Mississippi Valley Division,
Regional Planning and Environment Division South

Yazoo Backwater Area Water Management Project

APPENDIX K - Monitoring and Adaptive Management

June 2024

Table of Contents

List of Tables

List of Figures

SECTION 1

INTRODUCTION

This section describes an approach to monitor and adaptively manage resources within the Yazoo Study Area (YSA). The section follows the general format and outline utilized in other sections of the report, while addressing monitoring approaches and adaptive management strategies related to groundwater supply wells (Section 1.0), monitoring protocols for aquatic resources (Section 2.0), adaptive management goals for aquatic resources (Section 3.0), monitoring Pondberry colonies (Section 4), YSA Monitoring and Adaptive Management (Section 5) and adaptive management and mitigation for wetland resources (Section 6.0). While the authors recognize the interactions between these ecological components, this format was selected to highlight the different monitoring approaches and potential adaptive management opportunities applicable to these resources.

The United States Department of the Army (Army), the United States Environmental Protection Agency (EPA), and the United States Fish and Wildlife Service (USFWS) are committed to a collaborative and expeditious path forward to establish a flood risk reduction solution in the Yazoo Backwater Area; several Memorandum of Agreements are being developed to establish procedures regarding efficient and effective coordination in the development, review, approval, and oversight of Pump Operations, Monitoring and Adaptive Management and Compensatory Mitigation. The YSA program to monitor and adaptively manage the impacts of pump operations is being developed and will be incorporated into the final EIS. In addition to monitoring of the pump operations, monitoring and adaptive management is being proposed related to aquatic resources and wetlands (for mitigation) as discussed in this monitoring and adaptive management plan.

Basis of Monitoring and Adaptive Management (M&AM): For restoration and mitigation activities, the U.S. Army Corps of Engineers (USACE) is required to develop a Monitoring and Adaptive Management Plan (WRDA 2007 Section 2036(a) and 2039). The USACE is the lead agency for implementation of three actions in the National Action Plan (2011) associated with the recommendation to support Integrated Water Resources Management (IWRM):

1. Work with States and interstate bodies (e.g., Levee Boards, The Nature Conservancy, Lower Mississippi River Conservation Committee) to provide assistance needed to incorporate IWRM into their planning and programs, paying particular attention to climate change adaptation issues.
2. Working with States, review flood risk management and drought management planning to identify "best practices" to prepare for hydrologic extremes in a changing climate.
3. Develop benchmarks for incorporating **adaptive management into water project designs, operational procedures, and planning strategies** (emphasis added).

In reference to the Yazoo Backwater Area Water Management Project, management actions are defined as proposed or potential actions to be taken by the USACE to address the overall goal: Develop a M&AM plan that supports multiple functions and values of the Yazoo Backwater Area Water Management Project including socio- economic benefits, flood control, recreation, aquatic biota, water quality, environmental flows, connectivity, and ecological sustainability. M&AM plans contain both a monitoring component and an adaptive management component that is based on the results and interpretation of monitoring efforts as discussed herein.

SUPPLEMENTAL LOW FLOW GROUNDWATER WELLS

Background

Land-use alterations in the Big Sunflower–Steele Bayou drainage are environmental disturbances culminating over a century and resulting in stream degradation. The loss of forested riparian corridors, fine sediment accumulation in the channels, and reduction of surface flows are the principal or primary stressors to aquatic life in low-gradient warm water streams (Wang et al.1997, Wood and Armitage 1997). These stressors influence other parameters (e.g., nutrients, dissolved oxygen) in a hierarchical organization of environmental influences that determine fish composition (Dembkowski and Miranda 2012). Management of land-use disturbances, or the principal environmental variables impacting fish communities, can reverse or possibly restore stream habitat condition and recovery of the fish community.

The approach to developing measures that could potentially benefit recovery of the fish community relies on consideration of the life cycle of fishes and associated anthropogenic impairments to each life stage. Flood-induced hypoxia during the spring and early summer likely impacts successful spawning and rearing regardless of reforestation. Next, the juvenile and adult life stages that do survive through the flood season are faced with extreme low flows during the fall. Land use disturbances (i.e., accretion of sediment, lack of riparian buffers) and intermittent discharge during the fall present significant challenges across fish life cycles which can be better addressed by alternative actions.

A conceptual model is presented that addresses three principal stressors on fish communities in the Big Sunflower-Steele Bayou drainage, three management actions that can reduce or reverse the perturbations, and new associated ecological endpoints resulting from the management actions (Figure 4). In conclusion, reforestation is only one of several methods to improve the ecological function and structure of the Big Sunflower-Steele Bayou drainage. Hypoxia during backwater events limits the value of reforesting the floodplain. Low survival of fish during hypoxic floods followed by high mortality in the fall from low water and sedimentation prevents recovery. Reforestation alone does not address other impairments in the drainage such as sedimentation and low flows. Specific management actions described herein can be implemented either independent of reforestation, or as an integrated plan of reforestation and other land management practices to improve survival and growth of the overall aquatic community during all life stages. Water level management is the focus of this plan.

The first management action addressed herein is flow augmentation, or creation of environmental flows by pumping from re-charged aquifers. Restoring environmental (perennial) flows in the Big Sunflower-Steele Bayou drainage should consider at least three criteria in an adaptive management plan:

1. Provide adequate water to avoid desiccation of established mussel beds. Mussels are widespread and abundant in the Big Sunflower-Steele Bayou drainage and include regional and federally protected species (Jones et al. 2005). Empirical relationships between river stage and wetted perimeter of mussel beds can establish minimum discharge requirements for successful life cycles or recruitment.
2. Ensure periodic fish passage flows over weirs for spawning movements and recolonization. The old Lock and Dam on the Sunflower River and other weirs in the drainage are impediments to upstream/downstream movements of fish during low water. Environmental flows should consider the minimum water depth over the weir crest for passage of target species. The 10% elevation (90% exceedance) is 83.34, the 25% is 83.83, and the 50% is 84.77. The weir crest elevation is 83.5. Hence 75% of the year the water is 0.33 feet above the weir, and 50% it is 1.27 feet above the weir.
3. Manage hydraulic connectivity between the river channel and low-elevation floodplains or tributary mouths. Slight increases in discharge can potentially re-connect large areas of floodplains otherwise isolated during non-flowing conditions.

Purpose and Objectives

The following describes the M&AM plan for a proposed supplemental low flow groundwater wells (SLFG well) installation within the YSA. It includes a brief historic perspective on the ground and surface water interaction, an objective to restore baseflow similar to twentieth century conditions, and an approach to implement the objective.

A series of SLFG wells will be installed and operated during historic low flow periods to prevent desiccation of mussel beds and improve survival and year-class strength of fishes. The goal of the wells is to restore the unregulated rivers in Big Sunflower-Steele Bayou watershed to their historical observed low flow state of the twentieth century (Figures 1). The supplemental low flow groundwater wells will ideally contribute up to 100 cfs to the streams during low flow periods that will increase wetted surface, aquatic habitat and "living space" for mussels, fishes and other aquatic invertebrates including species of special concern in the basin. (Table 1). Monitoring of these resources are described in Section 3. Installation of the wells will be phased with one site being initially implemented and the design and implementation of subsequent wells refined based on initial site's lessons learned.

Hydrologic Setting

Historically, rivers and tributaries within the Yazoo Basin extend down into the top of the alluvial aquifer, allowing them to supplement their baseflow during dry periods. However, the lowering of the water levels of the aquifer due to agricultural withdrawals for irrigation has impeded the capture of baseflow into the channels, especially during dry periods in unregulated streams including the Big Sunflower- Steele Bayou drainage. Streams regulated by releases from the four upstream reservoirs (Arkabutala, Sardis, Enid, and Grenada) result in perennial flows in the Coldwater-Tallahatchie- Yalobusha-Yazoo Rivers during typically dry periods. Historically, environmental flow within the unregulated streams in the Yazoo Delta has declined from the twentieth century to the twenty-first century. Figures 1A and 1B show the annual minimum flow of the Big Sunflower River at the Sunflower gage from 1937 through 2019. Big Sunflower River at Sunflower was chosen as a control location because it is along one of the Yazoo Basin's major rivers and it is upstream of sensitive habitats that require significant environmental flow.

From 1937 through 1975, the annual minimum flow fell below 100 cubic feet per second (cfs) only six times. After 1975, the annual minimum flow dramatically decreased and typically ranges between 10 and 60 cfs. Annual precipitation, however, has not declined over this time period. In addition to the decline in the observed minimum flow, the Yazoo Basin typically experiences a dry period during the fall season, from July through November. Figure 1 shows the daily minimum, maximum, and median flow from 1 January 1936 through 19 November 2019 for the Big Sunflower River at Sunflower. July through November had the lowest median flow compared to spring months. The highest median flow, 1,910 cfs, occurred in March; whereas, the lowest median flow, 115 cfs, occurred in October. The extremely low baseflows, especially during already dry periods, have been dewatering mussel beds, reducing fish diversity, and impacting other sensitive environments within the Yazoo Basin (Killgore et al. 2024). In addition, the low baseflows cause a reduction in instream wetted habitat that can directly impact fisheries and other aquatic communities in addition to dewatering portions of affected mussel beds. This aspect highlights the needs of the entire aquatic community and not just the mussel community alone. Empirical relationships between river stage and wetted perimeter of mussel beds can establish minimum discharge requirements to maintain an adequate wetted surface within the stream channel.

As a result of inadequate environmental flow, mussel beds within the Big Sunflower River are being dewatered and exposed as seen below the Big Sunflower old Lock and Dam (Figure 2). Supplemental well fields located in the upper watershed will provide environmental flows to the middle and lower Big Sunflower River where impacts have accrued for decades (see Aquatic Appendix, Parts 3 and 4). Mussels are widespread and locally abundant in the Big Sunflower-Steele Bayou drainage and include regional and federally protected species (Jones et al. 2005).

Rheophilic fish species have declined due to low flows, the fish assemblage is highly altered compared to reference watersheds, and the majority of the fish assemblage now consists of habitat-tolerant species. Establishment of environmental flows is intended to improve the overall aquatic assemblages in the unregulated rivers of the Yazoo Basin.

Approach

The proposed locations of the supplemental low flow groundwater wells were chosen based on two criteria: 1) the wells are within 30,000 feet of the Mississippi River and have access to its abundant water supply and 2) the wells reside on the landside of the Yazoo Backwater levee and can provide water downstream to the mussel beds (Figure 3). The supplemental low flow groundwater wells would pull from the alluvial aquifer adjacent to the Mississippi River which is recharged annually. Each well is designed to pump up to 5 cfs. The locations of the proposed wells are provided in Figure 3 and the name of the watershed each well resides in is provided in Table 2.

Three reaches in the Big Sunflower were established to reflect benefits of low flows to endangered mussels (i.e., Rabbitsfoot and Sheepnose) that occur in the upper reach between Clarksdale and Indianola. Eleven wells in Harris Bayou and Hushpuckena River watersheds would supplement low flows in this reach. Eleven wells in the Bogue Phalia Basin watershed would augment flows in the middle Big Sunflower River from just above the Little Callao gage near the Old Lock and Dam to below the Anguilla gage near Holly Bluff. Established mussel beds occur in this reach, particularly below the Old Lock and Dam, although the two endangered species have been collected in this reach. Five wells in the Deer Creek watershed would augment flows in the lower Big Sunflower reach between the Steele Bayou structure and the Old Lock and Dam through Rolling Fork Creek. Recent sampling in the lower reach did not detect the two endangered species and they are unlikely to occur. In addition, five wells in Main Canal and two in upper Black Bayou (Fish Lake Bayou) will augment flows in the Steele Bayou watershed.

The wells would only be operated during the fall low flow period after irrigation return flows cease. Irrigation return flows from the agricultural fields maintain summer low flows in most of the stream channels. Minimum flow targets will be established for downstream locations based on the number of wells operated and will vary so that the target flows are met. The minimum flows will be established through the Monitoring and Adaptive Management Program for this project. The wells will be located in areas near the Mississippi River levee to minimize possible impacts to the alluvial aquifer. The groundwater elevation will be monitored at all sites to evaluate the impact of well usage to the aquifer. All wells will be located outside of the current zone of depression in the groundwater table. Wells will not be operated during major flood events.

SECTION 2

MONITORING AQUATIC RESOURCES

Purpose

The following describes the M&AM plan for water quality and aquatic habitat within the YSA. It includes strategies for baseline and post-project implementation monitoring as well as opportunities to maximize ecological benefits related to water quality and aquatic habitat through adaptive management. The selected approach is designed to decrease uncertainty through an iterative and flexible data driven process.

Objective

The M&AM plan describes a series of monitoring techniques and management objectives related to ecological functions within the project area. Specifically, water quality and aquatic habitat challenges will be addressed by seeking three management objectives: 1) increase environmental flows, 2) decrease the frequency and/or magnitude of low dissolved oxygen conditions, and 3) improve sediment and bedform conditions.

Initially, existing water quality data and associated GIS databases collected by the USACE and interagency partners as well as available datasets developed by others will be compiled and examined in a knowledge base including statistical relationships, variability, trends, cycles, correlations, and the identification of data gaps. Based on the objectives of the alternative and this adaptive management plan, if no data gaps are identified, additional field data will not be collected other than the continuation of ongoing ambient monitoring. If additional data needs are identified, a sampling regime will be designed according to established scientific principles and approaches. The monitoring will utilize cost effective *in situ* proxies and surrogates where possible. The data will be utilized in the adaptive operational management decision process.

