connectivity relationship for midrange connectivity not present within the Island 63 ecohydrology dataset. There may be midrange connectivity waterbodies present elsewhere in the LMR that could supplement model data or these waterbodies may be scarce due to natural or anthropogenic effects on connectivity. We assumed that summer represents the critical post-spawning period when isolation enhances survival of wetland young-of year fishes. Increased connectivity limits or reduces the habitat quality for wetland species by increasing riverine predator abundance impacting species abundance and increasing turbidity thus limiting aquatic plant growth, an important structural element of wetland habitat. Habitat variables other than connectivity influence species abundance and richness in wetland waterbodies, such as water quality, depth, and velocity, but decreased connectivity is assumed to be the primary limiting factor on maintaining the resilience of wetland fishes of the LMR.

Table 5. Species abundance of the wetland guild in the LMR floodplain waterbodies. Fish were collected with seines (n=18) as part of the Island 63 Ecohydrology study.

Species	Common Name	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Etheostoma chlorosoma	Bluntnose Darter	86	26.38	86	26.38
Fundulus olivaceus	Blackspotted Topminnow	68	20.86	154	47.24
Lepomis symmetricus	Bantam Sunfish	37	11.35	191	58.59
Etheostoma proeliare	Cypress Darter	30	9.2	221	67.79
Fundulus chrysotus	Golden Topminnow	28	8.59	249	76.38
Fundulus notatus	Blackstripe Topminnow	21	6.44	270	82.82
Centrarchus macropterus	Flier	19	5.83	289	88.65
Notropis maculatus	Taillight Shiner	15	4.6	304	93.25
Elassoma zonatum	Banded Pygmy Sunfish	13	3.99	317	97.24
Lepisosteus oculatus	Spotted Gar	7	2.15	324	99.39
Etheostoma asprigene	Mud Darter	2	0.61	326	100

Table 6. Parameter estimates for the wetland isolation model. The model represents the 95% quantile regression of wetland fish CPUE as a function of 2000-2015 cumulative connection frequency.

Parameter	DF	Estimate	Standard Error	95% Confidence Limits		t Value	Pr > |t|
Intercept	1	19.29	3.52	12.16	26.42	5.49	<.0001
2000-2015 cumulative connection frequency	1	-0.18	0.04	-0.26	-0.11	-5.00	<.0001

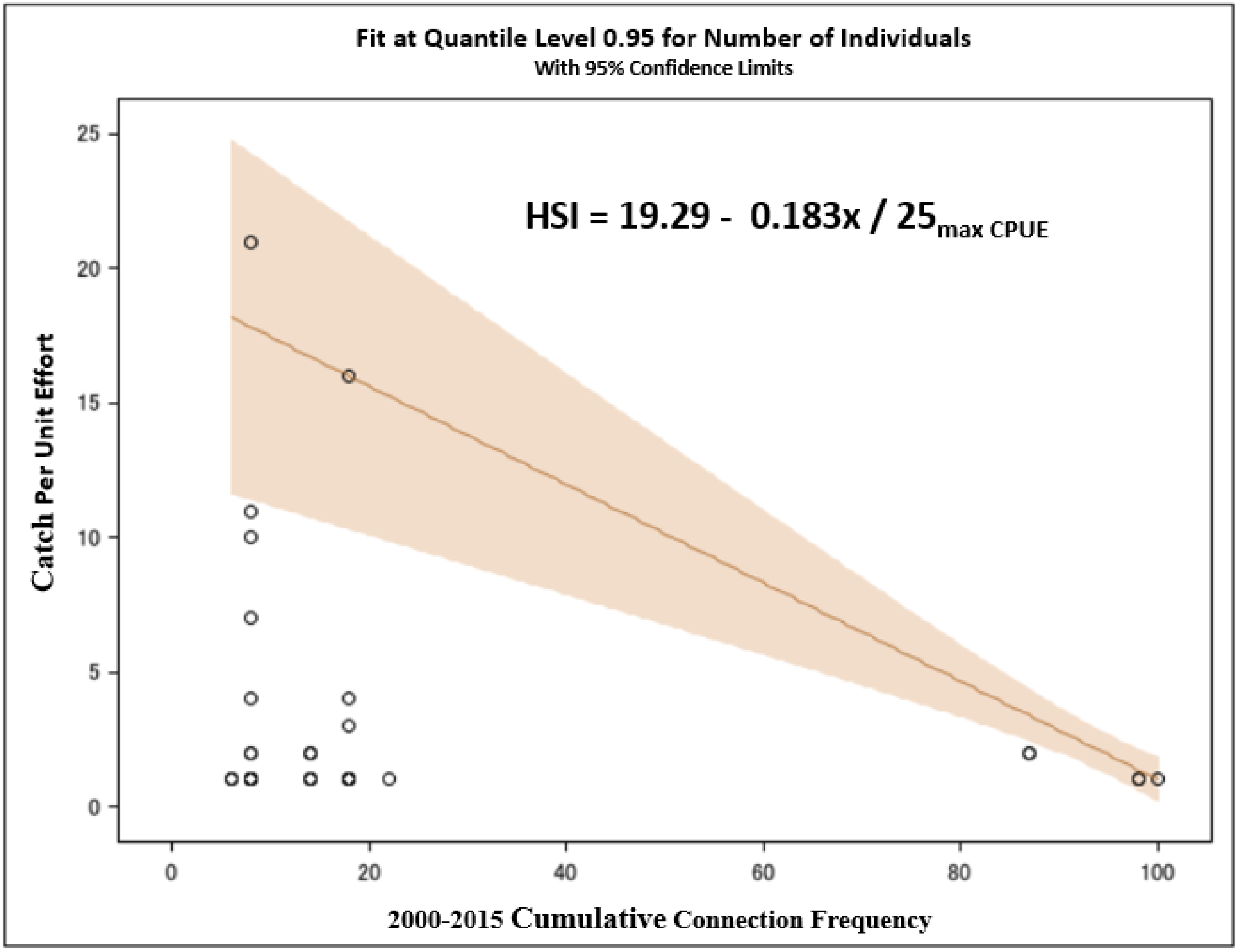


Figure 9. Quantile regression isolation model of wetland guild abundance (CPUE) in summer using seines as a function of the 2000-2015 cumulative connection frequency, which represents the percent days connected for the 15 year period prior to sampling.

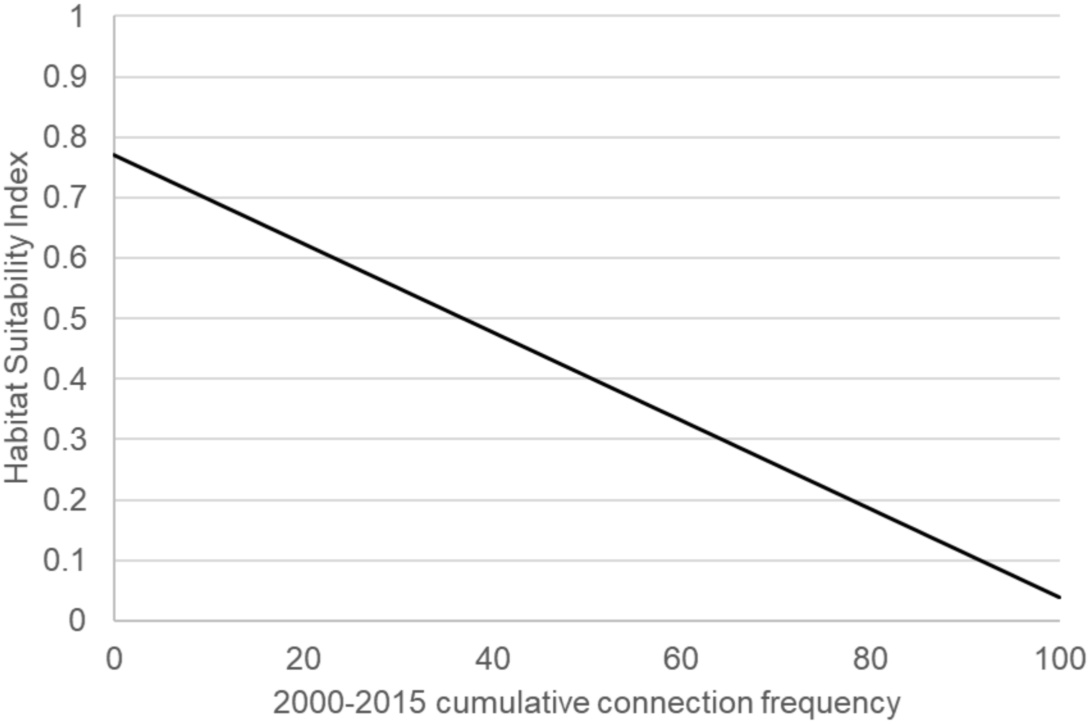


Figure 10. Habitat suitability Index graph of wetland guild abundance as a function of the 2000-2015 cumulative connection frequency of bidirectional floodplain waterbodies with the main channel.

4.4 LMR Aquatic Invertebrate Substrate Model

Applicability: The Substrate Model is a frequency bar chart measured on a categorical scale, standardized to a 0 to 1 rating. It predicts aquatic invertebrate richness (i.e., number of taxa) associated with different riverine benthic substrates. The model was developed to quantify restoring gravel bars by scouring or otherwise removing sand covering gravel substrates.

Data Sources: The Substrate Model was developed from the benthic sled invertebrate data. Different riverine substrates were sampled with the benthic sled from 2014 – 2021 in mainstem and secondary channels of the Lower Mississippi River. Visual estimates of substrate type were made after each benthic sled sample based on particle size ranging from clay to gravel following the Wentworth scale (Brunte and Abt 2001).

Methods: Because of the large difference in sample size between the different substrate types (Table 7), we rarified the taxa list for each substrate to only include taxa that occurred in at least 5% of the total samples for each substrate. This served to reduce the number of rare taxa (encountered extremely infrequently) that accumulate in taxa lists with extremely large sample sizes. The rarified richness totals were then used to directly compare different substrate types using frequency bar charts (Figure 11).

Results:

A total of 397 benthic sled samples were used to evaluate aquatic macroinvertebrate richness in riverine substrate types. After rarefaction of taxa collected with the benthic sled, gravel, clay, and silt had the highest richness values (Table 7, Figure 11). The most significant difference between the observed vs. rarified taxonomic richness was in sand samples, which were encountered most frequently, and contained 111 total taxa before rarefaction. Sand typically has a lower taxa richness compared to other substrate types in large rivers (Hynes 1970). Removal of sand over gravel bars is predicted to increase richness from 20 taxa to 35 taxa. A Habitat Suitability Index Model was developed from these datasets by assigning a HSI value of 1.0 for the substrate with the highest richness. Other types were scaled accordingly resulting in a model that provides eco-lift (increase in habitat suitability) depending on the project type (Figure 12). For LMRRA projects, an applicative example of model use is removing sand over gravel bars, which would result in an eco-lift from a HSI of 0.57 to 1.0.

Assumptions/Limitations: The riverine substrate model was developed specifically for secondary and main channel habitat of the LMR with unidirectional flow. The model assumes that macroinvertebrate taxonomic richness is a bio-indicator of substrate habitat quality and that gravel bars represent a high quality habitat supporting a diverse macroinvertebrate fauna in unidirectional river channels.

Table 7. Summary information for the benthic sled macroinvertebrate dataset.

Substrate	Number of Samples	Total Taxa Collected	Rarified Taxa
Clay	14	31	31
Mud	82	81	25
Silt	22	67	30
Fine Sand	25	41	18
Sand	217	111	20
Coarse Sand	25	41	19
Gravel	8	35	35
TOTAL	397		

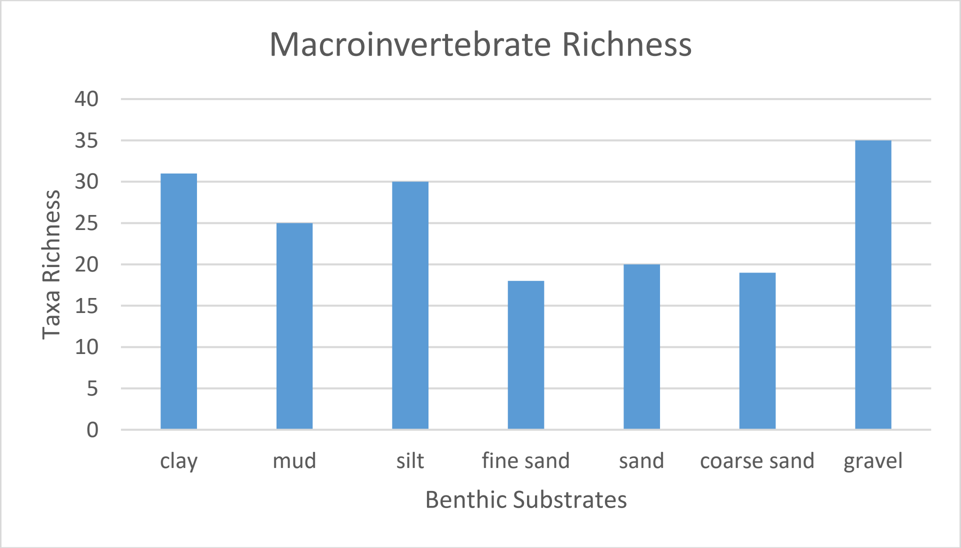


Figure 11. Rarified invertebrate richness by substrate type

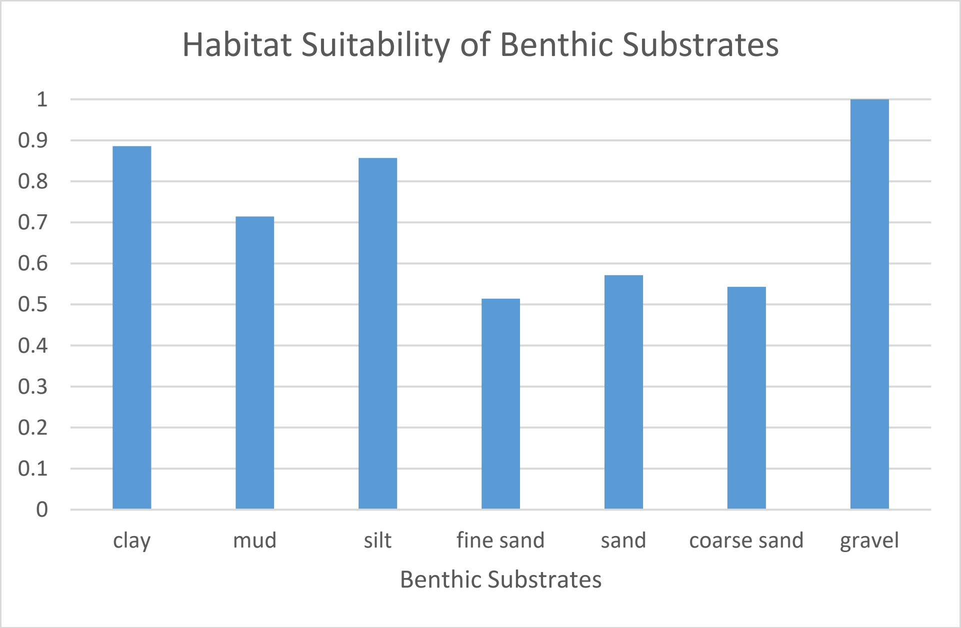


Figure 12. Habitat Suitability Index bar chart of benthic substrates in the Lower Mississippi River as a function of macroinvertebrate taxonomic richness.

4.5 Wood Traps Model

Applicability: The Wood Traps Model, standardized to a 0 to 1 rating, predicts *novel* aquatic invertebrate richness (i.e., number of taxa) associated with the addition of individual natural and artificial riverine substrates that produce instream structure. The model was developed to quantify benefits of re-establishing woody debris in flowing water habitats of the LMR that allows sensitive, clinging taxa to complete their life cycles and represents the addition of these novel taxa when structures are added to existing substrates of the LMR. The importance of these taxa to the river reach is threefold: 1- These taxa form an important forage base for many ecologically and economically important riverine fishes; 2- the taxa are necessary for chemical nutrient cycling through bioaccumulation; 3- through their emergence as adults, they transfer these nutrients back into the terrestrial environment by supporting a wide variety of birds, bats, and other terrestrial insectivores (Merritt et al.2019).

Data Sources: Model was developed from the combined data of two different field studies: benthic sled and colonization baskets (see database description above). Benthic riverine substrates were sampled with the benthic sled from 2014 – 2021 totaling 397 samples collected in mainstem and secondary channels of the lower Mississippi River. Colonization studies were conducted in 2019-22 to analyze invertebrate richness associated with different types of instream structure (woody debris, rip rap, leaves, ACM, river debris, and gravel) totaling 59 samples.

Methods: To assess the wood trap model, two datasets were used, the benthic sled dataset and the colonization dataset. The substrate dataset (x axis) was used first to identify taxonomic diversity within the river bed itself, which represents the without project condition. To assess the potential benefit of constructing structures of various materials on top of the native substrate, the colonization dataset was used. To assess the benefit of constructing a full wood trap structure, the taxa occurrences of woody debris, riprap, leaves, and river debris were added together assuming the wood traps would include a rip-rap base, wooden poles, and capture large woody debris, leaves, and river debris. To show the added benefit of constructing these structures atop various types of substrates, the number of additional *unique* taxa due to the structures not found in the underlying substrates were counted. Substrate taxa lists were based off the total taxa list from the benthic sled dataset.

Results: A total of 397 benthic sled samples (Table 7) and 59 colonization basket samples (Table 8) were used to evaluate aquatic macroinvertebrate richness. The addition of natural river structure components of gravel, leaves, and wood debris showed high increases in taxa richness across all sediment types, and the wood trap, which would be constructed of a combination of structure components, displayed a two-fold increase in richness across all sediment types (Figure 8a). The model was used to assess benefits of constructing a wood trap on various existing substrates. For example, constructing a wood trap on sand substrate, the most common substrate in mainstem and secondary channels of the LMR, has the potential to increase the macroinvertebrate richness from 20 to 89 taxa (an increase of 69 taxa, Figure 13). A Habitat Suitability Index Model was developed from these datasets by assigning a HSI value of 1.0 for wood traps based on the multiple types of instream structure and substrates that accumulate on these structures. Other types were scaled accordingly resulting in a model that provides eco-lift (increase in habitat suitability) depending on the project type (Figure 14). Establishing wood traps on sandbars would result in an eco-lift from a HSI of 0.2 to 0.86. Other substrates and instream structure can be evaluated with this model depending on the restoration objective.

Assumptions/Limitations: The riverine substrate model was developed specifically for secondary and main channel habitat of the LMR with unidirectional flow. The model assumes that macroinvertebrate taxonomic richness is a bio-indicator of substrate habitat quality and the benefits of adding structure to the riverine system. The sensitive, clinging taxa (Ephemeroptera, Plecoptera, Tricoptera), that colonize these structures can disperse as adults over 5 km away from the structure, fostering the transfer of nutrients from the aquatic environment to the terrestrial environment (Merritt et al. 2019).

Table 8. Summary information for the macroinvertebrate colonization study dataset.

Substrate	Number of Samples	Total Taxa Collected
Woody Debris	10	42
Rip rap	9	40
Leaves	9	38
Vicksburg ACM	10	44
Memphis ACM	10	37
Gravel	10	35
River Debris	1	7
TOTAL	59	

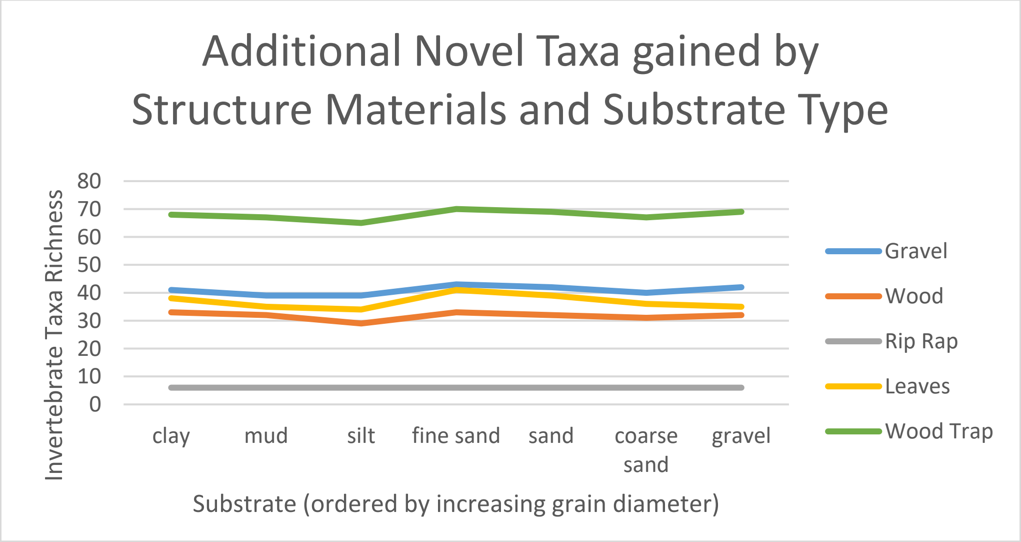


Figure 13. Increase in novel taxa richness by addition of instream structure by benthic substrate type

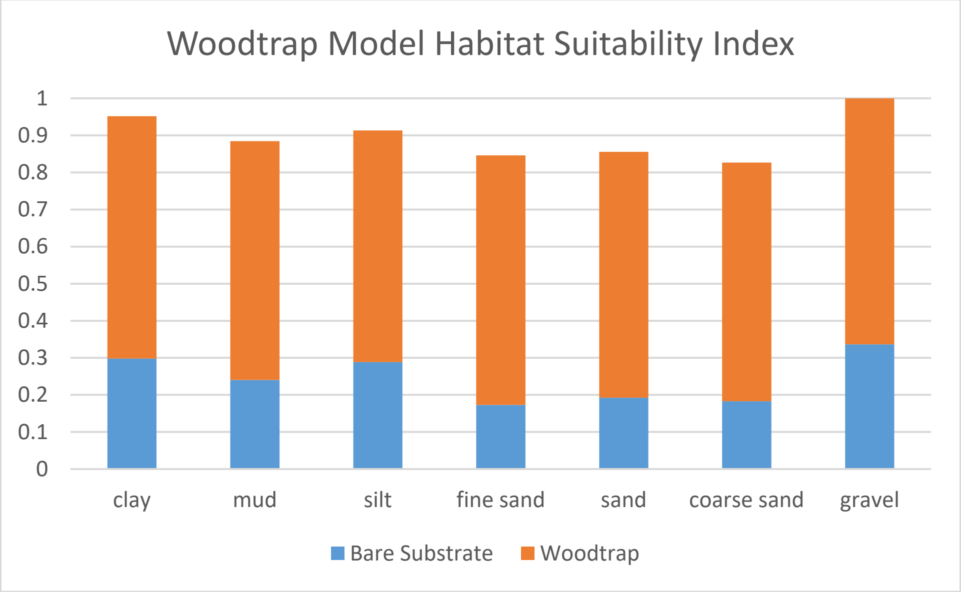


Figure 14. Habitat Suitability Index bar chart displaying the results of the Wood Traps Model for all substrates.

4.6 LMR River Training Structure Eddy Model

Applicability: The Eddy Model is a categorical bar chart standardized to a binary rating from 0.1 to 1, comparing species habitat utilization between main channel habitat and eddies along the channel border formed by point bars, dikes, and hardpoints. This model specifies just habitat forming eddies and non-habitat (binary), and is not intended to differentiate among different design options compared to more complex models that use multiple levels or a continuum of habitat quality. The model was developed from benthic trawling data and demonstrates the importance to a reach by increasing overall species richness along with creating habitat for other large-bodied, swiftwater, sand and gravel associated riverine fish (Maynord et al. 2005; Baker et al. 1991). The model targets the results of restoration projects such as hardpoints that form eddies, which are defined as an area of swirling water, counter to the main current, that forms downstream of an obstacle like a dike. These swirling currents carry and disorient small-bodied organisms attracting predators like Blue Catfish and Freshwater Drum and filter feeders like Paddlefish.

Data Sources: The Eddy Model was developed from a subset of the ERDC trawling dataset described previously. Data selection for the model was based upon previous studies that quantified flow characteristic in large alluvial river and found that eddy-like flows are created just downstream of point bars (Smit and Kaeser 2016).

Methods: The Eddy Model used data derived from an intensive (monthly or bi-monthly, 2003-4 and 2006-09) sampling program at two representative bendways (Mhoon and Walnut Bend, RM 680-697). Trawls were taken upstream, midway, and downstream of the point bars. Downstream of the Mhoon point bar, eddies formed that were considered representative of eddies that form downstream of other structures. Walnut Bend had river training structures that created complex currents but not typical of the downstream reach of point bars. Catch-per-unit-effort (CPUE) per 0.5 miles trawled was calculated for both upstream and downstream of the point bar by summarizing the total number of individuals for each species caught and dividing by number of trawl samples. Eco-lift was calculated by normalizing (i.e., dividing into the maximum observed value) CPUE for the main channel and downstream of the point bar (eddy) for fish species that represent large-bodied obligate riverine species.

Results: A total of 32 trawls averaging 0.5 miles per sample (22.5 cumulative miles) were completed at the two representative bendways. A total of 2085 fishes representing 22 species were collected (Table 9). Large-bodied obligate riverine fish species that utilized eddy habitat more frequently than main channel habitat were chosen for the model and included Paddlefish *Polyodon spathula*, Blue Catfish *Ictalurus furcatus*, and Freshwater Drum *Aplodinotus grunniens)*. These species were modelled by comparing normalized CPUE between main channel and eddy habitats (Figure 15). Blue Catfish and Freshwater Drum are important recreational and commercial species but are relatively abundant throughout the LMR. Paddlefish are a species of concern by numerous states, and their numbers have declined due to anthropogenic impacts. After normalization to a 0 to 1 scale, the model predicts that formation of eddies will increase the Paddlefish HSI from 0.1 to 1.0 with an eco-lift of 0.9 (Figure 15). Blue Catfish and Freshwater Drum also exhibited eco-lift indicating the importance of eddies to support multi-species assemblages.

Assumptions/Limitations: Eddies are generally formed downstream of a point bar and can contribute upwards of 6,250 square meters of circulating habitat in large rivers (Smit and Kaeser 2016). River straightening (channelization) reduces hydraulic and habitat complexity (Zhou and Endreny 2020), reducing the prevalence of point bar eddies. Even though eddies produced by river training structures may differ slightly in shape and size compared to those formed downstream of point bars, eddies from training structures provide similar habitats that are used by many riverine aquatic organisms. Although not included in the model because they are rarely captured in trawls, trotline and telemetry data indicate the federally endangered Pallid Sturgeon utilizes the transition zones between swift and slack water, typical of eddy environments (Killgore et al. 2007; Herrala et al. 2014). The spatial extent of an eddy is user specified, but for this project, two approaches were used for hardpoint measures. If the measure reduces future sedimentation, the entire chute acreage was used to denote benefits assuming an increased use of the reach by multiple biotic guilds including the target species. However, if the intention of the hardpoint is to increase habitat diversity, the aquatic acreage was the hardpoint footprint plus the additional area of bathymetric impact.

Table 9. Raw abundance (N) and catch-per-unit-effort (CPUE) of fish species collected with trawls at Mhoon Bend and Walnut Bend, Lower Mississippi River.

Common Name	Species	Upstream			Downstream	
		N	CPUE		N	CPUE
Shipjack Herring	*Alosa chrysochloris*	0	0.0		1	0.1
Freshwater Drum	*Aplodinotus grunniens*	28	1.3		57	5.7
River Carpsucker	*Carpiodes carpio*	1	0.0		3	0.3
Blacktail Shiner	*Cyprinella venusta*	0	0.0		1	0.1
Bluntnose Darter	*Etheostoma chloromoma*	1	0.0		0	0
Goldeye	*Hiodon alosoides*	2	0.1		0	0
Blue Catfish	*Ictalurus furcatus*	103	4.7		82	8.2
Channel Catfish	*Ictalurus punctatus*	352	16.0		153	15.3
Shoal Chub	*Macrhybopsis hyostoma*	727	33.0		212	21.2
Silver Chub	*Macrhybopsis storeriana*	32	1.5		54	5.4
River Shiner	*Notropis shumardi*	2	0.1		0	0
Channel Shiner	*Notropis wickliffi*	3	0.1		6	0.6
Stonecat	*Noturus flavus*	22	1.0		0	0
Freckled Madtom	*Noturus nocturnus*	2	0.1		3	0.3
River Darter	*Percina shumardi*	11	0.5		3	0.3
Bluntnose Shiner	*Pimephales notatus*	0	0.0		1	0.1
Bullhead Shiner	*Pimephales vigilax*	0	0.0		1	0.1
Paddlefish	*Polyodon spathula*	21	1.0		106	10.6
Flathead Catfish	*Pylodictis olivaris*	1	0.0		0	0
Sauger	*Sander canadensis*	0	0.0		1	0.1
Pallid Sturgeon	*Scaphirhynchus albus*	1	0.0		0	0
Shovelnose Sturgeon	*Scaphirhynchus platorynchus*	7	0.3		2	0.2
Young-of-year Sturgeon	*Scaphirhynchus sp*	78	3.5		0	0
Unidentified suckers	*Unidentified catostomid*	2	0.1		3	0.3
	TOTAL	1396			689	

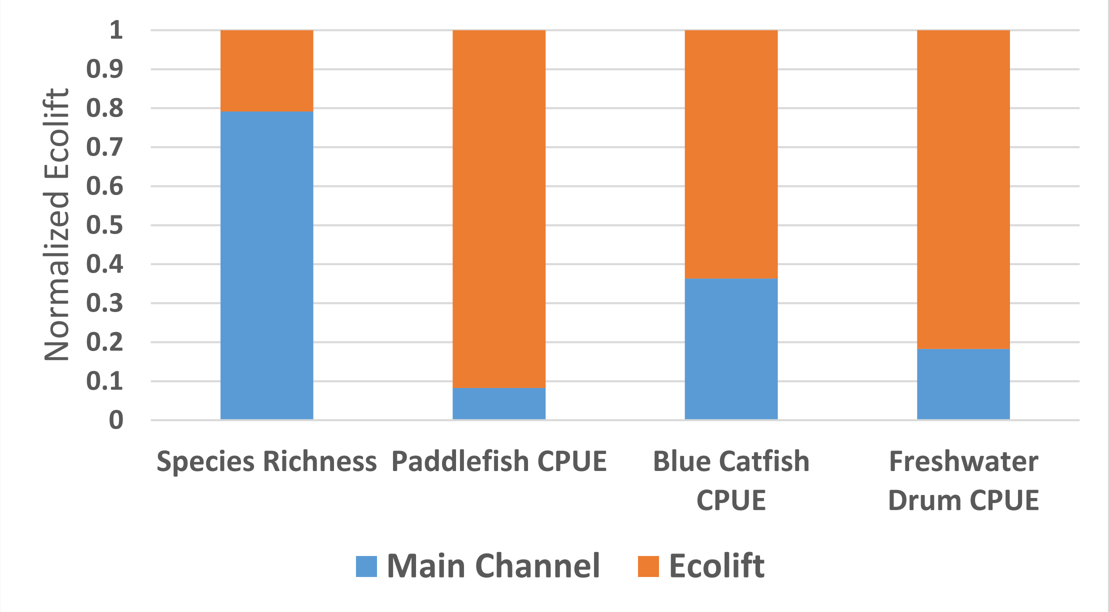


Figure 15. Catch Per Unit Effort (CPUE) for Paddlefish Polyodon spathula, Blue Catfish Ictalurus furcatus, Freshwater Drum Aplodinotus grunniens. Output is a binary response, for example without eddies Paddlefish HSI=0.1, with eddies the HSI=1.0.

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Model Name: Borrow Area Habitat Suitability Index Fish Diversity Models

Authors: Jack Killgore, Jan Hoover, Amanda Oliver, Todd Slack, Catherine Murphy.

Functional Area: Planning, Mississippi River Levees Supplemental Environmental Impact Statement #2

Geographic Application: Mississippi River Batture from Cape Girardeau, MO to Head of Passes, Louisiana

Model Proponent: USACE Districts Memphis, Vicksburg, and New Orleans

Model Developer: ERDC-EL

Abstract

A Habitat Suitability Index model for fish assemblages in borrow areas along the Mississippi River was developed using rotenone data collected in 1981 and 1996-97. The model will be used in the Habitat Evaluation Procedure to evaluate alternatives (i.e., number, size, and morphology of borrow areas) for the Mississippi River Levees Supplemental Environmental Impact Statement #2. Multiple regression was used to evaluate relationships between borrow area habitat features (e.g., depth morphometry, connectivity, water quality) and different species diversity measures including richness, evenness, and dominance. Standardized species richness based on rarefaction was selected as the final dependent variable in the model and was positively correlated to a volume development index (shape), maximum depth, the presence of some shallow water, and lower turbidity. A Relative Value Index was calculated from seining and gillnet data collected in 1997 and 2019 to compare the habitat value between riverside and landside borrow areas. Overall, riverside borrow areas were more diverse than landside. The model identifies significant habitat variables of borrow areas that maximize species richness and can be used to specify environmental design features during construction.

Background

The Mississippi River Levees (MRL) Supplemental EIS #2 was authorized under the Flood Control Act of 1928, as amended, and funds were appropriated by the Energy and Water Development, Mississippi River and Tributaries maintenance. The project includes raising and widening deficient portions of the levee to its authorized design grade and cross-section using material from borrow areas (also referred to as pits) or other sources, and installing measures to manage seepage during periods of high water in those areas at risk of losing levee foundation materials (Mike Thron, Memphis District, pers.com, May 2018). Measures to avoid and minimize impacts such as prioritizing borrow area excavation and placement, will be included in the alternative analyses. The project extends along the mainline levee system from Cape Girardeau, Missouri to Head of Passes, Louisiana.

A Supplemental Environmental Impact Statement is being prepared for this project to address an array of alternatives that include borrow pit construction. Statistical models were developed to predict fish diversity as a function of morphological and water quality attributes of borrow areas and normalized as Habitat Suitability Indices to evaluate environmental consequences of constructing these permanent or semi-permanent waterbodies in the Lower Mississippi River batture (i.e., floodplain). The Habitat Evaluation Procedure will be used to evaluate alternatives (i.e., number, size, and morphology of borrow areas) including environmental design features to optimize aquatic habitat of borrow areas. The HEP multiplies a Habitat Suitability Index (HSI) value ranging from 0 (no habitat value) to 1.0 (optimum Habitat Value), by area (e.g., acres) of the project location to obtain Habitat Units (HU's) (USFWS 1980). Comparison of HU's before and after project construction provides a measure of impacts or benefits to the aquatic ecosystem. Converting statistical models to a HSI value conforms to the application of the Habitat Evaluation Procedure to analyze an array of alternatives and conduct incremental analysis of project benefits.

Objectives

The objective of this analysis was to develop Habitat Suitability Index (HSI) models for USACE certification to predict changes in fish diversity as borrow areas are being created, enlarged, or deepened to raise the elevation of the Mississippi River mainline levee system. Data used in model construction were derived from 1-acre rotenone samples in 25 borrow pits collected in 1981 for the Lower Mississippi River Environmental Program, and 8 borrow areas in the mid-1990s for the original MRL project. In addition, riverside and landside borrow areas were sampled in 1997 and 2019 for a total sample size of 15 to compare differences in fish assemblages on both sides of the levee. These data will be used to develop a relative value index (RVI) for landside borrow areas not connected to the Mississippi River. The HSI models will eventually be used in the Habitat Evaluation Procedure to quantify changes in fishery habitat due to borrow area construction as part of the SEIS #2, and will provide guidance on the environmental design of borrow areas to maximize benefits to individual species and the fish assemblage as a whole.

