APPENDIX K: MONITORING AND ADAPTIVE MANAGEMENT

DRAFT YAZOO BACKWATER MONITORING AND ADAPTIVE MANAGEMENT PLAN

1.0 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 2.0), oxygen dynamics and environmental flows (Section 3.0), water quality (Section 4.0), adaptive management (Section 5.0), basin-wide assessment (Section 6.0) and wetlands (Section 7.0). 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.

Basis of Monitoring and Adaptive Management (M&AM): For restoration 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).

The 2007 Final Supplement No. 1 to the 1982 Yazoo Area Pump Project Final Environmental Impact Statement (2007 FSEIS) and the Yazoo Backwater Area Reformulation Main Report, dated October 2007 (2007 Main Report) predated the requirement of developing a M&AM plan. Adaptive management is a decision process that promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood (NRC 2004). Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process. The active form of adaptive management employs management actions in an experimental design aimed primarily at learning to reduce uncertainty and improve near-term benefits to the resource. The true measure of adaptive management, and its value to the USACE, is in how well it helps meet environmental, social, and economic goals; increases scientific knowledge; and reduces tensions among stakeholders.

Application to the Yazoo Area Pump Project: In light of uncertainty related to the effects of pumping surface water within the YSA "flexible decision making" process is required where operational adjustments and management can be explored and tested. We recognize the importance of natural variability to ecological resilience and productivity in the YSA area. Adaptive management is not a "trial and error" process, but rather emphasizes "learning while doing." By developing an M&AM plan, we can more effectively make operational decisions and enhance socio-economic and ecological benefits. In addition, based on the results and interim conclusions made during the prescribed monitoring process, adjustments can be made in the monitoring plan ("adaptive monitoring") to improve sampling efficacy and target key physiochemical and biological indicators.

In reference to the Yazoo Area Pump 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 Area Pump 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.

2.0 GROUNDWATER SUPPLY WELLS

2.1 PURPOSE

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.

2.2 OVERVIEW

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 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. 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 2 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. 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 Yazoo Basin are being dewatered and exposed as seen below the Big Sunflower old Lock and Dam (Figure 3). Mussels are widespread and 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.

2.3 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 the Yazoo Basin to their historical observed low flow state of the twentieth century (Figures 1A and 1B). The supplemental low flow groundwater wells will ideally contribute an increase of 0.1 to 0.3 cfs per square mile for each watershed in the Steele Bayou, Deer Creek, and Big Sunflower Basins, which are adjacent to the Mississippi River. This increase in flow per square mile will provide enough water to keep the mussel beds inundated and will lead to an increase in total flow for each watershed (Table 1).

2.4 BENEFITS

Stream morphology responses to improvements in flow and sediment regimes (discharge, seasonality, and variability), channel boundary characteristics (bed sediments, bank materials and vegetation), and water quality (temperature, turbidity, nutrients, and pollutants) to produce, maintain and renew habitat at a range of spatial and temporal scales. Increase in flow from supplemental low flow groundwater wells should result in several environmental benefits and ecosystem outcomes (i.e., ecological lift) including:

Hydroecologic:

1. Baseflow augmentation critical for establishing environmental flows especially during periods of drought. See Aquatic Resources Appendix.
2. Increase in advection and subsequent reduction in contact time between the water column and sediments thus reducing the net oxygen demand exerted on the water column.
3. Increase in wetted surface, aquatic habitat and "living space" for mussels, fishes and other aquatic invertebrates including species of special concern in the basin.

Hydrogeomorphic:

4. Increase in geomorphic processes in cross section maintaining sediment deposition on surfaces and benches above the low flow channel.
5. Increase, generally, in channel width, depth and the width/depth ratio, and increase in meander wave length.
6. Improved planform pattern by formation of a sinuous stream channel ("C" channel, Rosgen 1994) within the trapezoidal channel ("F" channel); increase in amplitude and decrease in radius-of-curvature.
7. Formation of a more stable stage of channel evolution from a widening type 3 to a type 4 channel (Schumm et al. 1984) with stabilized point and side bars.
8. Increase in helicoidal processes thus increasing point bar formation and subsequent bedform diversity.
9. Increase in bedform maintenance and diversity in longitudinal profile such as percent riffle/pool complexes.