The following steps in the sample design and analysis process will be applied:

1. Identify primary and secondary causes of 1) poor environmental flows, 2) suppressed dissolved oxygen (hypoxia), and 3) poor sediment processing and bedform conditions.
2. Define conceptually the aquatic population of interest and any adverse effects impacting the population of interest. A conceptual model has been created to identify potential pathways of stressors and the response of aquatic biota (Figures 9). In light of additional information from the examination of existing contemporary data, the conceptual model will be updated.
3. Extensive biological sampling has occurred in the project area over several decades. However, additional physical measurements including geomorphology and hydrology which are consistent with the application of the M&AM objectives and strategies will likely be required. Additional physicochemical and biological parameters may also be required including a potential suite of standard water quality measurements using a combination of *in situ* and laboratory approaches (examples provided in Tables 3 and 4).
4. A Quality Assurance Project Plan (QAPP) will be developed as part of the M&AM plan. The QAPP will include all aspects of the study (sample collection, handling, laboratory analysis, data coding, statistical analysis, and results reporting). The study will be conducted based on sound, well-documented protocols.
5. The uncertainty including assumptions in estimating quantities in variability, trends, cycles, and correlations will be assessed and reported.
6. Data analysis will follow standard protocols and apply accepted statistical approaches.
7. Results will be utilized to make adaptive management decisions, including operational management activities related to the stated management objectives.

Reporting and communication will be completed using technical reports and regularly scheduled meetings.

Aquatic Faunal Monitoring Protocol

General stream conditions (e.g., water temperature, specific conductance, pH, dissolved oxygen, and turbidity) will be characterized at each sample station using a YSI ProDSS® or equivalent. If water depth is greater than three feet, surface and bottom measurements are taken to document near-shore stratification. However, if the water depth exceeds 10 feet, the water column with be profiled at one- or two-foot intervals.

Each sample station will be georeferenced with a hand-held Garmin 64ST or equivalent (WGS84 datum, dd.ddd). Observations regarding stream attributes will be noted and Stream Condition Indices will be calculated (Pruitt et al. 2020). In addition, stream width and sampling distance will be measured using a Bushnell® laser rangefinder or equivalent. Water depth (stadia rod), velocity (Marsh-McBirney Flo-Mate or equivalent), and substrate type (visual) will be taken at 10 equidistant points along a cross sectional transect within the sampled reach. Land use and cover (Landsat) along the riparian corridor adjacent to the sampling station will be mapped. All data will be stored and available for analysis in an ACCESS file for the YSA. The dataset will be archived at ERDC.

Mussels

Faunal surveys will be continued at stream stations previously sampled to quantitatively describe relationships between biological variables (e.g., abundance, diversity, biotic indices) and environmental parameters (e.g., water quality, hydraulics, and geomorphological indices) and to evaluate long-term trends in the aquatic community pre- and post-project (see Aquatic Resources Appendix). However, the locations of historic stations may be "adaptively" adjusted to capture trends observed during post-project conditions.

Mussel efforts will consist of timed searches by a number of personnel with live mussels being located by feeling along the bottom and sifting through the substrate (i.e., polly-wog type search). Visual searches will also be conducted while walking upstream through shallow areas at those stations where water clarity is permitted. In addition to searching for live mussels, shorelines and emergent portions of sand/gravel bars will be searched for empty shells. These general sampling strategies are described in more detail in Strayer and Smith (2003). This approach provides a good baseline for developing future project goals and monitoring protocols.

Identification and enumeration of all mussel material will be conducted on site following all search efforts. Nomenclature will follow Williams et al. (2017). Live mussel specimens will be returned near the point of original capture and embedded firmly into the substrate. Select voucher specimens will be retained from non-living material. Categorization of empty shells as either freshly dead, weathered dead or relict shells will follow Haag and Warren (1998). Live individuals of State and Federally listed species will be identified in the field, measured (shell length), and photographed prior to release.

Benthic Macroinvertebrates

In wadable portions of streams, macroinvertebrates will be collected using rectangular kicknets using standard bioassessment protocols (Barbour et al. 1999). In a 100-meter reach, twenty 1 m^2 kicknet jabs will be taken, targeting available microhabitats in their proportional availability. Macroinvertebrates will be picked out of samples in the field and placed into a vial containing 70% ethanol and returned to the laboratory for quantification and identification using appropriate taxonomic keys (e.g., Merritt et al. 2018). If habitat is not suitable for kicknetting, benthic substrates will be sampled with a pole-mounted Ekman grab sampler, washed through a 500 μm sieve, and contents placed in 70% ethanol and returned to the laboratory for identification. If woody debris are present at sample sites, a representative wood sample will be fixed in 80% ethanol in plastic sample bags and returned to the laboratory for processing and invertebrate identification.

Fish Sampling

Fishes will be sampled as described in Aquatic Resources Appendix. All specimens will be preserved in the field and returned to the laboratory for identification and enumeration. Each individual will be measured for total length. Sampling efforts taken at each station will be pooled into a single composite sample. Live individuals of State and Federally listed species will be identified in the field, measured (total length), and photographed prior to release.

Adult and juvenile fish will be sampled with seines during the summer and fall. A total of 10 seine hauls per station will constitute a sample. Both stream physical and in situ water quality measures will be made during deployment. Typically, water quality parameters will be measured at a single representative point using a multi-parameter water quality probe as described earlier.

Reforested Floodplain

Five stream reaches were modeled using EnviroFish: Holly Bluff, Little Callao, Anguilla, Little Sunflower, Grace, and Steele Bayou (see Aquatic Resources Appendix) (Killgore et al. 2012). The overall goal is to maintain environmental gradients and continuum by reconnecting a mosaic of migration corridors, patches and ecosystem diversity including fish connectivity to adjacent floodplains on a frequent basis. We assume the adjacent floodplains within each of the aforementioned stream/floodplain corridors will reach full functionality within 10 years for spawning and rearing by creating an ecosystem continuum. The formation of ecosystem continuum represents and is dependent upon the range of hydrologic flux that will be created by the project. In this case, maintaining surface water connectivity and reforestation is important for the following reasons: 1) provides lateral movement (flood pulse) for fish and macroinvertebrates; 2) sustains endemic plants and animals unique to the area; and 3) reduces or precludes the invasion of nuisance and exotic species thus sustaining important wetland and stream ecosystems and the expression of characteristic unique and natural communities including imperiled plants and animals and species of special regional and national concern, functionality and value.

Reforested areas will be sampled over the 10-year period using direct measures similar to the Wetlands Section below. Parameters will include measurements of tree density (e.g., tree basal area, density by coverage), speciation (e.g., overstory composition), sustainability (e.g., regeneration, species represented in vertical strata), soil conditions (e.g., O and A horizon), and flood frequency and duration (overbank events).

Utilization of reforested areas by fish for rearing and other nekton (free swimming invertebrates) will be evaluated using larval light traps (Killgore 1994). Generally, light traps will be used on a diel basis, deployed in the afternoon and retrieved the next day around mid-morning. Light traps are typically soaked for 14-17 hours between afternoon deployment and morning recovery. Ten Plexiglas light traps will be set above, in, and below predetermined sample stations and baited with a Cyalume yellow chemical light stick. At each trap, water depth, and distance from shore will be measured and type of instream cover recorded (e.g., large woody debris, small woody debris, submersed aquatic vegetation, emergent grasses, overhanging brush, none). Position of each light trap will be recorded in field notes and/or established with GPS. On the following morning at the time of light trap retrieval, water quality will be recorded again (to document diel changes). Pans from the bottom of each light trap will be removed, rinsed, and material preserved in 10% formalin.

Stream Morphology

The overall goal of measuring stream morphology is to monitor the response of stream geometry to the operational management objectives described below in Section 5.0. Stream morphology measurements will include autonomous and surface (i.e., traditional surveying) methods.

Initially, a suite of methods will be tested and refined as part of the adaptive monitoring process. The following measures and metrics are represented (Table 4):

1. Stream type and development stage.
2. Cross-sectional geometry, longitudinal profile, and planform pattern.
3. Channel stability, flow, and bed material.

In order to draw correlations with aquatic fauna, stream morphology stations will be located at or near biological stations and at groundwater well locations.

Water Quality Monitoring Parameters

Temperature: Water temperature exerts a direct effect on aquatic life and an indirect effect on other critical life-supporting water quality parameters (e.g., dissolved oxygen saturation). It can cause an acute or chronic toxicological effect on aquatic biota. The majority of warm water species common in the Yazoo Basin (e.g., Smallmouth Buffalo, Flathead Catfish, Ghost Shiner, Shoal Chub) have a specific temperature range and tolerance. Water temperature can also function as a barrier to migration of fish within the Yazoo riverine system. Water temperature measurements are collected *in situ* using a variety of probes and data sondes. Temperature measurements can be used to document improved environmental flows and hydraulic circulation related to management objectives of the M&AM plan.

Specific Conductance: Specific conductance or conductivity is the ability of water to conduct an electric current. In general, specific conductance is related to total ionic dissolved solids in solution such as metals, minerals present within the water column. Conductivity measurements are collected *in situ* using a variety of probes and data sondes. Conductivity is typically higher in the Delta, partially due to runoff. Generally, it has a strong, positive correlated to biological impairment. Consequently, conductivity measurements can be used to document improved environmental flows and hydraulic circulation related to management objectives #1, #2, and #3 of the M&AM plan (Section 5.0).

Dissolved Oxygen: Dissolved oxygen in surface waters is critical to the survival of many aquatic species and low dissolved oxygen concentrations have negative impacts on fishes and other organisms. Water column dissolved oxygen concentrations vary as a function of: 1) surface water reaeration; 2) community metabolism (in the water column; biochemical oxygen demand; and 3) sediment oxygen demand. Additionally, temperature and other factors influence dissolved oxygen levels. As a result, monitoring dissolved oxygen levels directly relates to management objectives #1, #2, and #3 of the M&AM plan (Section 5.0). Dissolved oxygen measurements are collected *in situ* using a variety of probes and data sondes.

pH: The pH scale specifies the acidity or basicity of a liquid or soil solution. pH has a controlling factor on the chemical form and bioavailability of many nutrients, metals, and other substances in the environment. As a result, pH measurements are essential to documenting water quality and aquatic habitat conditions. pH measurements are collected *in situ* or in the laboratory using a variety of probes and data sondes. Measurements of pH indirectly inform management objectives #1, #2, and #3 of the M&AM plan (Section 5.0).

Oxidation-reduction potential: Oxidation-reduction (redox) potential is a quantitative measure of electron availability and is indicative of the intensity of oxidation or reduction in both chemical and biological systems (Faulkner et al. 1989). Redox potentials determine the oxidation state of redox active elements and compounds (e.g., O_2, NO_x, Fe, S) and document the degree of anaerobiosis in surface waters and sediments. As a result, monitoring redox potentials directly relates to management objective #2 of the M&AM plan (Section 5.0). Redox potential measurements are collected *in situ* using a variety of probes and data sondes.

Light Zonation: Vertical light zonation in the water column of lakes and backwaters is a major determinant regarding the structure and distribution of aquatic life. In general, the photic or euphotic zone extends from the lake surface vertically down to where light dims to approximately one percent relative to the surface. The lower boundary of the euphotic zone varies daily and seasonally in direct response to solar intensity and water transparency. For instance, the euphotic zone is reduced by turbidity from algae blooms and suspended sediment. Measurements of light zonation relate to water clarity, quality, circulation, and sediment processing and include turbidity and suspended sediment. As a result, light zonation measures can inform management objectives #1, #2, and #3 of the M&AM plan (Section 5.0). Light zonation is measured in-situ using a secchi disk or other light transparency method.

SECTION 3

ADAPTIVE MANAGEMENT FOR AQUATIC RESOURCES

Adaptive management to improve aquatic habitat and water quality in the YSA focuses on operational management of the pumps, SLFG well installation, and other infrastructure to achieve the management objectives described below. Notably, these management objectives are potential activities that may be implemented as part of the M&AM plan. In a sense, each potential M&AM action initiated to achieve the management objective represents a testable hypothesis that can inform the iterative learning process described herein.

Management Objective 1: Environmental Flows

Objective: Operate the pumps, SLFG wells, and other infrastructure in a manner to minimize rapid dewatering (ramping) which would improve aquatic habitat and water quality without compromising flood control benefits through management of environmental flows.

Problem: Improved environmental flows and connectivity between main-stem streams to secondary tributaries and drainage features are needed to enhance water quality, especially during low flow periods when habitat scarcity limits productivity.

Approach: Incorporate operational management and alternatives to improve environmental flows using infrastructure (e.g., pumps, gates, SLWG wells). The following tasks may be implemented in support of the management objective.

1 Improve stream classification (applicable to all management objectives). The classification of surface water features in the YSA is essential to documenting the effects of adaptive management action. Strategies to improve classification include:

   a. Provide inundation maps at several appropriate stages (e.g., elevations 85 feet, NGVD and higher);
   b. Develop habitat classification maps of wetlands and streams within the YSA (e.g., “Attributes of the Lower Mississippi River Batture (Biedenharn et al. 2018);
   c. Based on stratification by stream class, divide the YSA into model segments (or use existing hydrologic reaches) to account for environmental flows and water quality considerations (Yazoo River, Steele Bayou, Deer Creek, Big Sunflower, Little Sunflower).