Methods

Location

Ecological surveys of 25 main-line levee borrow areas along the lower Mississippi River were conducted in the early 1980's using rotenone to collect fish. Results were published in a series of four reports, one of which summarized fishery investigations (Cobb et al.1984) and another provided environmental design considerations for borrow areas (Aggus and Plosky 1986). In 1996-97, eight riverside borrow areas, seven of which were previously sampled by Cobb et al. (1984), were sampled with rotenone. These databases were combined for a total of 33 borrow areas sampled in the batture bordering Missouri, Tennessee, Arkansas, Mississippi, and Louisiana (Table 1). In addition, five riverside and four landside borrow areas were sampled with seines and gillnets. Precipitation maintains water levels in landside borrow areas whereas periodic connection to the river and hyporheic flow maintains water levels in riverside areas. The same five riverside borrow areas were sampled in 2019 using seines and gillnets, and an additional borrow area was added in 2019 at Modoc, AR for a total sample size of 15 borrow areas (Table 1).

Habitat Variables

Borrow areas were sampled in mid- to late summer during both decades when isolated from the Mississippi River. The same water quality, hydrologic, and morphometric variables measured by Cobb et al. (1984) were obtained by survey crews in 1996-97. Water quality was measured at the water's surface with calibrated multi-parameter meters. Variables included water temperature, dissolved oxygen, pH, conductivity, and turbidity. Bathymetric and ground surface elevations were measured by survey teams to calculate mean depth, maximum depth, area, volume, percent area with depth greater than 5-ft, and percent area with depth greater than 10 ft. The controlling elevation for each borrow area was used as the water surface elevation in calculating surface area and volume. The controlling elevation is the low point of the borrow area basin rim and is the elevation below which water cannot drain out by gravity, or conversely, the elevation of the river above which water must rise to enter the area. Borrow area flooding, or days flooded, was assumed to occur when river stage exceeded the controlling elevation taking into account major topographic features that could influence stages in the borrow area vicinity (Cobb et al. 1984).

Borrow area morphometry was expressed as a Volume Development Index (VDI) and Shoreline Development Index (SDI). Volume Development Index is the ratio of the calculated volume of the borrow area to the volume of a cone with basal area and height equal to the surface area and maximum depth. Thus, if VDI=1 the borrow area basin would resemble a cone; if VDI< l the borrow area basin would be very slender or rectangular; if VDI > 1 it would be more bowl-shaped. Shoreline Development Index is the ratio of the actual borrow area shoreline length to the circumference of a circle with the same area. Circular borrow areas have an SDI near 1.0, and SDI increases it becomes more elongated. The degree of shoreline irregularity and amount of littoral zone increase with increasing values of SDI (Cobb et al. 1984).

Fish Sampling

All borrow areas were sampled from late July to mid-September. For riverside borrow areas, two 1-acre plots were blocked off by nets with 0.5-inch mesh and rotenone applied to achieve a minimum of 1-2 mg/l concentration. Potassium permanganate was applied around the periphery of the plot to detoxify rotenone drifting outside the target area. Surfacing fish were collected, identified to species, measured (total length to the nearest mm), and weighed (Davies and Shelton 1983). Fish pickup occurred for 2 consecutive days after rotenone was applied. Fish assemblage of each borrow area was expressed on a per acre basis, which is the traditional method of reporting fish standing crop. However, number of fish per acre-ft can be calculated if volumetric estimates are required. These data were used to develop the HSI model.

Seines and gillnets were used in both riverside (1997 and 2019) and landside borrow areas (Table 1). Shoreline fishes were collected using a 20' X 8' seine with 3/16" mesh; standard effort was 10 hauls stratified among all apparent macrohabitats. Pelagic (offshore) fishes were collected with gillnets (90' X 6' with 0.75, 1.5, 2.0, 2.5, 3.0, 3.5" stretch mesh); standard effort was overnight sets of 3-5 gillnets set perpendicular to shore. Shoreline fishes were preserved in 10% formalin. Larger fishes were identified in the field and released. In the laboratory, fishes were washed, identified, and counted. Specimens were catalogued and deposited as holdings in the Museum of Natural Science, Jackson, MS. As mentioned previously, these data were used to compare fish assemblages between riverside borrow areas seasonally contiguous with the river and landside borrow areas permanently isolated from the river.

Model Development

Fish diversity of borrow areas was calculated from the all fish collections using Primer 7.0 (Clarke and Gorley 2015). Diversity is a collective property of fish communities and reflects species-abundance relationships of the collection. It is responsive to both species richness (the number of species) and species evenness (the distribution of individuals among those species). Diversity can be measured in various ways, but is typically expressed as "heterogeneity indices" that incorporate species richness and evenness into a single value, showing varying sensitivity to either richness or evenness components (Magurran, 1988).

Diversity measures used in this study are standardized species richness (S), Pielou's evenness index (J'), and Simpson's dominance index (D) (Magurran 1988; Ludwig and Reynolds 1988). Standardized species richness is a probability-based method that addresses disparate numbers of individuals in a series of collections by quantifying the number of species expected in a random sub-sample of individuals taken from each collection. It is calculated by a process called rarefaction, is expressed as the number of species expected for a sub-sample of given size, and can range from 1 to the total number of species in the community (S*) which is assumed to be the number observed in each collection. Mean abundance (i.e., number per acre) was used in calculating standardized species richness.

Evenness quantifies how individuals in a collection are distributed among species, specifically how they diverge from an equitable distribution among all the species. Pielous evenness index (J') is a ratio of an observed logarithmic function (Shannon's H') to a hypothetical community in which all species are equally common (H'_{max}): $J' = H' / \log_e S$, where S is total number of species. It ranges from values near 0.00 (numerical domination by one or a few species to values near 1.00 (comparable abundance of all species).

Dominance (D) is similar in concept to evenness but is an exponential function rather than a logarithmic function. This index quantifies the probability that two individuals drawn at random from a collection will be members of the same species. Dominance used in this analysis is designated as 1-Lambda' in Primer 7.0. It ranges from values near 0.00 (almost inevitable that two sequential draws will be from the same species) to values near 1 (unlikely that two sequential draws will be from the same species). Dominance (λ) is calculated as:

$$1-\lambda' = 1 - (\textstyle\sum_i N_i(N_i - l)) / (N(N-1))$$

where the abundance of the ith species is denoted by N, (i = 1, 2, .., S) and divided by their sum (N).

Multiple regression models were developed to predict diversity (dependent or response variable) as a function of habitat parameters (the independent or predictor) that describe the morphology and water quality of borrow areas (Table 2). Multiple regression equations are empirical, do not entail a priori decisions regarding relationships between habitat parameters and fishes, and thus reduce institutional bias. Instead, habitat value is assessed directly from baseline relationships between fish abundance (density or biomass) and physical habitat (area morphometry, flood frequency, and water quality). Multiple regression eliminates irrelevant variables from the final predictive model and quantifies correlation between habitat variables and fish abundance.

Multiple regression equations were generated with the REG Procedure in SAS v. 9.4 (SAS Institute Inc., Cary, NC, USA). A two-tailed entry level selection value of the independent variables was set at $\alpha = .05$, and any independent variable entered would remain in the model at a significance level of $\alpha < 0.05$. The final model is achieved when no variables outside of the model meet these criteria. These criteria aid in retaining independent variables that may be important in the final model. Not all model intercepts were statistically different from zero. Adjusted R-squared value (R^{2}), which was based on Pearson product-moment correlation coefficients and includes a penalty for over-fitting, was used to assess model fit after stepwise selection. Multicollinearity among independent variables was assessed by examining variance inflation factor, which estimates how much the variance of a regression coefficient is inflated due to multicollinearity in the model. Influence of outliers was determined objectively using a combination two statistical tests: studentized residual values and Cook's distance. Residual plots on predicted values were used to evaluate suitability of the final model. The model was suitable based on the symmetrical pattern and constant spread observed in the range of the residuals indicating that the variables used in the model adequately predict the response in fish diversity. Standardized species richness was calculated for the seine and gillnet data. Mean values were compared between riverside and landside borrow areas. A Relative Value Index (USFWS 1980) was calculated as follows: $((\Sigma x_i) / n) / (\Sigma y_i) / n))$, where x = richness value of landside borrow areas, y = richness values of riverside borrow areas, and n is the number of observations for each category. The RVI was used to weight the difference in HSI values between riverside and landside borrow areas.

The following are uses and model assumptions:

1) Model provides guidance on the construction of environmentally-enhanced borrow areas by identifying and quantifying correlations between physical habitat variables and species diversity.

2) Model only accounts for a portion of the variability in fish diversity and is sensitive to outliers.

3) Model does not imply causality.

4) Sampling methods must be similar for two samples to be compared by these indices and the communities to be compared should be taxonomically similar (Ludwig and Reynolds 1988). Since rotenone was used to collect fish, and all sampling was conducted in the LMR batture, these two requirements were met.

5) The model is not predictive for individual borrow areas over time because it does not address successional changes in physical habitat or hydrologic regime due to extremities in wet and dry

periods. However, if successional changes can be identified, then short-term and long-term habitat-based shifts in fish diversity can be forecast by adjusting habitat inputs in the model.

Results and Discussion

Habitat

Borrow areas sampled in the battue represented a wide range of morphometric and water quality characteristics. They ranged in size from 3 to 53 acres with mean depths ranging from less than 1 foot up to 7 feet (Table 2). Maximum depth measured in any one borrow area was 17.7 feet, but mean percent area greater than 10 feet was only 3%. Overall, the typical borrow area in the LMR batture was less than 20 acres and averaged 3 feet in depth. The mean Shoreline Development Index ranged from 2.1 to 2.7 depending on sampling years with a maximum value measured of 5.8. Most borrow areas are rectangular or bowl shaped (i.e., VDI>1.0) and shorelines often become more irregular over time increasing SDI above 2.0.

The number of days borrow areas were flooded ranged from 24 to 117 with means of 69 to 81 days depending on the year sampled (Table 2). Borrow areas were not connected to the river during summer sampling. However, most borrow areas are connected to the river each year as floodwater approaches the levees. Water quality was typical for summer conditions in relatively shallow, permanent waterbodies in the batture. Mean water temperature was high (>31 ºC) with no observable flow, and some borrow areas were hypoxic (< 3 mg/l dissolved oxygen) and turbid (> 50 NTU),

Principal Component Analysis of borrow area habitat illustrates the range of conditions sampled and changes in morphometry between 1981 and 1996-97 (Figure 1, Table 3). Depth decreased in all borrow areas between the two time periods. Borrow areas 2 and 13 had moderate reductions in depth, whereas borrow areas 6, 9, 15, 17 and 25 became much shallower and smaller over the 15-year period. Depth and area in number 17 was reduced by 50%, the highest value documented. Comparison among the two time periods indicate that most borrow areas are aggrading from vertical accretion during flood events, becoming shallower and smaller in size. This trend should be taken into account when annualizing project life span.

Fish Community

Overall, 75 species of fish were collected from riverside borrow areas in 1981 and 1996-1997 (Table 4). The number of species collected per borrow area ranged from 18 to 50 with a mean (±1SD) of 31 ± 8. The number of fish per acre ranged from 829 to 62,160 with a mean of 11,320 ± 11,579. Taxonomically dominant groups were minnows (16 spp) and sunfishes (13 spp). Catfishes, suckers, and darters were moderately speciose (7-8 spp.). Invasive carps (minnow family) were only collected in 1996-97: Grass Carp, Silver Carp, and Bighead Carp. Numerically abundant species were forage fishes including Gizzard Shad, Threadfin Shad, and juvenile sunfishes. None of the species collected are federally listed as threatened or endangered, but several species are regionally imperiled (Robison and Buchanan 1988; Jelks et al. 2008).

Paddlefish are listed by eight southern states, including Arkansas, are protected year-round in the state of Louisiana and seasonally in the state of Mississippi. Listing is proposed by the Committee on International Trade in Endangered Species (CITES) in 1998 (Cites 1997). Alligator Gar have declined substantially during the past 40 years and are listed by the states of Tennessee and Arkansas. Taillight shiner typically occur in undisturbed oxbow lakes and swamps and are listed by the state of Arkansas. Golden topminnow, also an inhabitant of oxbows and swamps, are assumed extirpated in Missouri and listed by the state of Tennessee. Borrow areas with riverine connections function similarly to oxbow lakes and may provide alternate habitat and refugia during high water events for riverine and wetland species declining elsewhere in their range (Miranda et al. 2013).

Borrow area fish communities were described using three different measures of species diversity. Standardized species richness ranged from 18 to 44 species/11,500 individuals (i.e., approximates mean number of fish per acre), similar to total observed number of species that ranged from 18 to 50 (Table 5). However, rarefaction is less bias to sample size than raw species richness. Pielou's evenness index ranged from 0.2, indicating the presence of a few dominant species, to 0.7 indicating similarity in abundances among the species. Simpson dominance index ranged from 0.2 to 0.9 corresponding to the evenness metric that some borrow areas are dominated by only a few species. Gizzard Shad, Threadfin Shad, and juvenile sunfishes comprised almost 75% of the total individuals in borrow areas contributing to low evenness and high dominance. Other species represented 5% or less of the total individuals.

Comparison of the diversity measures between decades showed species richness increasing from 1981 to 1996-97, evenness remaining steady, but dominance shifting either up or down (Table 3). In addition to the three dominant species mentioned previously, Bluegill Sunfish, Channel Catfish, Orangespotted Sunfish, and White Crappie were common in the collections and further contributed to low evenness and high dominance of riverside borrow area fish communities. These species are widespread throughout the LMR and most are considered generalists in their tolerance to habitat and water quality fluctuations.

Habitat Suitability Index Model

Habitat Suitability Index models were developed using multiple regression for the three measures of diversity. Models for species evenness and dominance had low to moderate predictive capability with adjusted R^2 values less than 0.45 even with outliers removed (Table 6). Significant variables used in the model required an entry level of $\alpha = .1$ and retention selection value of $\alpha = .05$ thus weighting their importance in predicting species richness. However, turbidity was the only independent variable that met these criteria for evenness and dominance. Low predictive capability and selection of only one independent variable may be due to the restricted range of possible values (as compared to species richness) and inherent bias of ratio-based measures.

Standardized species richness was highly significant, and with outliers removed, the adjusted R^2 was 0.83. Six outliers were removed, decreasing the sample size from 33 to 27, to increase R^2 while retaining significant independent habitat variables influencing species richness. Outliers removed either had high dominance of one or two species (i.e., Threadfin Shad, Gizzard Shad, and small sunfish), or spurious correlations to the independent habitat variables. A final set of observations highly influential to the coefficient values were removed if they had a high predictive residual (> 7), high student residual (>3), or high Cook’s D value (>0.3) (Zuur et al. 2010). These measures were used to maximize the coefficient of determination resulting in the removal of the six borrow areas to achieve an R^2 of 0.83. Residuals did not show an obvious pattern, indicating that errors have constant variance and there was no indication of correlated or missing variables (Figure 2). Therefore, the model met the assumption of independence for parametric analysis and errors were normally distributed.

The multiple regression analysis retained four independent variables: Volume Development Index, maximum depth, percent area greater than 5 ft, and turbidity. Volume Development Index and maximum depth were positively correlated to species richness, while percent area greater than 5 ft and turbidity were negatively correlated possibly due to low dissolved oxygen near the bottom. This combination of variables indicates that high species richness is associated with borrow areas more bowl-shaped than rectangular, areas with deep water (>6-7 feet), and lower turbidity. The negative correlation of percent area greater than 5 ft suggests that borrow areas with a combination of deep water and some areas less than 5 feet optimize species richness. Negative correlation of turbidity should be considered by creating riparian buffers around the borrow area to filter sediment runoff, provide additional windbreaks to reduce wave action, or implement some level of bank stabilization.

The predicted standardized species richness was divided by the maximum richness value (i.e., 43 species) observed in the 27 borrow areas retained in the analysis to normalize a HSI score between 0 and 1 (Equation 1).

Equation 1:

$$\mathbf{HSI} = \frac{31.2(\text{VDI}) + 2.2\,(\text{Maximum Depth}_{\text{ft}}) - 0.2(\text{Percent Area}{>}5\text{ft}) - 0.1(\text{Turbidity}_{\text{NTU}}) - 24.3}{43}$$

The model was highly significant (F=31.74, p<0.0001) with parameter estimates indicating that borrow area morphometry (i.e., VDI) has the greatest influence on HSI scores followed by maximum depth (Table 7). The presence of some shallow areas and reduced turbidity were statistically significant but were less influential on overall HSI scores. The variance inflation estimates, which indicate how much the variance of regression coefficients are inflated due to multicollinearity in the model, was low (1) to moderate (4) suggesting a moderate to high reliability in predicting species richness from a combination of these habitat variables (Table 7).

The calculated HSI may occasionally exceed 1.0 or fall below 0 when using habitat values outside the range of those measured in the borrow areas; these values will be rescaledto 0.1 or 1.0. For application to the MRL project, HSI values will be multiplied by area (acres of borrow areas) to express project alternatives as Habitat Units (HU).

Relative Value Index for Landside Borrow Areas

Rotenone sampling was not conducted in landside borrow areas. As an alternative to compare species assemblage differences between riverside and landside, seining and gillnets were used in both types of borrow areas. Overall, fish were more abundant and diverse in riverside borrow areas than landside. A total of 18 species were collected with gillnets in landside borrow areas during 1997 compared to 31 and 30 species in riverside borrow areas during 1997 and 2019, respectively (Table 8). Gizzard shad was the most abundant species in all borrow areas. Species associated with riverine environments were common in riverside borrow areas but mostly absent or in low abundance in landside borrow areas. These include Mooneye, Alligator Gar, White Bass, River Carpsucker, and Sauger. Seining had similar results. A total of 17 species were collected landside compared to 38 and 44 species riverside during the 2007 and 2019 collections, respectively (Table 9). Four species comprised over 80% of the total individuals in landside borrow areas: Orangespotted Sunfish, Largemouth Bass, Inland Silverside, and Bluegill. With the exception of Inland Silverside, the three remaining species are habitat generalists and often found in isolated ponds and lakes.

Species diversity measures showed the same trends (Tables 10 and 11). For gillnets, species richness was 25 to 33% higher and catch-per-unit-effort (i.e., number per 10 hauls) was more than twice as high in riverside borrow areas. However, landside borrow areas were more likely to be dominated (i.e., lower D score) by one species, usually Gizzard Shad (Table 8). Seining data were even more pronounced. Species richness was twice as high in riverside borrow areas for both years. Evenness was higher in riverside borrow areas characterized by a more equitable abundance among a more diverse assemblage. Mean catch-per-unit-effort was three times higher in riverside borrow areas. Similar to gillnet data, landside pits were more likely to be dominated by only a few, tolerant species (Table 9).

The average percent difference in standardized species richness between landside and riverside borrow areas was calculated separately by gear type, and the mean value was designated as the RVI. The two gears sample a different component of the fish assemblage and taking the mean value provides a more complete description of both small, littoral fish (seining) and larger pelagic fish (gillnets).

The RVI was calculated as follows:

Percent difference using gillnets: 3.8 / 5.4 = 0.70
Percent difference using seines: 9.5 \ 18.5 = 0.51
RVI, Mean of gillnets and seines: 0.6

For landside borrow areas, the HSI value calculated from Equation 1 will be multiplied by 0.6 prior to calculating Habitat Units. The resulting value takes into account lower species richness in landside borrow areas based on seining and gillnet data collected in each type.

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Table 1. Location of 31 borrow areas sampled in 1981, 1996-97, and/or 2019. Borrow areas with an asterisk designated as outliers for the standardized species richness model (see Table 6).

Borrow Area	Location	River Mile	Descending Bank	Distance to River (Miles)	Year Sampled Rotenone		Year Sampled Gillnet/Seine		USACE District
					1981	1996-97	1997	2019	
1*	Madison Parish, LA	431	R	0.3	X*				Vicksburg
2	Tensas Parish, LA	407	R	2.4	X	X			Vicksburg
3	East Carroll Parish, LA	469	R	0.4	X				Vicksburg
4*	East Carroll Parish, LA	482	R	0.4	X*				Vicksburg
5	East Carroll Parish, LA	462	R	0.6	X				Vicksburg
6	Madison Parish, LA	433	R	1.3	X	X			Vicksburg
7	Warren County, MS	460	L	0.9	X				Vicksburg
8	Bolivar County, MS	593	L	0.3	X				Vicksburg
9	Bolivar County, MS	595	L	1.1	X	X			Vicksburg
10	Madison Parish, LA	456	R	0.1	X				Vicksburg
11*	Bolivar County, MS	602	L	2.1	X*				Vicksburg
12	Concordia & Tensas Parish, LA	377	R	0.7	X				Vicksburg
13	Phillips County, AR	656	R	0.3	X	X*	X	X	Memphis
14	Desha County, AR	584	R	4.3	X				Memphis
15	Coahoma County, MS	659	L	1.8	X	X	X	X	Memphis
16	Concord Parish, LA	355	R	0.2	X				Vicksburg
17*	Mississippi County, AR	773	R	2.3	X*	X	X	X	Memphis
18	Concord Parish, LA	323	R	1.8	X				New Orleans
19	New Madrid County, MO	877	R	0.8	X				Memphis
20	Concord Parish, LA	305	R	0.3	X				New Orleans
21	New Madrid County, MO	881	R	2.5	X				Memphis
22	Concord Parish, LA	315	R	0.4	X				New Orleans
23	Shelby County, TN	720	L	1	X				Memphis
24	St. James Parish, LA	151	L	0.1	X				New Orleans
25*	Ascension Parish, LA	180	L	0.1	X*	X	X	X	New Orleans
Bayou Goula	Iberville Parish, LA	194	R	0.1		X	X	X	New Orleans
Lake Providence-1	East Carroll Parish, LA	497	R	3.6			X		Vicksburg

Lake Providence-2	East Carroll Parish, LA	494	R	3.5			X		Vicksburg
Lake Providence-3	East Carroll Parish, LA	493	R	2.3			X		Vicksburg
Lake Providence-4	East Carroll Parish, LA	492	R	1.8			X		Vicksburg
Modoc	Phillips County, AR	634	R	1.0				X	Memphis

Table 2. Mean values for water quality and morphometrics of borrow areas sampled in 1981 and 1996-97, Lower Mississippi River. Water quality was measured 0.5 m below water surface generally in the middle of the borrow area.

Year	Variable	Mean	Median	Standard Deviation	Minimum	Maximum
1981 N=25	Water Temperature, °C	31.7	31.8	2.0	27.0	35.5
	Conductivity, µmhos/cm	310.7	315.0	89.3	75.0	505.0
	Dissolved Oxygen, mg/l	6.8	6.5	2.5	0.6	11.0
	pH	8.1	8.2	0.6	7.0	9.4
	Turbidity, NTU	26.6	18.0	21.0	8.0	85.0
	Surface Area, acres	19.2	12.7	16.5	3.3	53.4
	Average Depth, ft	3.1	2.8	1.8	0.5	7.2
	Maximum Depth, ft	6.5	5.5	4.2	1.1	17.7
	Percent Area > 5 ft	27.5	17.1	27.6	0.0	71.7
	Percent Area > 10 ft	3.2	0.0	7.9	0.0	33.0
	Shoreline Length, ft	6471	4839	3941	1916	15224
	Shoreline Development Index	2.1	2.0	0.6	1.2	3.4
	Volume, ft^3	109039	71813	105021	4056	348228
	Volume Development Index	1.5	1.6	0.3	0.7	1.9
	Basin Slope	0.0	0.0	0.0	0.0	0.1
	Number of Days Flooded Annually	81.3	84.0	23.5	24.0	117.0
1996-97 N=8	Water Temperature, °C	31.4	31.7	4.4	24.2	37.9
	Conductivity, µmhos/cm	281	283	49	205	344
	Dissolved Oxygen, mg/l	6.8	7.3	1.7	3.6	8.6
	pH	8.0	8.0	0.4	7.5	8.4
	Turbidity, NTU	26	26.6	14	7	50
	Surface Area, acres	17.0	17.2	13.3	3.3	41.0
	Depth, ft	3.3	3.4	1.5	1.3	5.8
	Maximum Depth, ft	6.5	5.7	3.5	2.6	12.4
	Percent Area > 5 ft	15.9	10.9	19.6	0.0	53.8

	Percent Area > 10 ft	2.9	0	6.4	0	18
	Shoreline Length, ft	8456	7677	6491	1751	20297
	Shoreline Development Index	2.7	2.4	1.5	1.3	5.8
	Volume, ft^3	88249	77550	77519	7075	175935
	Volume Development Index	1.6	1.6	0.3	0.9	2
	Basin Slope	0.01	0.01	0.08	-0.17	0.1
	Number of Days Flooded	69	64	27	25	114

Table 3. Comparison of mean values of morphometric and water quality variables for riverside borrow areas in the Mississippi River measured during summer of 1981 (Cobb et al. 1984), and 1996-1997. Bayou Goula borrow area in the New Orleans District was not included because it was not sampled in 1981.

Variable	New Orleans		Vicksburg						Memphis					
	Number 25		Number 2		Number 6		Number 9		Number 13		Number 15		Number 17	
	1981	1997	1981	1996	1981	1996	1981	1996	1981	1997	1981	1997	1981	1997
Surface Area, acres	36.9	26.5	18.6	18.76	4.5	4.5	3.3	3.26	53.4	22.7	53.4	41.0	38.1	15.6
Mean Depth, ft	5.6	3.7	5.7	5.8	3.8	2.7	1.7	1.3	3.8	3.8	3.9	4.2	3.0	1.5
Maximum Depth, ft	10.3	7.1	10.4	10.7	6.0	5.3	3.5	2.6	16.9	12.4	7.5	6.1	5.7	2.6
Percent Area > 5 ft	66.9	26.7	71.0	53.8	55.5	0	1.6	0	30.9	21.7	44.6	25.0	21.9	0
Percent Area > 10 ft	7.6	0	21.4	5.1	0	0	0	0	8.3	18.0	0	0	0	0
Shoreline Length, ft	15,224	12,196	4,839	5336	5,737	3,135	1,916	1,751	14,008	20,297	8,881	12,626	10,498	10,015
Shoreline Development	3.4	3.2	1.5	1.7	1.5	2.0	1.4	1.3	2.6	5.8	1.6	2.7	2.3	3.5
Volume, yds^3	25,348	160,000	178,733	176,080	27,4421	19,708	9,780	7,075	309,178	131,476	348,228	170,985	183,100	23,624
Volume Development Index	1.6	1.6	1.6	1.6	1.9	1.6	1.5	1.6	0.7	0.9	1.6	2.0	1.6	1.8
Mean Basin Slope	0.07	0.10	0.05	0.048	0.02	0.001	0.03	0.012	0.05	0.012	0.02	0.0028	0.03	0.0025
Number of Days Flooded Annually	81	114	71	66	89	80	84	62	56	82	56	82	25	46
Dissolved Oxygen, mg/l	5.2	4.1	5.6	5.3	4.2	5.6	10.2	11.6	8.9	7.3	5.6	8.2	9.5	3.6
pH	7.9	7.4	8.1	7.7	7.6	8.1	8.2	8.9	8.4	7.5	7.7	8.4	8.1	7.5
Conductivity, µmhos/cm	336	282	205	344	341	342	432	287	318	269	368	228	234	205
Water Temperature, °C	32	31.6	32	31	32	32	31	29	34	35	33	36	33	24
Turbidity, NTU	10	35	42	22	18	15	13	44	8	7	10	33	16	27
Standardized Species Richness, S	26	40	28	40	33	38	27	26	29	44	32	43	20	33
Pielou's Evenness, J'	0.21	0.23	0.58	0.36	0.52	0.32	0.60	0.54	0.47	0.44	0.52	0.50	0.42	0.52
Simpson's Dominance, D	0.29	0.64	0.73	0.49	0.74	0.43	0.80	0.76	0.71	0.69	0.72	0.69	0.65	0.74

Table 4. Species abundance (number/acre) for fish collected in borrow areas during 1981 (n=25) and 1996-97 (n=8).

Family	Genus, Species	Common Names	1981	1996-1997	Totals
Polyodontidae (paddlefish)	*Polyodon spathula*	Paddlefish	44	41	85
Lepisosteidae (gars)	*Atractosteus spatula*	Alligator gar		1	1
	Lepisosteus oculatus	Spotted gar	587	407	994
	Lepisosteus osseus	Longnose gar	7	7	14
	Lepisosteus platyrhincus	Shortnose gar	289	11	300
	Lepisosteus sp.	Juvenile gar	20	3	23
Amiidae (bowfin)	*Amia calva*	Bowfin	42	49	91
Hiodontidae (mooneyes)	*Hiodon alosoides*	Goldeye	15	6	21
	Hiodon sp.	Juvenile Hiodontidae		24	24
Anguillidae (freshwater eels)	*Anguilla rostrata*	American eel	9		9
Clupeidae (herrings)	*Alosa chrysochloris*	Skipjack herring	1	10	11
	Dorosoma cepedianum	Gizzard shad	135590	25021	160611
	Dorosoma petenense	Threadfin shad	50285	7573	57858
	Dorosoma sp.	Juvenile shad	10	3529	3539
Cyprinidae (minnows)	*Ctenopharyngodon idella*	Grass carp		2	2
	Cyprinella lutrensis	Red shiner	20		20
	Cyprinella venusta	Blacktail shiner		2	2
	Cyprinus carpio	Common carp	6942	75	7017
	Hybognathus nuchalis	Mississippi silvery minnow		1	1
	Hypophthalmichthys molitrix	Silver carp		1	1
	Hypophthalmichthys nobilis	Bighead carp		2	2
	Lythrurus fumeus	Ribbon shiner	160		160
	Macrhybopsis storeriana	Silver chub		20	20
	Notropis atherinoides	Emerald shiner	100	1	101
	Notemigonus crysoleucas	Golden shiner	212	196	408
	Notropis blennius	River shiner	10		10
	Notropis maculatus	Taillight shiner	186	873	1059

	Notropis shumardi	Silverband shiner	67	8	75
	Opsopoeodus emiliae	Pugnose minnow	191	1151	1342
	Pimephales vigilax	Bullhead minnow	140	16	156
	Notropis sp.	Juvenile minnow/shiner	30	1	31
Catostomidae (suckers)	*Carpiodes carpio*	River carpsucker	357	11	368
	Carpiodes cyprinus	Quillback	3		3
	Carpiodes velifer	Highfin carpsucker	11		11
	Ictiobus bubalus	Smallmouth buffalo	775	192	967
	Ictiobus cyprinellus	Bigmouth buffalo	1355	216	1571
	Ictiobus niger	Black buffalo	138	72	210
	Minytrema melanops	Spotted sucker	7	4	11
	Catostomidae	Juvenile suckers	90		90
	Ictiobus sp.	Junveile buffalo		2	2
Ictaluridae (catfishes)	*Ameiurus natalis*	Yellow bullhead	335	66	401
	Ameiurus melas	Black bullhead	1304	14	1318
	Ameiurus nebulosus	Brown bullhead	2		2
	Ictalurus furcatus	Blue catfish	17	1	18
	Ictalurus punctatus	Channel catfish	2344	703	3047
	Noturus gyrinus	Tadpole madtom	158	66	224
	Noturus miurus	Brindled madtom[1]	10		10
	Pylodictis olivaris	Flathead catfish	15	5	20
Esocidae (pikes)	*Esox americanus*	Grass or Redfin pickerel		6	6
	Esox niger	Chain pickerel	1		1
Aphredoderidae (pirate perch)	*Aphredoderus sayanus*	Pirate perch		22	22
Muglidae (mullets)	*Mugil cephalus*	Striped mullet	2	2	4
Atherinopsidae (silversides)	*Labidesthes sicculus*	Brook silverside	1379	37	1416
	Menidia audens	Mississippi silverside	3035	260	3295
	Atherinopsidae	Juvenile silversides		11	11
Fundulidae (topminnows)	*Fundulus chrysotus*	Golden topminnow	11	17	28
	Fundulus dispar	Starhead minnow		16	16
	Fundulus notatus	Blackstripe topminnow	31	140	171

	Fundulus olivaceus	Blackspotted topminnow	283		283
Poeciliidae (livebearers)	*Gambusia affinis*	Western mosquitofish	4561	77	4638
Moronidae (temperate basses)	*Morone chrysops*	White bass	49	99	148
	Morone mississippiensis	Yellow bass	728	245	973
Centrarchidae (sunfishes)	*Centrarchus macropterus*	Flier		9	9
	Lepomis cyanellus	Green sunfish	36	83	119
	Lepomis humilis	Orangespotted sunfish	13035	2397	15432
	Lepomis gulosus	Warmouth	2907	1280	4187
	Lepomis macrochirus	Bluegill	14515	6562	21077
	Lepomis marginatus	Dollar sunfish		131	131
	Lepomis megalotis	Longear sunfish	4226	206	4432
	Lepomis microlophus	Redear sunfish	97	682	779
	Lepomis miniatus	Redspotted sunfish	32	47	79
	Lepomis symmetricus	Bantam sunfish		213	213
	Micropterus salmoides	Largemouth bass	647	983	1632
	Pomoxis annularis	White crappie	8320	1016	9336
	Pomoxis nigromaculatus	Black crappie	852	901	1753
	Lepomis sp.	Juvenile sunfish	44702	12951	57653
	Pomoxis sp.	Juvenile crappie		50	50
Percidae (perches)	*Etheostoma asprigene*	Mud darter		9	9
	Etheostoma chlorosomum	Bluntnose darter		3	3
	Etheostoma proeliare	Cypress darter		3	3
	Percina caprodes	Logperch	1	11	12
	Percina shumardi	River darter		2	2
	Sander canadense	Sauger	4	11	15
Sciaenidae (drums)	*Aplodinotus grunniens*	Freshwater drum	1943	1372	3315
Totals	75 Species		303275	70237	373512

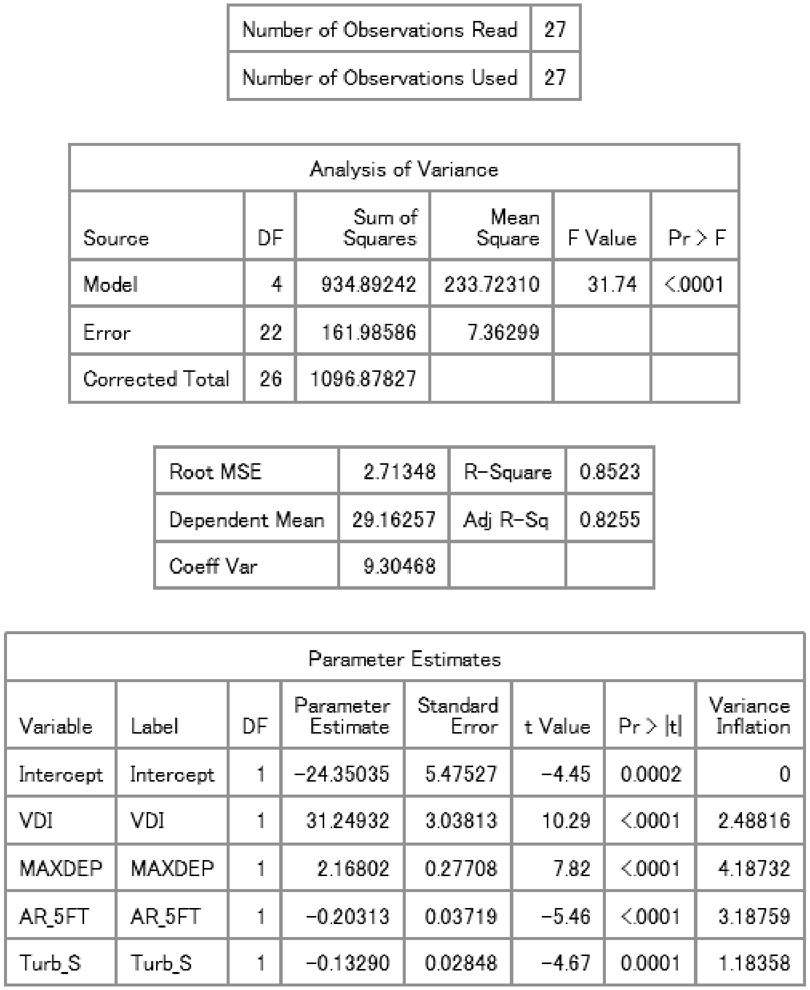
Table 5. Statistical properties of fish species diversity measures for 33 riverside borrow pits sampled in 1981 and 1996-97.