Baseflow augmentation is essential to maintain the low flow channel (thalweg), oxygen dynamics, bedform, and habitat diversity, as well as insect drift and fish migration (Bêche et al. 2009). The potential for a stream to support resilient and diverse ecosystems generally increases with its morphological diversity or increase in bedforms (Palmer et al. 2005). The additional discharge will convert the stream channel from a single bedform type to multiple bedforms. Other stream functions will be enhanced including: water storage and delayed release, biogeochemical processing and water quality enhancement, carbon export and food chain support, amphibian habitat, amphibian feeding, as well as breeding and refugia for aquatic organisms during high water events and other unfavorable in-stream conditions. Cross sectional sediment processes (e.g., helicoidal) will deposit sediment on point and side bars.

2.5 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 4). 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 4 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.

3.0 OXYGEN DYNAMICS AND ENVIRONMENTAL FLOWS

3.0 PURPOSE

The following describes the M&AM plan to enhance oxygen dynamics and improve environmental flows to sustain and enhance aquatic biology. It includes a brief historic background on the effects of hypoxia, an objective, and an approach.

3.1 OVERVIEW

Cost-effective remediation of hypoxia in the Big Sunflower river drainage will require better understanding of autotrophic and heterotrophic processes that control dissolved oxygen and the relationship of these processes to discharge (Shields and Knight 2011). Reforestation of the 2-year floodplain is the primary mitigation method to compensate for impacts of the project. However, based on previous studies (see Aquatic Resources Appendix), the majority of the YSA becomes hypoxic suggesting that reforested areas may have limited benefits to spawning and rearing fishes. When respiration exceeds production (photosynthesis), hypoxic conditions can occur (Figure 5); the depth at which hypoxia occurs can vary depending on light transparency (euphotic zone), rate of decomposition of labile organic carbon (community metabolism), nutrient and oxygen dynamics, and advection (inflow and outflow). Hypoxia refers to oxygen depletion below species-specific thresholds required to support the sustainability of aquatic life; herein hypoxia is also used to refer to the complete depletion of oxygen (i.e., anoxia, anaerobic conditions).

Wetland areas within the Lower Mississippi River Basin display high rates of primary productivity, even in early successional stages (Conner and Day 1976, Giese et al. 2003) contributing insitu water quality benefits such as higher rates of carbon accumulation and nutrient processing (e.g., denitrification, nutrient uptake) when compared to non-wetland ecosystems. These wetland functions highlight the water quality benefits (e.g., reduced nitrate export, reduced turbidity) of establishing and maintaining forested features on the landscape (DeLaune et al 1993, Cavalcanti et al. 2006, Theriot et al. 2013, Hurst et al. 2016). The benefit of exporting organic carbon from wetlands to downstream environments has also been recognized, particularly as a source of energy for the microbes at the base of the detrital food webs (Smith and Klimas 2002). Furthermore, exported organic carbon can promote instream nutrient processing including denitrification; however, carbon exports can also contribute to water quality problems including hypoxia as organic matter provides the substrate supporting depletion of oxygen from the water column.

Both forested and agricultural areas in the YSA produce biomass and nutrients that are available for downstream export, although form and timing of delivery of those materials may differ (Raymond et al. 2008, 2012). For example, agricultural areas introduce fertilizers to increase crop yields and remove a significant portion of the biomass produced during harvest on an annual basis. The remaining unsequestered organic matter and nutrients are more labile than materials generated in forests (Taylor et al. 2018) and can be readily transported and consumed in aquatic environments, resulting in oxygen consumption (Davidson et al. 2016). Notably, a much larger portion of the 2-year floodplain within the YSA is occupied by forests and woody areas (approximately 154,000 acres) than agricultural areas (approximately 45,000 acres). These forested areas also hold a larger amount of organic matter in the litter and soil than agricultural areas. The combination of a larger spatial extent and carbon pool provide increased opportunities for organic matter leaching and export from forests during periods of surface inundation compared with agricultural areas (Battle and Golladay 2001). On both land types, the long flood inundation periods induced by the operation of water control structures preventing drainage provides opportunities to further promote organic matter leaching and export to surface waters from agricultural and forested areas. As a result, the cause of hypoxia in the YSA cannot be attributed to a single land cover type or management activity. Instead the prevalence of hypoxia reflects a combination of factors related to carbon sources, fate and transport; watershed scale hydrology and hydrologic manipulation; and other biotic and abiotic factors. In response, multiple approaches to improve water quality are included in the M&AM plan, especially with regards to increasing the quality of fish and macroinvertebrate habitat.