2 Using results of Flood Event Assessment Tool model, estimate elevations at model segments and representative side channels or drainage features.

3 Ground truth (“surface assessments”) a statistical subset of stream classes identified above.

4 Identify appropriate areas to enhance baseflow augmentation (e.g., Bogue Phalia and Quiver) by groundwater discharge or other actions.

5 Conduct surface assessments by "walking in/out" of representative side channels. Set stage recorders at selected side channels or drainage features.
6 Monitor response of improved flow regimes on aquatic biota.

Application: Identify various alternatives regarding operational management (e.g., pumps, gates, SLFG wells) supportive of the management objective. Possible applications include:

1. Manage pumps and other infrastructure to increase the duration of river inundation and connectivity to low-elevation landscape features (e.g., feeder streams and wetlands) directly benefiting spawning and rearing of aquatic species and other ecological functions.
2. Manage pumps/structure to minimize rapid drawdown (ramping) of pool elevation below 87 feet, NGVD. This operational change will reduce stranding of fish, provide more time for aquatic biota to disperse into the rivers increasing survivability, and mimic a more natural flood pulse hydrograph
3. Manage SLWG wells to establish low flows to maintain an adequate wetted perimeter-discharge relationships associated with the mussel beds and provide for perennial flows during the fall to benefit fish survival and recruitment.

Documentation: Monitoring surface water elevations in combination with water quality and aquatic habitat assessments can identify the benefits of improved environmental flows and highlight opportunities to further enhance conditions through additional management activities.

Management Objective 2: Dissolved Oxygen Concentrations and Associated Water Quality Parameters

Objective: Increase dissolved oxygen during backwater events through improved hydraulic circulation and advection.

Problem: The static conditions during a prolonged flood event cause stratification and extreme low dissolved oxygen in the hypolimnion. Biological impairment has been identified in the YSA caused by nutrients, organic enrichment, low DO, cause unknown, sediment/siltation (303d listed by MDEQ and EPA). These constituents contribute to the oxygen demand on the water column, resulting in degraded water quality and habitat for aquatic species.

Approach: Evaluate temporal and spatial oxygen dynamics under a variety of operational management scenarios. Improving advection from operational management of the Little Sunflower water control structure, pump station, Steele Bayou water control structure, and other infrastructure may increase dissolved oxygen and decrease temperature. This may improve water quality within portions of the YSA. The following tasks may be implemented in support of the management objective.

1. Conduct *in-situ* water quality profiling and 48-hour diel studies to establish baseline conditions.
2. Expand existing *in-situ* water quality sampling efforts based on hydrologic reaches previously identified under management objective 1.
3. Collect dissolved oxygen measurements and surface water samples for analysis supportive of water quality documentation and modeling through multiple operational management events (e.g., increased advection activities, pulsing water levels to increase hydraulic circulation).

4. Compare fish models (e.g., EnviroFish) and other aquatic habitat indices against changes in oxygen dynamics.

Application: Identify various alternatives regarding operational management (e.g., pumps, gates, SLFG wells) supportive of the management objective. Possible applications include:

1. Manage pump stations and other infrastructure to increase the hydraulic circulation whenever possible to promote sediment transport. This may include operating infrastructure to increase turbulence, the introduction of supplemental surface or groundwater flows into the system, or other activities.
2. Manage pump station/water control structures to create a pulsing effect that can re-suspend sediments while decreasing stagnation associated with excess sediment deposition.
3. Install drop pipes at the edge of agricultural fields to reduce accelerated erosion and transport of fine sediment to wetlands and streams.
4. Removal of soft bottom substrate that adversely effects benthic communities.

Documentation: Monitoring bedform characteristics through repeated mapping and sample collection activities can document the benefits of improved bedform characteristics and identify opportunities to further enhance conditions through additional management practices. In addition, characterization of substrate types will provide crucial information regarding the magnitude of impacts to benthic communities.

Management Objective 3: Sediment and Bedform Characteristics

Objective: Increase hydraulic circulation to improve sediment transport and bedform habitat quality and diversity.

Problem: The high sedimentation rates in the YSA in combination with the static conditions established during flood events results in deposition of fine organic and inorganic sediments. The lack of hard-bottomed or coarse bedform components reduces habitat quality and diversity.

Approach: Evaluate the effects of operational activities on sediment circulation and transport within the YSA. Autonomous instrumentation can be employed to rapidly map bed material using high resolution, down and side-scan imagery. Additionally, water column and bedform sediment sampling can inform sediment cycling processes. The following tasks may be implemented to achieve the management objective.

1. Map bed material and associated habitat diversity (bedforms: sand, silt, clay, gravel, sapric material, etc.), in Big Sunflower and Steele Bayou using a rapid, AUV and boat-deployed down and side-scan instruments.

2. Bottom truth the imagery results using grab samples (e.g., Young dredge and core tubes).

3. Conduct repeated scans prior to, during, and following various management actions to document the operational effects.
4. Couple repeated discrete water column and bedform sediment sampling with mapping activities to evaluate sediment processing.

Application: Identify various alternatives regarding operational management (e.g., pumps, gates, SLFG wells) supportive of the management objective. Possible applications include:

1. Manage pump stations and other infrastructure to increase the hydraulic circulation whenever possible to promote sediment transport. This may include operating infrastructure to increase turbulence, the introduction of supplemental surface or groundwater flows into the system, or other activities.
2. Manage pump station/water control structures to create a pulsing effect that can re-suspend sediments while decreasing stagnation associated with excess sediment deposition.
3. Install drop pipes at the edge of agricultural fields to reduce accelerated erosion and transport of fine sediment to wetlands and streams.
4. Removal of soft bottom substrate that adversely effects benthic communities.

Documentation: Monitoring bedform characteristics through repeated mapping and sample collection activities can document the benefits of improved bedform characteristics and identify opportunities to further enhance conditions through additional management practices. In addition, characterization of substrate types will provide crucial information regarding the magnitude of impacts to benthic communities.

Performance Standards and Measures

Performance standards are observable or measurable physical (including hydrological), chemical and/or biological attributes that are used to determine if a compensatory mitigation project meets its objectives (2008 Mitigation Rule, USACE, 33 C.F.R. §332.2). Performance standards are also called success criteria, success standards or release criteria. Performance standards and measures (PSM) will be used herein. PSM defines the targeted restoration condition in terms of functionality and expected goods and services. Careful formulation of performance standards and associated measures ensures restoration project goals and outcomes are achievable in the YBA area. In addition, PSM provide measurable points along the scale of projected benefits over the project and monitoring horizon.

General monitoring objectives are described Section 4.5 above. As indicated in Section 4.5, a Quality Assurance Project Plan (QAPP) will be developed to ensure the measures of performance standards meet or exceed QA/QC standards. The monitoring plan includes assessment of baseline conditions and establishing monitoring protocols required for PSM (Table 6). In general, performance standards will be adapted to the observations made during establishing baseline and/or reference conditions. Once best attainable conditions are established within the Big Sunflower basin and/or other representative streams within the Lower Mississippi River Alluvial Plain (e.g., Cache, Middle White, and Big Black Rivers), performance standards will by numerated. For example, utilizing a suite of potential metrics (Table 3) highlights targeted components of the fish assemblage that could be evaluated to assess biotic responses due to operation of the SLFG wells. These metrics are based on long-term monitoring efforts within the Lower Mississippi River Basin and exemplify the diagnostic utility of establishing baseline and/or reference conditions for future monitoring efforts within the YBA area (Table 7). Success criteria and adaptive management trigger points would be developed for each metric to provide a guide for SLFG well operation. In the case for Metric 1, community structure, the success criteria would be defined as: difference in mean community metric value (e.g., evenness, richness) between baseline (pre SLFG wells) and post SLFG well condition ≥ X (i.e., post SLFG condition > pre SLFG). Similarly, the adaptive management trigger point is defined as: no change or reduction in mean community metric value between baseline and post SLFG well condition (difference ≤ X).

SECTION 4

PONDBERRY (*LINDERA MELISSIFOLIA*) MONITORING PLAN

This adaptive monitoring plan was prepared to monitor the effects of the Yazoo Backwater Area Management Project on the endangered plant, pondberry (Lindera melissifolia) (Walter) Blume. For a complete treatise of the distribution, life history, status, and habitat requirements including references, see Threatened and Endangered Species Appendix, Biological Assessment for Pondberry. Based on the findings reported in the Biological Assessment (BA), several environmental conditions were identified and have been incorporated in this monitoring plan. Baseline conditions (pre-project) of pondberry colonies within the project action area will be established which includes projections (trends) of future without project (FWOP) on a 12-year monitoring horizon. Baseline conditions will determine natural variability due to seasonality, herbivory, hydric regime, forest habitat metrics, and stem dieback not associated with the proposed project. The results of the baseline study will set the foundation for any positive or negative effects caused by the project including long-term effects caused by future with project (FWP). During the monitoring period, data will be processed, reduced, statistically analyzed, and entered into an adaptive monitoring framework to adjust future monitoring needs and protocols. Those protocols may include the type and frequency of measurements and their location. This monitoring plan will be submitted to the USFWS for concurrence.

To initiate a long-term monitoring plan, it will be necessary to fully understand the distribution of extant pondberry colonies within the Delta National Forest (DNF). In 2020, the ERDC-EL visited and assessed 50 of the DNF Gulf South Research Corporation colony sites (GSCR 1-46, 53-56), along with historical colony sites provided by the U.S. Fish and Wildlife Service (USFWS; McDearman Sites), and three sites provided by the US Forest Service (USFS; Williamson et al. 2019) where pondberry was documented in 2019 within DNF Compartments 9 and 25. In addition, ERDC-EL discovered 15 new pondberry colonies. There are approximately 100 additional historical pondberry colony locations in a GIS shapefile maintained by MVK that have not been visited or assessed since the 1990's. Questions remain regarding accuracy of historical pondberry location coordinates because of changes in GIS projections over the past two decades. The ERDC- EL will address these concerns by visiting coordinates (and in some cases of discrepancy, paired coordinate locations) and conducting discovery surveys as was done in 2020 and described in the BA. ERDC-EL also will consider additional spring discovery surveys when pondberry is in flower to identify additional new colonies (as described in the BA; Threatened and Endangered Species Appendix). The results of these comprehensive surveys will provide the baseline for executing this Monitoring Plan.

Several factors were identified in the BA that effect distribution, growth, and development of pondberry colonies (see Table 5 below for corresponding recommended metrics and methods of assessment):

1. In the 2007 Biological Opinion, the USFWS identified that hydroperiod affects the distribution, growth, and development of pondberry. In addition, the USFWS recognized the need to improve our understanding on the life-history of pondberry.

2. The USACE not only recognized the importance of hydroperiod, but also the effects of light availability which is influenced by canopy and midstory cover.
3. The USFWS has not proposed establishing pondberry critical habitat in either Mississippi or in other states in which the species is known to inhabit. However, the BA identified habitat characteristics associated with pondberry colonies found in Mississippi including mature bottomland hardwoods, low depressions dominated by vertical hydrology (rainfall and evapotranspiration), and soils with surface horizon characterized with silty clay to silt loam textures.
4. Competition from other plant species were reported in the BA including “weedy” species and vines (*Smilax* and *Vitus* spp.).
5. Within the DNF in Mississippi, the BA reported that the U.S. Forest Service determined a 100-foot undisturbed buffer around known pondberry colonies, along with a 40-acre size limit on clear-cut openings, would prevent any major changes in hydrology and maintain an adequate crown closure around a colony. Stem dieback, laurel wilt disease, feral hog activity, and herbivory all are potential stressors that may contribute to poor colony health. Herbivory has been observed by deer and insects (e.g., spicebush swallowtail caterpillar). The best available information suggests that stem dieback is related to fungal pathogens, drought, and the interactions between pathogens and drought. Though no data are available on impacts of feral hog activity on pondberry, the hog population in the DNF has increased over the past two decades. During the 2020 field season researchers noted significant hog activity (i.e., rooting, wallows) proximal to many of the pondberry colonies.

Since existing groundwater wells located in the project action area provide long-term data, a determination will be made on whether the existing wells adequately represent the hydrologic conditions at extant pondberry colonies (Figure 5). Key factors in making this decision will include similar elevations, plant species composition, drainage patterns, soil classification and hydric soil indicators. If the existing groundwater wells represent conditions at the colonies, the period-of-record will provide a more long-term measure of hydroperiod. If the existing wells do not represent the hydrologic conditions at colonies, new wells will be installed at an appropriate distance from colonies. Standard methods for shallow ground water well installation will be followed (USACE 2005). Methods and measures of other factors in Figure 5 are discussed in the threatened and Endangered Species Appendix.

SECTION 5

MAPPING AND REMOTE MONITORING OF INUNDATION EXTENT IN THE YAZOO STUDY AREA (YSA) OF MISSISSIPPI

The USACE ERDC has developed and promulgated data for better describing the hydrology of the Yazoo Study Area (YSA). These data underpin much of the analysis of the potential long-term impacts of the Proposed Plan to decrease flooding across almost 400,000 acres (>140,000 ha) in the YSA. EPA Office of Research and Development (ORD) scientists have been providing technical expertise to facilitate the analysis. USACE engineering models have described the watershed and in-channel hydrology of the system, and potential backwater flooding regimes have been approximated through GIS-based hydrological tools. Soil-water-table depth sampling have produced data indicating surface soil saturation and inundation in locations located across the YSA and across a variety of different flooding regimes (Berkowitz et al. 2020). These valuable spatial and hydrological data help better understand wetland hydrology within the YSA and provide data which could be used to quantify the potential influence of groundwater on surface water inundation, soil saturation and wetland characteristics at the select locations. However, interpolation of watershed-scale hydrology from a limited number of field-based data points can potentially provide an incomplete understanding of watershed hydrology.