Variable	Mean	Std Dev	Minimum	Maximum
Total species observed, S*	31	8	18	50
Standardized species richness, S/11,500 individuals	29.1	6.8	18.0	44
Evenness, J’	0.5	0.1	0.2	0.7
Dominance, D	0.6	0.2	0.2	0.9
Number of fish per acre	11330	11575	829	62160

Table 6. Multiple Regression Equations and statistical properties of diversity measures for borrow areas in the Lower Mississippi River

Diversity Index	n	Model - Parameter Estimates	Adj-R^2	F	Pr > F	OUTLIERS REMOVED (Borrow Area number/date)
Pielou's Evenness	29	$0.004(\text{Turbidty}_{NTU}) + 0.41$	0.43	22.17	0.0001	3/81, 21/81, 25/81, 23/81
Simpson Dominance	30	$0.003(\text{Turbidy}_{NTU}) + 0.60$	0.17	7.09	0.0127	3/81, 21/81, 23/81
Standardized Richness (Rarefaction)	27	$31.2(\text{VDI}) + 2.2(\text{Maximum Depth}_{ft}) - 0.2(\text{Percent Area}>5\text{ft}) - 0.1(\text{Turbidity}_{NTU}) - 24.3$	0.83	31.74	0.0001	1/81, 4/81, 11/81, 13/97, 17/81, 25/81

Table 7. Statistical output of the multivariate regression analysis for the dependent variable rarefaction (species richness) including parameter estimates and variance inflation scores.



Number of Observations Read	27
Number of Observations Used	27

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	934.89242	233.72310	31.74	<.0001
Error	22	161.98586	7.36299		
Corrected Total	26	1096.87827			

Root MSE	2.71348	R-Square	0.8523
Dependent Mean	29.16257	Adj R-Sq	0.8255
Coeff Var	9.30468		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	-24.35035	5.47527	-4.45	0.0002	0
VDI	VDI	1	31.24932	3.03813	10.29	<.0001	2.48816
MAXDEP	MAXDEP	1	2.16802	0.27708	7.82	<.0001	4.18732
AR_5FT	AR_5FT	1	-0.20313	0.03719	-5.46	<.0001	3.18759
Turb_S	Turb_S	1	-0.13290	0.02848	-4.67	0.0001	1.18358

Table 8. Number of fish collected by species with gillnets in landside and riverside borrow areas. Species are arranged in order of abundance.

Landside 1997, n=23			Riverside 1997, n=29			Riverside 2019, n=37		
Common Name	Frequency	Percent	Common	Frequency	Percent	Common	Frequency	Percent
Gizzard shad	68	37.36	Gizzard shad	98	21.03	Gizzard shad	74	18.78
Bigmouth buffalo	21	11.54	Spotted gar	78	16.74	Spotted gar	71	18.02
Common carp	21	11.54	Common carp	59	12.66	Smallmouth buffalo	46	11.68
Spotted gar	15	8.24	Bigmouth buffalo	32	6.87	Shortnose gar	41	10.41
White crappie	9	4.95	Smallmouth buffalo	30	6.44	Channel catfish	31	7.87
Channel catfish	7	3.85	Bowfin	27	5.79	Black buffalo	25	6.35
Bowfin	6	3.3	Channel catfish	27	5.79	River carpsucker	14	3.55
Freshwater drum	6	3.3	Black buffalo	16	3.43	Bigmouth buffalo	12	3.05
Black bullhead	5	2.75	Freshwater drum	14	3	Bowfin	10	2.54
Largemouth bass	5	2.75	Largemouth bass	14	3	Common carp	10	2.54
Threadfin shad	4	2.2	White crappie	9	1.93	Silver carp	10	2.54
Warmouth	4	2.2	Warmouth	8	1.72	Black crappie	8	2.03
Black crappie	3	1.65	Black crappie	6	1.29	Longnose gar	7	1.78
Bluegill	3	1.65	Bluegill	6	1.29	Threadfin shad	6	1.52
Black buffalo	1	0.55	Mooneye	6	1.29	Freshwater drum	5	1.27
Blue catfish	1	0.55	Black bullhead	4	0.86	Striped mullet	4	1.02
Paddlefish	1	0.55	Dollar sunfish	4	0.86	Blue catfish	3	0.76
Smallmouth buffalo	1	0.55	Paddlefish	4	0.86	Orangespotted sunfish	3	0.76
Yellow bass	1	0.55	Shortnose gar	4	0.86	Bluegill	2	0.51
			Yellow bass	4	0.86	Flathead catfish	2	0.51
			Flathead catfish	2	0.43	White crappie	2	0.51
			Spotted sucker	2	0.43	Lepomis sp.	1	0.25
			Threadfin shad	2	0.43	Morone sp.	1	0.25
			Yellow bullhead	2	0.43	Paddlefish	1	0.25
			Alligator gar	1	0.21	Quillback	1	0.25

			Blue catfish	1	0.21	Skipjack herring	1	0.25
			Redear sunfish	1	0.21	Spotted sucker	1	0.25
			River carpsucker	1	0.21	Warmouth	1	0.25
			Sauger	1	0.21	White bass	1	0.25
			White bass	1	0.21			

Table 9. Number of fish collected by species with seines in landside and riverside borrow areas. Species are arranged in order of abundance.

Landside 1997, n=4			Riverside 1997, n=5			Riverside 2019, n=6		
Common Name	Frequency	Percent	Common Name	Frequency	Percent	Common Name	Frequency	Percent
Orangespotted sunfish	713	36.3	Threadfin shad	2632	31.79	Lepomis sp.	2453	34.39
Largemouth bass	404	20.57	Orangespotted sunfish	1267	15.3	Orangespotted sunfish	2375	33.3
Inland silverside	282	14.36	Bluegill	935	11.29	Inland silverside	369	5.17
Bluegill	235	11.97	Pugnose minnow	804	9.71	Western mosquitofish	284	3.98
Golden shiner	112	5.7	Western mosquitofish	776	9.37	Threadfin shad	281	3.94
White crappie	61	3.11	Lepomis sp.	471	5.69	Bullhead minnow	277	3.88
Golden topminnow	37	1.88	Inland silverside	415	5.01	Bluegill	189	2.65
Gizzard shad	34	1.73	Gizzard shad	152	1.84	Longear sunfish	176	2.47
Threadfin shad	33	1.68	Warmouth	96	1.16	Channel catfish	149	2.09
Mosquitofish	28	1.43	Largemouth bass	90	1.09	Shoal chub	70	0.98
Channel catfish	9	0.46	Longear sunfish	89	1.08	Channel shiner	64	0.9
Black bullhead	5	0.25	Taillight shiner	88	1.06	Freshwater drum	58	0.81
Freshwater drum	5	0.25	Bantam sunfish	69	0.83	Blacktail shiner	51	0.71
Bigmouth buffalo	2	0.1	Blackstripe topminnow	60	0.72	Silver chub	40	0.56
Green sunfish	2	0.1	Redear sunfish	45	0.54	MS silvery minnow	37	0.52
Bantam sunfish	1	0.05	White crappie	43	0.52	Gizzard shad	27	0.38
White bass	1	0.05	Bullhead minnow	39	0.47	Warmouth	25	0.35
			Silver chub	34	0.41	Silverband shiner	24	0.34
17			Channel catfish	28	0.34	Black crappie	22	0.31
			Golden shiner	23	0.28	Redspotted sunfish	21	0.29
			Golden topminnow	21	0.25	Taillight shiner	21	0.29
			Green sunfish	18	0.22	Blackstripe topminnow	20	0.28
			Black crappie	17	0.21	Smallmouth buffalo	19	0.27
			Blackbanded darter	8	0.1	White crappie	12	0.17
			Smallmouth buffalo	8	0.1	Blackspotted topminnow	10	0.14
			Sailfin molly	7	0.08	Brook silverside	10	0.14
			Pirate perch	6	0.07	Pugnose minnow	9	0.13
			Freshwater drum	5	0.06	Bluntnose darter	7	0.1

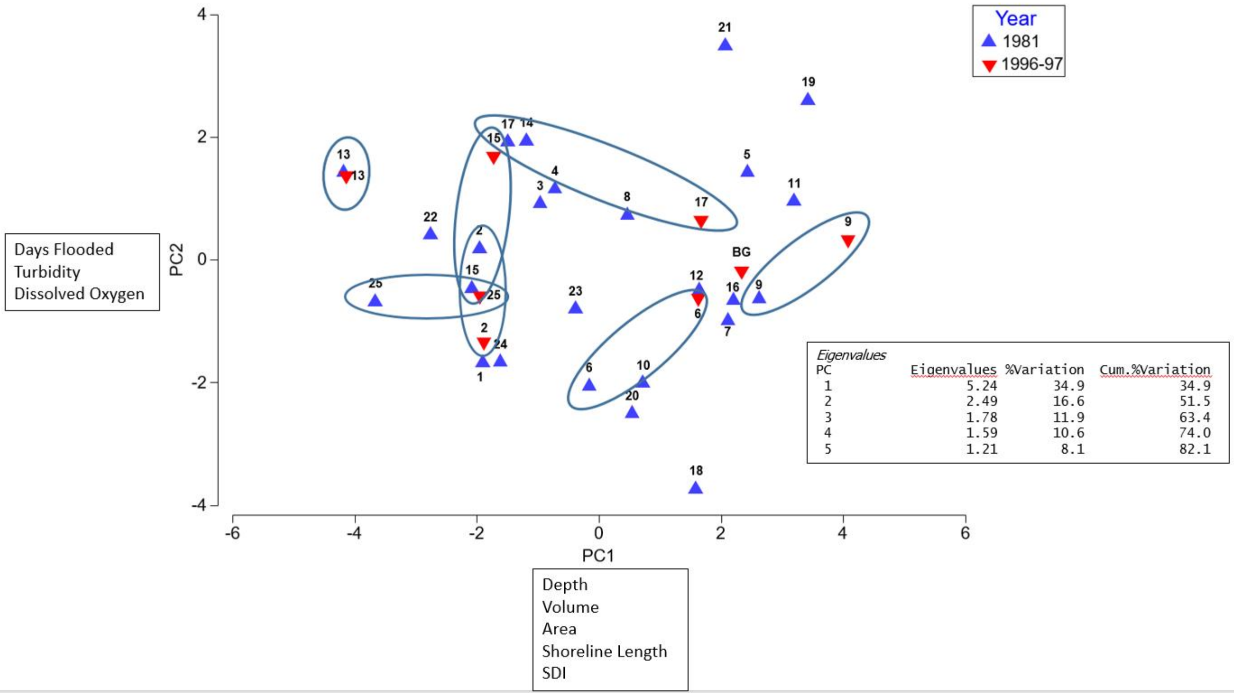
			Yellow bass	5	0.06	Blue catfish	5	0.07
			Bluntnose darter	4	0.05	Green sunfish	4	0.06
			Redspotted sunfish	4	0.05	Pirate perch	3	0.04
			Tadpole madtom	4	0.05	Spotted gar	3	0.04
			Mud darter	3	0.04	Flathead catfish	2	0.03
			Silverband shiner	3	0.04	River carpsucker	2	0.03
			Starhead topminnow	3	0.04	Spotted bass	2	0.03
			Bowfin	2	0.02	Tadpole madtom	2	0.03
			Gulf pipefish	2	0.02	White bass	2	0.03
			Longnose gar	2	0.02	Bantam sunfish	1	0.01
			Common carp	1	0.01	Emerald shiner	1	0.01
						Longnose gar	1	0.01
						Mud darter	1	0.01
						Sauger	1	0.01
						Shortnose gar	1	0.01
						Walleye	1	0.01
						Yellow bass	1	0.01

Table 10. Summary of fish species diversity measures for gillnets set in landside and riverside borrow areas sampled in 1997 and 2019.

Variable	Mean	Std Dev	Minimum	Maximum
	Landside 1997, n=23			
Total species observed, S*	4.0	2.6	0.0	8.0
Standardized species richness, S/12 individuals	3.8	2.4	0.0	8.0
Evenness, J’	0.9	0.2	0.5	1.0
Dominance, D	0.7	0.3	0.0	1.0
Number of fish per gillnet	7.9	6.1	0.0	22.0
	Riverside 1997, n=29			
Total species observed, S*	7.1	3.1	2.0	12.0
Standardized species richness, S/12 individuals	5.7	2.0	2.0	9.0
Evenness, J’	0.9	0.1	0.7	1.0
Dominance, D	0.8	0.1	0.6	1.0
Number of fish per gillnet	16.4	9.3	2.0	34.0
	Riverside 2019, n=37			
Total species observed, S*	5.5	2.4	1.0	13.0
Standardized species richness, S/12 individuals	5.1	1.8	1.0	8.6
Evenness, J’	0.9	0.1	0.7	1.0
Dominance, D	0.8	0.1	0.5	1.0
Number of fish per gillnet	10.4	6.0	1.0	27.0

Table 11. Summary of fish species diversity measures for seining in landside and riverside borrow areas sampled in 1997 and 2019.

Variable	Mean	Std Dev	Minimum	Maximum
	Landside 1997, n=4			
Total species observed, S*	9.5	2.4	8.0	13.0
Standardized species richness, S/1160 individuals	9.5	2.4	8.0	13.0
Evenness, J’	0.5	0.1	0.4	0.6
Dominance, D	0.6	0.1	0.5	0.6
Number of fish per 10-hauls	491	222	199	724
	Riverside 1997, n=5			
Total species observed, S*	19.4	3.8	14.0	24.0
Standardized species richness, S/1160 individuals	18.5	3.3	14.0	22.0
Evenness, J’	0.7	0.1	0.6	0.7
Dominance, D	0.8	0.0	0.8	0.9
Number of fish per 10-hauls	1656	1716	298	3991
	Riverside 2019, n=6			
Total species observed, S*	19.8	7.2	9.0	29.0
Standardized species richness, S/1160 individuals	18.4	5.9	9.0	26.0
Evenness, J’	0.6	0.1	0.3	0.7
Dominance, D	0.7	0.1	0.5	0.8
Number of fish per 10-hauls	1189	1431	66	3237



Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	5.24	34.9	34.9
2	2.49	16.6	51.5
3	1.78	11.9	63.4
4	1.59	10.6	74.0
5	1.21	8.1	82.1

Figure 1. Principal Component (PC) Analysis of morphometric and water quality variables measured in 25 borrow areas, seven of which were sampled twice for a total sample size of n=33. Boxes next to PC axis indicate high loading variables. Ellipses show the relative position of the same borrow areas sampled in 1981 and 1996-97. Cumulative variation accounted for by each PC axis is shown in the inset table.

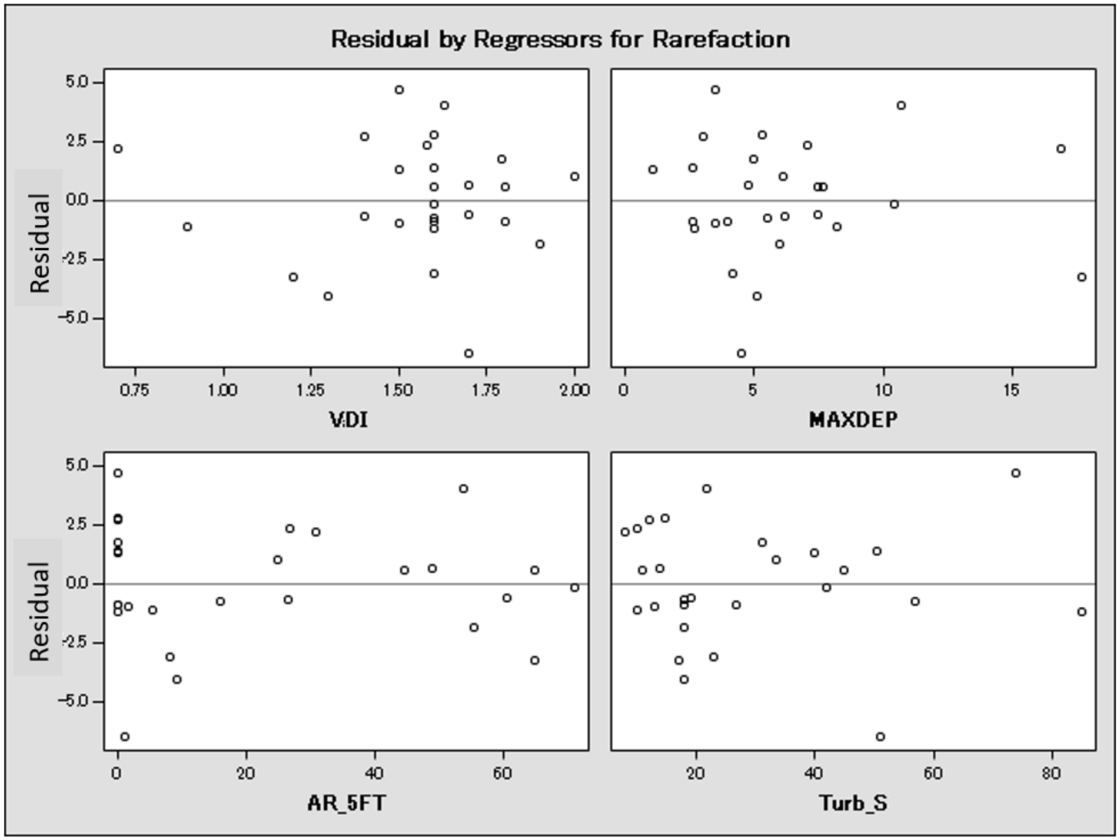


Figure 2. Plot of residuals between predicted rarified species richness and each independent variable: VDI (Volume Development Index, MAXDEP (Maximum depth in feet), AR_5ft (percent area greater than 5 feet in depth, Turb_S (Surface turbidity in NTU).

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Wetlands Regulatory Assistance Program

A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Functions of Forested Wetlands in the Mississippi Alluvial Valley

Elizabeth O. Murray and Charles V. Klimas

July 2013

Environmental Laboratory

Approved for public release; distribution is unlimited.

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A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Functions of Forested Wetlands in the Mississippi Alluvial Valley

Elizabeth O. Murray and Charles V. Klimas

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Final report

Abstract

The Hydrogeomorphic (HGM) Approach is a method for developing and applying indices for the site-specific assessment of wetland functions. 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. However, a variety of other potential uses have been identified, including the design of wetland restoration projects, and management of wetlands.

This *Regional Guidebook* presents the HGM Approach for assessing the functions of most of the wetlands that occur in the Mississippi Alluvial Valley (MAV). It consolidates and extends the coverage provided by two previous guidebooks for the Delta Region of Arkansas and the Yazoo Basin of Mississippi.

The report begins with an overview of the HGM Approach and then classifies and characterizes the principal indentified MAV wetlands. Detailed HGM assessment models and protocols are presented for five of those wetland types, or subclasses, representing most of the forested wetlands in the region other than those associated with lakes and impoundments. The following wetland subclasses are treated in detail: Flat, Low-Gradient Riverine Backwater, Low-Gradient Riverine Overbank, Isolated Depression, and Connected Depression. The appendices provide field data collection forms and spreadsheets for making calculations.

Contents

Figures and Tables

Figures

Tables

Preface

In 2002, the US Army Engineer Research and Development Center (ERDC) published *A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Selected Regional Wetland Subclasses, Yazoo Basin, Lower Mississippi River Alluvial Valley*, (Smith and Klimas 2002). This was followed in 2004 by *A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Forested Wetlands in the Delta Region of Arkansas, Lower Mississippi River Alluvial Valley* (Klimas et al. 2004, updated to Version 2.0 in 2011). This *Regional Guidebook* consolidates the two previously published guidebooks, and incorporates new sample data to extend coverage to all of the Mississippi Alluvial Valley (MAV) between the confluences of the Mississippi River with the Ohio River and the Red River. The current guidebook does not necessarily supersede those documents – users familiar with those earlier reports can continue to apply them within their regions of applicability if they prefer, and they will yield essentially the same results as this guidebook. However, this version is designed to be applied more quickly; it requires less data collection and provides simplified data input forms. This guidebook can also be used in parts of the MAV not covered by the previous guidebooks. This streamlined approach was originally developed for the Arkansas Delta Region by Sheehan and Murray (2011), based in part on earlier efforts to devise a more rapid HGM assessment approach by Tom Roberts (Tennessee Technological University).

The authors of this report are Research Ecologists with the Wetlands and Coastal Ecology Branch, Ecosystem Evaluation and Engineering Division, Environmental Laboratory, ERDC. However, much of the data collection, wetland classification, and model development were accomplished by groups of people who are credited as co-authors or advisors in the previous Mississippi and Arkansas guidebooks. Those guidebooks, in turn, were based in large part on an earlier document (*A Regional Guidebook for Assessing the Functions of Low Gradient, Riverine Wetlands of Western Kentucky* by Ainslie et al. 1999). The list of collaborators on all of these source documents is long, but major contributors included R.D. Smith, T. Foti, J. Pagan, H. Langston, W.B. Ainslie, and T. Roberts, in addition to the authors of this report. The work of all of these collaborators is included in this consolidated report, including portions of the text and

some figures that are taken directly from those earlier documents. However, they are not responsible for the modified and simplified version presented here.

Major funding for those various source documents was provided by Region 6 of the Environmental Protection Agency through programs administered by the Multi-Agency Wetland Planning Team of the State of Arkansas. Funding was also provided by the Corps of Engineers through research programs conducted by ERDC. The consolidated report and the field work to extend the guidebook coverage were funded by the Wetlands Regulatory Assistance Program (WRAP) and published by ERDC as part of the Hydrogeomorphic Assessment (HGM) Guidebook series. The ERDC WRAP Program Manager is Sally Yost.

This work was performed under the general supervision of Patrick O'Brien, Chief, Wetlands and Coastal Ecology Branch, Environmental Laboratory (EL); Dr. Edmond Russo, Chief, Ecosystem Evaluation and Engineering Division, EL; and Dr. Elizabeth C. Fleming, Director, EL.

COL Kevin J. Wilson was Commander of ERDC; Dr. Jeffery P. Holland was Director.

1 Introduction

The Hydrogeomorphic (HGM) Approach is a method for assessing the capacity of a wetland to perform ecological functions that are comparable to similar wetlands in a region. The HGM Approach initially was designed to be used in the context of the Clean Water Act, Section 404 Regulatory Program, to analyze project alternatives, minimize impacts, assess unavoidable impacts, determine mitigation requirements, and monitor the success of compensatory mitigation. However, a variety of other potential uses have been identified, including the determination of minimal effects under the Food Security Act, design of wetland restoration projects, and management of wetlands.

HGM assessments are conducted using methods that are developed for one or more wetland subclasses within a defined geographic region, such as a mountain range, river basin, or ecoregion. The wetland classification system and assessment approach for that region are published in a regional HGM guidebook, based on guidelines published in the National Action Plan (National Interagency Implementation Team 1996), which were developed cooperatively by the US Army Corps of Engineers (USACE), US Environmental Protection Agency (USEPA), US Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS), Federal Highway Administration (FHWA), and US Fish and Wildlife Service (USFWS). The Action Plan, available online at http://www.epa.gov/OWOW/wetlands/science/hgm.html, outlines a strategy for developing Regional Guidebooks throughout the United States.

This report is a regional guidebook developed for assessing wetlands that commonly occur in the Mississippi Alluvial Valley (MAV), an area encompassing parts of six states between the confluence of the Ohio and Mississippi Rivers southward to the confluence of the Red and Mississippi Rivers. This guidebook describes the wetlands of that region and presents models and methods for assessing their functional integrity.

The wetland classification system, models and methods incorporated in this guidebook were originally developed by two separate groups of technical advisors (i.e., “Assessment Teams”) who worked on earlier guidebooks published for portions of the region. The two portions of the region covered earlier were the Yazoo Basin in Mississippi (Smith and Klimas, 2002) and the Delta Region of Arkansas (Klimas et al. 2004; 2011). The 2004 Arkansas guidebook was structured to be consistent with the 2002 Yazoo Basin guidebook but included some refinements reflecting a more extensive reference dataset. The 2011 Arkansas guidebook incorporated some additional changes to how soil and hydrology variables are measured, based on user experience with the original version. In order to determine whether the model calibrations needed to be modified for the expanded region covered by this guidebook, additional reference data were collected in northeastern Louisiana, southeastern Missouri, and western Tennessee and Kentucky. Those data were compared to the existing assessment model calibration curves and species composition criteria, which were found to be applicable throughout the expanded region covered by the guidebook with only minor modifications. Consequently, this guidebook uses the 2011 Arkansas Delta guidebook as the basic template for all model variables and their calibration. The model structure and application methods also are consistent with the earlier guidebook, but have been simplified for easier application in the field based on a system developed by Sheehan and Murray (2011) in Arkansas. That system was reviewed and approved by members of the original Assessment Team; therefore, its adoption here is consistent with standard HGM procedure. Persons conducting assessments in the Arkansas or Mississippi portions of the MAV may wish to continue to use the older guidebooks for consistency with prior assessments or because they are familiar and comfortable with the methods. Otherwise, this version should provide similar results but is simpler to apply and is applicable over a larger area.

Note that the portion of the Lower Mississippi Valley south of the Red River is not included in this guidebook’s area of applicability. That region, which consists mostly of the Atchafalaya Basin, is a distributary landscape that is geologically distinct from the alluvial valley segment of the Lower Mississippi Valley (Saucier 1994). Therefore, all of the Lower Mississippi Valley south of the Red River confluence is included in a separate Southeastern Coastal Plain HGM guidebook (Wilder et al. 2013).

Also excluded from this guidebook is the batture, which is the regional name for the land between the mainstem levees of the large rivers in the MAV. No reference data were collected from the batture during the development of this or any other HGM guidebook. An earlier study of the batture forests (Klimas 1988) found wetland communities with composition and structure that were generally similar to the river-connected wetland subclasses described in this guidebook. However, most sites within the levee system are subject to periodic deep, high-velocity flows and extensive sediment redistribution events that are clearly influenced by the confining effects of the levee system. Therefore, users who choose to apply the models and reference data used here to batture sites should be aware that there are differences in fundamental processes between those areas and the reference sites used to develop this guidebook.

This guidebook adopts the perspective that the mainstem Mississippi River levee and related systemic flood-control features constructed in the 20th century are permanent, and constitute the "baseline condition" for the purposes of functional assessment.

The remainder of this report is organized in the following manner. Chapter 2 provides a brief overview of the major components of the HGM Approach. Chapter 3 characterizes the regional wetland subclasses in the MAV Region. Chapter 4 discusses the wetland functions, assessment variables, and functional indices used in the guidebook from a generic perspective. Chapter 5 applies the assessment models to specific regional wetland subclasses and defines the relationship of assessment variables to reference data. Chapter 6 outlines the assessment protocol for conducting a functional assessment. Appendix A presents preliminary project documentation and field sampling guidance. An example of field data sheets is presented in Appendix B; working versions that perform the required calculations must be downloaded from http://el.erdc.usace.army.mil/wetlands/guidebooks.cfm. Appendix C contains the common and scientific names of plant species referenced in the text and data sheets.

2 Overview of the Hydrogeomorphic Approach

The HGM approach incorporates consideration of (a) the HGM classification system, (b) the characteristics of reference wetlands, (c) assessment variables and assessment models from which functional indices are derived, and (d) assessment protocols.

Hydrogeomorphic classification

The HGM classification was developed specifically to support functional assessment (Brinson 1993a). It uses three criteria to group wetlands that function similarly: geomorphic setting, water source, and hydrodynamics. Geomorphic setting refers to the topography and landscape position of the wetland. Water source refers to the primary source of the water that sustains wetland characteristics, such as precipitation, floodwater, or groundwater. Hydrodynamics refers to the level of energy with which water moves through the wetland, and the direction of water movement.

Based on these three criteria, any number of functional wetland groups can be identified at different spatial or temporal scales. For example, at a continental scale, Brinson (1993a, b) identified five hydrogeomorphic wetland classes. These were later expanded to the seven classes described in Table 1 (Smith et al. 1995).

Generally, the level of variability encompassed by wetlands at the continental scale of hydrogeomorphic classification is too great to allow development of assessment indices that can be applied rapidly and still be sensitive to common types of wetland impacts. In order to reduce variability, the classification criteria are applied at a regional scale to create regional wetland subclasses. Examples of potential regional subclasses are shown in Table 2.

Reference wetlands

Reference wetlands are sites selected to represent the range of variability that occurs within a regional wetland subclass as a result of natural processes (e.g., succession, channel migration, fire, erosion, and sedimentation) as well as anthropogenic alteration (e.g., grazing, timber harvest, clearing). The reference domain is the geographic area occupied by the reference wetlands (Smith et al. 1995).

Table 1. Hydrogeomorphic wetland classes.

HGM Wetland Class	Definition
Depression	Depressional wetlands occur in topographic depressions (i.e., closed elevation contours) that allow the accumulation of surface water. Depressional wetlands may have any combination of inlets and outlets, or lack them completely. Potential water sources are precipitation, overland flow, streams, or groundwater flow from adjacent uplands. The predominant direction of flow is from the higher elevations toward the center of the depression. The predominant hydrodynamics are vertical fluctuations that may occur over a range of time, from a few days to many months. Depressional wetlands may lose water through evapotranspiration, intermittent or perennial outlets, or recharge to groundwater. Prairie potholes, playa lakes, and cypress domes are common examples of depressional wetlands.
Tidal Fringe	Tidal fringe wetlands occur along coasts and estuaries and are under the influence of sea level. They intergrade landward with riverine wetlands where tidal current diminishes and river flow becomes the dominant water source. Additional water sources may be groundwater discharge and precipitation. Because tidal fringe wetlands are frequently flooded and water table elevations are controlled mainly by sea surface elevation, tidal fringe wetlands seldom dry for significant periods. Tidal fringe wetlands lose water by tidal exchange, by overland flow to tidal creek channels, and by evapotranspiration. Organic matter normally accumulates in higher elevation marsh areas where flooding is less frequent and the wetlands are isolated from shoreline wave erosion by intervening areas of low marsh or dunes. *Spartina alterniflora* salt marshes are a common example of tidal fringe wetlands.
Lacustrine Fringe	Lacustrine fringe wetlands are adjacent to lakes where the water elevation of the lake maintains the water table in the wetland. Additional sources of water are precipitation and groundwater discharge, the latter dominating where lacustrine fringe wetlands intergrade with uplands or slope wetlands. Surface water flow is bidirectional. Lacustrine wetlands lose water by evapotranspiration and by flow returning to the lake after flooding. Organic matter may accumulate in areas sufficiently protected from shoreline wave erosion. Unimpounded marshes bordering the Great Lakes are an example of lacustrine fringe wetlands.
Slope	Slope wetlands are found in association with the discharge of groundwater to the land surface or on sites with saturated overland flow with no channel formation. They normally occur on slightly to steeply sloping land. The predominant source of water is groundwater or interflow discharging at the land surface. Precipitation is often a secondary contributing source of water. Hydrodynamics are dominated by down slope unidirectional water flow. Slope wetlands can occur in nearly flat landscapes if groundwater discharge is a dominant source to the wetland surface. Slope wetlands lose water primarily by saturated subsurface flows, surface flows, and by evapotranspiration. They may develop channels, but the channels serve only to convey water away from the slope wetland. Slope wetlands are distinguished from depression wetlands by the lack of a closed topographic depression and the predominance of the groundwater/interflow water source. Fens are a common example of slope wetlands.
Mineral Soil Flats	Mineral soil flats are most common on interfluves, extensive relic lake bottoms, or large alluvial terraces where the main source of water is precipitation. They receive virtually no groundwater discharge, which distinguishes them from depressions and slopes. Dominant hydrodynamics are vertical fluctuations. Mineral soil flats lose water by evapotranspiration, overland flow, and seepage to underlying groundwater. They are distinguished from flat non-wetland areas by their poor vertical drainage due to impermeable layers (e.g., hardpans), slow lateral drainage, and low hydraulic gradients. Pine flatwoods with hydric soils are an example of mineral soil flat wetlands.
Organic Soil Flats	Organic soil flats, or extensive peatlands, differ from mineral soil flats in part because their elevation and topography are controlled by vertical accretion of organic matter. They occur commonly on flat interfluves, but may also be located where depressions have become filled with peat to form a relatively large flat surface. Water source is dominated by precipitation, while water loss is by overland flow and seepage to underlying groundwater. They occur in relatively humid climates. Raised bogs share many of these characteristics but may be considered a separate class because of their convex upward form and distinct edaphic conditions for plants. Portions of the Everglades and northern Minnesota peatlands are examples of organic soil flat wetlands.
Riverine	Riverine wetlands occur in floodplains and riparian corridors in association with stream channels. Dominant water sources are overbank or backwater flow from the channel. Additional sources may be interflow, overland flow from adjacent uplands, tributary inflow, and precipitation. When overbank flow occurs, surface flows down the floodplain may dominate hydrodynamics. In headwaters, riverine wetlands often intergrade with slope, depressional, poorly drained flat wetlands, or uplands as the channel (bed) and bank disappear. Perennial flow is not required. Riverine wetlands lose surface water via the return of floodwater to the channel after flooding and through surface flow to the channel during rainfall events. They lose subsurface water by discharge to the channel, movement to deeper groundwater, and evapotranspiration. Bottomland hardwood forests on floodplains are examples of riverine wetlands.

Table 2. Potential regional wetland subclasses in relation to classification criteria.

Classification Criteria			Potential Regional Wetland Subclasses	
Geomorphic Setting	Dominant Water Source	Dominant Hydrodynamics	Eastern USA	Western USA/Alaska
Depression	Groundwater or interflow	Vertical	Prairie pothole marshes, Carolina bays	California vernal pools
Fringe (tidal)	Ocean	Bidirectional, horizontal	Chesapeake Bay and Gulf of Mexico tidal marshes	San Francisco Bay marshes
Fringe (lacustrine)	Lake	Bidirectional, horizontal	Great Lakes marshes	Flathead Lake marshes
Slope	Groundwater	Unidirectional, horizontal	Fens	Avalanche chutes
Flat (mineral soil)	Precipitation	Vertical	Wet pine flatwoods	Large playas
Flat (organic soil)	Precipitation	Vertical	Peat bogs; portions of Everglades	Peatlands over permafrost
Riverine	Overbank flow from channels	Unidirectional, horizontal	Bottomland hardwood forests	Riparian wetlands

Note: Adapted from Smith et al. 1995, Rheinhardt et al. 1997.

Reference standard wetlands are the subset of reference wetlands that function at a level that is characteristic of the least altered wetland sites in the least altered landscapes.