Adult fishes spawning during a flooding event must cope with the physiological stress of low dissolved oxygen, and once eggs hatch, larval fishes moving into deeper water encounter hypoxic conditions that likely leads to higher mortality. Therefore, reforestation may not be an ideal mitigation measure to improve aquatic life. Even though it is generally accepted that hypoxic conditions occur at dissolved oxygen concentrations below 3 mg/L, based on observations in the YSA, even slight increases in dissolved oxygen (> 2.0 mg/L) could lead to higher survival of many species after the flood recedes.

3.2 OBJECTIVE

The objective is to provide recommendations on alternative methods of mitigation other than reforestation. Consequently, this M&AM plan will evaluate alternatives that reduce the magnitude and duration of hypoxia during flood events within the YSA.

The supplemental low flow groundwater wells, discussed above, will operate during historic low flow periods to increase the flows to maintain benthic macroinvertebrates including mussel beds and increase the environmental flow and dissolved oxygen levels of the YSA. The positive cumulative effects of baseflow augmentation from the SLFG wells, increased advection, reduced water diversions, and reduced agricultural use of surface water will maintain minimum environmental flows and increase dissolved oxygen (Figure 6).

3.3 APPROACH

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 mitigation 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 mitigation measures.

3.4 DISCUSSION

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 7). 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.

3.4.1 Water Level Management

The first management action addressed herein is flow augmentation, or creation of environmental flows, which from either storage reservoirs, pumping from re-charged aquifers, or interbasin transfer act as alternative water level management considerations. 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% exceedence) 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.

4.0 WATER QUALITY

4.1 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.

4.2 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.

4.3 APPROACH

Overview: The following M&AM plan begins by introducing a series of monitoring parameters that can be applied to document ecological conditions within the YSA. These monitoring parameters have been utilized to assess water quality and aquatic habitat in a number of published studies. The monitoring parameters described herein were selected for their capacity to guide the adaptive management objectives described above. A brief description of each monitoring parameter is provided, followed by an example of how the data generated by each parameter relates to the stated management objective.

Following the description of monitoring parameters, the specific objectives of adaptive management are discussed including 1) establishing environmental flows, 2) decreasing the frequency and/or magnitude of low dissolved oxygen conditions, and 3) improve sediment and bedform conditions. Each management objective is described by defining the problem, introducing approaches to address the problem, discussing potential operational applications to achieve the objective, and describing metrics to document the result/outcome of the adaptive management action.

4.4 ASSUMPTIONS

1) The following assumes that the project will be constructed and that existing aquatic habitat and water quality data is sufficient to establish baseline conditions, or that adequate baseline data collection will be completed prior to full project implementation.
2) The M&AM plan can be adapted to achieve interagency buy-in to the extent practicable.
3) Monitoring and adaptive management will be supported for an extended period to capture pre-project conditions, initial post-project conditions, and mid- to long-term ecological changes related to the project and associated management actions.
4) The potential adaptive management activities described below can be implemented within existing operational and engineering constraints and applied to maximize ecological outcomes while achieving the overall project objectives (e.g., flood risk reduction).

4.5 MONITORING

4.5.1 Monitoring objectives, rationale, and requirements

Monitoring objectives: "…includes the systematic collection and analysis of data that provides information useful for assessing project performance, determining whether ecological success has been achieved, or whether **adaptive management** may be needed to attain project benefits (emphasis added)" (USACE CECW-PB, 8/31/09). With respect to the Proposed Plan, monitoring will focus on meeting the objectives of adaptive operational management and will generally include: 1) characterization of ambient conventional water quality parameters and analyte concentrations, and loadings of specific constituents; 2) identification of long-term, seasonal, and spatial trends including extreme events (*force majeure)*; 3) quantification of the cause-and-effect relationships between habitat impairment and biotic assemblages in space and through time; and 4) documentation of the effect of management activities on water quality and aquatic habitat conditions.