Watershed and in-channel models rely on site-specific gauges to calibrate the model to water levels and elevation models. These models are able to produce spatial extents of surface-water inundation for specific events but are only verified at the stage data locations (i.e., limited points within the channel) and thus the estimated surface water inundation extent remains unverified. Similarly, field measures of soil saturation and surface water inundation are essential to model validation and calibration but can reflect highly localized moisture patterns and are sensitive to fine-scale elevation measures so that the application of observations to basin hydrology, inundation extent and duration are difficult. Complementary remotely sensed data that is continuous in extent will strengthen the understanding of YSA hydrology and is critical to informed decision-making and needed for facts-based adaptive management. This component of the basin-wide assessment plan proposes the use of highly refined and accurate satellite-based remote sensing products (Vanderhoof et al. 2023) to: 1) validate and calibrate estimates of surface water inundation extents of existing USACE hydrology models and tools, 2) leverage field-based measurements of surface-water inundation and soil saturation with remote sensing data via machine learning models to allow for watershed-scale (i.e., beyond individual site) investigation of soil inundation and saturation patterns, and 3) facilitate the monitoring of existing conditions of surface water inundation and/or soil saturation, providing real-time responses to both emergent flood-extent determinations and water management decisions.

Capabilities of Remotely Sensed Data

The EPA ORD and USGS Geoscience and Environmental Change Science Center (GECSC) have developed and published multiple inundation algorithms for a set of diverse areas across the conterminous United States using multi-source remote sensing together with auxiliary datasets (Vanderhoof et al. 2023). These novel inundation algorithms developed for Sentinel-1 and Sentinel-2 satellite missions quantify open water and vegetated waters (e.g., bottomland hardwood and forested riverine backwater wetlands) with a high degree of accuracy (see Vanderhoof et al. 2023). With frequent passes of the two satellites, biweekly to monthly estimates of surface inundation patterns have been generated for multiple areas of interest across CONUS, including the lower Mississippi River alluvial valley (Vanderhoof et al. 2024): inundation algorithms have been used to map surface water extent across the YSA from 2017-2023 and can be summarized in a variety of ways to indicate patterns of inundation over a single year or for the entire time frame of available imagery (Figure 9).

Validating Existing Basin-Wide Models

Long-term inundation patterns of flooding frequency, extent, and duration are crucial to understand how the Yazoo Study Area rivers and streams, wetland systems, agricultural areas, and residential zones, and wildlife respond to seasonal variability, extreme climate events, and management actions. Remotely sensed surface water inundation products can be compared with the USACE modeling efforts to validate and potentially assist in future calibration of models. At least one model year from the HEC-HMS and HEC-RAS models used to quantify the changes in flood duration and extent overlaps with imagery dates for the year 2019 (see Appendix G – Engineering Report). Comparisons of the 2019 model-predicted inundation with the 2019 remotely sensed surface water inundation can help quantify uncertainty or conversely confidence, in the data. Potential discrepancies can help target where additional field-based data collection and or additional collaborative analyses that might be needed in the future.

Linking Field Data and Remote Sensing for Basin-Wide Application

USACE ERDC water table monitoring data provides important localized information on surface water inundation and soil saturation at select locations (see, e.g., Berkowitz et al. 2020). Remote sensing inundation products will be statistically related to field-based soil-saturation and surface-water measures as well as ancillary datasets to expand the interpretation of field data to larger areas. Machine learning models, developed with overlapping water-table monitoring data from the USACE, remotely sensed surface water inundation imagery from the USGS and EPA, and ancillary dataset like existing high-resolution elevation data, precipitation data, water management data, and soils data will be used to improve predictions of soil saturation duration and frequency under current conditions. This information will facilitate a better understanding of the broader utility of the water table monitoring wells and also potentially identify areas within the YSA that lack representation within the water table monitoring data. Through machine learning approaches (e.g., neural networks, Long Short-Term Memory Network, etc.), the analysis will define the patterns of surface water inundation and soil saturation under current water management conditions and set the baseline for proposed future changes.

Use for Future Monitoring and Adaptive Management

As the water management project progresses, remote sensing can be a critical component of monitoring and adaptive management. Within this monitoring effort, biweekly to monthly inundation products can continue to map inundation and responses of surface water inundation to water management can be documented (Figure 9). Such frequent monitoring up to and throughout the proposed water management project would provide a near real-time collaborative monitoring and assessment of surface water levels, important to meeting management goals and adaptive approaches. As USACE continues to monitor and produce water table saturation and inundation data, these inundation products will continue to refine the relationship between the field sites and remote sensing as both document the effects of water management on the YSA and help to refine the tools used to make large-scale management decisions.

Summary

Overall, this portion of the basin-wide Assessment would include scientific monitoring efforts to support and enhance adaptive management plans by providing:

- Data on the timing, frequency, and extent of open and vegetated surface water extents across the YSA derived from high resolution satellite imagery at a 2-week time step, currently reaching from 2017-2023, and extended to include future years as data becomes available.
  - Satellite- and engineering model-based estimates of surface water inundation to improved calibration and validation, as well as application to stakeholder derived data products (e.g., improved 2-, 5-, 25-, 50-yr flood prone extent derivation, improved estimates of agricultural and residential inundation frequency and extent, etc.).
  - A machine learning model relating water-table monitoring well saturation and inundation to basin-wide measures of inundation, topography, soil characteristics, and precipitation to identify current patterns of surface saturation and inundation.
  - Long-term monitoring of inundation patterns and wetland hydrology in response to future operational water management actions (i.e., floodgate closures and surface water pumping) in the YSA.

SECTION 6

WETLANDS COMPENSATORY MITIGATION MONITORING AND ADAPTIVE MANAGEMENT (M&AM) PLAN

Purpose

The following describes a M&AM strategy to document the benefits of a project-specific constructed compensatory mitigation implemented to offset unavoidable impacts to wetland resources. The proposed mitigation plan is described in Appendix J. If USACE constructs a mitigation project to meet the compensatory mitigation needs for the Yazoo Backwater Area Water Management Project a monitoring and adaptive management plan for wetlands will be required. This M&AM plan for Wetlands outlines the procedures used to verify that mitigation activities are restoring the wetland functions with the project area. Once a specific mitigation site is selected (See Appendix J Compensatory Mitigation) site specific M&AM will be outlined based on the site conditions using the general framework described in this Section. The following also identifies restoration milestones (performance criteria or success criteria) designed to ensure that projected wetland mitigation benefits are being generated and discusses strategies (Adaptive Management) to make adjustments if mitigation targets are not achieved. A discussion of the need for robust water table monitoring within the study area is also included.

Objective

Utilize established monitoring techniques and published scientific resources to 1) document increases in wetland functions as a result of compensatory mitigation, 2) identify data-driven mitigation success trajectories and milestones, and 3) adaptively manage wetland conditions within the project area based upon observed data related to changes in wetland functional capacity over time. The M&AM plan also addresses the need to monitor wetland hydrology conditions within the study area to evaluate the effects of the proposed plan on wetland hydroperiods.

Approach

The M&AM plan 1) describes how restoration milestones/thresholds were identified for wetland mitigation lands used to offset unavoidable impacts associated with implementation of the proposed Yazoo Backwater Project; 2) provides a detailed monitoring plan and protocol to document changes in wetland functions using the Hydrogeomorphic (HGM) methodology (Smith and Klimas 2013); 3) outlines a monitoring plan to evaluate potential changes in wetland hydrology across flood duration and frequency intervals and associated implications for wetland functional capacity in the study area; and 4) discusses corrective adaptive management actions that would be implemented if the mitigation areas fail to offset impacts to wetland resources as intended.

Development of Mitigation Restoration Trajectories and Milestones

The M&AM plan assumes that compensatory mitigation would be initiated under the proposed plan using similar approaches applied at previously completed projects within the Yazoo Basin. This includes the acquisition of parcels currently managed as active agricultural land, fallow land, pastureland or other non-forested land cover types. The parcels would exhibit hydric soils and would be planted a mixture of hydrophytic saplings that typically include a mixture of Fraxinus pennsylvanica, Quercus texana, Quercus lyrata, Carya aquatica, and other flood-tolerant hydrophytes associated with high wetland habitat values described in Smith and Klimas (2002). Afforestation typically occurs via row planting at seedling spacings of three to four meters.

Although the specific locations of all compensatory mitigation locations have not been finalized, data from existing mitigation sites in the Yazoo Basin can be used to estimate ecological conditions expected on new mitigation lands and how those conditions will change over time. This data informs the inputs for the HGM variables used to determine both wetland functional impacts and mitigation requirements under the proposed plan. Additionally, the established forested wetland mitigation chronosequence detailed in Berkowitz (2018) provides inputs for other HGM variables up to 20 years and estimated variable metric scores for areas > 20 years post restoration are described in Smith and Klimas (2002).

Collectively, these resources provide data to conduct the HGM assessment across the 50-year period of analysis and identify wetland functional milestones to incorporate into the M&AM plan. Tables 5 through 9 in the Wetlands Appendix display the subset of HGM variables that are not expected to change over the 50-year period of analysis. These variable inputs serve as guidance for the final site selection, which should exhibit the following characteristics where possible: areas with large interconnected forested tracts (VTRACT), forested areas adjacent to the mitigation properties (VCONNECT), large interior areas (VCORE), occur within the ≤ 4-year floodplain (VFREQ), and experience wetland hydroperiods for ≥ 5.0% of the growing season (VDUR). If the criteria cannot be met during the acquisition of compensatory mitigation areas, the acreage required for compensatory mitigation would be adjusted accordingly.

A subset of the HGM variables is expected to change over time in response to patterns of forest succession. As a result, they provide mitigation success criteria and monitoring milestones that can be tracked over the 50-year period of analysis (Tables 10 through 21 in the Wetlands Appendix). Visual representations of the variable metric values and variable subindex scores are provided in Figures 10-20. These monitoring milestones provide a quantitative procedure to document the performance of compensatory mitigation sites over time, ensuring that impacts to wetland functions are being recovered and will be used as the performance/success criteria for a migration site.

The HGM functional scores associated with each target year are similarly reported in Table 22 in Wetlands Appendix. A visual representation of the HGM FCI values is presented in Figure 6, providing another way to track and report the functional improvements generated at compensatory mitigation sites. Additionally, the FCUs produced for each wetland function during target year intervals are provided in Figure 7. The monitoring milestones outlined for the variable metric values, subindex scores, FCI values, and AAFCUs provide for a robust quantitative procedure to document the performance of compensatory mitigation sites over time, ensuring that impacts to wetland functions are being offset by functional increase in mitigation areas.

Monitoring Mitigation Restoration Trajectories and Milestones

The HGM approach should be applied as part of the M&AM plan to establish baseline conditions at mitigation locations and document changes in wetland function over time. The method proven effective for identifying shifts in wetland functional capacity over multiple time intervals including short- (e.g., 0 - 5 year), mid- (e.g., 5 - 10 year) and long (e.g., > 20 year) and implementation of a multi-year HGM assessment protocol will document functional capacity changes over the period of analysis (Berkowitz 2018).

A repeated measures approach of data collected using the HGM wetlands assessment within mitigation sites will include data gathered at mitigation sites upon acquisition and at a minimum frequency of five-year intervals during the 0 - 20-year post mitigation period and at 10 year intervals during the 20 - 50 year post mitigation period. This approach ensures that the compensatory mitigation efforts effectively offset impacts to wetland resources and inform adaptive management strategies if the mitigation sites fail to meet the milestones outlined above. The sampling design would follow the conventions outlined in Berkowitz (2018), which included the establishment of transects at each mitigation location and an average sampling rate of approximately one HGM sample plot per 50 acres. At each sampling interval, the HGM variable metrics will be determined in addition to the HGM subindex scores, FCI values and FCUs. In cases where the mitigation areas fail to meet the wetland functional milestones outlined above, adaptive management can be initiated.

Monitoring Changes in Wetland Hydrology in the Yazoo Study Area

In addition to the documentation of HGM functional responses to implementation of the proposed plan and the associated compensatory mitigation, an evaluation of potential changes in wetland hydroperiods will be conducted. The hydrology of wetlands within the study area has been identified as an area of concern, including the potential to decrease the duration or frequency of wetland hydroperiods and periods of flood water inundation. Other portions of this document identify anticipated shifts in flood durations under the proposed plan.

While hydrologic studies have been completed in the region (Berkowitz et al., 2019), additional hydrologic monitoring are needed. Hydrologic monitoring conducted using shallow groundwater wells has proven effective in identifying both hydroperiod and hydropatterns within wetlands in the study area. The goal of water table monitoring is to acquire data related to potential hydrologic changes resulting from operation of the project, provide explanatory data related to observed changes in forested wetland function, and support adaptive operation of the project to improve wetland conditions if required.

The location of monitoring sites would consider multiple factors including: 1) flood duration and frequency, 2) proximity to surface waters and other hydrologic sources, 3) availability of historic or ongoing data collection efforts, 4) site access and continuity considerations, 5) forest successional stage and substrate (i.e., soils), and forested wetland condition (e.g., restored vs mature second growth wetlands).