Assessment models and functional indices

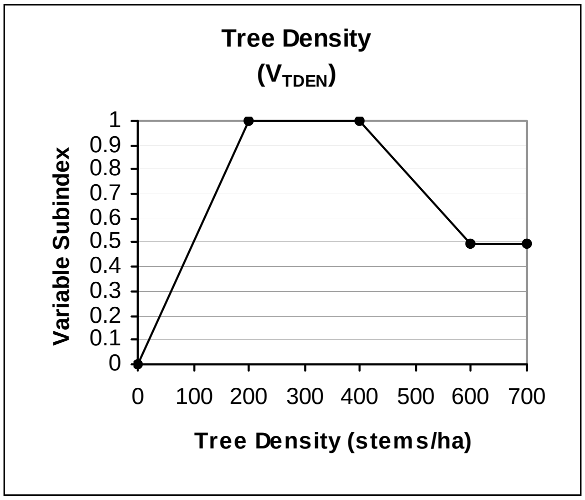
In the HGM Approach, an assessment model is a simple representation of a function performed by a wetland ecosystem. The assessment model defines the relationship between one or more characteristics or processes of the wetland ecosystem. Functional capacity is the ability of a wetland to perform a specific function in a manner comparable to that of reference standard wetlands. Application of assessment models results in a Functional Capacity Index (FCI) ranging from 0.0 to 1.0. Wetlands with an FCI of 1.0 perform the assessed function at a level that is characteristic of reference standard wetlands. A lower FCI indicates that the wetland is performing a function at a level below the level that is characteristic of reference standard wetlands.

For example, the following equation (model) could be used to assess a function commonly of interest with regard to riverine wetlands: the capacity of the wetland to detain floodwater.

$$FCI = V_{FREQ} \times \left[\frac{(V_{LOG} + V_{GVC} + V_{SSD} + V_{TDEN})}{4} \right]$$

The assessment model for floodwater detention has five assessment variables: frequency of flooding (V_{FREQ}): this variable represents the frequency at which the wetland is inundated by stream flooding, and a set of structural measures that represent resistance to flow of floodwater through the wetland. These are log density (V_{LOG}), ground vegetation cover (V_{GVC}), shrub and sapling density (V_{SSD}), and tree stem density (V_{TDEN}).

Figure 1. Example subindex graph for the Tree Density (V_{TDEN}) assessment variable for a particular wetland subclass.



Each of the variables in the model is scaled against the range of values observed in the reference wetlands. The values, or metrics, are measures appropriate for characterizing the particular variable, such as percent cover for the V_{GVC} variable, or number of trees per hectare for the V_{TDEN} variable. Based on the metric value, an assessment variable is assigned a variable subindex. When the metric value of an assessment variable is within the range of conditions exhibited by reference standard wetlands, a variable subindex of 1.0 is assigned. As the metric value deflects in either direction from the reference standard condition, the variable subindex decreases. Figure 1 illustrates the relationship between metric values of tree density (V_{TDEN}) and the variable subindex for an example wetland subclass. As shown in the graph, tree densities of 200 to 400 stems/ha represent reference standard conditions, based on field studies, and a variable subindex of 1.0 is assigned for assessment models where tree density is a component. Where tree densities are higher or lower than those found in reference standard conditions, a lesser variable subindex value is assigned.

Assessment protocol

All of the steps described in the preceding sections concern development of the assessment tools and the rationale used to produce this *Regional*

Guidebook. Although users of the guidebook should be familiar with this process, their primary concern will be the protocol for application of the assessment procedures. The assessment protocol is a defined set of tasks, along with specific instructions, that allows resource professionals to assess the functions of a particular wetland area. The first task includes characterizing the wetland ecosystem and the surrounding landscape, describing the proposed project and its potential impacts, and identifying the wetland areas to be assessed. The second task is collecting field data. The final task is performing an analysis that involves calculation of functional indices. These steps are described in detail in Chapter 6, and the required data sheets, spreadsheets, and supporting digital spatial data are provided in the Appendices.

3 Characterization of Wetland Subclasses in the Mississippi Alluvial Valley

Reference domain

Figure 2. The Mississippi Alluvial Valley reference domain.

The reference domain for this guidebook (i.e., the area from which reference data were collected and to which the guidebook can be applied) is the MAV, exclusive of the batture lands between the mainstem Mississippi River levees. The MAV is defined according to Saucier (1994), who distinguishes it from the Lower Mississippi Valley, which extends from the mouth of the Ohio River to the Gulf of Mexico, and includes the deltaic and chenier plain deposits in southern Louisiana. Saucier limits the MAV to that segment of the Lower Mississippi Valley that lies north of the head of the Atchafalaya River, which marks the upstream end of the deltaic plain from a geologic perspective. For the purposes of this guidebook, the southern boundary of the MAV is delimited by the meander belt of the Red River, which is confluent with the Mississippi at the same location as the Atchafalaya. Excluded from the MAV is Crowley's Ridge, a strip of Tertiary-age upland in northeastern Arkansas and southeastern Missouri. The area covered by the guidebook includes all other parts of Louisiana, Mississippi, Arkansas, Missouri, Tennessee and Kentucky that lie within the MAV (Figure 2).

Climate

The northern portion of the MAV has a humid temperate climate with about 48 inches of rain annually. The southern end of the valley is humid subtropical, with 56 inches of rainfall on average. The distribution of precipitation is such that excess moisture is present in the winter and spring months, and frequent soil moisture deficits occur in the months of June through September.

The MAV has temperate winters and long, hot summers, with prevailing southerly winds that carry moisture from the Gulf Coast, creating high humidity levels and a high incidence of thunderstorms. Freezing temperatures reach much of the area for short periods in most years, and tornadoes and ice storms commonly occur (Brown et al. 1971, Southern Regional Climate Center 2012).

Geology and geomorphology

The most recent synthesis of the geologic history and major physiographic divisions within the MAV was by Saucier (1994). This guidebook relies primarily on his interpretations, and much of the following discussion is adapted directly from that publication.

Surface topography within the alluvial valley is defined by the characteristics of a deep alluvial fill that overlies coastal plain geologic formations and deeper Paleozoic and older rocks. The MAV is bounded on the east and west by exposures of the coastal plain sediments and by the Ouachita and Ozark mountains in Arkansas and Missouri. Remnant coastal plain deposits also form a narrow elongated upland “island,” Crowley’s Ridge, which is not considered to be part of the MAV. It extends more than 125 miles through southeastern Missouri and northeastern Arkansas, but is less than 10 miles wide on average. In places it rises as much as 250 feet above the elevation of the adjacent alluvial deposits of the MAV. There are various wetlands on Crowley’s Ridge, such as seeps and small stream bottoms, but they are discussed in a separate publication (Klimas et al. 2005), and are not included in this guidebook.

About half of the alluvial valley is made up of terraces that are remnants of multiple glacial outwash events during Wisconsin glacial cycles. Other Pleistocene terraces that were established between outwash episodes are composed primarily of meandering-river depositional features. Holocene (post-glacial) meander belt features make up nearly all of the remainder of the MAV. Each of these surfaces has unique features, and their distribution and varying elevations divide the MAV into six major sub-basins. Figure 3 illustrates the distribution of the major geomorphic settings and sub-basins within the MAV, and Figure 4 presents a generalized view of the relative landscape positions of the principal deposits. The characteristics of those features and the major sub-basins are described in the following sections.

Figure 3. Distribution of the major lowland basins and principal Quaternary deposits in the Mississippi Alluvial Valley as well as the deltaic plain and chenier plain deposits south of the Red River (adapted from Saucier (1994)).

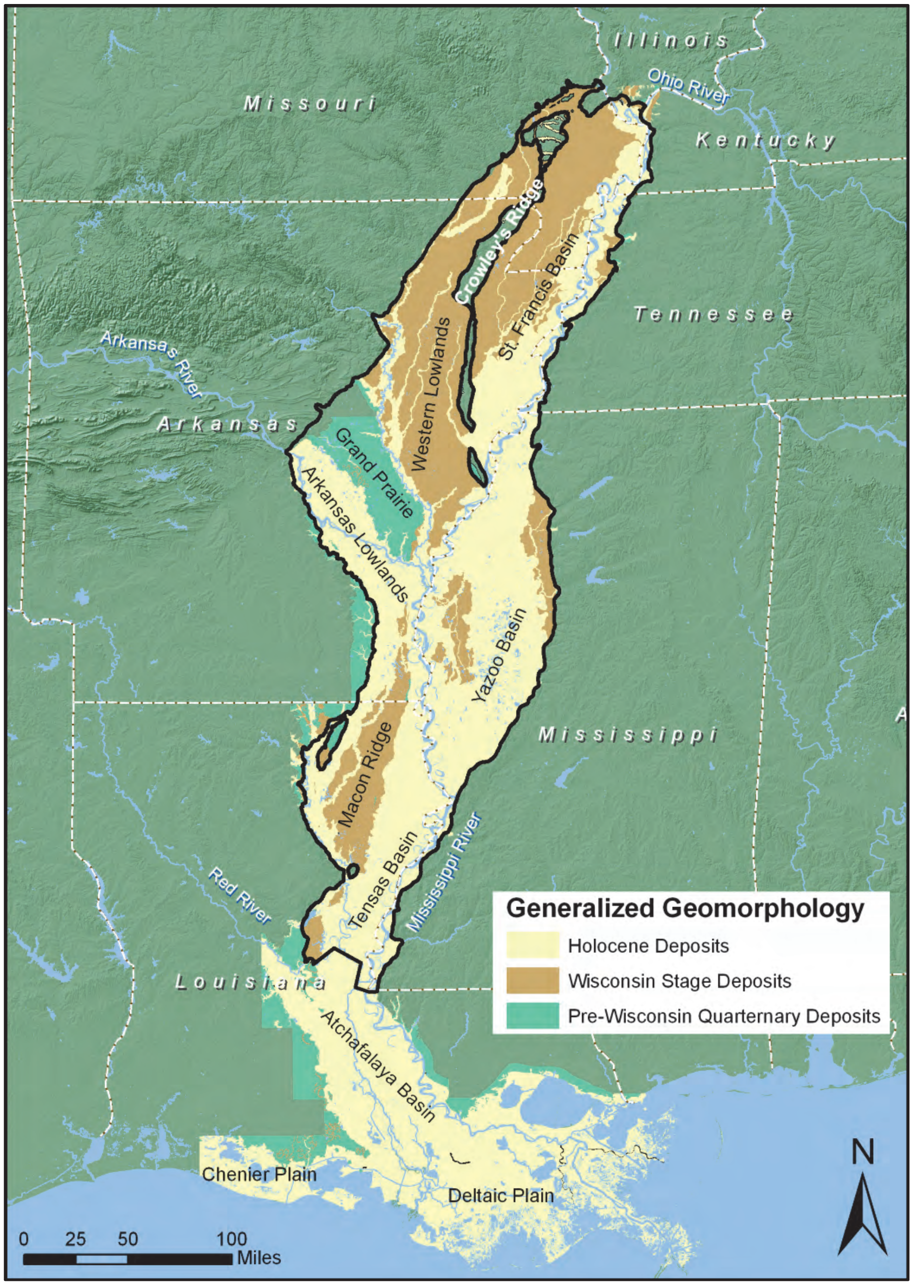
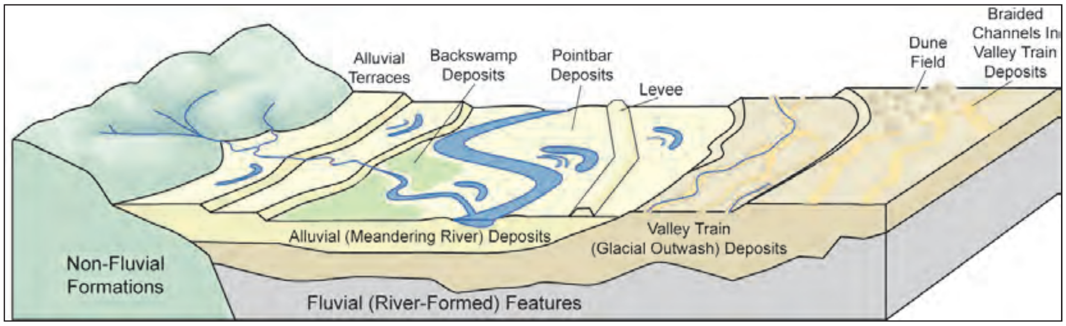


Figure 4. Principal geomorphic settings and features of the Mississippi Alluvial Valley.



Pleistocene Terraces

The northern third of the MAV – as well as Macon Ridge in Louisiana and southern Arkansas – consists primarily of Pleistocene deposits of glacial outwash that flushed into the Mississippi Valley during periods of waning Late Wisconsin continental glaciation. Sometimes called “valley train” terraces, they are composed of relatively unsorted, coarse materials deposited in a braided-stream environment, and capped with a veneer of fine-grained, well-sorted sediments deposited later by meandering streams. Valley train deposits usually occur in the form of multiple distinct terrace surfaces, with the oldest and highest being 30 feet or more above the modern floodplain. On the lower and younger terraces, the remnant outwash channels are often distinctly visible, and may carry smaller modern streams within them. Some of the valley train surfaces are covered with extensive dunefields made up of wind-blown sand and silt deflated from younger outwash channels and deposited on adjacent older surfaces.

In addition to the glacial outwash terraces, remnants of pre-Wisconsin Arkansas and Mississippi River meander belts also remain in the MAV as high terraces, primarily within Arkansas along the western valley wall, and as the extensive terrace peninsula known as the Grand Prairie (Figure 3). There are also much later, lower elevation Wisconsin-age alluvial terraces along the southern margin of the Grand Prairie and adjacent to the Cache River. All of the alluvial terraces are characterized by features typical of meandering streams, as described for Holocene meander belts, below, rather than the braided channel features found on valley train terraces.

Holocene Meander Belts

Point bars. Point bar deposits predominate within the Holocene meander belts in the MAV. They generally consist of relatively coarse-grained materials (silts and sands) laid down on the inside (convex) bend of a meandering stream channel. The result is a characteristic pattern of low arcuate ridges separated by swales ("ridge and swale" or "meander scroll" topography). Point bar swales range from narrow and shallow to broad and deep, and usually are closed at each end to form depressions. The scale and depth of point bar swales depend on the depositional environment that formed the adjacent ridges and the degree of sedimentation within the swale since it formed.

Abandoned channels. These features are the result of cutoffs, where a stream abandons a channel segment, usually because migrating bendways intersect and channel flow moves through the neck. The typical sequence of events following a neck cutoff is that the upper and lower ends of the abandoned channel segment quickly fill with coarse sediments, creating an open oxbow lake. Usually, small connecting channels maintain a connection between the river and the lake, at least at high river stages, so riverborne fine-grained sediments gradually fill the abandoned channel segment. If this process is not interrupted, the lake eventually fills completely, the result being an arcuate swath of cohesive, impermeable clays within a better drained point bar deposit. Often, however, the river migrates away from the channel segment and the hydraulic connection is lost, or the connection is interrupted by later deposition of point bar or natural levee deposits. In either case, the filling process is dramatically slowed, and abandoned channel segments may persist as open lakes or depressions of various depths and dimensions.

Abandoned courses. An abandoned course is a stream channel segment left behind when a stream diverts flow to a new meander belt. Abandoned course segments can be hundreds of miles long, or only short segments may remain where the original course has been largely obliterated by subsequent stream activity. In some cases, the abandoned course is captured by smaller streams, which meander within the former channel and develop their own point bars and other features. Where the stream course is abandoned gradually, the remnant stream may fill the former channel with point bar deposits even as its flow declines. Thus, while abandoned channels often become depressions with fine-textured soils, abandoned courses are more likely to be fairly continuous with the point bar deposits of the original stream, or to become part of the meander belt of a smaller stream.

Natural levees. A natural levee forms where overbank flows result in deposition of relatively coarse sediments (sand and silt) adjacent to the stream channel. The material is deposited as a continuous sheet that thins with distance from the stream, resulting in a relatively high ridge along the bankline and a gradual backslope that becomes progressively more fine-grained with distance from the channel. Along the modern Mississippi River, natural levees rise about 4.5 m above the elevation of the adjacent floodplain and may extend for several kilometers or more from the channel. Natural levees formed by smaller streams or over short periods of time tend to be proportionately smaller, but the dimensions and composition of natural levee deposits are the product of various factors, including sediment sources and the specific mode of deposition.

Backswamps. As natural levees and point bars accrete sediments along active streams, a meander belt ridge forms that is higher than the adjacent land surfaces. Where alluvial ridges (or other elevated features such as uplands or terraces) are configured so as to form a basin between them, they collect runoff, pool floodwaters, and accumulate fine sediments. The resulting backswamp environments typically have substrates of massive clays, and are incompletely drained by small, sometimes anastomosing streams. They may include large areas that do not fully drain through channel systems but remain ponded well into the growing season. In much of the MAV, backswamp deposits are 12 m thick or more.

Hydrology

The dominant drainage feature of the MAV is the Mississippi River. The drainage area of the Mississippi River basin is approximately 3,227,000 sq km, which is about 41 percent of the land area of the continental United States (USACE 1973). Major floods on the lower Mississippi River usually originate in the Ohio River basin, and can crest in any month from January to May. High flows that originate in the upper Mississippi River system generally occur in late spring and early summer (Tuttle and Pinner 1982).

Groundwater also is a significant component of the hydrology of the MAV. The alluvial aquifer occupies coarse-grained deposits that originated as glacial outwash and from more recent alluvial activity. Generally, the surface of the alluvial aquifer is within 10 m of the land surface, and it is approximately 38 m thick. It is essentially continuous throughout the MAV. Where the top stratum is made up of coarse sediments or thinly veneered with fine sediments, the alluvial aquifer is recharged by surface waters. Discharge is primarily to stream channels, which contribute to stream baseflow during low-flow periods (Saucier 1994, Terry et al. 1979).

All of the major elements of the drainage system and hydrology of the MAV have been modified to varying degrees in historic times. At the time of European settlement, major Mississippi River floods would have inundated about half of the MAV (Moore 1972). Much of the region also was subject to prolonged, extensive ponding following the winter wet season in virtually all years, localized short-term ponding following rains at any time of year, and extensive inundation within tributary floodbasins due to rainfall in headwater areas in most years. Engineering projects and agricultural activities have incrementally altered and continue to alter these various sources of wetland hydrology, as described in the Alterations to Environmental Conditions section, below.

The MAV is subdivided into six major lowland areas or basins, each of which is a distinct hydrologic unit draining southward (Figure 3). The basins are separated by Pleistocene terraces, Holocene meander belt ridges, or by Crowley's Ridge.

Western Lowlands

The Western Lowlands is the designation for the second-largest of the sub-basins in the MAV. It spans much of northeastern Arkansas and south-eastern Missouri, where it is bounded on the west and north by the Ozark escarpment, on the west and south by the Grand Prairie, and on the east by Crowley's Ridge.

Various streams enter the basin from the Ozark Plateau to the west, including the Black, Current, Spring, White, and Little Red Rivers. The Cache River and Bayou De View originate within the lowlands on the eastern side of the basin. All of these streams drain to the White River, which discharges to the Arkansas River.

All of the major streams in the basin are flanked by relatively narrow floodplains with recent (Holocene) landforms that are typical of meandering river systems, including poorly drained backswamps, better-drained point bars, and well-drained natural levees. Abandoned channel segments form crescent-shaped oxbow lakes and depressions. However, most of the Western Lowlands region is made up of much older Pleistocene valley train terraces that form five distinct surfaces in the Western Lowlands, with the oldest and highest being 10m or more above the modern floodplain. On the lower and younger terraces, the remnant outwash channels are often distinctly visible, and may carry smaller modern streams within them. Some of the valley train surfaces are covered with extensive dunefields made up of wind-blown sands deflated from younger outwash channels and deposited on adjacent older surfaces.

Arkansas Lowlands

The Arkansas Lowlands area lies immediately north and east of the Arkansas River, and is bounded on the north by the Grand Prairie. It is the smallest of the major MAV sub-basins. Bayou Meto and Bayou Two Prairie are the only major streams in the basin.

All of the landforms in the Arkansas Lowlands are Holocene deposits of the Arkansas River. They are composed of features typical of meandering streams, such as point bar, backswamp, natural levee, and abandoned channel deposits.

St. Francis Basin

The St. Francis Basin is the northernmost lowland area in the MAV, extending through southeastern Missouri and northeastern Arkansas between Crowley’s Ridge and the modern meander belt of the Mississippi River. The principal streams are the St. Francis, Tyronza, and Little Rivers, as well as Pemiscot Bayou.

The southern third of the basin, in Arkansas, is made up primarily of Holocene meander belt deposits of the Mississippi River, while the rest of the area is largely composed of valley train deposits. As in the Western Lowlands, there are multiple levels of valley train terraces in the St. Francis basin, but the lowest and most extensive levels are products of the most recent episodes of Pleistocene glacial meltwater moving down the valley, and many of the braided outwash channels are distinctly visible. Relict sand bars and wind-blown sand are also apparent on the surface of some valley train deposits, and there are numerous more recent features known as “sand blows” composed of previously buried outwash sands ejected during the New Madrid earthquakes of 1811 and 1812.

Yazoo Basin

The largest of the lowland areas in the MAV is located in northwestern Mississippi, where the area is bounded on the east by rolling uplands and on the west by the current meander belt of the Mississippi River. The majority of the area consists of multiple Holocene meander belts of the Mississippi River and extensive intervening backswamp environments. Limited areas of Pleistocene valley train also are present, but they are not as distinctly elevated above the Holocene deposits as they typically are in other basins.

All surface water discharge from the Yazoo Basin is through the Yazoo River, which enters the Mississippi River at the southern end of the basin. Most of that water originates in the uplands along the eastern flank of the basin and is carried to the Yazoo via the Coldwater, Yocona, Tallahatchie, and Yalobusha Rivers, as well as via several smaller streams. Interior drainage is provided by numerous small streams that discharge to Deer Creek, the Big Sunflower River, Steele Bayou, or Bogue Phalia, which then flow to the lower Yazoo River. The pattern of drainage within the basin is generally southward, but can be quite convoluted, reflecting the influence of the complex topography dominated by abandoned meander belts of the Mississippi River.

Tensas Basin

The Tensas Basin extends from near the mouth of the Arkansas River in eastern Arkansas to the mouth of the Red River in Louisiana. It is bounded by the current Mississippi River meander belt on the east and the outwash terraces of Macon Ridge on the west. All of the landforms in the basin are made up of Holocene meander belt deposits, primarily of Mississippi and Arkansas River origins. The Tensas River and Bayou Macon are the principal streams in the northern and central parts of the study area, and Black River drains the southern part, where it is formed from the confluence of the Tensas River with the Ouachita River which enters the basin from the west. Various smaller streams arise within the basin and flow to one of those major drainages.

Boeuf Basin

The Boeuf Basin is a narrow lowland that lies between Macon Ridge on the east and uplands on the west. Geologically, it is a continuation of the

Arkansas Lowlands, but is separated from them by the Arkansas River. It is made up of Holocene meander belt and backswamp deposits laid down by the Arkansas River when it flowed far to the south of its present location. It is named after the Boeuf River, but in Arkansas that stream flows entirely within the Macon Ridge uplands to the east before entering the lowlands in Louisiana. In Arkansas, the principal stream is Bayou Bartholomew, which flows within an abandoned course of the Arkansas River. The largest stream in the basin is the Ouachita River, which enters the western side of the basin near Monroe, Louisiana. It follows an abandoned Arkansas River channel as it collects the flow of all other drainages and exits the basin at Sicily Island near the southern terminus of Macon Ridge.

Soils

Parent materials of soils in the MAV are fluvial sediments. The alternating periods of meander belt development and glacial outwash deposition produced complex but characteristic landforms where sediments were sorted to varying degrees based on their mode and environment of deposition. The sorting process has produced textural and topographic gradients that are fairly consistent on a gross level and result in distinctive soils. Generally, within a Holocene meander belt, surface substrates grade from relatively coarse-textured, well-drained, higher elevation soils on natural levees directly adjacent to river channels through progressively finer textured, and less well-drained materials on levee backslopes and point bar deposits to very heavy clays in closed basins such as large swales and abandoned channels. Backswamp deposits between meander belts also are filled with heavy clays. Valley train deposits typically have a top stratum (upper 0.2–3 m) of fine-grained material (clays and silts) that blankets the underlying network of braided channels and interfluves. On older, higher valley train deposits, the top stratum contains considerable loess, and in some areas consists of sandy dunes. The lowest, most recent valley trains have surface soils that are derived primarily from Mississippi River flooding (Brown et al. 1971, Saucier 1994).

The gradient of increasingly fine soil textures from high-energy to low-energy environments of deposition (natural levees and point bars to abandoned channels and backswamps) implies increasing soil organic matter content, increasing cation exchange capacity, and decreasing permeability. However, all of these patterns are generalizations, and quite different conditions occur regularly. The nature of alluvial deposition varies between and within flood events, and laminated or localized deposits of varying textures are common within a single general landform. Thus, natural levees dominated by coarse-textured sediments may contain strata with high clay content, and valley train surfaces that are usually fine-grained may have some soil units with high sand content. Point bar deposits, which typically have less organic matter incorporated into the surface soils than backswamps or abandoned channels, may actually contain more total organic matter on a volume basis due to the presence of large numbers of buried logs and other stream-transported organic material (Saucier 1994).

Within the Holocene meander belts, soils of older meander belts are likely to show greater A horizon development than soils in equivalent positions within younger meander belts (Autin et al. 1991). Similarly, older soils are likely to be more acidic and deeper, show less depositional stratification and more horizonation, and otherwise exhibit characteristics of advanced soil development not seen in soils of younger meander belts.

Individual soil series descriptions can be found at: http://soils.usda.gov/technical/classification/scfile/index.html.

Vegetation

Forests of the MAV are referred to as bottomland hardwoods, a term that incorporates a wide range of species and community types that can tolerate inundation or soil saturation for at least some portion of the growing season (Wharton et al. 1982).

Bottomland hardwood forests are among the most productive and diverse ecosystems in North America. Under presettlement conditions, they were essentially continuous throughout the Lower Mississippi Valley, and they interacted with the entire watershed, via floodwaters, to import, store, cycle, and export nutrients (Brinson et al. 1980, Wharton et al. 1982). Although these conditions have changed dramatically in modern times, the remaining forests still exist as a complex mosaic of community types that reflect variations in alluvial and hydrologic environments. Within-stand diversity varies from dominance by one or a few species to forests with a dozen or more overstory species, and diverse assemblages of understory, ground cover, and vine species (Putnam 1951, Wharton et al. 1982).

Most major overviews of bottomland hardwood forest ecology emphasize the relationship between plant community distribution and inundation, usually assuming that floodplain surfaces that occupy different elevations in relation to a river channel reflect different flood frequency, depth, and duration (e.g., Brinson et al. 1981; Wharton et al. 1982). This leads to classification of forests in terms of hydrologic “zones,” each zone having characteristic plant communities. Zonal characterization systems generally reference most sites to a presumed stream entrenchment process that leaves a stepwise sequence of terraces. However, zonal concepts have limited utility in much of the MAV where Pleistocene landforms and multiple abandoned Holocene meander belts dominate the landscape. In addition, features such as natural levees and abandoned channels, which may be rather minor components of some southeastern floodplains, often occupy large areas within the MAV. In much the same way, the general zonal models imply that the principal hydrologic controls on community composition are flood frequency, depth, and duration, as indicated by elevation relative to a stream channel. However, stream flooding is just one of many important sources of water in forested wetlands of the MAV, and factors such as ponding of precipitation and poor drainage may be more important than flooding effects in many landscape settings.

Despite the complexity of the landscape, plant communities do occur on recognizable combinations of site hydrology and geomorphology within the MAV. The synthesis documents of Putnam (1951) and Putnam et al. (1960) adopt a perspective that recognizes the unique terrain of the region, and summarize the principal combinations of lowland landscape setting, drainage characteristics, and flood environment as they influence plant community composition. Table 3 is based on that approach. However, the first two cover types in Table 3, where a variety of oak species are listed as commonly present, actually encompass a wide array of sites where species dominance patterns vary greatly.

Under natural conditions, forest stands within the MAV undergo change at various temporal and spatial scales. Primary succession occurs on recently deposited substrates, which include abandoned stream channels, point bars, crevasse splays, and abandoned beaver ponds. A sequential replacement of pioneer species with longer-lived, heavy-seeded species occurs over time, and usually involves changes in substrate elevation as additional sedimentation occurs. This pattern was common when stream channels migrated freely, but in historic times channel stabilization has reduced the creation of new substrates dramatically.

Table 3. Composition and site affinities of common forest communities in the MAV (after Putnam (1951)).

Forest Cover Type	Characteristic Species	Site Characteristics
Sweetgum - Water Oaks	*Liquidambar styraciflua* *Quercus nigra* *Quercus texana* *Quercus phellos* *Ulmus americana* *Celtis laevigata* *Fraxinus pennsylvanica*	In first bottoms except for deep sloughs, swamps, fronts, and poorest flats. Also on terrace flats.
White Oaks - Red Oaks - Other Hardwoods	*Quercus michauxii* *Quercus similis* *Quercus pagoda* *Quercus shumardii* *Quercus falcata* *Fraxinus americana* *Carya* spp. *Nyssa sylvatica* *Ulmus alata*	Fine, sandy loam and other well-drained soils on first bottom and terrace ridges.
Hackberry - Elm - Ash	*Celtis laevigata* *Ulmus americana* *Fraxinus pennsylvanica* *Carya aquatica* *Quercus phellos*	Low ridges, flats, and sloughs in first bottoms, terrace flats, and sloughs. Occasionally on new lands or fronts.
Overcup Oak - Water Hickory	*Quercus lyrata* *Carya aquatica*	Poorly drained flats, low ridges, sloughs, and backwater basins with tight soils.
Cottonwood	*Populus deltoides* *Carya illinoensis* *Platanus occidentalis* *Celtis laevigata*	Front land ridges and well-drained flats.
Willow	*Salix nigra*	Front land sloughs and low flats.
Riverfront Hardwoods	*Platanus occidentalis* *Carya illinoensis* *Fraxinus pennsylvanica* *Ulmus americana* *Celtis laevigata* *Acer saccharinum*	All front lands except deep sloughs and swamps.
Cypress - Tupelo	*Taxodium distichum* *Nyssa aquatica* *Nyssa sylvatica* var. *biflora*	Low, poorly drained flats, deep sloughs, and swamps in first bottoms and terraces.

The typical natural regeneration process in established forest stands is initiated by single tree-falls, periodic catastrophic damage from fire or windstorm, and inundation mortality due to blocked drainage or beaver dams. Small forest openings occur due to windthrow, disease, lightning strikes, and similar influences that kill individual trees or small groups of trees (Dickson 1991). The resulting openings are rapidly colonized, but the composition of the colonizing trees may vary widely depending on factors such as existing advanced reproduction, seed rain from adjacent mature trees, and importation of seed by animals or floodwaters. Often, this pattern results in small, even-aged groves of trees, sometimes of a single species (Putnam et al. 1960).

In presettlement conditions, fire may have been a significant factor in stand structure, but the evidence regarding the extent of this influence is unclear. Putnam (1951) stated that southern bottomland forests experience a “serious fire season” every 5–8 years, and that fires typically destroy much of the understory and cause damage to some larger trees, which eventually provides points of entry for insects and disease. Similarly, it is difficult to estimate the influence of beaver in the presettlement landscape, because they were largely removed very early in the settlement process. However, it is likely that the bottomland forest ecosystem included extensive areas that were affected by beaver and were dominated by dead timber, open water, marsh, moist soil herbaceous communities, or shrub swamp at any given time.

Alterations to environmental conditions

The physical and biological environment of the MAV has been extensively altered by human activity. Isolation and stabilization of the Mississippi and Arkansas Rivers have effectively halted the large-scale channel migration and overbank sediment deposition processes that created and continually modified the Holocene landscapes of the alluvial valley. At the same time, sediment input to depressions and sub-basins within the area has increased manyfold in historic times due to erosion of uplands and agricultural fields (Kleiss 1996, Saucier 1994, Smith and Patrick 1991). The Mississippi River no longer overwhelms the landscape with floods that course through the basin, but it continues to influence large areas through backwater flooding. Patterns of land use and resource exploitation have had differential effects on the distribution and quality of remaining forest communities. Assessment of wetland functions in this highly modified landscape requires an understanding of the scope of the more influential changes that have taken place.

Land use and management

Natural levees, which commonly are the highest elevations in the landscape of the MAV and often are in direct proximity to water, have been the focus of human settlement during both prehistoric and historic times (Saucier 1994). At the time of the first European explorations of the region in the 16th century, natural levees of the major rivers were extensively used for maize agriculture by Native Americans (Hudson 1997). By the time detailed surveys of the Mississippi River were first made in the 1880s, European settlers were farming nearly all of the natural levees adjacent to the river through the MAV (Mississippi River Commission 1881–1897). Lower terrain had not been similarly developed (Barry 1997).

In the last two decades of the 19th century, local flood control and drainage efforts began to have widespread effects in the region, and railroads were constructed in formerly remote areas. These changes allowed logging and agricultural development to proceed on a massive scale throughout the MAV. As the 20th century progressed, improvements to farming equipment and crops and the initiation of coordinated Federal flood control efforts allowed further conversion of forested land to agriculture. From an estimated original area of 9 to 10 million hectares, Lower Mississippi Valley forests had been reduced by about 50 percent by 1937, and 50 years later less than 25 percent of the original area remained forested (Smith et al. 1993). Much of the remaining forest is highly fragmented, with the greatest degree of fragmentation occurring on drier sites (such as natural levees), and the largest remaining tracts being in the wettest areas (Rudis 1995). Nearly all of the remaining forests within the basin have been harvested at least once, and many have been cut repeatedly and are in degraded condition due to past high-grading practices (Putnam 1951; Rudis and Birdsey 1986).

Hydrology

The hydrology of the MAV has been modified extensively and purposefully. Unconnected wetlands associated with the higher alluvial terraces (such as Grand Prairie) and with the valley train terraces were not subject to major river flooding in historic times, and they were readily drained with simple ditch systems and planted with row crops. The lowlands were far more difficult to convert to agricultural uses. By the mid-19th century, many individual plantations along the Mississippi River were protected with low levee systems, often built with slave labor, that were sufficient to exclude most floods, but not the periodic catastrophic event (Barry 1997). Additional drainage and levee building were accomplished under the provisions of the Federal Swamp Lands Act passed in 1849 and 1850 (Holder 1970), but the first truly extensive and effective efforts were undertaken in the late 19th century and into the first few decades of the 20th century, when numerous local levee and drainage districts were created and funded by land taxes and the sale of bonds.

Despite the successes of the early drainage districts, their efforts could not overcome the effects of the Mississippi, Yazoo, Red, and Arkansas Rivers in flood stage; and periodic widespread destruction occurred (Barry 1997). A devastating flood in 1927 finally prompted Congress to direct the US Army Corps of Engineers to implement a comprehensive federal flood control plan for the entire Lower Mississippi Valley. The approach included construction of larger and stronger levees as well as various channel modifications, bank protection works, and other features. The multiple elements of this plan and its subsequent modifications collectively comprise the Mississippi River and Tributaries Project (MR&T), which is the largest flood-control project in the world (US Army Engineer Division, Mississippi Valley 1998).

Congress directed changes to the MR&T plan in the 1930s and 1940s that included the addition of cutoffs, tributary reservoirs, and an emphasis on maintenance of a stable, deep Mississippi River channel as a levee protection measure and a means of providing navigation benefits. In the 1950s, 1960s, and 1970s the project was expanded to include numerous tributary modifications, pump stations, harbor improvement projects, and lock and dam projects, as well as channel and levee projects throughout the system. During this last period, fish and wildlife considerations also became authorized project purposes. Meeting fish and wildlife objectives generally involved constructing water control structures within floodways and sump areas to allow habitat management for waterfowl (Moore 1972).

The cornerstone of the Federal flood-control effort in the Lower Mississippi Valley is the mainstem levee system, which is essentially continuous on the western side of the Mississippi River from Cape Girardeau, MO, to Venice, LA, about 16 km above the mouth of the river, except where tributaries enter. Levees also extend up the tributaries and they are used to create backwater areas that are used as water storage basins during major Mississippi River floods.