Statement of problem and rationale for monitoring: Biological impairment caused by nutrients, organic enrichment, low dissolved oxygen, causes unknown, and sediment/siltation has been identified in the YSA (303d listed by MDEQ and EPA); these constituents contribute to the 1) lack of environmental flows, 2) oxygen demand on the water column, and 3) poor substrate habitat quality addressed in the adaptive management objectives identified herein. Bioaccumulation of mercury has also been identified as a water quality concern in the region. Monitoring is required to document these impaired conditions and track the effects of management activities on water quality and aquatic habitat.

This following provides a general background and underpinnings on water quality processes and parameters with an emphasis on the interaction between physical and chemical parameters and ultimately, the effects on aquatic biota.

4.5.2 Assessing baseline conditions and establishing monitoring protocols

An assessment of the YSA will be initiated to identify existing water quality and aquatic habitat conditions, detail major water resources problems and opportunities, and provide recommendations for improvement. The assessment will be conducted with collaboration and input from State, Federal and non-Federal sponsors. Overall, the assessment can be used in the planning process to (adapted from Pruitt et al. 2020):

1. Prioritize stream segments for restoration, enhancement, preservation (conservation), and future risk of aquatic impacts.
2. Identify potential performance standards and success criteria applicable to restoration actions.
3. Address potential impacts or improvements beyond the footprint of the project.
4. Establish monitoring plans including adaptive management.
5. Forecast future ecosystem outcomes or ecological lift.
6. Initiate adaptive management actions in support of the management objectives.

Biological endpoints are paramount to successful implementation of the M&AM plan. The importance of incorporating biological endpoints in aquatic ecosystem assessments and restoration efforts cannot be over emphasized. That importance is written into USACE guidance, "ecosystem restoration objectives are clearly written statements that prescribe specific actions to be taken to improve the ecosystem, or fish and wildlife resources" (USACE, CECW-P 2000, pg. 2-2 and E-2).

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 Proposed Plan objectives 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 7 and 8). 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.

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

4.5.3 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.

4.5.3.1 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.

4.5.3.2 Benthic Macroinvertebrates

In wadeable 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.

4.5.3.3 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.

4.5.3.4 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 maintained 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.

4.5.4 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 5):

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. Observations at permanent stations will be extrapolated using three state-of-the-science geophysical instruments: an autonomous underwater vehicle (AUV) (Pruitt et al. 2020), underwater electrical resistivity, and a subbottom profiler (SBP) (Pruitt 2009). The AUV will be equipped with a bio-geophysical array of bathymetric (Pathfinder depth/ velocity logger) and water quality instruments that rapidly and accurately measure the spatial extent of sediment, submerged aquatic vegetation (SAV), and water quality conditions (Emery et al. 2001; Sabol et al. 2002). The AUV will be equipped with a side scan sonar unit to record underwater structures found in each reach. The SBP has the capacity to penetrate the bottom to 40 meters deep and discriminate between historic and contemporary (recent) sediment. Stream bottom conditions will be mapped for spatial extent of sediment and bedform diversity, SAV, and important water quality constituents critical to environmental and human health. Once statistical correlations are fully developed and validated, surrogates and proxies will be utilized for long-term monitoring of water and sediment quality. Consequently, the method will use less personnel but at the same time, create higher resolution data. This technological transition represents a method that identifies and maps sediment and water quality conditions more expeditious and accurately than traditional bottom profiling and sediment characterization. In addition, this method will exemplify the science of limnology through the statistical correspondence between the biological (fish and aquatic macroinvertebrates), geophysical (sediment deposition), and physiochemical attributes (water quality).

4.5.5 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.

Alkalinity: Alkalinity measures the capacity of a water to neutralize acid or buffer against changes in pH. As a result, alkalinity measurements help document water quality and aquatic habitat conditions. Alkalinity is measured in the laboratory by titration. Alkalinity indirectly informs management objectives #1, #2, and #3 of the M&AM plan (Section 5.0).