Although establishment of probabilistic sampling approaches to groundwater monitoring studies are challenging, efforts should be made to incorporate representative and/or statistically derived monitoring location selection where possible. At a minimum of 120 groundwater monitoring wells would be installed throughout the study area and triplicate monitoring locations would be established at each mitigation area. In order to link hydropatterns with measures of wetland function the HGM assessment would be conducted at five-year intervals at the location of all monitoring wells. All well installation and monitoring activities would follow the recommendations of USACE (2005). The estimated period of groundwater monitoring would extend from pre-project conditions through the project implementation, and across multiple periods of project operation.

Adaptive Management for Wetland Compensatory Mitigation

A number of adaptive management strategies exist to address wetland functional gaps identified following implementation of the proposed plan based upon data collected during monitoring activities. These strategies would be initiated if 1) the impacts to wetlands within the impact area are more severe than anticipated or 2) the estimated benefits of mitigation activities fail to achieve the milestones outlined above. The data collection and monitoring activities outlined above provide opportunities to identify the need for remedial action and determine what type of corrective actions are required to address a wetland functional shortfall. For example, if the hydrologic monitoring detects shifts in flood duration or frequency that exceed the estimates described in Table 53 in Wetlands Appendix then the unanticipated decrease in AAFCUs can be determined and addressed through implementation of additional compensatory mitigation. Also, if repeated measures HGM monitoring data demonstrates that the compensatory mitigation areas are not achieving the milestones outlined above adaptive management can conducted. For example, if mitigation locations do not display sufficient microtopography the soil surface can be contoured to create depressions that would retain water, improve habitat, and increase the wetland functional outcomes.

Three options exist to conduct adaptive management to address unanticipated impacts to wetland resources or shortfalls in mitigation performance. First, forested wetland conditions at established mitigation areas can be improved to increase functional capacity, generating additional FCUs and increasing the amount of AAFCUs provided by the mitigation lands over the period of analysis. Second, additional mitigation areas can be acquired and restored, increasing the AAFCUs generated over time. The third potential approach to increasing the performance of mitigation areas involves identifying opportunities to alter the operation of the project to increase wetland functional capacities.

A number of adaptive management techniques are available to improve wetland functions in established compensatory mitigation areas. Mitigation areas offer many opportunities for manipulation prior to seedling installation because most mitigation occurs on agricultural tracts devoid of native vegetation. For example, newly acquired fields can be shaped to increase microtopography and improve surface water storage capacity. Local hydrology can be manipulated to increase connectivity with surface water sources or decrease drainage rates through alteration of existing ditches. At a landscape perspective wetland functional score can be improved by linking forested tracts to increase connectivity with adjacent habitat. Once mitigation areas are established, active management of forest conditions may include re-planting areas subject to poor survival; selective removal or girdling trees to decrease stand density, improving conditions for adjacent tree growth, and provide for recruitment of snags/woody debris into forest stands.

Examples of specific actions that would improve functional outputs include: improved connectivity with sources of wetland hydrology (e.g., resizing culverts, maintenance of natural drainage features) to increase VFREQ and VDUR; expansion of adjacent forested tracts to increase VTRACT, VCORE, and VCONNECT; planting of desirable flood tolerant vegetation species and select species management (e.g., invasive/nuisance species control) to increase VCOMP; manipulation of ground conditions to increase ponding and storage of flood/rain water to increase VPOND, selective thinning to improve conditions for tree growth to increase VTBA, VSNAG, and other variables; and the removal/incorporation of carbon sources into the system to increase VWD, VLOG, VOHOR and other variables. Each of these activities alone would increase the functional status of wetlands. Implemented collectively have the potential to significantly improve functional wetland status within the compensatory mitigation tracts. However, the remedy selected should incorporate components which individually or collectively address the specific shortcomings identified in the HGM and hydrology monitoring phases described above. For example, if the mitigation tracts already display variable subindex score of 1.0 for VCOMP, additional manipulation of species composition will not result in additional increases in FCI values. One major benefit of these ground-level adaptive management strategies is that they increase the generation of FCUs without requiring the acquisition of additional mitigation acres. Also, these activities can be accomplished without altering the operation of the project.

The acquisition of additional mitigation lands may be necessary if sufficient increases in wetland functions cannot be achieved through the active management of existing mitigation areas. Any additional land acquisitions should target the landscape conditions described above and adhere to the monitoring protocols, trajectories, and milestones herein. Mitigation areas are estimated to provide 4.78 AAFCUs per acre over the 50-year period of analysis (Table 23 and 24 in the Wetlands Appendix). As a result, a wetland functional shortfall of -478 AAFCUs would require establishment of 100 acres of additional compensatory mitigation. In some cases, alternative operation of the pump station may have the potential to result in higher levels of wetland function. Considering alternative pump station operation scenarios is complex due to the competing interests of flood risk reduction, water quality management, and natural resource benefits (including wetland functions). However, in some cases changing operational procedures may be applicable to the adaptive management of wetlands. For example, the project may have the capacity to maintain water levels during excessive drought periods to support wetland hydrology without increasing flood risk to infrastructure. Also, there may be benefits to alternating higher and lower water levels to increase the export of organic carbon to downstream environments, remove additional pollutants from surface waters, and improve habitat for floral and faunal communities. Whether remedial activities occur the adaptive management of existing mitigation areas, the acquisition of additional mitigation parcels, or innovative operation of the pump station or other structures, the HGM and hydrology monitoring data provides valuable insight into the effect of any action. This targeted approach provides the best possible scenario under which to implement an adaptive management plan.

Summary

A robust monitoring approach incorporating ground water hydrology and wetland functional assessment is required to conduct effective adaptive management. These approaches will need to be conducted both within the study area and at compensatory mitigation sites. Fortunately, there is substantial published data available to inform establishment of restoration trajectory milestones in support of the adaptive management approach for wetlands described above. This includes specific quantitative milestones for HGM variable inputs and forest wetland functional capacities at various stages of forest succession. Additionally, numerous management strategies exist at both landscape and field scales to increase wetland functional outcomes. The combination of available existing data and strategies for targeted remedial interventions provides an ideal opportunity to implement a M&AM plan.

Figures

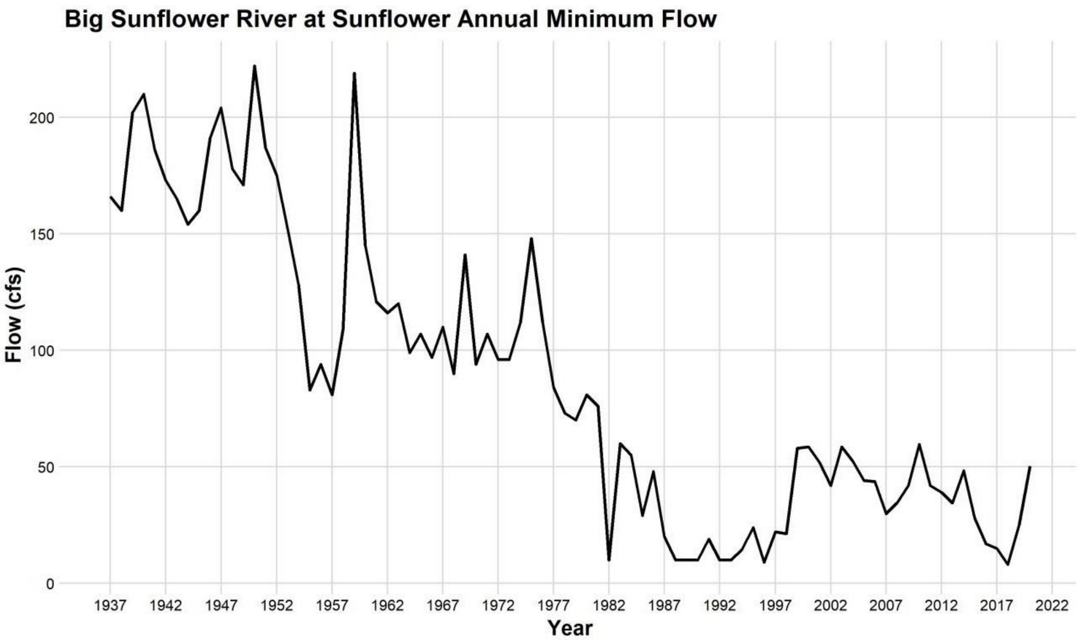

FIGURE 1: ANNUAL MINIMUM FLOW AT THE BIG SUNFLOWER RIVER AT SUNFLOWER FROM 1937 THROUGH 2019

Photo credit: KJ Killgore, ERDC

FIGURE 2: MUSSEL BEDS BELOW THE BIG SUNFLOWER LOCK AND DAM THAT HAVE BEEN DEWATERED DUE TO LOW ENVIRONMENTAL FLOW

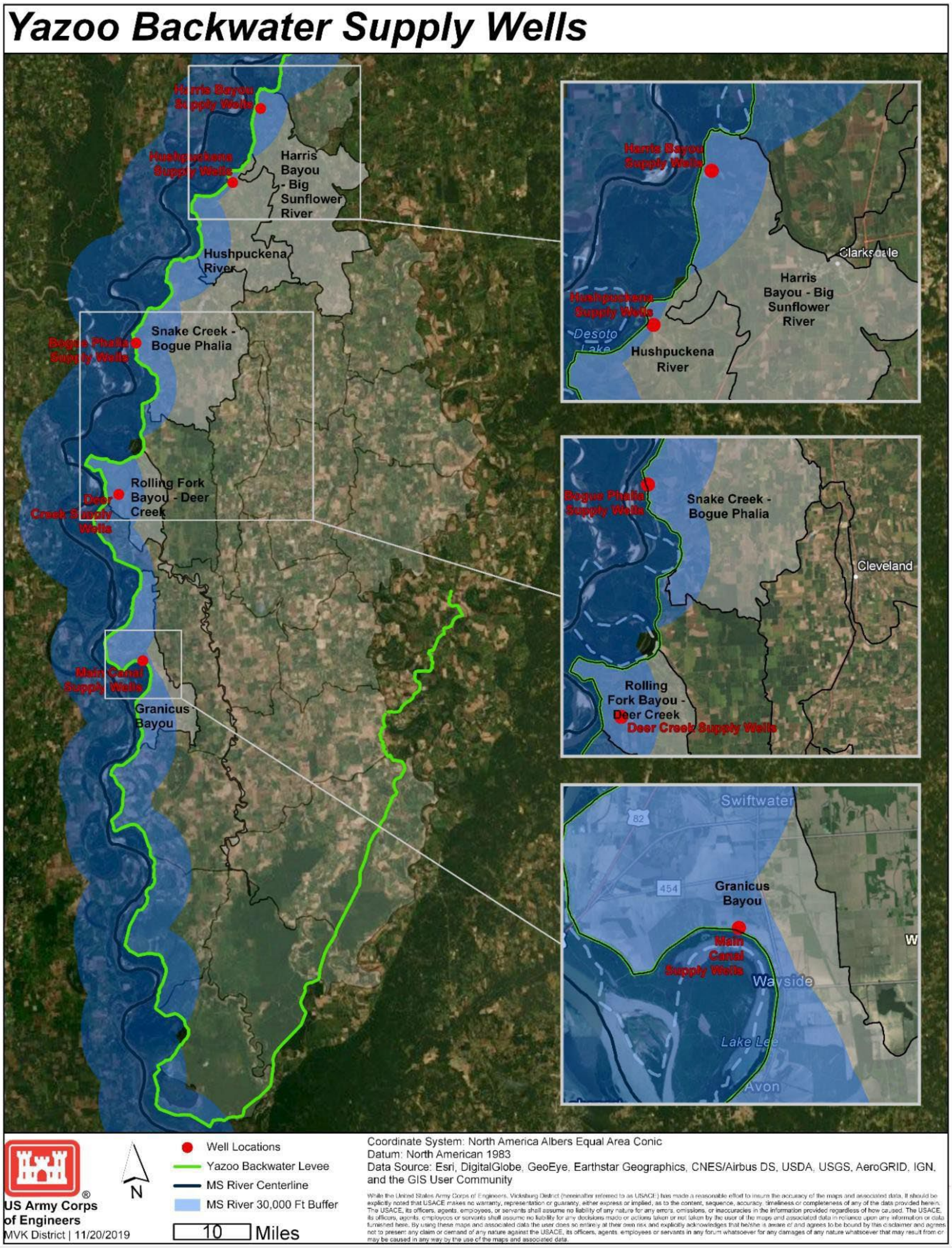

FIGURE 3: FAVORABLE LOCATIONS FOR SLFG WELLS WERE BASED ON CLOSE PROXIMITY TO THE MISSISSIPPI RIVER AND RESIDING ON THE EAST SIDE OF THE YAZOO BACKWATER LEVEE