Definition and identification of the HGM classes and subclasses

Brinson (1993a) identified five wetland classes based on hydrogeomorphic criteria, as described in Chapter 2. Wetlands representing four of these classes (Flat, Riverine, Depression, and Fringe wetlands) and a variety of subclasses occur within the MAV. However, categorical separation of these classes is sometimes difficult because of the complexity of the landscape and hydrology within the basin and because features of wetlands intergrade and overlap among types. Consequently, a set of specific criteria has been established to assist the user in assigning any particular wetland in the region to the appropriate class, subclass, and community type. These criteria are presented in the form of dichotomous keys in Figures 5 and 6. In addition, each wetland type identified in the keys is described in the following section, which also includes a series of block diagrams illustrating the major wetland types and their relationships to various landforms and man-made structures. These relationships also are summarized in Table 4.

Figure 5. Key to the wetland classes in the MAV.

Key to Wetland Classes in the Mississippi Alluvial Valley

1. Wetland is not within the 5-year floodplain of a stream **2**

1. Wetland is within the 5-year floodplain of a stream **3**

    2. Topography generally flat, principal water source is precipitation .... **Flat**

    2. Topography is depressional, or within the 5-year floodplain of a stream **3**

3. Wetland is not in a topographic depression or impounded........................ **Riverine**
3. Wetland is in a topographic depression, or impounded **4**

    4. Wetland is associated with a beaver impoundment, or with a shallow impoundment managed principally for wildlife (e.g., greentree reservoirs or moist soil units) .... **Riverine**

    4. Wetland is in an impoundment or depression other than above **5**

5. Wetland is associated with a water body that has permanent water more than 2 m deep in most years .... **Fringe**

5. Wetland is associated with a water body that is ephemeral or less than 2 m deep in most years .... **Depression**

Figure 6. Key to the wetland subclasses and community types in the MAV (Sheet 1 of 2).

Key to Wetland Subclasses and Community Types in the Mississippi Alluvial Valley		
CLASS: FLAT	**Subclass**	**Community Type**
1. Soil reaction acid	Non-Alkali Flat (2)	
1. Soil reaction circum-neutral to alkaline (lake bed deposits)		
2. Vegetation dominated by graminoids		*wet tallgrass prairie*
2. Vegetation dominated by woody species		
2a. Vegetation dominated by pine		*pine flat*
2b. Vegetation dominated by post oak		*post oak flat*
2c. Vegetation dominated by hardwoods other than post oak		*hardwood flat*
3. Vegetation dominated by graminoids		*alkali wet prairie*
3. Vegetation dominated by post oak		*alkali post oak flat*
CLASS: RIVERINE	**Subclass**	**Community Type**
1. Wetland associated with low-gradient stream (Stream Orders > 6, or other alluvial streams)	3	
1. Wetland associated with mid-gradient stream (Stream Orders 4–6)	Mid-Gradient Riverine (2)	
2. Water source primarily overbank flooding or lateral saturation		*mid-gradient floodplain*
2. Water source primarily backwater flooding, wetland typically located at confluence of two streams		*mid-gradient backwater*
3. Wetland not an impoundment	Low-Gradient Riverine (5)	
3. Wetland an impoundment	Riverine Impounded (4)	
4. Wetland impounded by beaver		*beaver complex*
4. Wetland impounded for wildlife management (greentree reservoirs and moist soil units)		*managed wildlife impoundments*
5. Water source primarily overbank flooding (5-year zone) that falls with stream water levels, or lateral saturation from channel flow		*low-gradient overbank*
5. Water source primarily backwater flooding or overbank flows (5-year zone) that remain in the wetland due to impeded drainage after stream water levels fall		*low-gradient backwater*

Figure 6. (Sheet 2 of 2).

CLASS: DEPRESSION	Subclass	Community Type
1. Depression not subject to direct stream flooding during a 5-year event; precipitation, runoff, and groundwater are the dominant inflows	2	
1. Depression has significant direct stream inflows and outflows relative to stored volume and/or is influenced by overbank or backwater flooding during a 5-year event	4	
2. Depression discharges water to surface channels, but has no significant surface inflows relative to discharge	Headwater Depression	*headwater swamp*
2. Depression has no significant direct surface outlet to a stream channel, or outflows are minor relative to stored volume	Unconnected Depression (3)	
3a. Precipitation-dominated depression in dunefields		*sandpond*
3b. Depressional feature in abandoned meander features (oxbows or swales) not subject to 5-year flood flows		*unconnected alluvial depression*
3c. Depressional feature in relict glacial outwash channel		*valley train pond*
4. Significant, perennial streamflow enters and leaves depression	Not Depression Class: see Riverine Class	
4. Depression not subject to perennial flow, but receives overbank or backwater flooding during 5-year events	Connected Depression	*floodplain depression*

CLASS: FRINGE	Subclass	Community Type
1. Wetland on the margin of a man-made reservoir	Reservoir Fringe	*reservoir shore*
1. Wetland on the margin of water body other than a reservoir	2	
2. Water body subject to stream flooding during 5-year flood events	Connected Lacustrine Fringe	*connected lake margin*
2. Water body not subject to flooding during a 5-year event	Unconnected Lacustrine Fringe	*unconnected lake margin*

Some of the criteria that are used in the keys in Figures 5 and 6 require some elaboration. For example, a fundamental criterion is that a wetland must be in the 5-year floodplain of a stream system to be included within the Riverine Class. This return interval is regarded as sufficient to support major functions that involve periodic connection to stream systems. It was also selected as a practical consideration, because the hydrologic models used to develop flood return interval maps generally include the 5-year return interval.

Table 4. Hydrogeomorphic Classification of Forested Wetlands in the MAV and Typical Geomorphic Settings of Community Types.

Wetland Classes, Subclasses, and Communities	Typical Geomorphic Setting
CLASS: FLAT	
SUBCLASS: ALKALI FLAT	
Alkali Post Oak Flat	Lacustrine sediments deposited in lake systems impounded by glacial outwash.
SUBCLASS: NON-ALKALI FLAT	
Hardwood Flat	Backswamp and point bar environments on Pleistocene and Holocene meander-belt topography, and on interfluves on valley trains.
Post Oak Flat	Pleistocene terraces.
CLASS: RIVERINE	
SUBCLASS: MID-GRADIENT RIVERINE	
Mid-Gradient Floodplain	Point bar and natural levee deposits within active meander belts of streams transitioning from uplands to alluvial plain, or dissecting terrace deposits.
Mid-Gradient Backwater	Backswamp and point bar deposits within active meander belts of mid-gradient streams near point of confluence with major alluvial river.
SUBCLASS: LOW-GRADIENT RIVERINE	
Low-Gradient Overbank	Point bar and natural levee deposits within active meander belts of alluvial streams.
Low-Gradient Backwater	Backswamp, point bar, and low-lying valley train deposits within and between both active and inactive meander belts of alluvial streams.
SUBCLASS: IMPOUNDED RIVERINE	
Beaver Complex	All flowing waters.
Wildlife Management Impoundment	Various settings.
CLASS: DEPRESSION	
SUBCLASS: HEADWATER DEPRESSION	
Headwater Swamp	In relict outwash channel, adjacent to scarp of a higher valley train terrace.
SUBCLASS: UNCONNECTED DEPRESSION	
Sand Pond	Eolian sand deposits (dunefields) on valley trains.
Valley Train Pond	Depressions atop buried braided outwash channels on valley trains.
Unconnected Alluvial Depression	Abandoned channels and large swales in former and current meander belts of larger rivers (including both Holocene and Pleistocene meander belt deposits).
SUBCLASS: CONNECTED DEPRESSION	
Floodplain Depression	Abandoned channels and large swales in former and current meander belts of larger rivers.
CLASS: FRINGE	
SUBCLASS: UNCONNECTED LACUSTRINE FRINGE	
Unconnected Lake Margin	Abandoned channels in meander belts and adjacent to man-made impoundments.
SUBCLASS: CONNECTED LACUSTRINE FRINGE	
Connected Lake Margin	Abandoned channels in meander belts and adjacent to man-made impoundments.

The classification system recognizes that certain sites functioning primarily as fringe or depression wetlands also are regularly affected by stream flooding, and therefore have a riverine functional component. This is incorporated in the classification system by establishing "river-connected" subclasses within the Fringe and Depression Classes.

The classification system addresses a major confounding aspect of overlap among wetland types that arises from the characteristic topographic variation within certain wetland types. Sites that function primarily as riverine wetlands and flats often incorporate small, shallow depressions, sometimes characterized as vernal pools and microdepressions. These features are regarded as normal components of the riverine and flat ecosystems, and are not separated into the Depression Class unless they meet specific criteria. Other significant criteria relating to classification are elaborated in the wetland descriptions in the following paragraphs.

The following sections briefly describe the classification system developed for this guidebook for wetlands in the MAV. All of the wetland types are described, but assessment models and supporting reference data were developed for only a subset of these types, as described in Chapter 4.

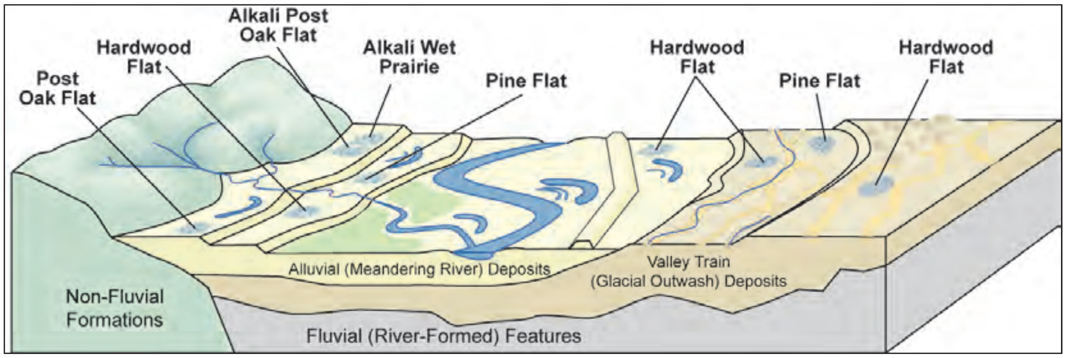
Class: Flat

Flats have little or no gradient, and the principal water source is precipitation. There is minimal overland flow into or out of the wetland except as saturated flow. Wetlands on flat areas that are subject to stream flooding during a 5-year event are classified as Riverine. Small ponded areas within flats are considered to be normal components of the Flat Class if they do not meet the criteria for the Depression Class. Sites are considered to be Slope wetlands rather than Flats if they have sufficient gradient to cause runoff in a single direction (however, slope wetlands are rare in the MAV), and as Slope or Depression wetlands if groundwater discharge is the principal water source within the wetland. There are two subclasses and six community types in the Flat Class, all of which occur within the MAV.

Figure 7 illustrates common landscape positions where wetlands in the Flat Class are found. See Figure 7 to identify land surfaces.

Subclass: alkali flat. Alkali flats (also called sodic or saline flats) have soils with high pH and high levels of sodium or magnesium salts in or near the surface layer. They typically have very poor drainage and a shallow

Figure 7. Common landscape positions of wetland community types in the Flat Class.



hardpan. The combination of impeded drainage and unusual soil chemistry restricts the potential plant communities, and provides habitats for certain rare species. The two community types in this subclass are separated based on predominant vegetation, but in fact probably represent a continuum of change in soil conditions, where the forested community occurs on soils with deeper hardpans than the prairie community. Most sites with alkali soils are believed to be former Pleistocene lake beds.

Alkali flats are not common in the MAV, and assessment models applicable to these types are not presented in this guidebook.

Community types. The following communities occur within the alkali flats subclass:

a. *Alkali post oak flat.* Alkali post oak flats occur on sites where the soils have extremely poor drainage and concentrations of salts accumulate near or on the soil surface. These sites are believed to have been occupied by shallow lakes during the Pleistocene. Repeated filling and drying of the lakes caused salts to accumulate, and today the ancient lakebeds are flats that support unique wetlands with characteristic plants that are tolerant of the high salt concentrations and impeded drainage conditions. In most cases, alkali flats are a mosaic of prairie and unvegetated “slick spots” on soils with salts at or very near the surface, while soils with less surface salt or somewhat better drainage support stunted post oak trees.

b. *Alkali wet prairie.* The ancient Pleistocene lake beds that support alkali post oak flats also support small areas of alkali wet prairie (also called saline prairie) where soil salinity is highest or drainage is very poor. Where the salts accumulate on the surface, it is common to find a hard white or gray surface, termed a “slick spot.” These areas may have salt crystals visible on the surface during dry periods, and they are largely devoid of vegetation. The perimeter of the slick spot often supports a crust of lichens, mosses, and liverworts. Beyond the slick spot edge, prairie species are able to colonize as the depth to the zone of concentrated salts increases, and stunted trees and shrubs occur on still deeper soils.

Subclass: non-alkali flat. Flats with neutral and acid soils can support a variety of community types. They are differentiated based on predominant vegetation types, which generally reflect drainage conditions. Fire history may also be an important factor in certain instances. These wetlands are widely distributed within the MAV, and provide habitat for numerous plant and animal species. Because wet flats are maintained by precipitation rather than flooding, many were relatively easy to convert to agriculture with fairly minor changes to drainage conditions, and extensive flat areas have been cleared. In addition, many sites that were historically subject to regular flooding have been disconnected from streamflows by modern man-made levees, and these sites are now classified as flats.

This guidebook includes assessment models applicable to all of the forested non-alkali flats in the MAV. Assessment models were not developed for the wet tallgrass prairie type, for which few high quality reference sites could be located.

Community types: The following communities are found in non-alkali flats:

a. *Wet tallgrass prairie.* The wet tallgrass prairie community type typically occurs within broad basins or headwater draws that have poor drainage, or in minor swales within larger expanses of dry prairie. All of these sites tend to stay wet, with areas of standing surface water, through spring. They usually become extremely dry in late summer. Wet tallgrass prairie is dominated by typical prairie species such as big bluestem (*Andropogon gerardii*), little bluestem (*Andropogon scoparius*), Indian grass (*Sorghastrum nutans*), switch grass (*Panicum virgatum*), and numerous perennial forbs. However, it also includes wetland species such as beakrush (*Rhynchospora* spp.), marsh fleabane (*Pluchea foetida*), sundews

(*Drosera* spp.) and sphagnum moss (*Sphagnum* spp.). Fire is essential to maintain prairies — without fire, trees will gradually establish.

b. *Pine flat.* Pine flats, also called pine flatwoods, are common in the Coastal Plain, but in the MAV they are restricted to valley train deposits, on silt loam soils that are acid to strongly acid and with a high water table throughout the winter and spring. In the modern landscape, most of these sites have been dramatically altered by forest management, drainage, and by changes in fire frequency, timing, and intensity.

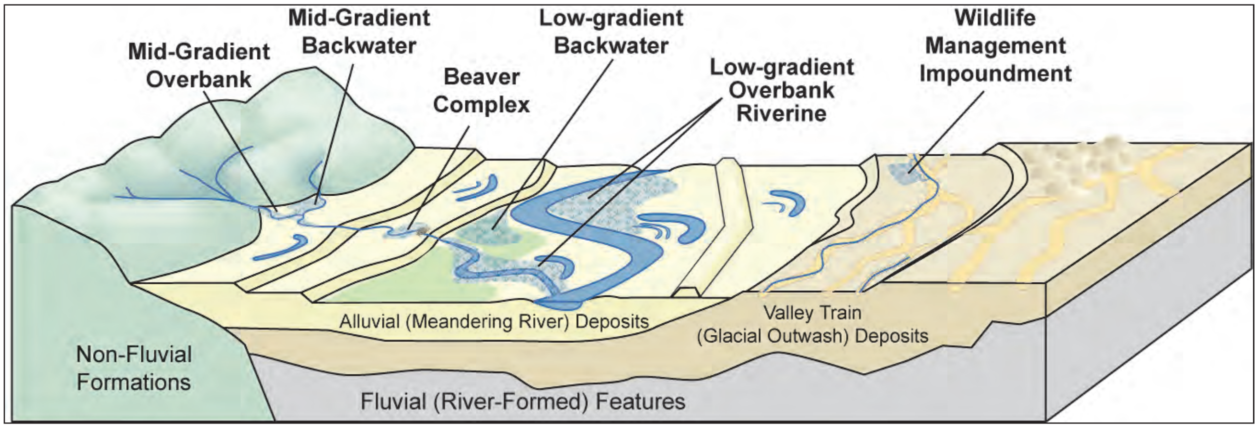
c. *Hardwood flat.* Hardwood flats occur on fairly level terrain that is not within the 5-year floodplain of stream systems, but that nevertheless remains wet throughout winter and spring due to rainfall that collects in small shallow pools. These pools often refill and remain wet for days or weeks following summer rains. Hardwood flats often are dominated by Nuttall oak (*Quercus texana*) in Holocene environments, and by water or willow oaks on older surfaces, where they are sometimes called oak flatwoods.

d. *Post oak flat.* Post oak flats occur on clay soils with poor drainage, generally on the margins of the Grand Prairie, where they may intergrade with hardwood flats, but are distinctively dominated by post oak or Delta post oak. These sites are saturated to the surface in the wet season and following rains, but become extremely dry and hard in summer. Mima (or pimple) mounds often are present, and contribute to the extensive ponding on these sites by impounding rainwater and impeding runoff. Tree growth tends to be very slow, although trees are not stunted as they are on alkali post oak flats.

Class: Riverine

Riverine wetlands are those areas directly flooded by streamflow, including backwater and overbank flow, at least once in five years on average (i.e., they are within the 5-year floodplain). Depressions and fringe wetlands that are within the 5-year floodplain are not included in the Riverine Class, but beaver ponds and wildlife management impoundments are usually considered to be riverine. Riverine wetlands encompass many different types of wetland communities; there are three subclasses and six community types in the Riverine Class in the MAV (Table 4, Figure 8).

Figure 8. Common landscape positions of wetland community types in the Riverine Class.



Subclass: mid-gradient riverine. Mid-gradient riverine wetlands are associated with streams (typically 4th – 6th order) that have significant floodplain development, but are upstream of the meandering portion of a stream system. They are important sources for input of organic material to the stream system. Mid-gradient systems are of limited distribution in the MAV, being restricted to sites transitional to the Coastal Plain, the Tertiary uplands flanking the upper part of the valley, and to some parts of the drainages flanking the Grand Prairie and Crowley's Ridge.

Due to the limited distribution of mid-gradient riverine systems in the MAV and consequent limited extent of potential reference wetlands for this subclass, no specific applicable assessment models have been developed for this guidebook.

Community types. The following community types occur within the mid-gradient riverine subclass:

a. *Mid-gradient floodplain*. Mid-gradient floodplain wetlands occur along small streams with significant bar and floodplain formation. Riparian wetlands along mid-gradient streams are usually fairly small floodplain units that occur repeatedly, often alternating from one side of the channel to the other. They combine elements of upland and lowland forests, and can be highly diverse. Species such as river birch (*Betula nigra*), red maple (*Acer rubrum*), American elm (*Ulmus americana*), and green ash are characteristic. In the northern portion of the region, silver maple (*Acer saccharinum*) is a common component.

b. *Mid-gradient backwater*. Mid-gradient backwater wetlands occur at the confluence of streams where high flows on the larger channel cause backwater flooding in the lower reaches of the mid-gradient tributary. They are sites where sediments accumulate rapidly, building natural levees and creating extensive backwater areas that drain slowly. Mid-gradient backwater systems tend to support plant communities that are more tolerant of flooding and sedimentation than the communities on most other mid-gradient floodplains. Species typical of adjacent hillslopes are not successful within the backwater zone, and some portions of the floodplain are occupied by species such as baldcypress (*Taxodium distichum*), that are more typical of lowland swamps.

Subclass: low-gradient riverine. Low-gradient riverine wetlands occur within the 5-year floodplain of meandering streams (usually 7th order or higher). They include a wide variety of community types, and have important functions related to habitat as well as sediment and water storage.

Community types. The following community types occur within the low-gradient riverine subclass:

a. *Low-gradient backwater*. Low-gradient backwater wetlands occupy sites that flood frequently (1- to 5-year flood frequency), but flooding is primarily by slack water, rather than by the high-velocity flows that predominate in overbank flood zones. Backwater flooding usually occurs when mainstem streams are in high stages, impeding the discharge of tributaries and causing them to back up onto their floodplains. This process results in sediment accumulation and ponding that persists long after water levels have fallen in the stream channels. Sediments tend to be fine textured, with considerable accumulation of organic material. Backwater sites that flood for long durations and are very poorly drained are usually dominated by overcup oak (*Quercus lyrata*) and water hickory (*Carya aquatica*). Less flooded sites are often dominated by green ash, Nuttall oak, willow oak (*Quercus phellos*), or by pin oak (*Quercus palustris*) in the northern part of the region, and the driest backwater sites may have species such as water oak (*Quercus nigra*) and cherrybark oak (*Quercus pagoda*) as important components in the overstory. As with flats, vernal pools may be an important component of the low-gradient backwater community type. Many sites that were subject to backwater flooding in historic times are now protected by levees. Wetlands on these altered sites are classified as flats.

b. *Low-gradient overbank.* Low-gradient overbank wetlands occur on regularly flooded sites (1- to 5-year flood frequency zone) along or near streambanks and on bars and islands within channel systems. These sites are usually point bar deposits, often with a natural levee veneer. This type differs from the low-gradient backwater community type because floodwater usually moves through the overbank zone at moderate to high velocities, parallel to the channel. Sediments, nutrients, and other materials are exported downstream or imported from upstream sites differently than they are in backwater wetlands. Backwater sites may tend to accumulate fine sediments and organic material and to export dissolved materials in the water column. Overbank sites tend to be subject to scour or deep deposition of coarse sediments, and litter and other detritus may be completely swept from a site or accumulated in large debris piles. In-channel sandbars and riverfront areas usually are dominated by willows, sycamore (*Platanus occidentalis*), cottonwood, and similar pioneer species, while older and less exposed substrates support more diverse communities. In most cases, however, plant communities in the overbank flood zone tend to be dominated by species with broad tolerances for inundation, sedimentation, and high-velocity flows. Overbank sites sometimes include vernal pools, usually in the form of long, arched swales between the depositional ridges of meander-scroll topography, rather than the irregularly shaped pools typically found in backwater areas.

Subclass: impounded riverine. These wetlands occur in shallow impoundments that detain and slow stream flows, but generally remain flow-through systems. They include highly dynamic and unique beaver-dominated wetlands, as well as systems that are intensively managed to benefit particular groups of wildlife species.

There are no HGM models specific to beaver complexes, but the recommended approach is to regard them as a fully functional component of any riverine system being assessed. Because the hydrological modifications and management techniques used in managed impoundments do not reflect the patterns observed in reference systems, this guidebook does not include models designed specifically for application in those areas.

Community types. The following community types occur within the impounded riverine subclass:

a. *Beaver complex*. Beaver complexes were once nearly ubiquitous in the continental United States, but became relatively uncommon during the past two centuries following the near-extirpation of beaver. In their most common form, they consist of a series of impounded pools on flowing streams. Beavers cut trees for dams and food, and they have preferences for certain species (e.g., sweetgum (*Liquidambar styraciflua*)), which alters the composition of forests within their foraging range. Tree cutting and tree mortality from flooding create patches of dead timber surrounded by open water, shrub swamps, or marshes. Beaver complexes may be abandoned when the animals exhaust local food resources or when they are trapped out. Following abandonment, the dams deteriorate, water levels fall, and different plants colonize the former ponds. When beavers reoccupy the area, the configuration changes again, the result being that systems with active beaver populations are in a constant state of flux.

b. *Wildlife management impoundment*. Wildlife management impoundments are areas managed specifically to provide habitat for waterfowl and other waterbirds. There are two common versions of this management approach within the MAV: greentree reservoirs and moist soil units. They are included in the Riverine Class because they usually draw water from and return it to stream systems, but the wetlands are contained within low levee systems that allow managers to create shallow flooding conditions suitable for use by foraging and resting birds. Greentree reservoirs are leveed sections of mature oak bottomland forest, which provide access to acorns and forest invertebrates when artificially flooded to provide shallow water for waterfowl foraging. Moist soil units are leveed cleared fields where water management and farm machinery are employed to maintain marshlike conditions, which provide small seeds and different invertebrates than are found in forested wetlands.

Class: Depression

Depression wetlands occur in topographic low points where water accumulates and remains for extended periods. Sources of water include precipitation, runoff, groundwater, and stream flooding.

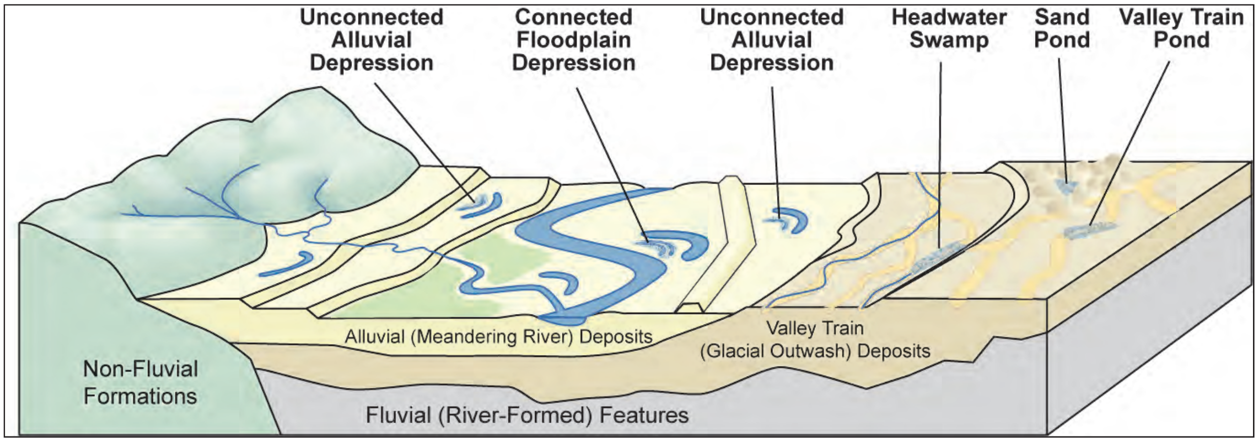
Depressions (both unconnected and connected) are distinguished from the ponded areas that occur within the Flat and Riverine Subclasses in several ways. Depressions tend to occur in abandoned channels, abandoned courses, and large point bar swales, while vernal pools within Flat and Riverine wetlands occur in minor swales or in areas bounded by natural levee deposits. Depressions hold water for extended periods due to their size, depth, and ability to collect surface and subsurface flows from an area much larger than the depression itself. They tend to fill during the winter and spring, and dry very slowly. Prolonged rains may fill them periodically during the growing season, after which they again dry very slowly. Vernal pools in Flats and Riverine settings, in contrast, fill primarily due to direct precipitation inputs and dry out within days or weeks. Depression Subclass wetlands usually exhibit two or more of the following characteristics:

- Depressional soils may have one or both of the hydric soil indicators F2 (Loamy Gleyed Matrix) or A4 (Hydrogen Sulfide) (USDA NRCS 2010).
- Depressions are distinct, closed units with relatively abrupt transitions to flats, riverine wetlands, or uplands (as opposed to extensive riverine backwater zones).
- Vegetation in depressions is usually dominated by one or more of the following species: baldcypress, water tupelo (*Nyssa aquatica*), swamp privet (*Forestiera acuminata*), water elm (*Planera aquatica*), and buttonbush (*Cephalanthus occidentalis*). Many depressions are fringed (and some are dominated) by species such as overcup oak and water hickory.

In the MAV, there are three subclasses and five community types in the Depression Class (Table 4, Figure 9).

Subclass: headwater depression. Headwater depressions have one or more outlets that form the headwaters of perennial streams. They export materials such as nutrients and organic matter to downstream systems, and contribute to maintenance of stream baseflow. They differ from Connected Depressions in that they do not have a surface stream input; rather, they are fed by groundwater, precipitation, and/or local runoff.

Figure 9. Common landscape positions of wetland community types in the Depression Class.



Community type. The following community type occurs within the headwater depression subclass:

a. *Headwater swamp*. Few examples of this wetland type are known, but those that have been examined appear to be restricted to basins formed in ancient glacial outwash channels that receive groundwater from adjacent higher terraces. The nearly constant water supply into the depression creates swamp conditions, where baldcypress and water tupelo are the most common tree species. Few species are present in the understory, and herbaceous species grow primarily on stumps or from a zone of mosses on tree trunks at the level where water tends to stabilize during the growing season. The perimeter forest is dominated by typical lowland species, such as green ash, overcup oak, and Nuttall oak. All known examples of this wetland type are in Monroe or Phillips Counties in Arkansas – including the largest example – which is located at the Louisiana Purchase State Park.

Subclass: unconnected depression. Unconnected depressions are found in a variety of landscape settings. They are maintained by precipitation, runoff, and sometimes by groundwater. Some may have small (non-perennial) inflow and outlet channels, but they are not overwhelmed by floodwaters during 5-year events; therefore, the import or export of materials is not a significant function of these wetlands except during extreme events. Their disconnection from river systems may result in very different wildlife functions than those associated with connected depressions. For example, unconnected depressions may lack predatory fish populations, and thereby provide vital habitat for certain invertebrate and amphibian species.

Community types. The following community types occur within the unconnected depressions subclass:

a. *Sand pond*. Sand ponds are depressions within dunefields on valley train terraces. The dunes are wind-blown accumulations of sediments that were deposited in waning glacial outwash channels, and date from 12,000 and 30,000 years before present. Individual dunes typically are 3 to 5 m high, and support upland forests or have been converted to agriculture. Numerous small, enclosed depressions are confined by the dunes, resulting in a poorly drained environment that ponds rainwater and possibly intercepts local groundwater for extended durations. As a result, distinctive, unconnected wetlands form that usually include swamp species such as baldcypress or water tupelo in the deepest interior areas, and successively less water-tolerant species around the perimeter of the depression. Many sand ponds, particularly those in the northern part of their distribution, contain the shrub species pondberry (*Lindera melissifolia*) and corkwood (*Leitneria floridana*), which do not commonly occur in any other habitat in the region.

b. *Unconnected alluvial depression*. Unconnected alluvial depressions occur in major river floodplains that have been cut off from the channel by levees, and on terraces (former floodplains that are higher than the modern floodplain). They are not affected by river flooding during common flood events (1- to 5-year flood frequency zone). This lack of connection to the river distinguishes this wetland type from floodplain depressions; otherwise, the two types are very similar. Unconnected alluvial depression wetlands typically occur in abandoned river channels and large swales. Depressions that are deep enough to hold water year-round will have an open-water zone (less than 2 m deep) in the center, with baldcypress and buttonbush in areas that are rarely dry, and relatively narrow zones of progressively “drier” plants, such as overcup oak, around the depression perimeter. Many of these wetlands have been altered by agricultural activities, including drainage works that either reduce or increase water storage within the depression.

c. *Valley train pond*. Valley train ponds are unconnected wetlands associated with glacial outwash ("valley train") deposits. They form in very shallow basins that are the remnants of ancient braided channel systems. Plant species in valley train ponds on the youngest outwash deposits (e.g., much of the St. Francis basin) are similar to those found in the alluvial depressions of active stream meander belts, such as baldcypress and water tupelo. Ancient sandbars within the valley train depressions may support species that are not commonly seen in swamps, but are more typical of sandy riverfront areas, such as sycamore and river birch. Older valley train deposits, where outwash channels are largely filled by stream backwater sediments, loess, or erosion from surrounding surfaces, have fewer, shallower ponds than younger surfaces, and tend to be dominated by species less tolerant of water such as willow and water oaks. Water sources for valley train ponds may include groundwater connections through the subsurface, sand-filled paleo-channel system, in addition to precipitation and local runoff.

Subclass: connected depression. Connected depressions occur within the 5-year floodplain of streams, or have perennial streams flowing in and out of them. They are integral components of the stream ecosystem with regard to materials exchange and storage. They often are used by fish and other aquatic organisms that move in and out of the wetland during floods.

Community type. The floodplain depression is the sole community type described within the connected depression subclass:

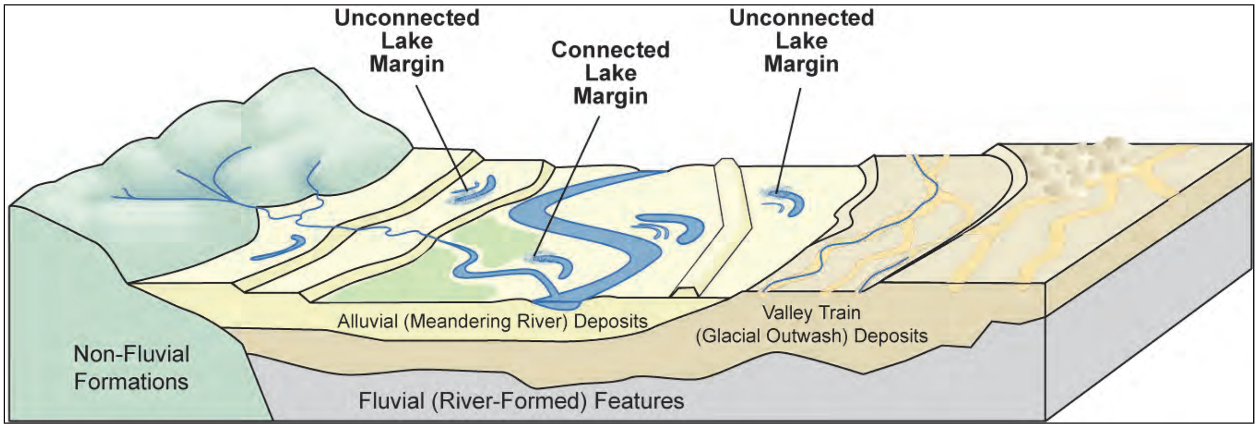
a. *Floodplain depression*. Floodplain depression wetlands are most commonly found in remnants of abandoned stream channels, or in broad swales left behind by migrating channels. They are usually near the river, and are flooded by the river during the more common (1- to 5-year) flood events, or are directly connected to perennial streams. They typically support swamp forests or shrub swamps in deeper water zones that remain flooded most of the time, and overcup oak-water hickory forests in areas that dry out in summer. Floodplain depression wetlands were once common in the MAV, but as effective flood-control works have been developed along major rivers, many depressions have become disconnected from stream systems and now function as unconnected alluvial depressions (discussed previously).

Class: Fringe

Fringe wetlands occur along the margins of lakes. By convention, a lake must be more than 2 m deep; otherwise, associated wetlands are classified as Depressional.

In the MAV, natural lakes occur mostly in the abandoned channels of large rivers (oxbows), but numerous man-made impoundments also support fringe wetlands. Typical examples include the baldcypress fringe common on oxbow lakes, or the black willow fringe that is often associated with borrow pits. There are three subclasses and three community types in the Fringe Class (Table 4, Figure 10). No assessment models have been developed for any of the Fringe wetland subclasses in the MAV, primarily because no single reference system can reflect the range of variability they exhibit. In particular, many water bodies that support fringe wetlands are subject to water-level controls, but the resulting fluctuation patterns are highly variable depending on the purpose of the control structure.

Figure 10. Common landscape positions of wetland community types in the Fringe Class.



Subclass: reservoir fringe. Wetlands that occur within the fluctuation zone of man-made reservoirs are classified as Reservoir Fringe. Reservoirs are distinguished from other man-made water bodies (such as borrow pits) in that they are specifically constructed and operated to store water for flood control, water supply, or similar purposes. As a result, they tend to have fluctuation regimes that are different from any natural pattern in the region.