Nutrients: Nutrients are key ingredients to biological life in aquatic environments. Due to their controlling influence over water quality in most aquatic systems, monitoring often focuses on nitrogen and phosphorus dynamics. Nutrient sources to riverine systems such as the YSA include:

1. Natural decomposition of organic matter from allochthonous (e.g., leaf litter, detritus) and autochthonous (e.g., algae) sources;
2. Non-point sources such as the natural weathering of geologic parent material (rocks and soil);
3. Non-point, anthropogenic sources such as domestic livestock and agricultural fertilizers;
4. Atmospheric deposition; and
5. Point sources such as National Pollutant Discharge Elimination System permitted discharges from municipal and industrial facilities.

Common inorganic nitrogen species used in water quality analysis include: ammonia (NH_3-N), nitrite-nitrate (NO_2-NO_3-N). Additionally, total kjeldahl nitrogen (TKN) is often measured to estimate the organic nitrogen content of surface waters (TKN = organic nitrogen + NH_3). Nitrogen analysis is either conducted in the laboratory or in the field by using ion-specific probes. Because elevated unionized ammonia can have chronic or acute (i.e., NH_3) toxicity to aquatic biota, it will be calculated from temperature and pH. Nitrogen analysis indirectly informs management objectives #1, #2, and #3 of the M&AM plan (Section 5.0).

Phosphorus is another controlling nutrient for water quality and is commonly the limiting nutrient in freshwater systems in the region. Phosphorus occurs in both dissolved and particulate (organic and inorganic) forms. Soluble reactive phosphorus is of particular interest due to its bioavailability, however total phosphorus measurements are also often employed. Total, dissolved, and particulate phosphorus analysis are conducted in the laboratory. Because elevated phosphorus levels can impact water quality, its measurement is recommended as part of the monitoring protocol. Phosphorus analysis indirectly informs management objectives #1, #2, and #3 of the M&AM plan (Section 5.0).

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.

4.5.6 Pondberry (*Lindera melissifolia*) Monitoring Plan

This adaptive monitoring plan was prepared to monitor the effects of the Yazoo Backwater Project (YBP) 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 6 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.
6. 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 9). 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 9 are discussed in the Threatened and Endangered Species Appendix.

5.0 ADAPTIVE MANAGEMENT

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.

5.1 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.

5.2 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 station and other infrastructure to increase the hydraulic circulation during backwater events and other periods when low oxygen levels impact water quality and aquatic habitat. This may include opening structures to increase turbulence, the introduction of oxygen rich waters into the system, or other activities.
2. Manage pump station/water control structures to create a pulsing effect that can increase advection while decreasing stagnation associated with establishment of stratification and/or low dissolved oxygen conditions.

Documentation: Monitoring water column dissolved oxygen concentrations (discrete vertical profiling and diel) in combination with water quality sampling can document the benefits of improved hydraulic circulation and identify opportunities to further enhance conditions through additional management practices.

5.3 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 effects 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.

5.4 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 are essential components of the M&AM "adaptive" process. PSM allow the USACE to determine if the objectives of this M&AM plan are met or exceeded. "Projects are analyzed and described in terms of their expected performance" (Performance Monitoring System, ER1105-2-100). In addition, performance standards are required in mitigation plans (33 C.F.R. §332). PSM provide: 1) a means of validating and gaging success toward project goals and objectives; 2) data used to improve the performance and success of the project ("adaptively"); 3) quantitative and qualitative characteristics that indicate the restoration action is proceeding toward the desired ecosystem outcome (ecological lift); 4) an opportunity for contingencies and adaptive management; and 5) participation by interagency, interdisciplinary teams and stakeholders. In addition, performance standards focus monitoring on specific measures of success which reduces the amount of data that must be collected pre- and post-project thus reducing project time and cost and improving benefits.

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. Pertinent Federal Regulations, Guidance and Authorities related to mitigation and PSM include:

1. Planning Guidance Notebook (ER1105-2-100).
2. Section 2039 of WRDA 2007.
3. Section 404 Clean Water Act, compensatory mitigation requirements.
4. Section 10 of the Rivers and Harbors Act.
5. The 2008 Mitigation Rule (33 C.F.R. §332).
6. Performance standards and project goal and objectives (33 C.F.R. §332.5).