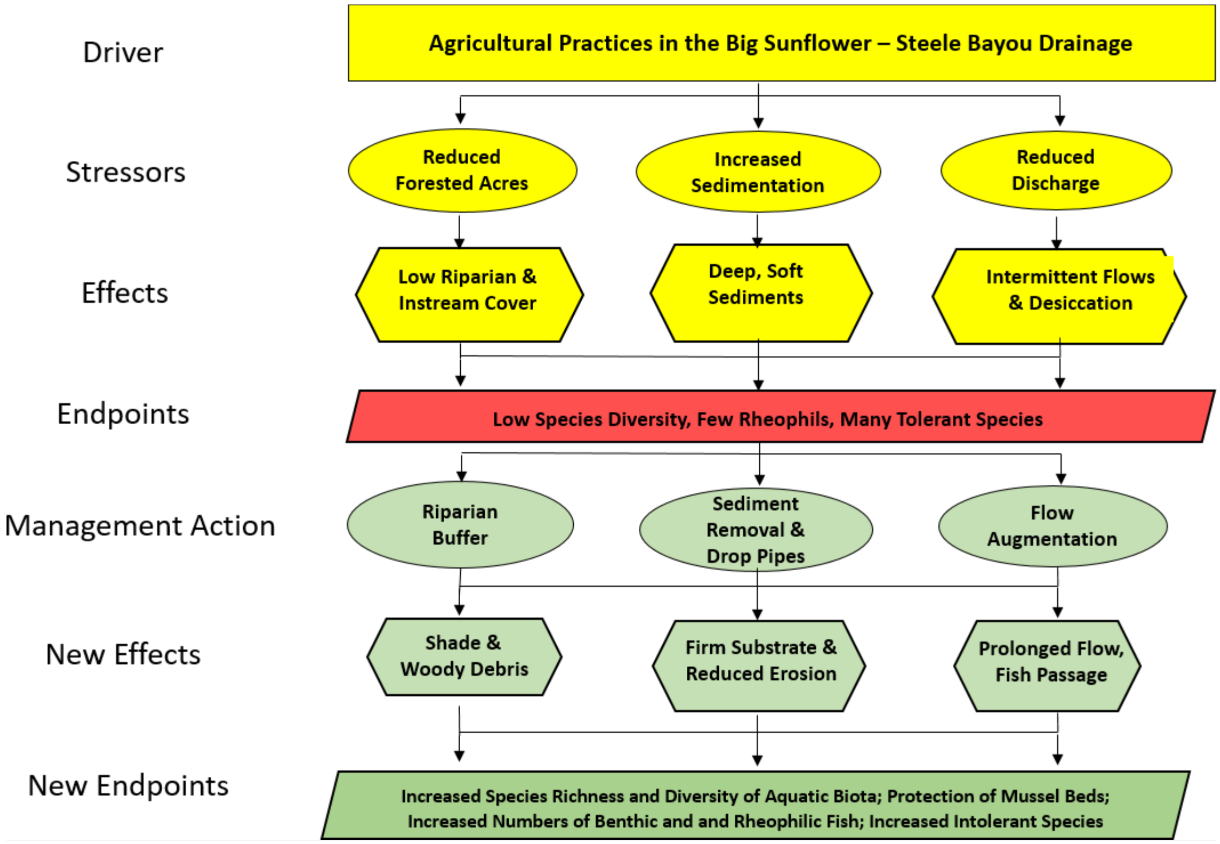

FIGURE 4: A CONCEPTUAL MODEL OF THE EFFECT OF AGRICULTURAL PRACTICES AND FLOOD CONTROL IN THE BIG SUNFLOWER - STEELE BAYOU DRAINAGE ON FISH COMMUNITIES, ALONG WITH MANAGEMENT OPTIONS AND THE ENDPOINTS OF RESTORATION OR MITIGATION ACTIVITIES (ADAPTED FROM HOOVER ET AL. 2008, KILLGORE ET AL. 2008).

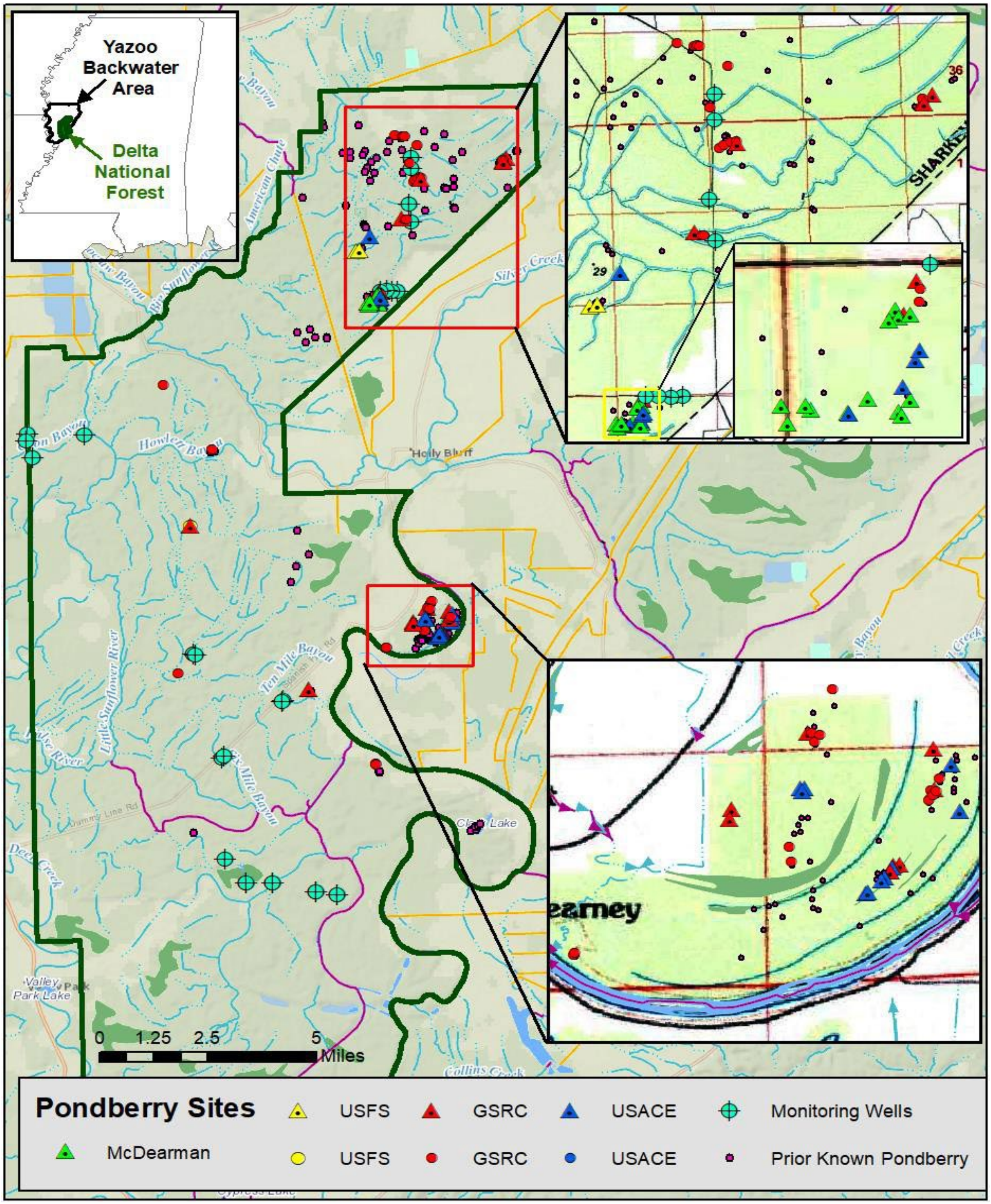

FIGURE 5: LOCATION OF PONDBERRY COLONIES IN RELATION TO EXISTING MONITORING WELLS

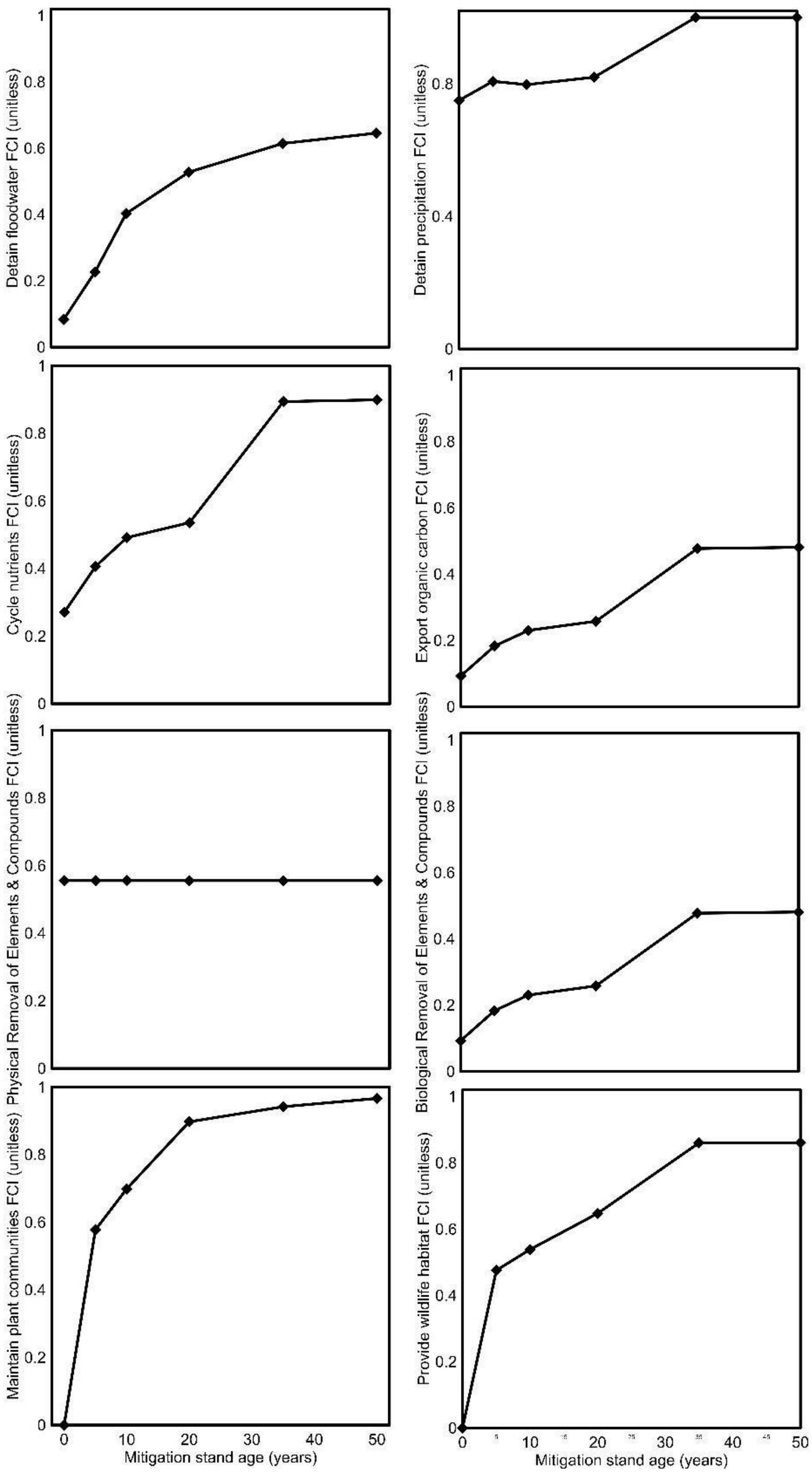

FIGURE 6: COMPENSATORY MITIGATION MILESTONES FOR HGM FUNCTIONS OVER THE PERIOD OF ANALYSIS

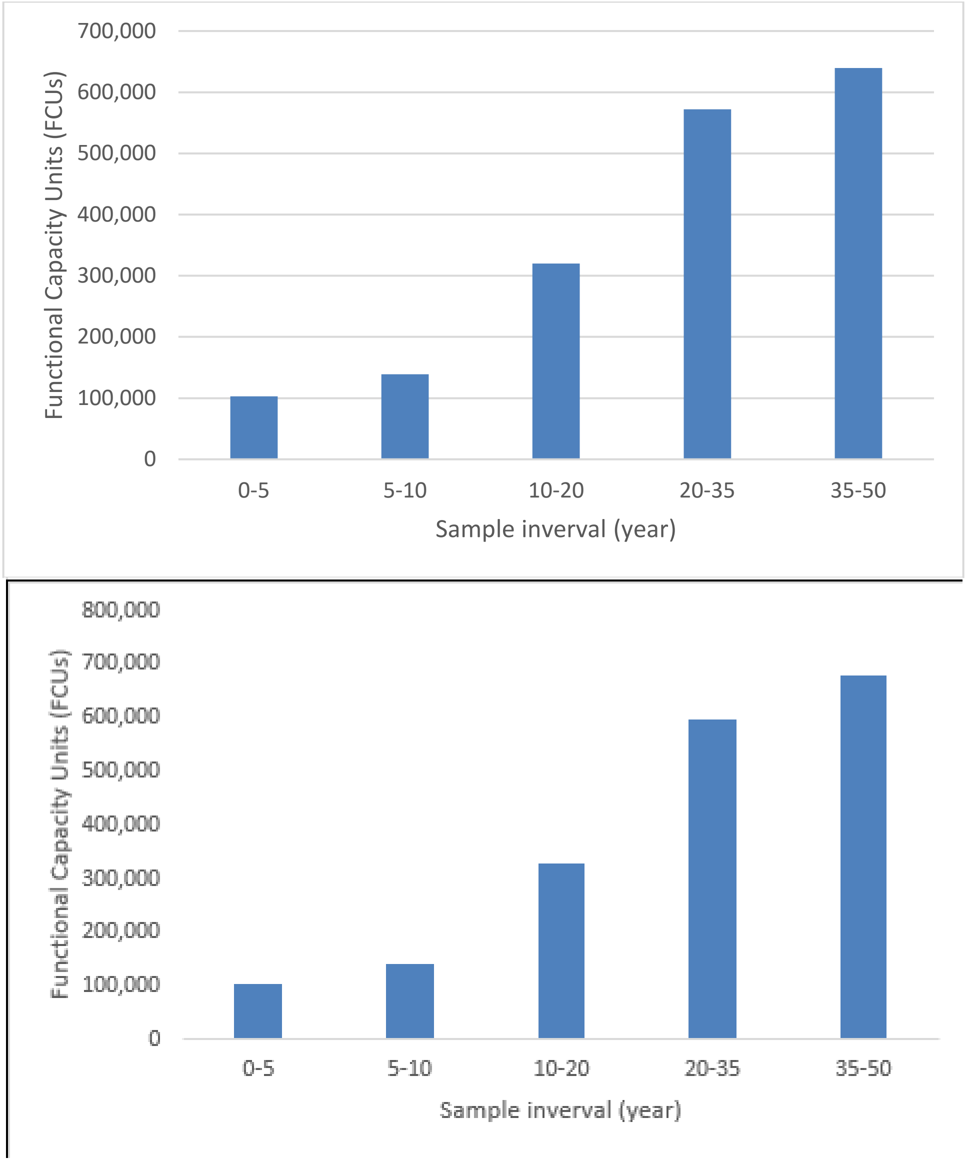

FIGURE 7: COMPENSATORY MITIGATION MILESTONES (FCUS) FOR ALTERNATIVE 1 (TOP PANEL) AND ALTERNATIVE 2 (LOWER PANEL) OVER THE PERIOD OF ANALYSIS