Community type. The reservoir shore is the sole community type described within the reservoir fringe subclass:

a. *Reservoir shore.* Man-made reservoirs include a wide array of features, such as large farm ponds, municipal water storage reservoirs, and state recreational lakes. In almost all cases, these lakes are managed specifically to modify natural patterns of water flow; therefore, their shoreline habitats are subjected to inundation at times and for durations not often found in nature. Steep reservoir shores usually support little perennial wetland vegetation other than a narrow fringe of cattails and rushes and willows. The most extensive wetlands within reservoirs usually occur where tributary streams enter the lake, and sediments accumulate to form deltas. These sites may be colonized by various marsh species, and sometimes black willow or buttonbush, but even these areas are vulnerable to extended drawdowns, ice accumulation, erosion due to boat wakes, and similar impacts.

Subclass: connected lacustrine fringe. Fringe wetlands are considered to be “connected” to other aquatic systems if they become contiguous with riverflows during a 5-year flood event, or have perennial streams flowing into and out of them. This means that aquatic organisms can move freely between the river and the lake on a regular basis; and nutrients, sediments, and organic materials are routinely exchanged between the riverine and lake systems.

Community type: The connected lake margin is the sole community type described in the connected lacustrine fringe subclass:

a. *Connected lake margin.* Connected lake margin wetlands occur primarily in oxbow lakes near large rivers, where they are frequently inundated during floods (that is, they are within the 1- to 5-year flood frequency zone) or directly connected to perennial streams. Many lakes that would have met this criterion early in the 1900s have gradually been disconnected from riverflows due to the completion of large levees and other flood-protection works, and the wetlands in those lakes are now classified as unconnected lake margins. Connected lake margins differ from unconnected systems in that they routinely exchange nutrients, sediments, and aquatic organisms with the river system. Shoreline cypress-tupelo stands and fringe marshes are common, and the upper reaches of oxbow lakes often contain buttonbush swamps and expansive marsh systems. In addition to natural oxbows, there are man-made bodies of water, such as borrow pits, which support connected fringe wetlands. Connected lake margin fringe wetlands are common along large rivers within the MAV.

Subclass: unconnected lacustrine fringe. These fringe wetlands occur on lakes that are not within the 5-year floodplain of a river, although they may have small (non-perennial) inflow and outflow streams. Many oxbow lakes that have been disconnected from big rivers by levees are in this category. Managed flood-control and water supply reservoirs are not included here, but deeply flooded borrow pits are included.

Community type. The unconnected lake margin is the sole community type described in the unconnected lacustrine fringe subclass:

a. *Unconnected lake margin.* Unconnected lakes are lakes that are not within the portion of a floodplain that is inundated by a river on a regular basis (that is, they are not within the 1- to 5-year floodplain). They are similar in appearance to connected lake margins but are classified separately because they do not regularly exchange nutrients, sediments, or fish with river systems. Most are associated with oxbow lakes, where baldcypress wetlands normally form in a narrow band along the shoreline. Shallow filled areas in the upper and lower ends of the lake sometimes develop more extensive wetland complexes of willows, buttonbush, and marsh species.

Most of these natural lake systems have been modified in various ways. Frequently, their outlets have been fitted with control structures to allow added storage and manipulation of water. Inflows have been altered by farm drainage and other diversions, and adjacent lands have been cleared or developed in many areas. All of these actions have caused accelerated sedimentation within the lakes.

Naturally occurring unconnected lake margins are most common in the former floodplains of large rivers, especially the Mississippi, Yazoo, Red, and Arkansas Rivers, where levees now prevent flooding. Man-made lakes in this subclass can occur anywhere.

4 Wetland Functions and Assessment Models

This *Guidebook* uses five sets of assessment models applicable to wetlands in the MAV. Only forested wetlands (or sites that could support forested wetlands) are intended to be assessed using these models. No rapid assessment models were developed for the Alkali Flat subclass, Headwater Depression subclass or the Mid-Gradient Riverine subclass, because relatively few examples of these wetlands exist in the MAV. None of the Fringe Class or Riverine Impounded subclass wetlands are addressed in the guidebook because impacts to these wetlands are likely to involve subtle changes in water level management, which are beyond the scope of a rapid assessment technique.

The MAV wetlands that can be assessed with the models presented here include all of the subclasses and community types not specifically excluded in the preceding paragraph, and represent most of the common forested wetland types in the region. For simplicity, the Non-Alkali Flat subclass will be referred to simply as the Flat subclass.

The output from the assessment models is a Functional Capacity Index (FCI) for each assessed function. This can be multiplied by some measure of affected area (usually hectares or acres) to generate Functional Capacity Units (FCU). Generally, FCUs are the most convenient basis for discussing and comparing among various potential impacts to wetlands, mitigation options, and similar potential actions affecting wetland functions.

The five wetland subclasses addressed with models in this guidebook are as follows:

1. Flat.
2. Low-Gradient Riverine Overbank.
3. Low-Gradient Riverine Backwater.
4. Unconnected Depression.
5. Connected Depression.

The following functions are assessed:

1. Detain Floodwater.
2. Detain Precipitation.

3. Cycle Nutrients.
4. Export Organic Carbon.
5. Maintain Plant Communities.
6. Provide Habitat for Fish and Wildlife.

It should be noted that not all functions are performed by each regional wetland subclass. Thus, assessment models for each subclass may not include all six functions. In addition, the form of the assessment model that is used to assess functions can vary from subclass to subclass.

Function 1: Detain Floodwater

This function reflects the ability of wetlands to store, convey, and reduce the velocity of floodwater as it moves through a wetland. The potential effects of this reduction are damping of the downstream flood hydrograph, maintenance of post-flood base flow, and deposition of suspended sediments from the water column to the wetland. This function is assessed for the following regional wetland subclasses in the MAV: Low-Gradient Riverine Overbank, Low-Gradient Riverine Backwater, and Connected Depression. The recommended procedure for assessing this function involves estimation of “roughness” within the wetland, in addition to a change in flood frequency. A potential independent, quantitative measure for validating the functional index is the volume of water stored per unit area per unit time (m^3/ha/time), at a discharge equivalent to the average annual peak event.

The assessment model for the Detain Floodwater function includes the following assessment variables:

V_{FREQ} = change in flood return interval
$V_{DWD\&S}$ = down woody debris and snags
V_{STRATA} = number and top strata present
V_{TBA} = tree basal area

1. Flat.

Not Assessed

2. Low-Gradient Riverine Overbank.

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

3. Low-Gradient Riverine Backwater.

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

4. Unconnected Depression.

Not Assessed

5. Connected Depression.

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

Function 2: Detain Precipitation

This function is defined as the capacity of a wetland to prevent or slow runoff of rainfall to streams. This is accomplished chiefly by microdepressional storage, infiltration, and absorption by organic material and soils. Both floodprone (riverine) wetlands and nonflooded wetlands (flats) are assessed for this function. Depressional wetlands also perform a precipitation storage function, but are not assessed for that function within the MAV. Precipitation storage in depressions is related to local runoff to varying degrees, and it is difficult to consistently define source areas and available storage volumes in the context of a rapid field assessment. In contrast, precipitation storage in flats and riverine wetlands is more often a local effect related to microdepressional storage and infiltration capacity. Three wetland subclasses are assessed for the precipitation detention function in the MAV: Flat, Low-Gradient Riverine Overbank, and Low-Gradient Riverine Backwater.

The recommended procedure for assessing this function is estimation of available micro-depression storage and characterization of the extent of organic surface accumulations available to improve absorption and infiltration. A potential independent direct measure would be calculation of onsite storage relative to runoff predicted by a storm hydrograph for a given rainfall event.

The assessment model for the Detain Precipitation function includes the following assessment variables:

V_{POND} = percent of area subject to ponding
V_{SOIL} = soil integrity
V_{LITTER} = percent cover of the litter layer

1. Flat.

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

2. Low-Gradient Riverine Overbank.

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

3. Low-Gradient Riverine Backwater.

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

4. Unconnected Depression.

Not Assessed

5. Connected Depression.

Not Assessed

The assessment model has two components, which are weighted equally. The percentage of the assessment area subject to ponding V_{POND} is based on a field estimate. The second component expression is an average based on field measures of soil integrity, V_{SOIL} and the percentage of the ground surface covered by litter V_{LITTER}.

Function 3: Cycle Nutrients

This function refers to the ability of the wetland to convert nutrients from inorganic forms to organic forms and back through a variety of biogeochemical processes, such as photosynthesis and microbial decomposition. The nutrient cycling function encompasses a complex web of chemical and biological activities that sustain the overall wetland ecosystem, and it is assessed in all five wetland subclasses.

The assessment procedure described here utilizes indicators of the presence and relative magnitude of organic material production and storage, including living vegetation strata, dead wood, detritus, and soil (organic matter measured as non-altered soils). Potential independent, quantitative measures for validating the functional index include net annual primary productivity (gm/m^2), annual litter fall (gm/m^2), or standing stock of living and/or dead biomass (gm/m^2).

The model for assessing the Cycle Nutrients function includes the following assessment variables:

V_{TBA} = tree basal area
V_{STRATA} = number and top strata present
$V_{TREESIZE}$ = number and top tree size present
V_{SOIL} = soil integrity
$V_{DWD\&S}$ = down woody debris and snags

The model can be expressed in a general form:

1. Flat.

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

2. Low-Gradient Riverine Overbank.

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

3. Low-Gradient Riverine Backwater.

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

4. Unconnected Depression.

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

5. Connected Depression.

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

The two constituent expressions within the model reflect the two major production and storage compartments: living and dead organic material. The first expression is composed of indicators of living biomass, expressed as tree basal area V_{TBA}, number and top strata present (V_{STRATA}), and the number of and top tree size classes present ($V_{TREESIZE}$). V_{STRATA} reflects varying levels of nutrient availability and turnover rates, with the aboveground portion of ground cover biomass being largely recycled on an annual basis, while understory and tree components incorporate both short-term storage (leaves) as well as long-term storage (wood). Similarly, the second expression includes organic storage compartments that reflect various degrees of decay. Down woody debris and snags $V_{DWD\&S}$ represent relatively long-term storage compartments that are gradually transferring nutrients into other components of the ecosystem through the mediating activities of fungi, bacteria, and higher plants. The soil alteration variable (where a high index is indicated by low alteration rates) represents a shorter-term storage compartment of largely decomposed, but nutrient-rich organics on the soil surface. All of these components are combined here in a simple arithmetic model, which weights each element equally. Note that one detrital component, litter accumulation, is not used in this model. That is because it is a relatively transient component of the onsite nutrient capital, and may in fact be readily exported. Therefore, it is used as a nutrient-related assessment variable only in the carbon export function, discussed in the next section.

Function 4: Export Organic Carbon

This function is defined as the capacity of the wetland to export dissolved and particulate organic carbon, which may be vitally important to downstream aquatic systems. Mechanisms involved in mobilizing and exporting nutrients include leaching of litter, flushing, displacement, and erosion. This assessment procedure employs indicators of organic production, the presence of organic materials that may be mobilized during floods, and the occurrence of periodic flooding to assess the organic export function of a wetland. This function is assessed in wetlands that have outflow to streams, which includes three subclasses assessed by the rapid assessment: Low-Gradient Riverine Overbank, Low-Gradient Riverine Backwater, and Connected Depression. An independent quantitative measure of this function is the mass of carbon exported per unit area per unit time (g/m^2/year).

The model for assessing the Export Organic Carbon function includes the following assessment variables:

V_{FREQ} = change in frequency of flooding
V_{LITTER} = percent cover of the litter layer
$V_{DWD\&S}$ = down woody debris and snag biomass
V_{TBA} = tree basal area
V_{STRATA} = number and top strata present

1. Flat.

Not Assessed

2. Low-Gradient Riverine Overbank.

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

3. Low-Gradient Riverine Backwater.

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

4. Unconnected Depression.

Not Assessed

5. Connected Depression.

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

This model is similar to the model used to assess the nutrient cycling function in that it incorporates most of the same indicators of living and dead organic matter. The living tree and strata components (V_{TBA}, V_{STRATA}) represent primarily organic production, indicating that materials will be available for export in the future. The dead organic fraction represents the principal sources of exported material, represented by litter, snags, and woody debris (V_{LITTER}, $V_{DWD\&S}$). This model differs from the nutrient cycling model in that materials stored in the soil are not included due to their relative immobility, and flooding is a required component of this model, because the export function is largely dependent on inundation and continuity with stream flows (V_{FREQ}). This model also includes litter as a component of the dead organic fraction, despite the fact that it is a highly seasonal functional indicator that is difficult to estimate reliably, and consequently is not included in other models where it may seem appropriate. However, it is included in this model because it represents the most mobile dead organic fraction in the wetland, and because it may be the only component of that fraction that is present in young or recently restored systems.

Function 5: Maintain Plant Communities

This function is defined as the capacity of a wetland to provide the environment necessary for characteristic plant community development and maintenance. In assessing this function, one must consider both the extant plant community as an indication of current conditions and the physical factors that determine whether or not a characteristic plant community is likely to be maintained in the future. This function is assessed in all five subclasses in the MAV. Various approaches have been developed to describe and assess plant community characteristics that might be appropriately applied in developing independent measures of this function; however, all such methods require extensive field sampling and data analysis conducted by ecologists familiar with the plant communities of the region.

The model for assessing the Maintain Plant Communities function includes the following assessment variables:

V_{TBA} = tree basal area
$V_{TREESIZE}$ = tree size classes
V_{COMP} = composition of tallest woody stratum
V_{SOIL} = soil integrity
V_{DUR} = change in growing season flood duration
V_{POND} = microdepressional ponding

1. Flat.

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

2. Low-Gradient Riverine Overbank.

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

3. Low-Gradient Riverine Backwater.

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

4. Unconnected Depression.

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

5. Connected Depression.

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

The first expression of the model has two components. One component describes the structure of the overstory stratum of the plant community in terms of tree basal area and size classes (V_{TBA} and $V_{TREESIZE}$). Together these indicate whether the stand has a structure typical of a mature forest with "gap" regeneration processes in place. The second term of the expression (V_{COMP}) considers the species composition of the dominant stratum, which will be the overstory in most instances, but which may be the shrub or ground cover layers in communities that are in earlier (or arrested) stages of development. This allows recognition of the faster recovery trajectory likely to take place in planted restoration sites versus abandoned fields.

The second expression of the model considers three specific site factors that may be crucial to plant community maintenance under certain conditions. V_{SOIL} is a simple indicator of the level of disturbance or integrity of the soil. As described in the section "Vegetation" in Chapter 3, plant communities of the MAV are strongly affiliated with particular soil types; these are the product of distinct alluvial processes. The V_{SOIL} variable allows recognition of sites where the native soils have been replaced or buried by sediments inappropriate to the site, or where the native soils have been damaged significantly, as by compaction. Periodic flooding is important to the composition and structure of lowland plant communities, and its occurrence is accounted for in the flood duration variable. Shifts in frequency are not likely to affect plant community composition and structure as significantly as changes to flood duration and ponding, so only the latter two hydrologic variables are included in this model. Flood duration (V_{DUR}) has been shown to be a major factor affecting the health and composition of lowland forest trees, especially where flooding has been artificially extended into the growing season, in either spring or fall. The V_{POND} variable focuses on a specific aspect of site alteration—the removal of microtopography and related ponding of water on flats and riverine wetlands. As described previously, ponding of precipitation is a crucial mechanism for maintaining wetland character in many wetlands in the MAV.

Function 6: Provide Habitat for Fish and Wildlife

This function is defined as the ability of a wetland to support the fish and wildlife species that utilize wetlands during some part of their life cycles. Terrestrial, semiaquatic, and aquatic animals use wetlands extensively. Maintenance of this function ensures habitat for a diversity of vertebrate organisms, contributes to secondary production, and maintains complex trophic interactions. Habitat functions span a range of temporal and spatial scales, and include the provision of refugia and habitat for wide-ranging or migratory animals as well as highly specialized habitats for endemic species. However, most wildlife and fish species found in wetlands of the MAV depend on certain aspects of wetland structure and dynamics, such as periodic flooding or ponding, specific vegetation composition, and proximity to other habitats. This function is assessed in all five subclasses in the MAV. Potential independent, quantitative measures of this function are animal inventory approaches, which require extensive field data collection and analysis by ecologists experienced with such methods, as well as specific knowledge of the fauna and habitats of the region.

The model for assessing the Provide Habitat for Fish and Wildlife function includes the following assessment variables:

V_{FREQ} = change in frequency of flooding
V_{DUR} = change in growing season flood duration
V_{POND} = microdepressional ponding
V_{COMP} = tree composition
$V_{DWD\&S}$ = down woody debris and snags
V_{STRATA} = number and top strata present
V_{TBA} = tree basal area
V_{TRACT} = wetland tract size

$V_{CONNECT}$ = habitat connections
V_{CORE} = core area

1. Flat.

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

2. Low-Gradient Riverine Overbank.

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

3. Low-Gradient Riverine Backwater.

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

4. Unconnected Depression.

$$FCI = \left(\left[\frac{(V_{COMP} + V_{STRATA} + V_{DWD\&S} + V_{TBA})}{4} \right] \times \left[\frac{(V_{TRACT} + V_{CONNECT} + V_{CORE})}{3} \right] \right)^{1/2}$$

5. Connected Depression.

$$FCI = \left(\left[\frac{(V_{FREQ} + V_{DUR})}{2} \right] \times \left[\frac{(V_{COMP} + V_{STRATA} + V_{DWD\&S} + V_{TBA})}{4} \right] \times \left[\frac{(V_{TRACT} + V_{CONNECT} + V_{CORE})}{3} \right] \right)^{1/3}$$

The expressions within the model reflect the major habitat components described. The first expression concerns hydrology, and includes indicators of both seasonal inundation, which allows river access by aquatic organisms (V_{DUR} and V_{FREQ}) and the periodic occurrence of temporary, isolated aquatic conditions (V_{POND}). The second expression includes four indicators of forest structure and diversity, specifically overstory basal area (V_{TBA}), composition (V_{COMP}), down woody debris and snag density ($V_{DWD\&S}$) and a measure of structural complexity and maturity (V_{STRATA}). Together these variables reflect a variety of conditions of importance to wildlife, including forest maturity and complexity and the availability of food and cover. Three landscape-level variables are incorporated within the last term of the model to reflect the importance of habitat fragmentation and interhabitat continuity as considerations in determining habitat quality many wildlife species within the MAV: the size of the overall wetland complex independent of the boundaries of the assessment area (V_{TRACT}); the proportion of the assessment area that is buffered from surrounding land uses and edge effects (V_{CORE}); and the proportion of the assessment area boundary that is connected to other suitable habitats ($V_{CONNECT}$).

5 Variables and Data Collection

Information used to assess the functions of regional wetland subclasses in the MAV is collected at several different spatial scales, and entered into the data forms provided in Appendix A. Landscape-level variables that might be best addressed using maps or aerial photographs are listed first, followed by variables that are assessed after a walk-through of the entire Wetland Assessment Area (WAA) or estimated at representative points within the WAA. Previous HGM guidebooks for the region used a more intensive sampling approach to collect variable values.

Note that different wetland subclasses use different subsets of the assessment variables, and the ranges of values offered for these variables change depending on the subclass chosen in the top Site Information section of the data sheet (Appendix B). Thus, it is imperative that the subclass is selected prior to printing out the data sheets for the field. Table 5 indicates which variables are used for each subclass assessment. Any variables not required for assessment will have “Not Used” next to them in the data sheet once a subclass is selected, so the user doesn’t spend time in the field trying to collect them. Species names used in the data sheets are provided in Appendix C, and pictures of several indicators are included in Appendix D.

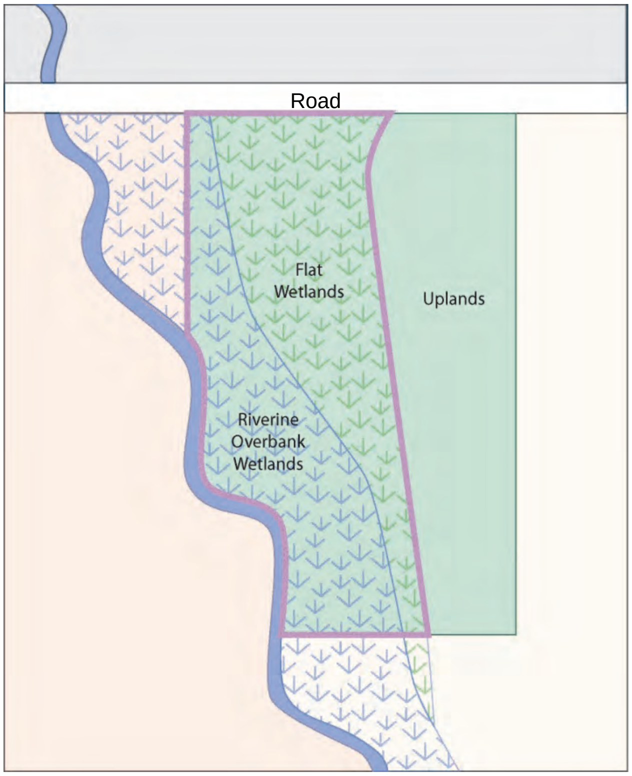
The procedure for conducting an assessment requires only one tool, a specialized 10-factor basal area measuring prism. All other variables are estimated visually and assigned a subindex score based on ranges of values. Directions for estimating and entering data for each variable are presented below. Some of these procedures are identical to those used in the previous HGM guidebooks published for the region, but most are simplified. However, the subindex values generated by the simplified field procedures are based on the same extensive reference data set as the more complicated, previously published procedures. Additional reference site samples were collected and included to allow the extension of this guidebook to the entire MAV. Therefore, the use of data ranges will yield subindex values that are similar or identical to those calculated using the previous, more labor-intensive field sampling procedures.

Table 5. Applicability of Variables by Regional Wetland Subclass

Variable Code	Variable Name	Flat	Riverine Backwater	Riverine Overbank	Unconnected Depression	Connected Depression
V_{TRACT}	Tract Size	+	+	+	+	+
$V_{CONNECT}$	Percent Connectivity	+	+	+	+	+
V_{CORE}	Percent Core	+	+	+	+	+
V_{FREQ}	Change in Flood Frequency	Not Used	+	+	Not Used	+
V_{POND}	Percent Ponding	+	+	+	Not Used	Not Used
V_{DUR}	Change in Flood Duration	Not Used	+	+	Not Used	+
V_{SOIL}	Soil Alteration	+	+	+	+	+
$V_{DWD\&S}$	Downed Woody Debris and Snags	+	+	+	+	+
V_{LITTER}	Percent Litter	+	+	+	Not Used	+
V_{STRATA}	Strata Present	+	+	+	+	+
$V_{TREESIZE}$	Tree Size Classes	+	+	+	+	+
V_{COMP}	Vegetation Composition	+	+	+	+	+
V_{TBA}	Tree Basal Area	+	+	+	+	+

The variables and methods are described below in the order they appear in the data sheets. Note that although this guidebook employs metric units, there is an option to "Select for English Units" on the data input calculator and field data sheets that will allow the entire assessment to be conducted and summarized in English units.

Figure 11. Wetland subclasses (purple line indicates extent of "wetland tract")



V_{TRACT} - Wetland Tract

This variable is defined as the area of contiguous forested wetland that includes the WAA (Figure 11). Adjacent wetlands need not be in the same regional subclass as the assessment area to be part of the wetland tract.

Determine the approximate size of the wetland tract using the following procedure:

1. Measure the size in hectares of the forested wetland area that is contiguous and directly accessible to any wildlife utilizing the WAA (including the WAA itself). Use topographic maps, aerial photography, GIS, field reconnaissance or another appropriate method.
2. Select the range of values on the data sheet that includes the forested wetland area in hectares. The variable subindex (VSI) will be calculated automatically based on reference data as shown in Table 6.

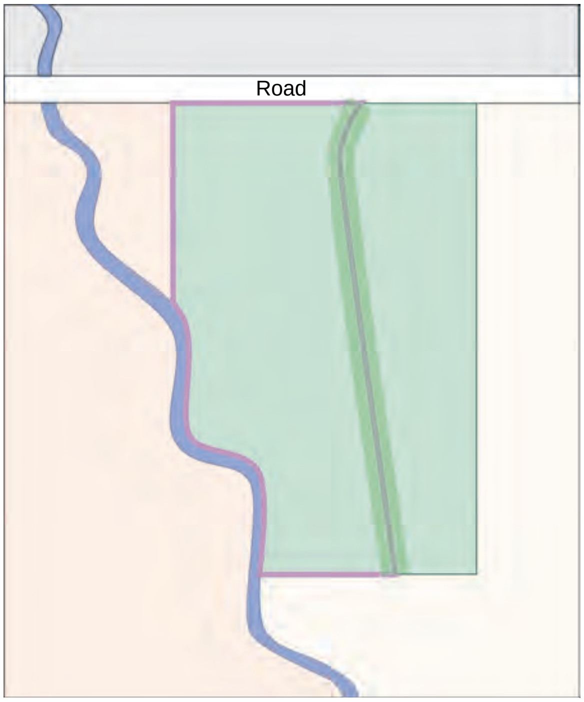
Table 6. Variable Sub Indices for V_{TRACT}

VSI	1.0	0.7	0.4	0.1
V_{TRACT} Range	3000 ha or more	1750-3000 ha	500-1750 ha	Less than 500 ha

$V_{CONNECT}$ – Percent Connectivity

This variable is defined as the proportion of the perimeter of a forested wetland tract that is connected to suitable wildlife habitat such as upland forests or other wetlands vegetated with native species, including recovering harvested areas (Figure 12). Agricultural fields, orchards, pastures dominated by non-native species, mined areas, and developed areas are examples of unsuitable habitats, regardless of whether they meet the criteria for federally jurisdictional wetlands or not. Note that because this is a landscape-level variable, the "tract" is not limited to the WAA under consideration, but includes all contiguous forested wetlands (Figure 12).

Figure 12. Identification of "connected perimeter" (green line).



The percentage of the forested wetland tract boundary that is "connected" is used to quantify this variable. Note that the "tract" is not limited to the WAA under consideration, but includes all contiguous forested wetlands. An adjacent habitat is considered connected if it is within 0.5 km (0.31 mile) of the boundary of the forested wetland tract. Measure it using the following procedure:

1. Determine the length of the forested wetland tract boundary. Use field reconnaissance, topographic maps, aerial photography, Geographic Information System (GIS), or another suitable method or tool.
2. Measure the length of the forested wetland tract boundary that is within 0.5 km (0.31 mile) of suitable habitats like those described previously.
3. Divide the length of connected forested wetland tract boundary by the length of the total forested wetland tract boundary, and then multiply by 100. The resulting number is the percent of the wetland tract boundary that is connected.
4. Select the range of values on the data sheet that includes the percent connectivity. The variable subindex will be calculated automatically based on reference data, as shown in Table 7.

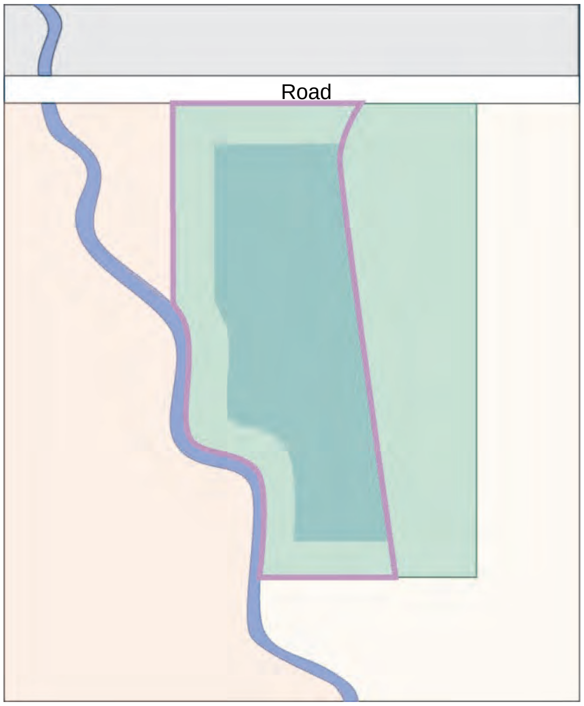
Table 7. Variable Sub Indices for $V_{CONNECT}$

VSI	1.0	0.7	0.4	0.1
$V_{CONNECT}$ Range	20% or more	10-19%	1-9%	0%

V_{CORE} – Percent Core

This variable is defined as the portion of a wetland tract that lies to the inside of a 100-m (330-ft) buffer interior of the boundary of the entire forested area (Figure 13). The percentage of a wetland tract that lies to the inside of this 100-m (330-ft) buffer zone is the metric used to quantify this variable. Note that the tract is not limited to the WAA under consideration, but includes all contiguous forested wetlands. Determine the value of this metric using the following procedure:

Figure 13. Identification of "core area."



1. On a map or photo, draw a continuous line 100 m inside the boundary of the entire contiguous forested area.
2. Calculate the size of the wetland tract that lies inside this line. This is the core area.
3. Divide the size of the core area by size of the wetland tract and multiply by 100. The resulting number is the percent of the wetland tract that is the core area.
4. Select the range of values on the data sheet that includes the forested wetland area in hectares. The variable subindex will be calculated automatically based on reference data, as shown in Table 8.

Table 8. Variable Sub Indices for V_{CORE}

VSI	1.0	0.7	0.4	0.1
V_{CORE} Range	20% or more	10-19%	1-9%	0%

V_{FREQ} – Change in Flood Frequency

Frequency of flooding refers to the frequency (return interval in years) with which overbank or backwater flooding from a stream inundates the WAA. In the classification employed here, where the 5-year return interval distinguishes connected from unconnected wetlands, the frequencies of interest are the 1-, 2-, 3-, 4-, and 5-year return intervals. However, in the context of the assessment models where the V_{FREQ} variable is used, there is no implication that more frequent flooding translates to higher functionality. Rather, all connected wetlands are assumed to be fully functional with regard to the V_{FREQ} variable unless there has been a change in flood frequency, and any such change, whether more or less frequent, will have adverse effects on the wetland communities and processes currently in place. (Note: As with the classification system, flood frequencies established as a result of the major river engineering projects in the mid-twentieth century are considered to be the baseline condition in most assessment scenarios.) In practice, the change in flood frequency will be a consideration most often where the hydrology of a site has been recently modified, as through a levee, drainage, or pumping effort. This variable is only assessed for river-connected subclasses (riverine and connected depression subclasses).

1. After walking the entire WAA, and completing a reconnaissance of the surrounding areas, check all documentation check-boxes that best describe the WAA. Condition categories and documentation are as follows (VSIs based on reference data are shown in parentheses):

- Natural flood return interval (VSI=1.0).

    - No artificial levees, spoil piles or other obstructions to water entering the site from the adjacent stream
    - No stream channelization
    - No lateral cutting or bank erosion of stream
    - No channel downcutting
    - Gauge data
    - Local knowledge

- Moderately impacted return interval (1-3 year change in return interval) (VSI=0.5).

    - Artificial levees or other obstructions present, but overbank flooding persists
    - <50% of stream reach channelization
    - Moderate lateral cutting or bank erosion of stream
    - Moderate channel downcutting
    - Gauge data
    - Local knowledge

- Severely impacted return interval (>3 year change in return interval) (VSI=0.1).

    - Artificial levees or other obstructions significant
    - >50% of stream reach channelization
    - Severe lateral cutting or bank erosion of stream
    - Severe channel downcutting
    - Gauge data
    - Local knowledge

2. Select the return interval choice (natural, moderately impacted, or severely impacted) on the data sheet that includes the preponderance of documentation boxes checked in step 1. The variable subindex will be calculated automatically, as described above.

V_{POND} – Percent Ponded Area

Percent Ponded Area refers to the percent of the WAA ground surface likely to collect and hold precipitation for periods of days or weeks at a time. (Note: This is distinct from the area that is prone to flooding, where the surface of the WAA is inundated by overbank or backwater connections to stream channels). The smaller (microtopographic) depressions are usually a result of tree “tip ups” and the scouring effects of moving water, and typically they are between 1 and 10 m^2 in area. Larger vernal pools (usually at least 0.04 ha) occur in the broad swales typical of meander scroll topography, or in other areas where impeded drainage produces broad, shallow pools during rainy periods. The wetlands where these features are important typically have a mix of both the small microdepressions and the larger vernal pools.

Estimate percent ponded area using the following procedure:

1. During a reconnaissance walkover of the entire WAA, estimate the percentage of the assessment area surface having microtopographic depressions and vernal pool sites capable of ponding rainwater. Base the estimate on the actual presence of water immediately following an extended rainy period – if possible – but during dry periods, use indicators such as stained leaves or changes in ground vegetation cover. Generally, it is not difficult to visualize the approximate percentage of the area subject to ponding, but it is important to base the estimate on a walkover of the entire assessment area.
2. Select the range of values on the data sheet that includes the percent of ponded area. The variable subindex will be calculated automatically based on reference data (Table 9), and the geomorphic surface selected in the Site Information section of the data sheet. Geomorphic surfaces can be identified using the maps developed by Saucier (1994), which are available at http://lmvmapping.erdc.usace.army.mil.

Table 9. Variable Sub Indices for V_{POND}

VSI		1.0	0.7	0.4	0.1
V_{POND} Range	Flat – Holocene	50-85%	30-50% or 85-90%	20-30% or > 90%	<20%
	Flat – Pleistocene Alluvial Terrace	25-60%	15-25% or 60-80%	5-15% or >80%	<5%
	Flat – Pleistocene Valley Train	30-80%	20-30% or 80-90%	10-20% or >90%	<10%
	Riverine Backwater	20-70%	15-20% or 70-85%	5-15% or >85%	<5%
	Riverine Overbank	0-40%	40-70%	>70%	N/A

V_{DUR} – Change in Flood Duration

Flood duration refers to the maximum number of continuous days in the growing season that overbank or backwater flooding from a stream inundates the WAA. Riverine and Connected Depression wetlands may flood as infrequently as one year in five (see the discussion of the V_{FREQ} variable in the following section). However, when flooding does occur, it usually extends for some days or weeks into the growing season, and strongly influences plant and animal communities. The V_{DUR} variable is intended to reflect changes in function that result from changes in growing season hydrology. Increases or decreases in growing season flood durations are assumed to cause reduced function relative to the pre-impact condition for the Maintain Plant Communities and Provide Wildlife Habitat functions.

Changes in flood duration are grouped into three condition categories: natural flood duration, moderately impacted flood duration (1-3 week change in flood duration) and severely impacted flood duration. As with the flood frequency variable, a series of field observations are made, and a majority of documentation indicators in a condition category indicate the appropriate condition choice.

1. After walking the entire WAA and completing a reconnaissance of the surrounding areas, check all documentation boxes that best describe the WAA, and select the best supported condition.

- Natural flood duration (VSI=1.0).

    - No artificial obstructions prevent drainage of the WAA (e.g., roads, blocked culverts)
    - No basal swelling (Appendix D1). Note that basal swelling differs from the natural flaring or buttressing that is common on certain lowland species such as elms and baldcypress. Basal swelling principally affects oaks and is expressed as a distinct swollen zone along the lower portion of the trunk, sometimes larger than the area immediately below it. If in doubt as to the reason for any observed trunk swelling, do not use this indicator.
    - No tip dieback (Appendix D2). Note that the tip dieback is common on lowland trees and should be used as indicator of water stress only when it is extensive and clearly reflects declining tree health.
    - No ditches promote the drainage of the WAA

    - No ditches bring additional water to the WAA
    - Local knowledge

- Moderately impacted flood duration (1-3 week change in flood duration) (VSI=0.5).

    - Artificial obstructions present, but removable, or only partially affect drainage
    - Basal swelling limited to area immediately around (within 10 meters) of an obvious obstruction (e.g., blocked culvert) but not found throughout the WAA.
    - Tip dieback limited to area immediately around (within 10 meters) of an obvious obstruction (e.g., blocked culvert) but not found throughout the WAA.
    - Some ditching promotes the drainage of the WAA
    - Ditches add some water to the WAA
    - Local knowledge

- Severely impacted flood duration (>3 week change in duration) (VSI=0.1).