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 7). 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 4) 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 8). 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).

6.0 BASIN-WIDE ASSESSMENT PLAN

The watershed monitoring will be part of the Proposed Plan as described above. However, the USACE will entertain the possibility of extending the study to a basin-wide assessment and strategic plan which includes the Big Sunflower River and Steele Bayou watersheds. The extended study is contingent on buy-in and matching funds from collaborators (State, Federal and non-Federal sponsors). If stakeholders are amendable to the study through matching funds, the watershed assessment will be prepared under the authority of Section 729 of the Water Resources Development Act of 1986, as amended, which authorizes the USACE to undertake watershed planning. The assessment will identify existing conditions within the watershed, detail the major water resources problems and opportunities in the watershed, and provide recommendations for implementation. Overall, the results of watershed assessment can be used in the planning process to support this Proposed Plan.

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

7.1 PURPOSE

The following describes a M&AM strategy to document the benefits of compensatory mitigation implemented to offset unavoidable impacts to wetland resources as described in the Wetlands Appendix. The M&AM plan outlines the procedures used to verify that mitigation activities are restoring the wetland functions with the project area. The following also identifies restoration milestones designed to ensure that projected wetland mitigation benefits are being generated and discusses strategies to make adjustments if mitigation targets are not achieved. A discussion of the need for robust water table monitoring within the YSA is also included.

7.2 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 YSA to evaluate the effects of the Proposed Plan on wetland hydroperiods.

7.3 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 Plan; 2) provides a detailed monitoring plan and protocol to document changes in wetland functions using the Hydrogeomorphic (HGM) methodology; 3) outlines a monitoring plan to evaluate potential changes in wetland hydrology across flood duration intervals and associated implications for wetland functional capacity in the YSA; and 4) discusses corrective adaptive management actions that would be implemented if the mitigation areas fail to offset impacts to wetland resources as intended.

7.4 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, pasture land 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 mixtures 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 identified, 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 11 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 site selection during the identification of potential mitigation areas, which should exhibit the following characteristics where possible: areas with large interconnected forested tracts (V_{TRACT}), forested areas adjacent to the mitigation properties ($V_{CONNECT}$), large interior areas (V_{CORE}), occur within the ≤ 4-year floodplain (V_{FREQ}), experience wetland hydroperiods for ≥ 5.0% of the growing season (V_{DUR}), and display bedding, furrows, or other topographic homogeneity that provide microtopography (V_{POND}). 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 are 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 12 through 21 in the Wetlands Appendix). Visual representations of the variable metric values and variable subindex scores are provided in Figures 9-19. 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.

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 20, 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 21. 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 sin mitigation areas.

7.5 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 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.

7.6 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 YSA has been identified as an area of concern, including the potential to decrease the duration 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 following project construction are needed. Hydrologic monitoring conducted using shallow groundwater wells has proven effective in identifying both hydroperiod and hydropatterns within wetlands in the YSA. 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 potentially allow for adaptive operation of the project to improve wetland conditions if required.

The location of monitoring locations 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 five groundwater monitoring wells would be installed in each flood duration interval and triplicate monitoring locations would be established at each mitigation area. The HGM assessment would be conducted at five year intervals at the location of all monitoring wells in order to link hydropatterns with measures of wetland function. 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.

7.7 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 the wetland functional shortfall. For example, if the hydrologic monitoring detects shifts in flood duration that exceed the estimates described in Table 69 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 exists 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 scores 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 V_{FREQ} and V_{DUR}; expansion of adjacent forested tracts to increase V_{TRACT}, $V_{CORE,}$ and $V_{CONNECT}$; planting of desirable flood tolerant vegetation species and select species management (e.g., invasive/nuisance species control) to increase V_{COMP}; manipulation of ground conditions to increase ponding and storage of flood/rain water to increase V_{POND}, selective thinning to improve conditions for tree growth to increase V_{TBA}, V_{SNAG}, and other variables; and the removal/incorporation of carbon sources into the system to increase V_{WD}, V_{LOG}, V_{OHOR} 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 V_{COMP}, 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.

8.0 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 YSA and at compensatory mitigation sites. Fortunately, there is substantial published data available to support 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.