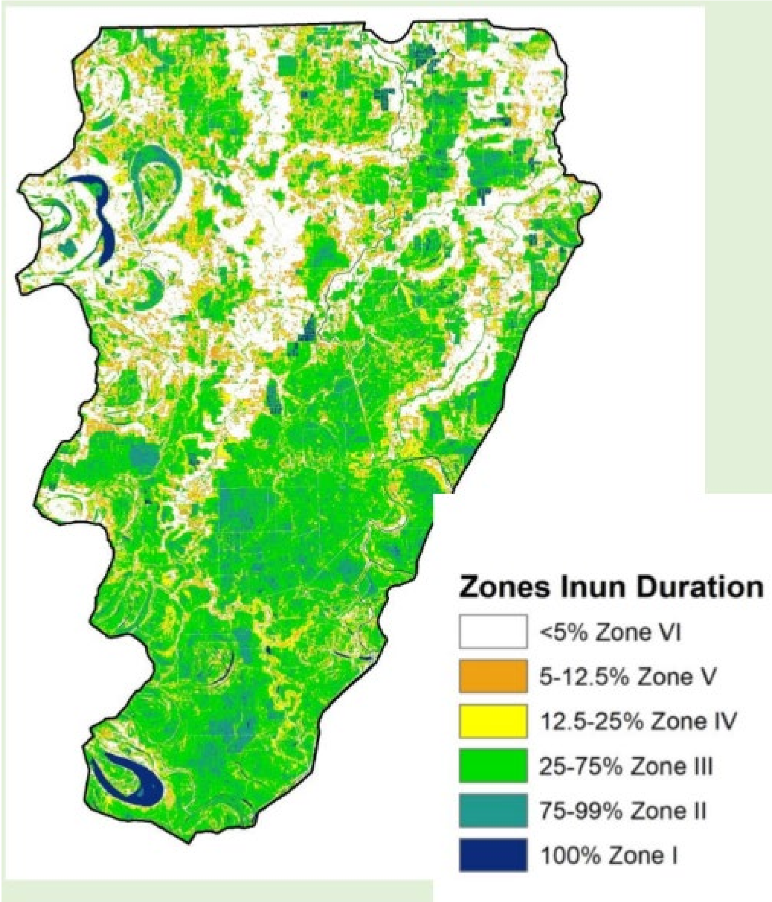

FIGURE 8: ESTIMATED ZONES OF PERCENT INUNDATION DURATION FOR THE YEAR 2018
According to Open and Vegetated Surface Waters Derived from Cumulative Imagery from Sentinel 1

.

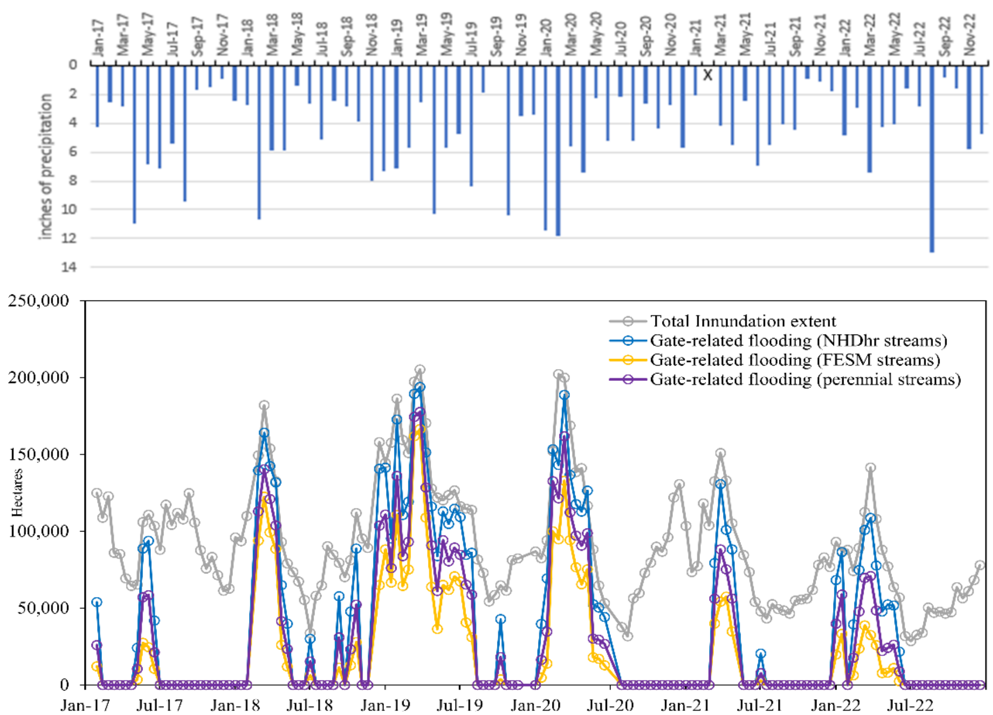

FIGURE 9: TEMPORAL TIME PATTERN OF INUNDATION DURATION FOR THE YEARS 2017-2022 WITH THE GREY LINE REPRESENTING TOTAL INUNDATION (COLORED LINES REPRESENT VARYING AMOUNTS OF INUNDATION CONNECTED TO THE STREAM/RIVER NETWORK)

Tables

TABLE 1: WATERSHEDS WITH INCREASED FLOW DUE TO THE PROPOSED SLFG WELLS AND THEIR EXPECTED INCREASED FLOW IN CFS.

Watershed	*Expected Increased Flow (cfs)*
Harris Bayou – Big Sunflower River	30
Hushpuckena River	20
Snake Creek – Bogue Phalia	20
Rolling Fork Bayou – Deer Creek	10
Granicus Bayou	20

TABLE 2: THE NAMES OF THE PROPOSED SLFG WELLS AND THE WATERSHEDS IN WHICH THEY RESIDE

Supply Well	*Watershed*
Harris Bayou	Harris Bayou – Big Sunflower River
Hushpuckena	Hushpuckena River
Bogue Phalia	Snake Creek – Bogue Phalia
Deer Creek	Rolling Fork Bayou – Deer Creek
Main Canal	Granicus Bayou

TABLE 3: SUGGESTED BIOTIC METRICS FOR YAZOO DELTA STREAMS

Community Characteristic	Metric	Rationale
Taxonomic: Richness, Evenness, Dominance	Rarefaction, Hurlberts Evenness Index, Simpsons Dominance	Spatially complex habitats provide greater numbers of microhabitats and support higher numbers and species of fish.
Trophic composition	Proportion of individuals within functional feeding guilds (e.g., omnivores, invertivores, piscivores)	Trophically complex food webs provide diverse forage and promotes a diverse fish assemblage.
Tolerance	Number of “intolerant” species	Benign water quality and availability of physical cover allow “sensitive” species to co-exist with ubiquitous, tolerant species.
Abundance	Catch-per-unit-effort (CPUE)	Consistent recruitment results in high standing crops (numbers, and biomass).
Affinity for flowing water	Proportion of rheophilic individuals	Flowing water is required by certain fishes for successful reproduction and feeding.

TABLE 4: STREAM MORPHOLOGICAL MEASURES AND METRICS

Reach Classification	Cross-Sectional Geometry
Station ID	Channelfull Dimensions
Coordinates	Width
Field Personnel	Maximum Depth
Drainage Area	Average Depth
Date	Cross-Sectional Area
Stream Class	Bankfull Dimensions
Channel Evolutionary Stage	Width
General Land Use/Cover	Maximum Depth
Planform	Average Depth
Meander Wave Length	Width/Depth Ratio
Radius of Curvature	Cross-Sectional Area
Amplitude	Wetted Perimeter
Valley Length	Hadraulic Radius
Sinuosity	Flood-Prone Area Width
Longitudinal Profile	Entrenchment Ratio
Channel Slope (per bedform)	**Flow**
Water Slope (per bedform)	Tapedown
Bedforms	Mean Velocity
Run	Discharge
Pool	**Channel Bed Material (per bedform)**
Glide	Particle Size Distribution
Riffle	Estimated Organic Matter
Channel Stability	Turbidity
Stream Condition Index (SC)	
Bank Erosion Hazard Index (BEHI)	

TABLE 5: MEASUREMENT TYPES AND FREQUENCY PER ENVIRONMENTAL FACTORS IDENTIFIED ABOVE (FACTOR NUMBERS CORRESPOND TO TEXT ABOVE)

Factor	Metric/Method	Frequency
1. Hydroperiod	Phreatic water surface, Groundwater Wells	Autonomous Wells and Stage Recorders
a. Connectivity	Hydrologic Indicators	Seasonal
b. Depth to Water Table	Systematic Observations Around Wells	Seasonal
2. Light Availability	Forest Canopy Cover; Densiometer	Seasonal
3. Soils	Hydric Indicators; Classification,	Annual
4. Competition	Understory Plant Species and Structure	Annual
5. Forested Buffer	GIS Tools, Aerial Photos & Field Recon.	Every 2 years
6a. Predation, Disease	Pondberry Vigor, Stem Dieback, Infection	Seasonal
6b. Herbivory and Hog Disturbance	Soil disturbance and leaf herbivory; Enclosures and trail cameras	Seasonal

TABLE 6: PERFORMANCE STANDARDS AND ASSOCIATED MEASURES AND METHODS

No.	Performance Standard	Measure	Methods
1	Increase minimum flow in Big Sunflower to 90% exceedance (discharge from 34 SLFG wells). Maintain eflows.	Historic and contemporary gage records during pre- and post-project; Establish additional gage stations, as needed.	Engineering Report and this Appendix, Section 2.0.
2	Avoid desiccation of mussel beds by increasing wetted surface area in Big Sunflower stream channel.	Measure wetted surface area during pre- and post-project conditions.	Aquatic Resources Appendix and this Appendix Section 3.5.1.
3	Maintain sediment transport and bedform habitat quality and diversity for aquatic fauna.	Measure sediment yield and bedform diversity pre- and post-project.	Aquatic Resources Appendix and this Appendix Sections 3.5.2 and 4.5.3.
4	Increase average dissolved oxygen and reduce extent of hypoxia relative to baseline and reference stream reaches.	Establish baseline oxygen dynamics conditions in the Big Sunflower and reference conditions in similar streams within the Lower Mississippi River Alluvial Plain (e.g., Cache, Middle White, and Big Black Rivers).	Water Quality Appendix and this Appendix Section 4.5.
5	Improve the hydrogeomorphology and channel stability in the receiving tributaries from the SLFG well discharge.	Measure the changes in channel cross-sectional and longitudinal geometry pre- and post-project.	This Appendix Section 4.5.4.
6	*In-situ* water quality parameters relative to baseline and reference stream reaches.	Water temperature, specific conductivity, pH, alkalinity, hardness, light transparency, and nutrients within range of reference conditions.	Water Quality Appendix and this Appendix Section 4.5.5.
7	Maintain condition and extent of pondberry colonies.	Measure growth, vigor and spatial distribution pre- and post-project (See Section X).	Threatened and Endangered Species and Migratory Birds Appendix and this Appendix Section 4.5.6.
8	Restoration of wetland functions.	Application of the HGM functional assessment approach.	This Appendix, Section 7.0
9	Maintain environmental gradients between lotic and lentic ecosystems (floodplain reforestation and connectivity).	Tree density, speciation, sustainability, soil conditions, and hydroperiod.	This Appendix, Section 7.0.