    - Artificial obstructions significantly prevent drainage of WAA
    - Extensive basal swelling throughout WAA
    - Extensive tip dieback throughout WAA
    - Extensive ditching promotes the drainage of the WAA
    - Ditches add excessive water to the WAA
    - Local knowledge

2. Select the flood duration choice (natural, moderately impacted, or severely impacted) on the data sheet that includes the preponderance of documentation boxes checked in step 1. The variable subindex will be calculated automatically as described above.

V_{SOIL} - Soil Alteration

This variable is measured as the percent of the assessment area with altered soils. Altered soils exhibit evidence of fill, excavation, compaction, bedding, land-leveling, or ripping. Normal tilling is not considered to constitute soil alteration for the purposes of this assessment. Measure soil alteration with the following procedure:

1. As part of the reconnaissance walkover of the entire WAA, estimate the percentage of the site in which the soils have been altered. In particular, look for evidence of excavation fill, severe compaction, bedding, or agricultural activities.
2. Select the range of values on the data sheet that includes the percent area of altered soils. The variable subindex will be calculated automatically based on reference data as shown in Table 10.

Table 10. Variable Sub Indices for V_{SOIL}

VSI	1.0	0.7	0.3	0.0
V_{SOIL} Range	5% or less	6-50%	51-80%	more than 80%

$V_{DWD\&S}$ – Downed Woody Debris Biomass and Snags

Woody debris is an important habitat and nutrient cycling component of forests. In a functioning wetland forest, there are multiple size classes of standing and downed dead wood: standing snags and stumps, fallen logs (>3” in diameter), fallen branches (1-3” in diameter), and twigs (<1” in diameter). These break down over different lengths of time to release carbon back to the soil, where it can be cycled into living biomass.

1. This variable is evaluated in multiple plots located within the WAA and entered on the Plot Data Sheet (see Chapter 5, Assessment Protocol, for plot sampling instructions). For each plot, check all documentation checkboxes that best describe the WAA. Condition categories and documentation are as follows:

- Natural amount of down woody debris and snags present (VSI=1.0).
    - All classes of woody debris (snags, logs, branches, twigs) are present in expected amounts (10-25% cover combined, Appendix D3a)
    - No indication that water stress has increased woody debris or snags
    - No indication that the site has been recently cleared of woody debris
    - Any excessive woody debris is caused by temporary tornado or ice damage
    - Woody debris temporarily absent due to controlled burn

- Moderately impacted amount of woody debris and snags, but likely to recover (VSI=0.5).
    - No snags, but mature trees present
    - Woody debris cleared for nonpermanent shift in use, such as agroforestry
    - Excessive woody debris from logging operations
- Severely impacted amount of woody debris and snags, not likely to recover (VSI=0.1)
    - No snags or trees present
    - Woody debris cleared for permanent shift in use
    - Excessive woody debris (>25% cover) and snags due to unresolved water stress (Appendix D3c)

2. Select the down woody debris choice (natural, moderately impacted, or severely impacted) on the data sheet that includes the preponderance of documentation boxes checked in step 1. The variable subindex will be calculated automatically, as described above.

V_{LITTER} – Percent Litter

Litter cover is estimated as the average percent of the ground surface covered by recognizable dead plant materials (primarily decomposing leaves and twigs). This estimate excludes undecomposed woody material large enough to be accounted for in the woody debris variable above. It also excludes organic material sufficiently decayed to be included in the soil O horizon. The percent cover of litter is determined as follows:

1. This variable is evaluated in multiple plots located within the WAA and entered on the Plot Data Sheet (see Chapter 5, Assessment Protocol, for plot sampling instructions). For each plot, estimate the percentage of the ground surface that is covered by litter.
2. Select the range of values on the data sheet that includes the percent area of covered by litter. The variable subindex will be calculated in the green cell automatically based on reference data, as shown in Table 11.

Table 11. Variable Sub Indices for V_{LITTER}

VSI		1.0	0.7	0.4	0.1
V_{LITTER} Range	Flat	90% or more	60-89%	30-59%	less than 30%
	Riverine Backwater	50% or more	35-49%	10-34%	less than 10%
	Riverine Overbank	90% or more	70-89%	10-69%	less than 10%
	Unconnected Depression	N/A	N/A	N/A	N/A
	Connected Depression	50% or more	35-49%	10-34%	less than 10%

V_{STRATA} – Strata Present

The number of and types of vegetation layers (strata) present in a forested wetland reflects the diversity of food, cover, and nest sites available to wildlife – particularly to birds – but also to reptiles, invertebrates, and arboreal mammals. Estimate the vertical complexity of the WAA using the following procedure:

1. This variable is evaluated in multiple plots located within the WAA and entered on the Plot Data Sheet (see Chapter 5, Assessment Protocol, for plot sampling instructions). For each plot, identify which of the following vegetation layers are present and account for at least 10 percent cover, on average, throughout the site. Check all checkboxes on the data sheet that apply:

- Trees (greater than or equal to 10 cm dbh).
- Shrubs and Saplings (shrubs and saplings less than 10 cm dbh but at least 4.5 ft tall).
- Ground cover (woody plants less than 4.5 ft tall and herbaceous vegetation).

2. The variable subindex will be calculated automatically based on the number of strata, and the top stratum present, based on reference data (e.g., a single stratum of trees will have a higher variable subindex than a single stratum of groundcover), as shown in Table 12.

$V_{TREESIZE}$ – Tree Size Classes

The number of tree size classes indicates the maturity and complexity of the forest. Even-aged stands are often recovering from clearcut forestry practices. Uneven-aged stands with some larger trees represent mature

Table 12. Variable Sub Indices for V_{STRATA}

Top Stratum	Top Stratum Partial VSI		Number of Strata	Number of Strata Partial VSI	
	Riverine Subclasses	Flats / Depressions Subclasses		Riverine Subclasses	Flats / Depressions Subclasses
Tree	1.0	1.0	3	1.0	1.0
Sapling and Shrubs	0.4	0.4	2	0.7	1.0 / 0.7*
Ground Cover	0.2	0.2	1	0.3	0.7 / 0.3*
No Veg	0.0	0.0	0	0.0	0.0
VSI = (Top Stratum Partial VSI + Number of Strata partial VSI) / 2					

* First number is partial VSI if trees are the top stratum, second number is partial VSI otherwise

forests where single trees die and leave gaps, allowing younger trees to replace them. Since the rapid assessment procedure does not require tree DBHs or density to be measured, this variable is intended to indicate the complexity of the forest. It complements – rather than replaces – the Tree Basal Area variable, which indicates biomass, but doesn't distinguish between small trees very close to the point measured and much larger trees further away. Estimate the tree age complexity of the WAA using the following procedure:

1. This variable is evaluated in multiple plots located within the WAA and entered on the Plot Data Sheet (see Chapter 5, Assessment Protocol, for plot sampling instructions). For each plot, identify which of the following tree size classes are present and account for at least 10 percent cover. It should be possible to visually estimate the class that a given tree belongs in. Check all boxes that apply:

- 10-25 cm dbh
- 25.1-50 cm dbh
- 50.1-75 cm dbh
- >75 cm dbh

2. The variable subindex will be calculated automatically based on the number of tree classes and the top tree class present, based on reference data as presented in Table 13.

Table 13. Variable Sub Indices for $V_{TREESIZE}$

Top Size Class (DBH)	Top Size Class Partial VSI			Number of Size Classes	Number of Size Classes Partial VSI		
	Riverine	Flats	Depressions		Riverine	Flats	Depressions
>75 cm	1.0	1.0	1.0	4	1.0	1.0	1.0
50.1 - 75 cm	0.8	1.0	1.0	3	0.8	1.0	1.0
25.1 - 50 cm	0.6	0.8	0.7	2	0.5	0.8	0.7
10 - 25 cm	0.3	0.4	0.3	1	0.3	0.5	0.3
No trees	0.0	0.0	0.0	0	0.0	0.0	0.0
VSI = (Top Stratum Partial VSI + Number of Strata partial VSI) / 2							

V_{COMP} – Vegetation Composition

This variable represents the species composition of the tallest woody stratum present in the assessment area, and the exotics present anywhere on the WAA. The tallest stratum could be the tree, shrub-sapling, or seedling stratum. Percent concurrence with reference wetlands of the dominant species in the dominant vegetation stratum is used to quantify this variable. The species lists in the calculator enumerate the scientific names of the relevant species. However, the “Check for Common Names” box may be selected, and the lists will be generated using common names instead. Measure the composition variable using the following procedure:

1. This variable is evaluated in multiple plots located within the WAA and entered on the Plot Data Sheet (see Chapter 5, Assessment Protocol, for plot sampling instructions). For each plot, determine percent cover of the tree stratum by visually estimating what percentage of the sky is blocked by leaves and stems of the tree stratum, or vertically projecting the leaves and stems to the forest floor. If the percent cover of the tree stratum is estimated to be at least 20 percent, go to Step 2. If the tree stratum does not have at least 20 percent cover, determine the tallest woody stratum with at least 10 percent total cover, and use it as the tallest stratum.
2. Within the tallest stratum, identify the dominant species based on percent cover using the 50/20 rule (US Army Corps of Engineers 1992): rank species in descending order of percent cover and identify dominants by summing relative dominance in descending order until 50 percent is exceeded; additional species with 20 percent relative dominance should also be included. Check these species on the data sheet within composition groups 1, 2, and 3. Accurate identification of woody species is critical for determining the dominant species in each plot. In most cases, the principal

dominant species are apparent and field calculations using the 50/20 rule will not be necessary.

3. Check all species in group 4 within the WAA, regardless of whether they are dominants, or which strata they are in.
4. The variable subindex is calculated automatically by creating a weighted average with the following weights: Group 1, 1.0; Group 2, 0.66; Group 3, 0.33; Group 4, 0.

V_{TBA} - Tree Basal Area

Trees are defined as living woody stems greater than or equal to 10 cm (4 in) dbh. Tree basal area is a common measure of abundance and dominance in forest ecology that has been shown to be proportional to tree biomass (Whittaker 1975). This variable is evaluated in multiple plots located within the WAA and entered on the Plot Data Sheet (see Chapter 5, Assessment Protocol, for plot sampling instructions). In each plot, stand at the plot center and measure tree basal area using the following procedure:

1. Use a basal area wedge prism (or other basal area estimation tool) as directed to tally eligible tree stems. Basal area prisms are available in various Basal Area Factors, and in both SI (metric) and non-SI (English) versions. Some are inappropriate for use in collecting the data needed here, because they are intended to be used for large-diameter trees in areas with little understory. The non-SI 10-factor prism works well in forests of the MAV, and it is readily available.
2. Select the range of values on the data sheet that includes the tree tally counted in Step 1. The variable subindex will be calculated automatically based on reference data as shown in Table 14.

Table 14. Variable Sub Indices for V_{TBA}

VSI		1.0	0.7	0.4	0.1
V_{TBA} Tree Count Range	Flat	>10	7-10	1-6	0
	Riverine Backwater	>10	7-10	1-6	0
	Riverine Overbank	>14	9-14	1-8	0
	Unconnected Depression	>14	9-14	1-8	0
	Connected Depression	>14	9-14	1-8	0

6 Assessment Protocol

Previous chapters of this *Regional Guidebook* have provided background information on the HGM Approach, characterized regional wetland subclasses, and documented the variables, functional indices, and assessment models used to assess regional wetland subclasses in the MAV. This chapter outlines the procedures for collecting and analyzing the data required to conduct an assessment.

In most cases, permit review, restoration planning, and similar assessment applications require that pre- and post-project conditions of wetlands at the project site be compared to develop estimates of the loss or gain of function associated with the project. Both the pre- and post-project assessments should be completed at the project site before the proposed project has begun. Data for the pre-project assessment represent existing conditions at the project site, while data for the post-project assessment are normally based on a prediction of the conditions that can reasonably be expected to exist following proposed project impacts. A well-documented set of assumptions should be provided with the assessment to support the predicted post-project conditions used in making an assessment.

Where the proposed project involves wetland restoration or compensatory mitigation, this guidebook can also be used to assess the functional effectiveness of the proposed actions. The final section of this chapter provides recovery trajectory curves for selected variables that may be employed in that analysis.

A series of tasks are required to assess regional wetland subclasses in the MAV using the HGM Approach:

- Document the project purpose and characteristics.
- Screen for red flags.
- Define assessment objectives and identify regional wetland subclass(es) present, and assessment area boundaries.
- Collect field data.
- Analyze field data.
- Document assessment results.
- Apply assessment results.

The following sections discuss each of these tasks in greater detail.

Document the project purpose and characteristics

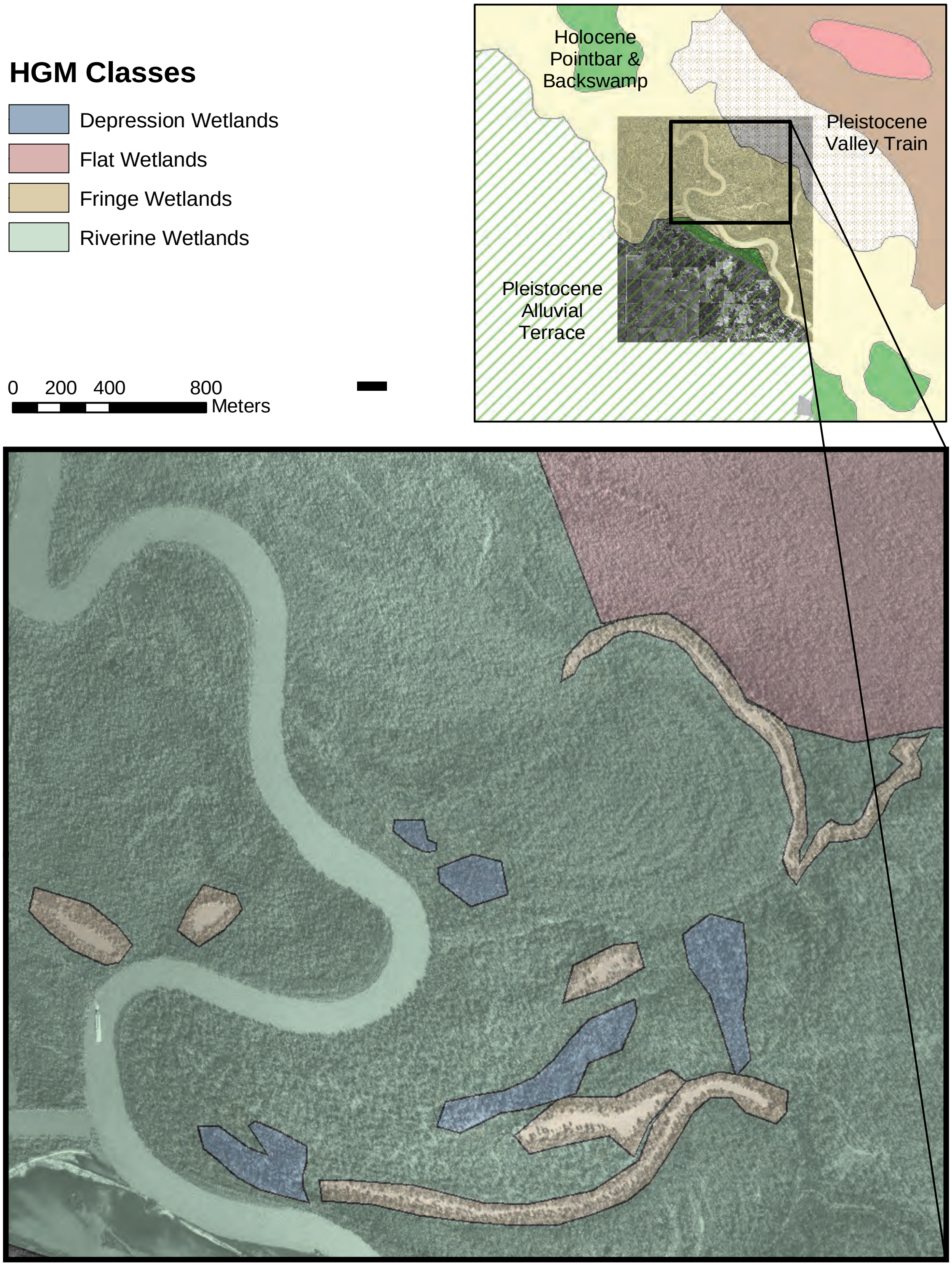
Data Sheet A1 in Appendix A (Site or Project Information and Assessment Documentation) provides a checklist of information needed to conduct a complete assessment, and serves as a cover sheet for all compiled assessment maps, drawings, data sheets, and other information. It requires the assignment of a project name, identification of personnel involved in the assessment, and attachment of supporting information and documentation. The first step in this process is to develop a narrative explanation of the project, with supporting maps and graphics. This should include a description of the project purpose and project area features, which can include information on location, climate, surficial geology, geomorphic setting, surface and groundwater hydrology, vegetation, soils, land use, existing cultural alteration, proposed impacts, and any other characteristics and processes that have the potential to influence how wetlands at the project area perform functions. The accompanying maps and drawings should indicate the locations of the project area boundaries, jurisdictional wetlands, wetland assessment areas (described later in this chapter), proposed impacts, roads, ditches, buildings, streams, soil types, plant communities, threatened or endangered species habitats, and other important features.

Many sources of information may be useful in characterizing a project area:

- Aerial photographs
- Topographic maps
- Geomorphic maps (Saucier 1994)
- County soil survey
- National Wetland Inventory maps
- Chapter 3 of this *Regional Guidebook*

For large projects or complex landscapes, it is usually beneficial to use aerial photos and geomorphic information to develop a preliminary classification of wetlands for the project area and vicinity prior to going to the field. Figure 14 illustrates this process for a typical MAV lowland wetland complex. The rough wetland map can then be taken to the field to refine and revise the identification of wetland subclasses.

Figure 14. Example application of geomorphic mapping and aerial photography to develop a preliminary wetland classification for a proposed project area.



The final map should be attached to the completed Site or Project Description sheet.

Screen for red flags

Screening for red flag features helps determine whether the wetlands or other natural resources around the project area require special consideration or attention that may preempt or postpone a wetland assessment. For example, if a proposed project has the potential to adversely affect threatened or endangered species, an assessment may be unnecessary since the project may be denied or modified based on the impacts to the protected species alone.

Define assessment objectives, identify regional wetland subclass(es) present, and identify assessment area boundaries

Begin the assessment process by unambiguously stating the objective of conducting the assessment. Most commonly, this will be simply to determine how a proposed project will impact wetland functions. However, there are other potential objectives:

- Compare several wetlands as part of an alternatives analysis.
- Identify specific actions that can be taken to minimize project impacts.
- Document baseline conditions at a wetland site.
- Determine mitigation requirements.
- Determine mitigation success.
- Evaluate the likely effects of a wetland management technique.

Frequently, there will be multiple objectives, and defining these objectives in a clear and concise manner will facilitate communication and understanding among those involved in conducting the assessment, as well as other interested parties.

Figures 15 through 18 present a simplified project scenario to illustrate the steps used to designate the boundaries of Wetland Assessment Areas (WAA), each of which will require a separate HGM assessment. Figure 15 illustrates a land cover map for a hypothetical project area. Figure 16 shows the project area (in yellow) superimposed on the land cover map. To determine the boundaries of the WAAs, first use the Keys to Wetland Classes and Subclasses (Figures 5 and 6) and identify the wetland subclasses within and contiguous to the project area (Figure 17). Overlay the project area

Figure 15. Land cover.

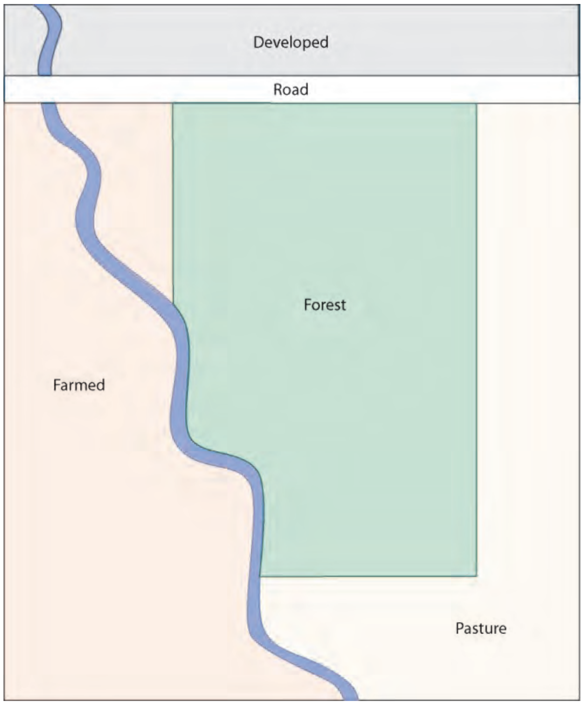


Figure 16. Project area (in yellow).

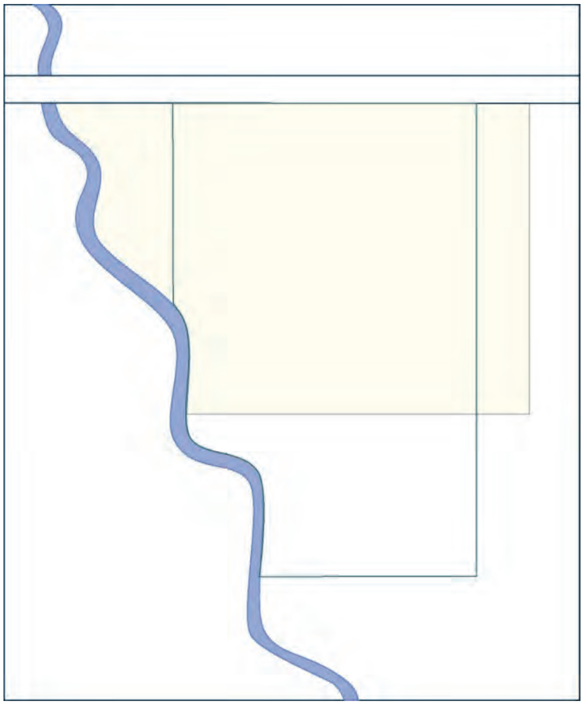


Figure 17. Wetland subclasses (purple line indicates extent of the "wetland tract").

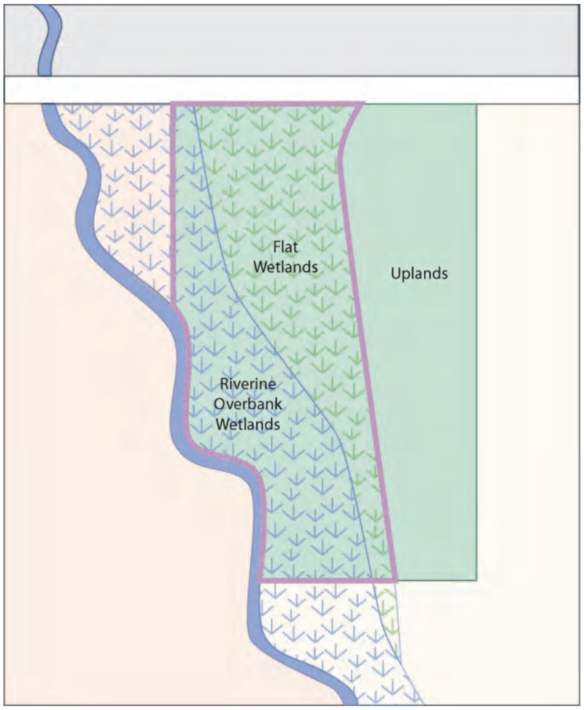
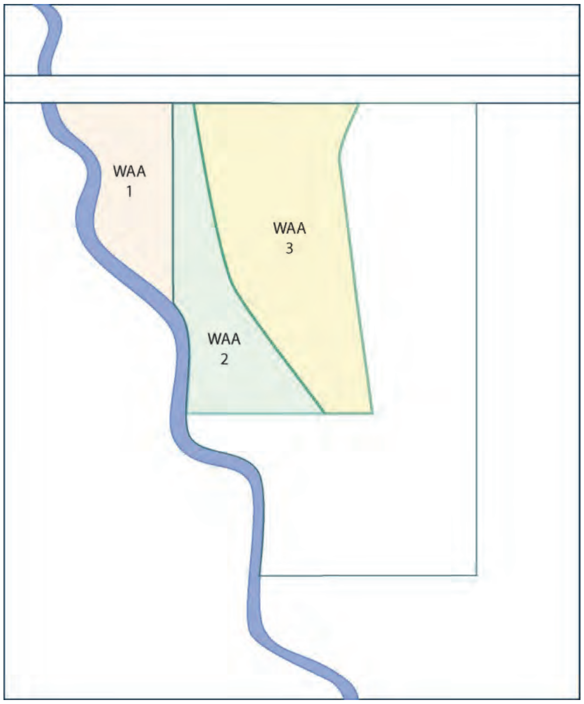


Figure 18. WAAs.



boundary and the wetland subclass boundaries to identify the WAAs for which data will be collected (Figure 18). Attach these maps, photos, and drawings to the Documentation Sheet (Appendix A) and assign an identifying number to each WAA, specifying the subclass it belongs to, and calculating the area in hectares or acres.

Each WAA is a portion of the project area that belongs to a single regional wetland subclass and is relatively homogeneous with respect to the criteria used to assess wetland functions (i.e., hydrologic regime, vegetation structure, topography, soils, successional stage). However, as the size and heterogeneity of the project area increase, it is more likely that it will be necessary to define and assess multiple WAAs within a project area.

At least three situations can be identified that necessitate defining and assessing multiple WAAs within a project area. The first situation occurs when widely separated areas of wetlands belonging to the same regional subclass occur in the project area. Such noncontiguous wetlands must be designated as separate WAAs, because the assessment process includes consideration of the size and isolation of individual wetland units. The second situation occurs where more than one regional wetland subclass occurs within a project area, as illustrated in Figure 17, where both Flat and Low-Gradient Riverine Overbank wetlands are present within the project area. These must be separated because they are assessed using different models and reference data systems. The third situation occurs where a contiguous wetland area of the same regional subclass exhibits spatial heterogeneity in terms of hydrology, vegetation, soils, or other assessment criteria. This is illustrated in Figure 18, where the area designated as Riverine Overbank Wetlands in Figure 17 is further subdivided into two WAAs based on land use and vegetation cover. The farmed area clearly will have different characteristics from those of the forested wetland, and they will be assessed separately (though using the same models and reference data).

In the MAV, the most common scenarios requiring designation of multiple WAAs involve tracts of land with interspersed regional subclasses (such as depressions scattered within a matrix of flats or riverine wetlands) or tracts composed of a single regional subclass that includes areas with distinctly different land use influences that produce different land cover. For example, within a large riverine backwater unit, the following WAAs may be defined: cleared land, early successional sites, and mature forests.

However, users should be cautious about splitting a project area into many WAAs based on relatively minor differences, such as local variation due to canopy gaps and edge effects. The reference data used in this document (Chapter 5) incorporate such variation, and splitting areas into numerous WAAs based on subtle differences will not materially change the outcome of the assessment. It will, however, greatly increase the sampling and analysis requirements. Field experience in the region should provide a sense of the range of variability that typically occurs, and is sufficient to make reasonable decisions in defining multiple WAAs.

Collect field data

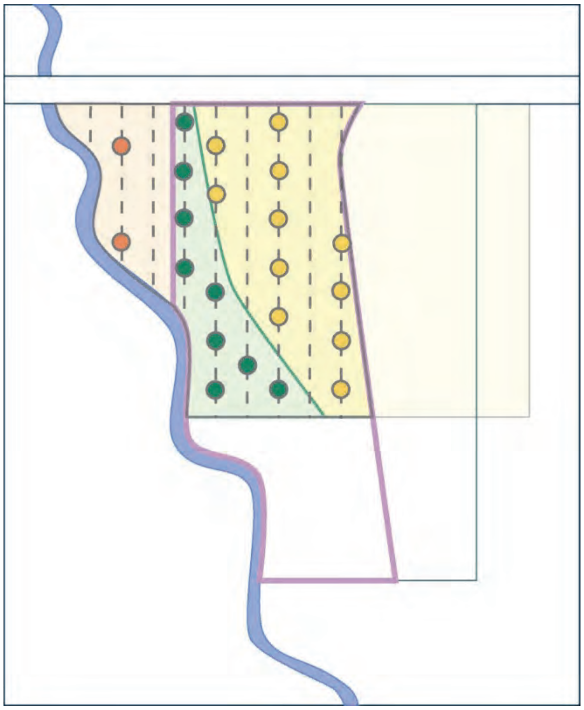
Chapter 5 (Variables and Data Collection) describes how to make the observations and estimates needed to complete the assessment, and the data sheets provide prompts for use in the field. When all the data are entered into the data sheet and calculator, a summary at the end presents the variable subindices and the Functional Capacity Indices (FCIs) for each function; the variable subindices and the FCIs are calculated using the models previously described. Functional Capacity Units (FCUs) are then calculated by multiplying the FCIs by the WAA area in hectares. Depending on the site (Project Site or Mitigation Site) and timing (Before Project or After Project) the user selected from drop down menus at the top of the sheet, a message appears above the table of FCIs and FCUs instructing the user which section of the Mitigation Sufficiency Calculator the results should be entered into. This is only necessary to do if the results are being used to determine a mitigation need. An error message of “Check Data” indicates that a vital piece of information is missing from the data entry, and the FCIs cannot be calculated without it. It should be noted that although FCIs are unitless, FCUs are in the area unit used, so it is important to know whether the default hectares are used, or the English units (acres). The units used will display in the Wetland Size data entry space, and the FCUs match whichever unit is shown there.

The data sheets provided in Appendix B are organized to facilitate data collection at each of the several spatial scales of interest. For example, the first group of variables (Site and WAA Field Data Sheet) contains information about landscape scale or WAA-scale characteristics collected using aerial photographs, maps, and hydrologic information regarding each WAA and vicinity, or collected during a walking reconnaissance of the WAA. Data collected for these variables are entered directly on the Data Sheets, and do not require plot-based sampling. Information on the next group of variables is collected in sample plots placed in representative locations throughout the WAA. Data from a single plot are recorded on the Plot Data Sheet, which is two pages long. Additional copies of the Plot Data Sheet are completed for each plot sampled within the WAA.

All of the data sheets shown in Appendix B are printouts from the MAV Data Sheets and Calculator (the Calculator), a single spreadsheet that allows raw data entry; the spreadsheet automatically calculates variable subindices, FCIs, and FCUs. Printouts of the Data Sheets from the spreadsheet must be printed out and taken to the field, and then the raw data may be entered in the same form in the Excel spreadsheet, so that automated calculations occur.

All data from each of the Plot Data Sheets are compiled automatically by the Calculator. These summarized data are then used by the Calculator to automatically determine the Functional Capacity of the wetland being assessed and reported in the Summary section of the MAV Data Sheets and FCI Calculator, once the Subclass is selected and raw data are entered.

Figure 19. Example sample distribution. Refer to Figure 18 for WAA designations.



The sampling procedures for conducting an assessment require few tools, but a specialized basal area estimation or measurement tool, reference materials for plant identification, and this guidebook will be necessary. Generally, all measurements should be taken in metric units (although English unit equivalents may be selected on the spreadsheet before the data are entered). Plots should be approximately 0.04 ha in diameter (a tenth of an acre), but the data collected within plots are not area dependent, so plot boundaries can be visually estimated. The most efficient approach is to establish a center point and make estimates in a circle around that point that has a radius of approximately 10m. A typical layout for the establishment of sample plots and transects in the hypothetical WAAs is shown in Figure 19. As in defining the WAA, there are elements of subjectivity and practicality in determining the number of sample locations for collecting plot-based and transect-based site-specific data. The exact numbers and locations of the plots and transects are dictated by the size and heterogeneity of the WAA. If the WAA is relatively small (i.e., less than 2–3 acres, or about a hectare) and homogeneous with respect to the characteristics and processes that influence wetland function, then three or four 0.04-ha plots in representative locations are probably adequate to characterize the WAA.

However, as the size and heterogeneity of the WAA increase, more sample plots are required to represent the site accurately. Large forested wetland tracts usually include a mix of tree age classes, scattered small openings in the canopy that cause locally dense understory or ground cover conditions, and perhaps some very large individual trees or groups of old-growth trees. The sampling approach should not bias data collection to differentially emphasize or exclude any of these local conditions, but should represent the site as a whole. Therefore, on large sites the best approach often is a simple systematic plot layout, where evenly spaced parallel transects are established (using a compass and pacing) and sample plots are distributed at regular paced intervals along those transects. For example, a 12-ha tract, measuring about 345 m on each side, might be sampled using two transects spaced 100 m apart (and 50 m from the tract edge), with plots at 75-m intervals along each transect (starting 25 m from the tract edge). This would result in eight sampled plot locations, which should be adequate for a relatively diverse 12-ha forested wetland area. In Figure 19, WAA 2 illustrates this approach for establishing fairly high-density, uniformly distributed samples. Larger or more uniform sites can usually be sampled at a lower plot density. One approach is to establish a series of transects, as described, and sample at intervals along alternate transects (see WAA 3 in Figure 19). Continue until the entire site has been sampled at a low plot density, then review the data and determine whether the variability in overstory composition and basal area has been largely accounted for. That is, as the number of plots sampled has increased, are new dominant species no longer being encountered, and has the average basal area for the site changed markedly with the addition of recent samples? If not, there is probably no need to add further samples to the set. If overstory structure and composition variability remains high, then return to the alternate, unsampled transects and continue sampling until the data set is representative of the site as a whole, as indicated by a leveling off of the dominant species list and basal area values. Other variables may level off more quickly or slowly than tree composition and basal area, but these two factors are generally good indicators, and correspond well to the overall suite of characteristics of interest within a particular WAA. In some cases, such as sites where trees have been planted or composition and structure are highly uniform (e.g., sites dominated by a single tree species), it may be apparent that relatively few samples are adequate to reasonably characterize the wetland. In Figure 19, this is illustrated by the sample distribution in WAA 1, which is a farmed area where few variables are likely to be measurable, or at least will vary little from plot to plot. In this case, every other plot location is sampled along every other transect.

The information on the Site, the WAA Data Sheet, and the multiple copies of the Plot Data Sheet is compiled automatically by the Calculator in the Data Summary. These summarized data are then used by the Calculator to automatically determine the Functional Capacity of the wetland being assessed on the FCI/FCU Calculation Summary tab of the Calculator for each WAA.

Apply assessment results

Once the assessment and analysis phases are complete, the results can be used to compare the same WAA at different points in time, compare different WAAs at the same point in time, or compare different alternatives to a project. The basic unit of comparison is the FCU, but it is often helpful to examine specific impacts and mitigation actions by examining their effects on the FCI independent of the area affected. The Calculator is a particularly useful tool for testing various scenarios and proposed actions — it allows experimentation with various alternative actions and areas affected to help isolate the project options with the least impact or the most effective restoration or mitigation approaches.

Note that the assessment procedure does not produce a single grand index of function; rather, each function is separately assessed and scored, resulting in a set of functional index scores and functional units. How these are used in any particular analysis depends on the objectives of the analysis. In the case of an impact assessment, it may be reasonable to focus on the function that is most detrimentally affected. In cases where certain resources are particular regional priorities, the assessment may tend to focus on the functions most directly associated with those resources. For example, wildlife functions may be particularly important in an area that has been extensively converted to agriculture. Hydrologic functions may be of greatest interest if the project being assessed will alter water storage or flooding patterns. Conversely, this type of analysis can help the user to recognize when a particular function is being maximized to the detriment of other functions, as might occur when a wetland is created as part of a stormwater facility; vegetation composition and structure, detritus accumulation, and other variables in such a setting would likely demonstrate that some functions are maintained at very low levels, while hydrologic functions are maximized.