TABLE 7: EXAMPLE OF PERFORMANCE METRICS FOR FISHES IN THE LOWER MISSISSIPPI RIVER BASIN INCLUDING THE BIG SUNFLOWER RIVER AND REFERENCE SITES

Metric	Big Sunflower n=120	Big Sunflower Gravel Bars n=7	Cypress Bayou n=26	Red n=10	White n=13
Species Richness - Rarefaction	12.2 (3.1)[a] 4-20	13.2 (3.2)[b] 9-17	14.8 (4.0)[b] 10-27	18.5 (2.7)[b] 6-19	17.7 (6.1)[b] 9-26
Percent Minnows	0.33 (0.29)[a] 0-0.95	0.8 (0.21)[b] 0.35-0.95	0.32 (0.23)[a] 0-0.76	0.85 (0.14)[b] 0.5-0.98	0.71 (0.29)[b] 0.06-0.99
Percent *Lepomis*	0.23 (0.24)[a] 0-0.89	0.01 (0.01)[b] 0-0.02	0.19 (0.16)[a] 0.02-0.51	0.01 (0.02)[b] 0-0.05	0.02 (0.05)[b] 0-0.15
Percent *Micropterus*	0[a] 0-0.01	0[a] 0	0.03 (0.02)[b] 0-0.09	0 (0.01)[b] 0-0.04	0.01 (0.01)[b] 0-0.05
Percent Darters	0 (0.01)[a] 0-0.06	0 (0)[a]	0.06 (0.05)[b] 0-0.24	0 (0)[a]	0.06 (0.09)[b] 0-0.32
Percent Orange Spotted Sunfish	0.11 (0.15)[a] 0-0.8	0 (0)[b] 0-0.01	0 (0)[b]	0 (0.01)[b] 0-0.03	0 (0)[b] 0-0.01
Percent Habitat Intolerant	0.01 (0.06)[a] 0-0.65	0.22 (0.09)[b] 0.1-0.36	0.17 (0.17)[b] 0-0.58	0.10 (0.08)[c] 0-0.28	0.2 (0.15)[b] 0-0.49
Percent Water Quality Intolerant	0 (0)[a]	0 (0)[a]	0.04 (0.08)[b] 0-0.26	0.09 (0.08)[c] 0-0.28	0.05 (0.06)[b] 0-0.24
Percent Rheophilic	0.35 (0.27)[a] 0-0.95	0.65 (0.2)[b] 0.32-0.93	0.44 (0.17)[a] 0.11-0.86	0.66 (0.21)[b] 0.38-0.91	0.57 (0.22)[b] 0.07-0.83

Un-transformed mean (standard deviation), minimum-maximum, values of biotic metrics by drainage basin. Fish were collected with seines at multiple sites per drainage basin. Collections occurred periodically between 1990 and 2014. Mean metric values with different superscript letters along the row are significantly different ($P < 0.05$) among drainage basins according to the Student–Newman–Keuls multiple range test. Data was transformed (Log_{10} for richness, Arcsine for percent values) prior to ANOVA.

SECTION 7

REFERENCES

Barbour, M.T., Gerritsen, J., Snyder, B.D., and Stribling, J.B. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates, and fish. Second edition. US Environmental Protection Agency 841-B-99-002.

Battle, J. and S. Golladay. 2001. Hydroperiod influence on breakdown of leaf litter in cypress-gum wetlands. The American Midland Naturalist. 146(1):128–145.

Bêche L.A., P.G. Connors, V.H. Resh, and A.M. Merenlender. 2009. Resilience of fishes and invertebrates to prolonged drought in two California streams. Ecography 32: 778–788, 2009. DOI: 10.1111 /j.1600-0587.2009.05612.x.

Benke, A. C., and J. B. Wallace. 2003. Influence of wood on invertebrate communities in streams and rivers. Pages 149-177 in S. V. Gregory, K. L. Boyer, and A. A. Gurnell, editors. The Ecology and Management of Wood in World Rivers. American Fisheries Society, Symposium 37, Bethesda, Maryland.

Berkowitz, J.F., 2018. Quantifying functional increases across a large-scale wetland restoration Chronosequence. Wetlands, 39(3), pp.559-573.

Berkowitz, J.F., D.R. Johnson, and J.J Price. 2019. Forested Wetland Hydrology in a Large Mississippi River Tributary System. Wetlands. doi:10.1007/s13157-019-01249-5.

Berkowitz, J.F., Johnson, D.R, Price J.J. 2020. Forested wetland hydrology in a large Mississippi River tributary system. Wetlands. 40, 1133-1148.

Biedenharn, D.S., K.J. Killgore, C.D. Little, Jr., C.E. Murphy, and B.A. Kleiss. 2018. Attributes of the Lower Mississippi River batture. USACE, ERDC, MRG&P Technical Note No. 4.

Cavalcanti, G.G. and B.G. Lockaby. 2006. Effects of sediment deposition on aboveground net primary productivity, vegetation composition, and structure in riparian forests. Wetlands. 26:400–409.

Conner, W.H. and J.W. Day Jr. 1976. Productivity and composition of a baldcypress-water tupelo site and a bottomland hardwood site in a Louisiana swamp. American Journal of Botany. 63:1354–1364.

Davidson, E.A., R.L. Nifong, R.B. Ferguson, C. Palm, and D.L. Osmond. 2016. Nutrients in the nexus. Journal of Environmental Studies and Sciences 6: 25–38.

Delaune, R.D., R.S. Boar, C.W. Lindau, and B.A. Kleiss. 1993. Denitrification in bottomland hardwood soils of the Cache River, Arkansas. Wetlands. 16(3):309–320.

Dembkowski, D. J., and L. E. Miranda. 2012. Hierarchy in factors affecting fish biodiversity in floodplain lakes of the Mississippi Alluvial Valley. Environmental Biology of Fishes 93:357-368.

Emery, W.J. & Thomson R.E. 2001. Data analysis methods in physical oceanography. Gulf Professional Publishing. p. 83. ISBN 978-0-444-50757-0.

Faulkner, S.P., W.H. Patrick, Jr., and R.P. Gambrell. 1989. Field techniques for measuring wetland soil parameters. Soil Sci. Soc. Am. J. 53:883-890.

Giese, L.A.B., W.M. Aust, R.K. Kolka, and C.C. Trettin. 2003. Biomass and carbon pools of disturbed riparian forests. Forest Ecology and Management 180: 493–508.

Haag, W.R. and M.L. Warren, Jr. 1998. Freshwater mussels of the Delta National Forest, Mississippi. Final report submitted to the National Forests in Mississippi and FS/BLM National Aquatic Monitoring Center.

Hurst, N., J. R. White, and J. Baustian. 2016. Nitrate reduction in a hydrologically restored bottomland hardwood forest in the Mississippi River watershed, Northern Louisiana. Soil Science Society of America Journal. 80:1698–1705.

Jones, R. L., W. T. Slack, and P. D. Hartfield. 2005. The freshwater mussels (Mollusca: Bivalvia: Unionidae) of Mississippi. Southwester Naturalist 4(1):77-92.

Killgore KJ, Hoover JJ, Miranda LE, Slack WT, Johnson DR and Douglas NH. 2024. Fish conservation in streams of the agrarian Mississippi Alluvial Valley: conceptual model, management actions, and field verification. Front. Freshw. Sci. 2:1365691. doi: 10.3389/ffwsc.2024.1365691

Killgore, K.J., B. Bruchman, R. Hunt, L. Yu Lin, J.J. Hoover, Don Johnson, Dave Johnson, G. Young, K. Parrish, R. Goldman, and A. Casper. 2012. EnviroFish, Version 1.0: User's Manual. ERDC/EL TR-12-19, Vicksburg, MS: Engineer Research and Development Center.

Killgore, K. J., Hoover, J. J., Murphy, C. E., Parrish, K. D., Johnson, D. R., and Myers, K. F. 2008. Restoration of Delta Streams: A Case History and Conceptual Model, EMRRP-ER-08, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Killgore, K.J. 1994. Design and application of a larval fish trap. American Currents, Vol. 29. No. 1.

Merritt, R.W., Cummins, K.W., Berg, M.B. 2019. Aquatic Insects of North America. Kendall Hunt Publishing, New York.

National Action Plan. 2011. Priorities for managing freshwater resources in a changing climate, Interagency Climate Change Adaptation Task Force, October 2011.

Palmer, M.A., E.S. Bernhardt, J.D. Allan, P.S. Lake, G. Alexander, S. Brooks, J. Carr, S. Clayton, C.N. Dahm, Shah.J. Follstad, D.L. Galat, S.G. Loss, P. Goodwin, D.D. Hart, B. Hassett,
R. Jenkinson, G.M. Kondolf, R. Lave, J.L. Meyer, T.K. O'Donnel, L. Pagano, and E. Sudduth. 2005. Standards for ecologically successful river restoration. Journal of Applied Ecology 42: 208–217. DOI: 10.1111/j.1365-2664.2005.01004.x

Price, J.J. and Berkowitz, J.F., 2020. Wetland Functional Responses to Prolonged Inundation in the Active Mississippi River Floodplain. Wetlands, pp.1-8.

Pruitt, B.A. 2009. Sediment depth profile using subbottom profiling (SBP), near Panama City, Florida. Open file report.

Pruitt, B.A. and A.W. Katzenmeyer. 2020. Report to Fort Gordon DPW-DNR. Sediment mapping for sediment TMDL study, Gordon Lake using an autonomous underwater vehicle (AUV), Fort Gordon, Georgia.

Raymond, P.A., N.H. Oh, R. E. Turner, and W. Broussard. 2008. Anthropogenically enhanced fluxes of water and carbon from the Mississippi River. Nature 451:449-452.

Raymond, P., M.B. David, and J.E. Saiers. 2012. The impact of fertilization and hydrology on nitrate fluxes from Mississippi watersheds. Current Opinion in Environmental Sustainability 4:212-218.

Rosgen, D.L. 1994. A classification of natural rivers. Catena 22 (1994), pp. 169-199.

Schumm, S.A., M.D. Harvey, and C.C. Watson. 1984. Incised channels: morphology, dynamics and control. Water Resources Publications, Littleton, Colorado.

Shields, F. Douglas, Jr. and Scott S. Knight, 2011. Significance of Riverine Hypoxia for Fish: The Case of the Big Sunflower River, Mississippi. Journal of the American Water Resources Association (JAWRA) 48(1): 170–186. DOI: 10.1111/j.1752-1688.2011.00606.x

Smith, R. D. and C.V. Klimas, C. V. 2002. "A regional guidebook for applying the hydrogeomorphic approach to assessing wetland functions of selected regional wetland subclasses, Yazoo Basin, Lower Mississippi River Alluvial Valley," ERDC/EL TR-02-4, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Smith, R.D. and J. Lin. 2007. Yazoo Backwater Project: Assessing Impacts to Wetland Functions and Recovery of Wetland Functions in Restoration Areas. U.S. Army Engineer Research and Development Center, Waterways Experiment Station, Environmental Laboratory, Vicksburg, MS. Report to the U.S. Army Corps of Engineers - Vicksburg District.

Strayer, D.L. and D.R. Smith. 2003. A Guide to Sampling Freshwater Mussel Populations. American Fisheries Society, Monograph 8, Bethesda, Maryland. 103 p.

Taylor, J.M., R.E. Lizotte Jr. and S. Testa III. 2018. Breakdown rates and associated nutrient cycling vary between novel crop-derived and natural riparian detritus in aquatic agroecosystems. Hydrobiologia 827:211–224.

Theriot, J.M, J.L. Conkle, S.R. Pezeshki, R.D. Delaune, and J.R. White. 2013. Will hydrologic restoration of Mississippi River riparian wetlands improve their critical biogeochemical functions? Ecological Engineering. 60:192–198.

U.S. Army Corps of Engineers (USACE). 2005. Technical standard for water-table monitoring of potential wetland sites. ERDC TNWRAP- 05-02. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

USACE (United States Army Corps of Engineers). 2019. RiverGages.com. Accessed: Oct. 2019.

USACE, CECW-PD. 2009. Implementation guidance for Section 2039 of the Water Resources Development Act of 2007 (WRDA 2007) – monitoring ecosystem restoration.

USACE, CECW-P. 2000. Planning guidance notebook. Engineer Regulation 1105-2-100.

Vanderhoof, M.K., Alexander, L., Christensen, J., Solvik, K., Nieuwlandt, P., Sagehorn, M. 2023. High-frequency time series comparison of Sentinel-1 and Sentinel-2 for open and vegetated water across the United States (2017-2021). Remote Sensing of Environment. 288, 113498, https://doi.org/10.1016/j.rse.2023.113498.

Vanderhoof, M. K., Christensen, J. R., Alexander, L. C., Lane, C. R., & Golden, H. E. (2024). Climate change will impact surface water extents and dynamics across the central United States. Earth's Future, 12(2), e2023EF004106. https://doi.org/10.1029/2023EF004106

Wang, L., J. Lyons, P. Kanehl and R. Gatti. 1997. Influences of watershed land use on habitat quality and biotic integrity in Wisconsin streams. Fisheries 22:6-12.

Williams, J. D., A.E. Bogan, R.S. Butler, K.S. Cummings, J.T. Garner, J.L. Harris, N.A. Johnson and G.T. Watters. 2017. A revised list of the freshwater mussels (Mollusca: Bivalvia: Unionida) of the United States and Canada. Freshwater Mollusk Biology and Conservation 20(2):33-58.

Williamson, S., J. W. Crews, S. Allison, and R. Pearce. 2019. U.S. Forest Service, National Forests in Mississippi, Delta National Forest Post-Flood Observations. PowerPoint file, September 2019.

Wood, P. J. and P. D. Armitage. 1997. Biological effects of fine sediment in the lotic environment. Environmental Management 21 (2):203-217.

LIST OF ACRONYMS AND ABBREVIATIONS

Term	Definition
Term	Definition