Generally, comparisons can be made only between wetlands or alternatives that involve the same wetland subclass, although comparisons between subclasses can be made on the basis of functions performed rather than the magnitude of functional performance. For example, riverine subclasses have import and export functions that are not present in flats or unconnected depressions. Conversely, unconnected depressions are more likely to support endemic species than are river-connected systems. These types of comparisons may be particularly important where a proposed action will result in a change of subclass. When a levee, for example, will convert a riverine wetland to a flat, it is helpful to be able to recognize that certain import and export functions will no longer occur.

Users of this guidebook must recognize that not all situations can be anticipated or accounted for in developing a rapid assessment method. In particular, users must be able to adapt the material presented here to special or unique situations encountered in the field. For example, most of the reference standard conditions identified in the field were mature forests with high species diversity, and typically the riverine and flats subclasses were dominated by a variety of oak species while the depressional subclasses were dominated by baldcypress and overcup oak. Sites that deviate from these reference conditions may produce low scores for some functions. However, there are situations where deviation from the reference standard condition is appropriate, and should be recognized as such. In most of these cases, alternative reference standards have been identified in the discussions of assessment variables (e.g., cottonwood or willow dominating on new substrates is recognized as an appropriate V_{COMP} condition). In other instances, however, professional judgment in the field is essential to proper application of the models. For example, some depression sites with near-permanent flooding are dominated by buttonbush. Where this occurs because of water control structures or impeded drainage due to roads, it should be recognized as having arrested functional status, at least for some functions. However, where the same situation occurs because of beaver activity or changes in channel courses, the buttonbush swamp should be recognized as a functional component of a larger wetland complex, and the V_{COMP} weighting system can be adjusted accordingly. Another potential way to deal with beaver in the modern landscape is to adopt the perspective that beaver complexes are fully functional but transient components of riverine wetland systems for all functions. At the same time, if beaver are not present (even in an area where they would normally be expected to occur), the resulting riverine wetland can be assessed using the models, but the overall WAA is not penalized either way. Other situations that require special consideration include areas affected by fire, sites damaged by ice storms, and similar occurrences. Note, however, that normal, noncatastrophic disturbances to wetlands (i.e., tree mortality causing small openings) are accounted for in the reference data used in this guidebook.

Because the HGM models are calibrated with reference to mature, complex plant communities, and the wildlife habitat models emphasize the requirements of species needing large, contiguous blocks of habitat, early successional wetlands in fragmented landscapes will receive very low assessment scores for the wildlife habitat function. In such situations, it may be useful to supplement the wildlife habitat assessment models with alternative methods such as the Habitat Evaluation Procedures (HEP) (US Fish and Wildlife Service 1980). This approach can provide a more sensitive assessment of the early developmental period following wetland restoration or changes in management than the HGM models presented here.

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Appendix A: Preliminary Project Documentation

SITE or PROJECT INFORMATION and ASSESSMENT DOCUMENTATION

(Complete one form for entire site or project area)

Date: _________________________________
Project/Site Name: _______________________
Person(s) involved in assessment:

Field ____
____

Computations/summarization/quality control: ______________________________
____

The following checked items are attached:

_____ A description of the project, including land ownership, baseline conditions, proposed actions, purpose, project proponent, regulatory or other context, and reviewing agencies.

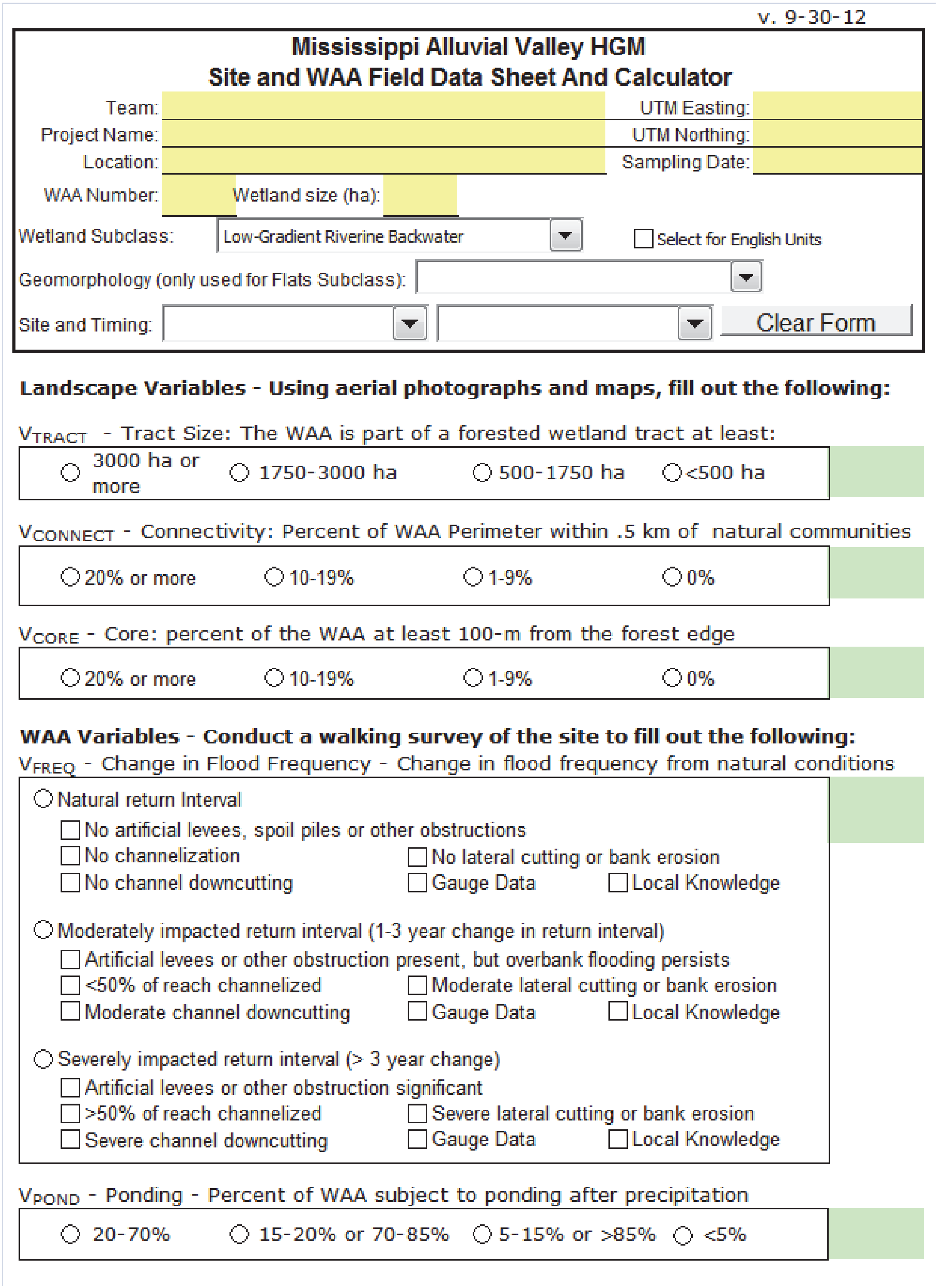
_____ Maps, aerial photos, and /or drawings of the project area, showing boundaries and identifying labels of Wetland Assessment Areas and project features.

_____ Other pertinent documentation (describe): __________________________
____

_____ Field Data Sheets and assessment summaries

Appendix B: Field Data Sheets

Please note that the data sheets will vary slightly depending on the HGM subclass being assessed. Please print data sheets directly from the calculator after selecting a subclass. This appendix is for illustrative purposes only.



v. 9-30-12

Mississippi Alluvial Valley HGM
Site and WAA Field Data Sheet And Calculator

Team:
Project Name:
Location:
WAA Number:
Wetland size (ha):
UTM Easting:
UTM Northing:
Sampling Date:

Wetland Subclass: Low-Gradient Riverine Backwater

☐ Select for English Units

Geomorphology (only used for Flats Subclass):

Site and Timing:

Landscape Variables - Using aerial photographs and maps, fill out the following:

V_{TRACT} - Tract Size: The WAA is part of a forested wetland tract at least:

○ 3000 ha or more ○ 1750-3000 ha ○ 500-1750 ha ○ <500 ha

$V_{CONNECT}$ - Connectivity: Percent of WAA Perimeter within .5 km of natural communities

○ 20% or more ○ 10-19% ○ 1-9% ○ 0%

V_{CORE} - Core: percent of the WAA at least 100-m from the forest edge

○ 20% or more ○ 10-19% ○ 1-9% ○ 0%

WAA Variables - Conduct a walking survey of the site to fill out the following:

V_{FREQ} - Change in Flood Frequency - Change in flood frequency from natural conditions

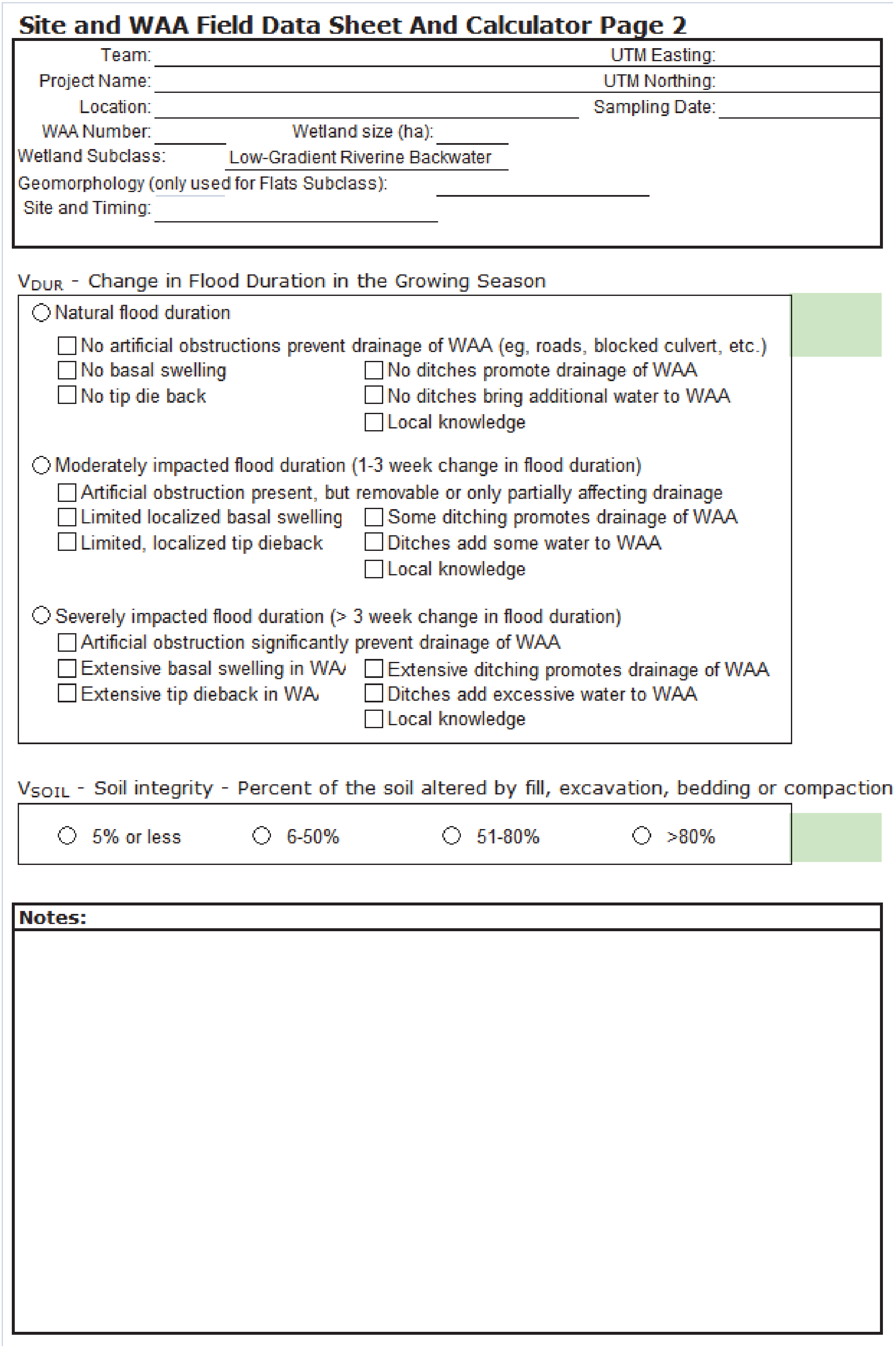
○ Natural return Interval
- ☐ No artificial levees, spoil piles or other obstructions
- ☐ No channelization ☐ No lateral cutting or bank erosion
- ☐ No channel downcutting ☐ Gauge Data ☐ Local Knowledge

○ Moderately impacted return interval (1-3 year change in return interval)
- ☐ Artificial levees or other obstruction present, but overbank flooding persists
- ☐ <50% of reach channelized ☐ Moderate lateral cutting or bank erosion
- ☐ Moderate channel downcutting ☐ Gauge Data ☐ Local Knowledge

○ Severely impacted return interval (> 3 year change)
- ☐ Artificial levees or other obstruction significant
- ☐ >50% of reach channelized ☐ Severe lateral cutting or bank erosion
- ☐ Severe channel downcutting ☐ Gauge Data ☐ Local Knowledge

V_{POND} - Ponding - Percent of WAA subject to ponding after precipitation

○ 20-70% ○ 15-20% or 70-85% ○ 5-15% or >85% ○ <5%



Site and WAA Field Data Sheet And Calculator Page 2

Team: ____________________ UTM Easting: ________
Project Name: ____________________ UTM Northing: ________
Location: ____________________ Sampling Date: ________
WAA Number: ________ Wetland size (ha): ________
Wetland Subclass: Low-Gradient Riverine Backwater
Geomorphology (only used for Flats Subclass): ________
Site and Timing: ________

V_{DUR} - Change in Flood Duration in the Growing Season

○ Natural flood duration
- ☐ No artificial obstructions prevent drainage of WAA (eg, roads, blocked culvert, etc.)
- ☐ No basal swelling
- ☐ No tip die back
- ☐ No ditches promote drainage of WAA
- ☐ No ditches bring additional water to WAA
- ☐ Local knowledge

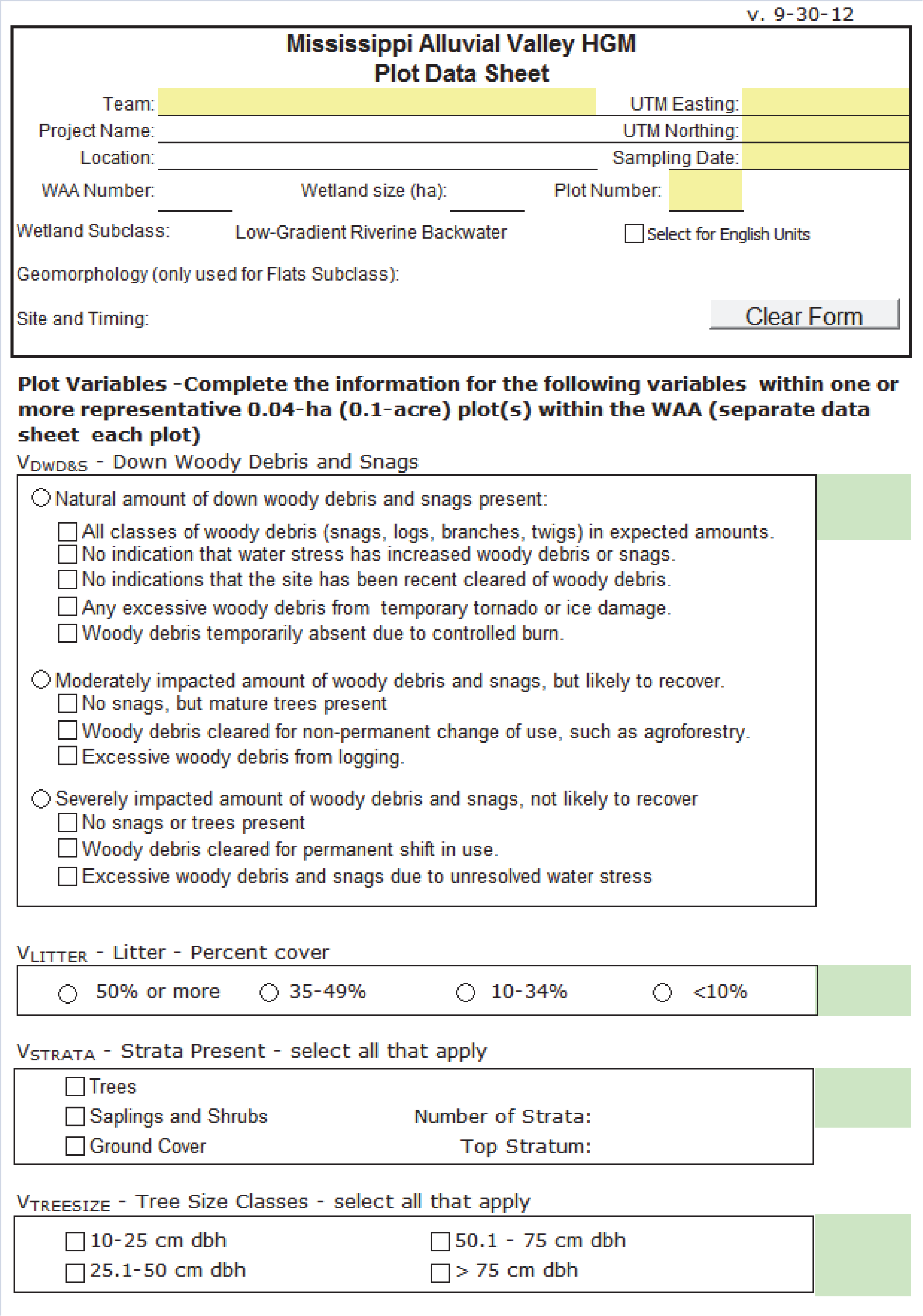
○ Moderately impacted flood duration (1-3 week change in flood duration)
- ☐ Artificial obstruction present, but removable or only partially affecting drainage
- ☐ Limited localized basal swelling
- ☐ Limited, localized tip dieback
- ☐ Some ditching promotes drainage of WAA
- ☐ Ditches add some water to WAA
- ☐ Local knowledge

○ Severely impacted flood duration (> 3 week change in flood duration)
- ☐ Artificial obstruction significantly prevent drainage of WAA
- ☐ Extensive basal swelling in WA
- ☐ Extensive tip dieback in WA
- ☐ Extensive ditching promotes drainage of WAA
- ☐ Ditches add excessive water to WAA
- ☐ Local knowledge

V_{SOIL} - Soil integrity - Percent of the soil altered by fill, excavation, bedding or compaction

○ 5% or less ○ 6-50% ○ 51-80% ○ >80%

Notes:



v. 9-30-12

Mississippi Alluvial Valley HGM
Plot Data Sheet

Team:
Project Name:
Location:
UTM Easting:
UTM Northing:
Sampling Date:
WAA Number:
Wetland size (ha):
Plot Number:
Wetland Subclass: Low-Gradient Riverine Backwater
☐ Select for English Units
Geomorphology (only used for Flats Subclass):
Site and Timing:

Plot Variables -Complete the information for the following variables within one or more representative 0.04-ha (0.1-acre) plot(s) within the WAA (separate data sheet each plot)

$V_{DWD\&S}$ - Down Woody Debris and Snags

○ Natural amount of down woody debris and snags present:
  - ☐ All classes of woody debris (snags, logs, branches, twigs) in expected amounts.
  - ☐ No indication that water stress has increased woody debris or snags.
  - ☐ No indications that the site has been recent cleared of woody debris.
  - ☐ Any excessive woody debris from temporary tornado or ice damage.
  - ☐ Woody debris temporarily absent due to controlled burn.

○ Moderately impacted amount of woody debris and snags, but likely to recover.
  - ☐ No snags, but mature trees present
  - ☐ Woody debris cleared for non-permanent change of use, such as agroforestry.
  - ☐ Excessive woody debris from logging.

○ Severely impacted amount of woody debris and snags, not likely to recover
  - ☐ No snags or trees present
  - ☐ Woody debris cleared for permanent shift in use.
  - ☐ Excessive woody debris and snags due to unresolved water stress

V_{LITTER} - Litter - Percent cover

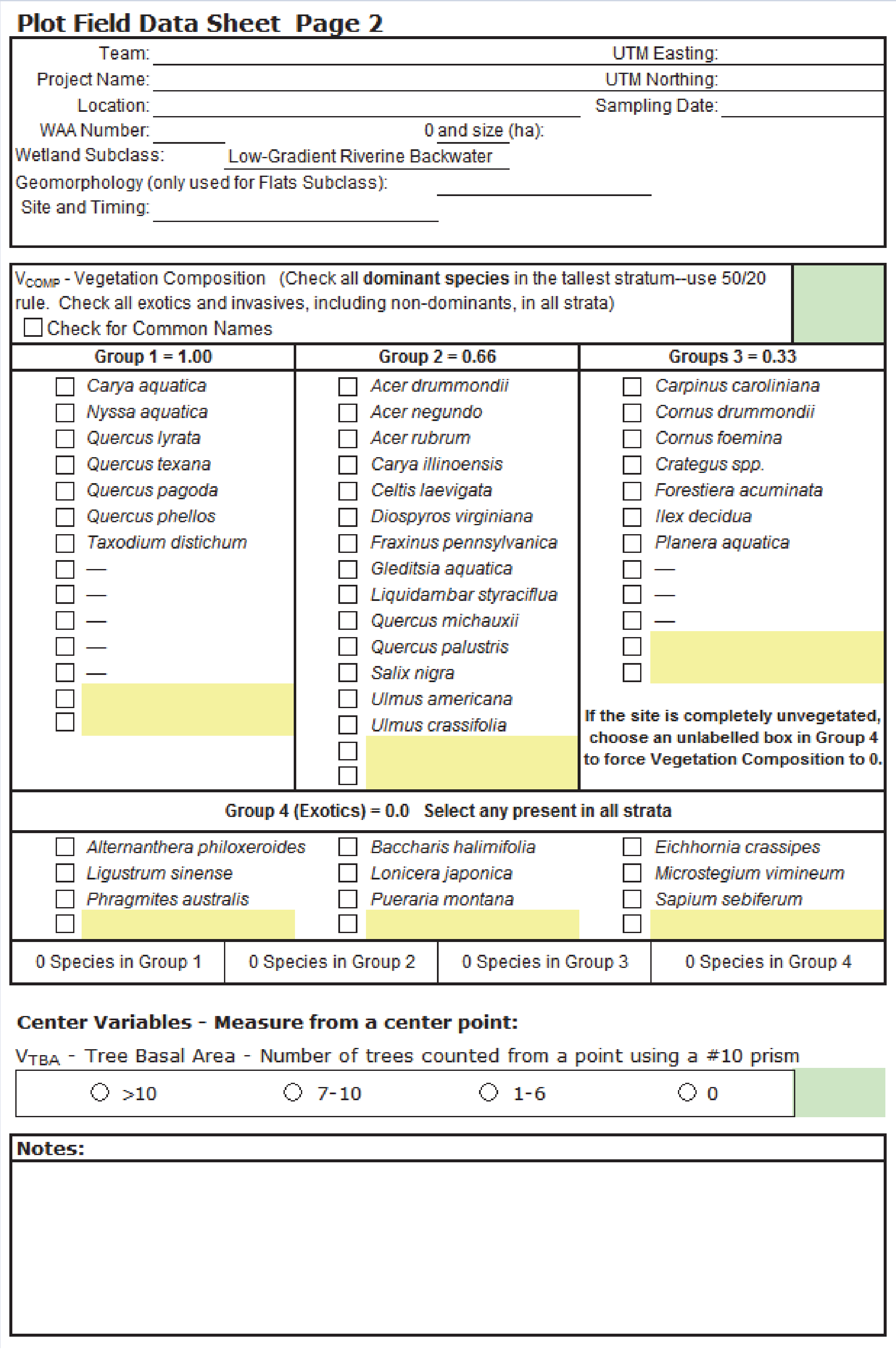
○ 50% or more ○ 35-49% ○ 10-34% ○ <10%

V_{STRATA} - Strata Present - select all that apply

☐ Trees
☐ Saplings and Shrubs
☐ Ground Cover
Number of Strata:
Top Stratum:

$V_{TREESIZE}$ - Tree Size Classes - select all that apply

☐ 10-25 cm dbh
☐ 25.1-50 cm dbh
☐ 50.1 - 75 cm dbh
☐ > 75 cm dbh



Plot Field Data Sheet Page 2

Team: ______ UTM Easting: ______
Project Name: ______ UTM Northing: ______
Location: ______ Sampling Date: ______
WAA Number: ______ 0 and size (ha):
Wetland Subclass: Low-Gradient Riverine Backwater
Geomorphology (only used for Flats Subclass): ______
Site and Timing: ______

V_{COMP} - Vegetation Composition (Check all **dominant species** in the tallest stratum--use 50/20 rule. Check all exotics and invasives, including non-dominants, in all strata) 🟩

☐ Check for Common Names

Group 1 = 1.00	Group 2 = 0.66	Groups 3 = 0.33
☐ *Carya aquatica*	☐ *Acer drummondii*	☐ *Carpinus caroliniana*
☐ *Nyssa aquatica*	☐ *Acer negundo*	☐ *Cornus drummondii*
☐ *Quercus lyrata*	☐ *Acer rubrum*	☐ *Cornus foemina*
☐ *Quercus texana*	☐ *Carya illinoensis*	☐ *Crategus spp.*
☐ *Quercus pagoda*	☐ *Celtis laevigata*	☐ *Forestiera acuminata*
☐ *Quercus phellos*	☐ *Diospyros virginiana*	☐ *Ilex decidua*
☐ *Taxodium distichum*	☐ *Fraxinus pennsylvanica*	☐ *Planera aquatica*
☐ —	☐ *Gleditsia aquatica*	☐ —
☐ —	☐ *Liquidambar styraciflua*	☐ —
☐ —	☐ *Quercus michauxii*	☐ —
☐ —	☐ *Quercus palustris*	☐
☐ —	☐ *Salix nigra*	☐
☐	☐ *Ulmus americana*	**If the site is completely unvegetated, choose an unlabelled box in Group 4 to force Vegetation Composition to 0.**
☐	☐ *Ulmus crassifolia*	
	☐	
	☐	

Group 4 (Exotics) = 0.0 Select any present in all strata

☐ *Alternanthera philoxeroides*	☐ *Baccharis halimifolia*	☐ *Eichhornia crassipes*
☐ *Ligustrum sinense*	☐ *Lonicera japonica*	☐ *Microstegium vimineum*
☐ *Phragmites australis*	☐ *Pueraria montana*	☐ *Sapium sebiferum*
☐	☐	☐

0 Species in Group 1	0 Species in Group 2	0 Species in Group 3	0 Species in Group 4

Center Variables - Measure from a center point:

V_{TBA} - Tree Basal Area - Number of trees counted from a point using a #10 prism

○ >10 ○ 7-10 ○ 1-6 ○ 0 🟩

Notes:

Appendix C: Common and Scientific Names of Plant Species Referenced in Text and Data Sheets

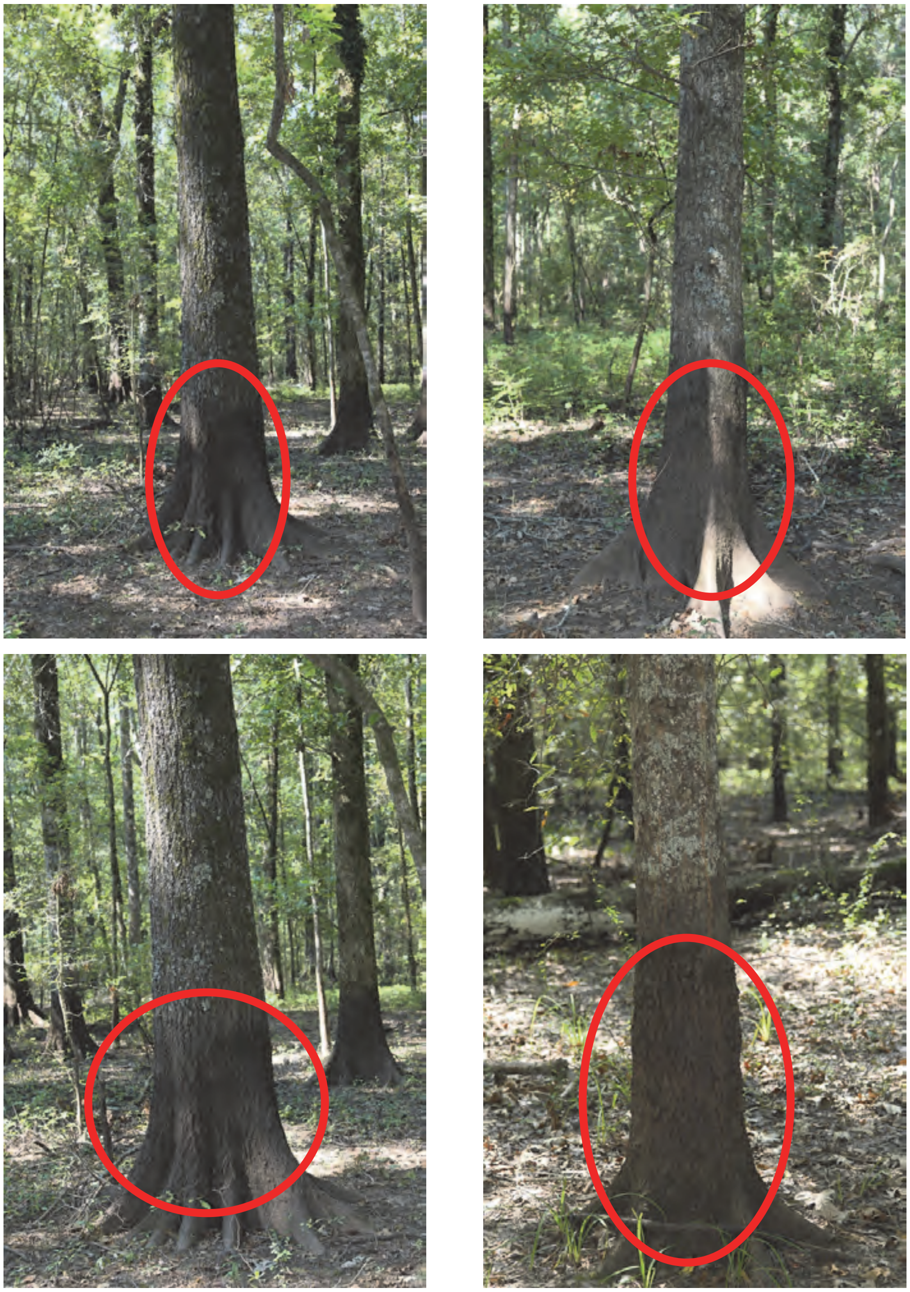
Scientific Name	Common Name
Acer drummondii	Swamp red maple
Acer negundo	Box elder
Acer saccharinum	Silver maple
Alternanthera philoxeroides	Alligator weed
Amorpha fruticosa	Leadplant
Asimina triloba	Paw-paw
Baccharis halimifolia	Baccharis
Betula nigra	River birch
Callicarpa americana	Beautyberry Car
Carpinus caroliniana	Ironwood
Carya aquatica	Water hickory
Carya cordiformis	Bitternut hickory
Carya illinoensis	Pecan
Carya laciniosa	Shellbark hickory
Carya ovata	Shagbark hickory
Carya tomentosa	Mockernut hickory
Catalpa speciosa	Catalpa
Celtis laevigata	Sugarberry
Cephalanthus occidentalis	Buttonbush
Cornus drummondii	Smooth dogwood
Cornus florida	Flowering dogwood
Cornus foemina	Swamp dogwood
Crataegus spp.	Hawthorn
Diospyros virginiana	Persimmon
Eichornia crassipes	Water hyacinth
Forestiera acuminata	Swamp privet
Fraxinus americana	White ash
Fraxinus pennsylvanica	Green ash
Gleditsia aquatica	Water locust
Gleditsia triacanthos	Honey locust

Scientific Name	Common Name
Hibiscus spp.	Hibiscus
Ilex decidua	Deciduous holly
Itea virginica	Virginia willow
Leitneria floridana	Corkwood
Ligustrum sinense	Japanese privet
Ligustrum spp.	Common privet
Lindera melissifolia	Pondberry
Liquidambar styraciflua	Sweetgum
Lonicera japonica	Japanese honeysuckle
Microstegium vimineum	Japanese stiltgrass
Morus rubra	Red mulberry
Nyssa aquatica	Water tupelo
Nyssa sylvatica	Blackgum
Phragmites australis	Common reed
Pinus taeda	Loblolly pine
Planera aquatica	Water elm
Platanus occidentalis	Sycamore
Populus deltoides	Eastern cottonwood
Populus heterophylla	Swamp cottonwood
Prunus angustifolia	Chickasaw plum
Prunus serotina	Black cherry
Pueraria montana	Kudzu
Quercus acutissima	Sawtooth oak
Quercus falcata	Southern red oak
Quercus lyrata	Overcup oak
Quercus macrocarpa	Bur oak
Quercus michauxii	Cow oak
Quercus nigra	Water oak
Quercus texana	Nuttall oak
Quercus pagoda	Cherrybark oak
Quercus palustris	Pin oak
Quercus phellos	Willow oak
Quercus shumardii	Shumard oak
Quercus similis	Delta post oak
Quercus stellata	Post oak
Quercus velutina	Black oak

Scientific Name	Common Name
Rubus spp.	Blackberry
Salix nigra	Black willow
Sambucus canadensis	Elderberry
Styrax americana	Storax
Taxodium distichum	Baldcypress
Triadica sebifera	Chinese tallow tree
Ulmus alata	Winged elm
Ulmus americana	American elm
Ulmus crassifolia	Cedar elm
Ulmus rubra	Slippery elm
Vaccinium spp.	Blueberry
	(concluded)

Appendix D: Photos of Indicators used in the MAV HGM Data collection

D1: Basal Swelling



Examples of basal swelling (adapted from Sheehan and Murray 2011, photo by Mike Wintroath).

D2: Tip Dieback

Red circles show tip dieback (adapted from Sheehan and Murray 2011, photo by Mike Wintroath).

D3: Woody Debris

a. Low amount of WD -0% to 10%

b. Medium amount of WD - 10% to 25%

c. High amount of WD - 25% to 100% (adapted from Sheehan and Murray 2011, photo by Mike Wintroath).

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13. SUPPLEMENTARY NOTES

14. ABSTRACT:

The Hydrogeomorphic (HGM) Approach is a method for developing and applying indices for the site-specific assessment of wetland functions. 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. However, a variety of other potential uses have been identified, including the design of wetland restoration projects, and management of wetlands. This Regional Guidebook presents the HGM Approach for assessing the functions of most of the wetlands that occur in the Mississippi Alluvial Valley (MAV). It consolidates and extends the coverage provided by two previous guidebooks for the Delta Region of Arkansas and the Yazoo Basin of Mississippi.

The report begins with an overview of the HGM Approach and then classifies and characterizes the principal indentified MAV wetlands. Detailed HGM assessment models and protocols are presented for five of those wetland types, or subclasses, representing most of the forested wetlands in the region other than those associated with lakes and impoundments. The following wetland subclasses are treated in detail: Flat, Low-Gradient Riverine Backwater, Low-Gradient Riverine Overbank, Isolated Depression, and Connected Depression. The appendices provide field data collection forms and spreadsheets for making calculations.

15. SUBJECT TERMS

Wetlands	HGM	Hydrogeomorphic
Mississippi Alluvial Valley (MAV)	Functional Assessment	Bottomland Hardwoods

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