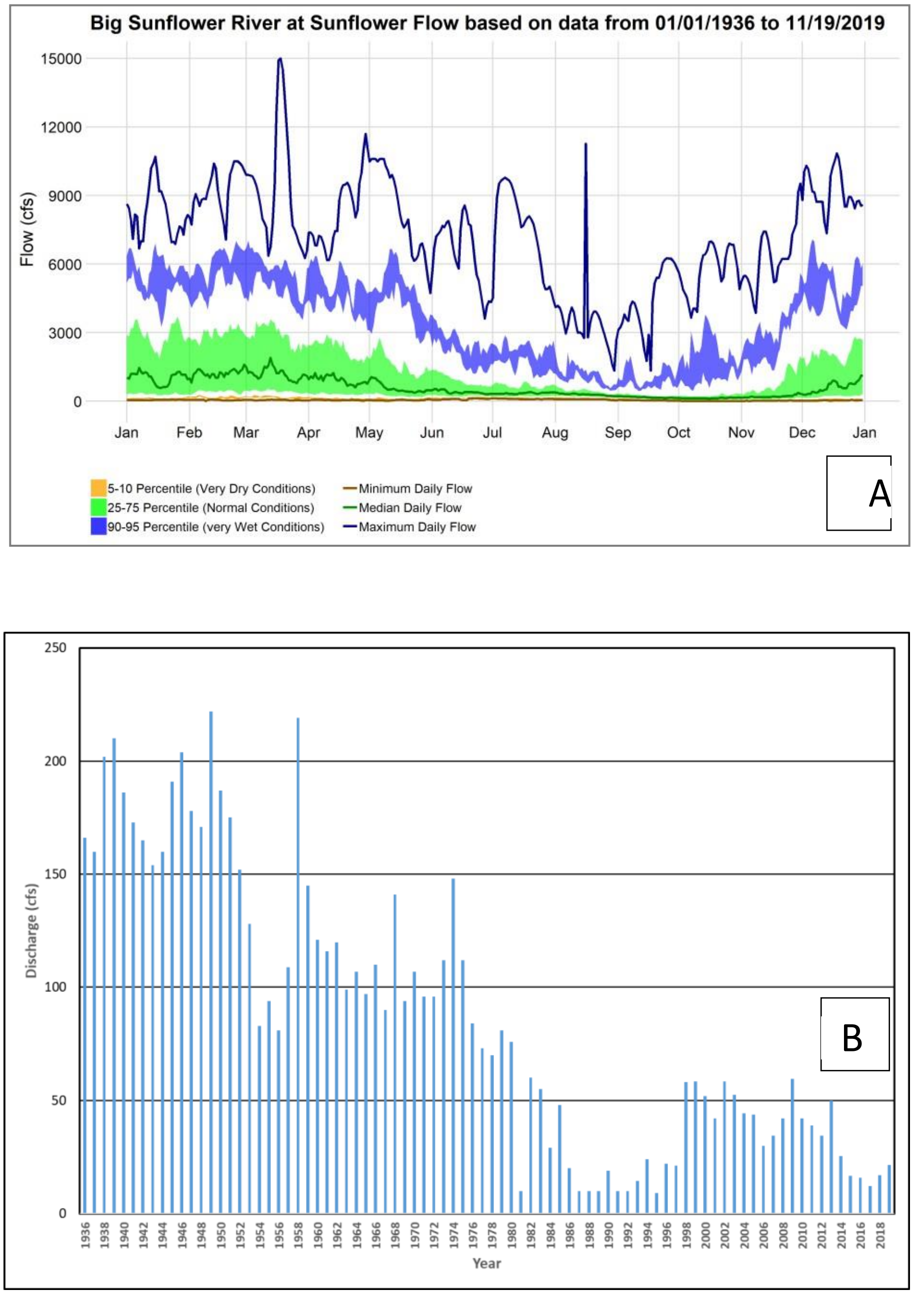

Figure 1A and 1B. 1A. Maximum, minimum, and median daily flow from 1 January 1936 through 19 November 2019. The 5- through 10-percentile, 25- through 75-percentile, and 90- through 95- percentile ranges for daily flow are also depicted. 1B. Big Sunflower River annual minimum flow from 1939 through 2019.

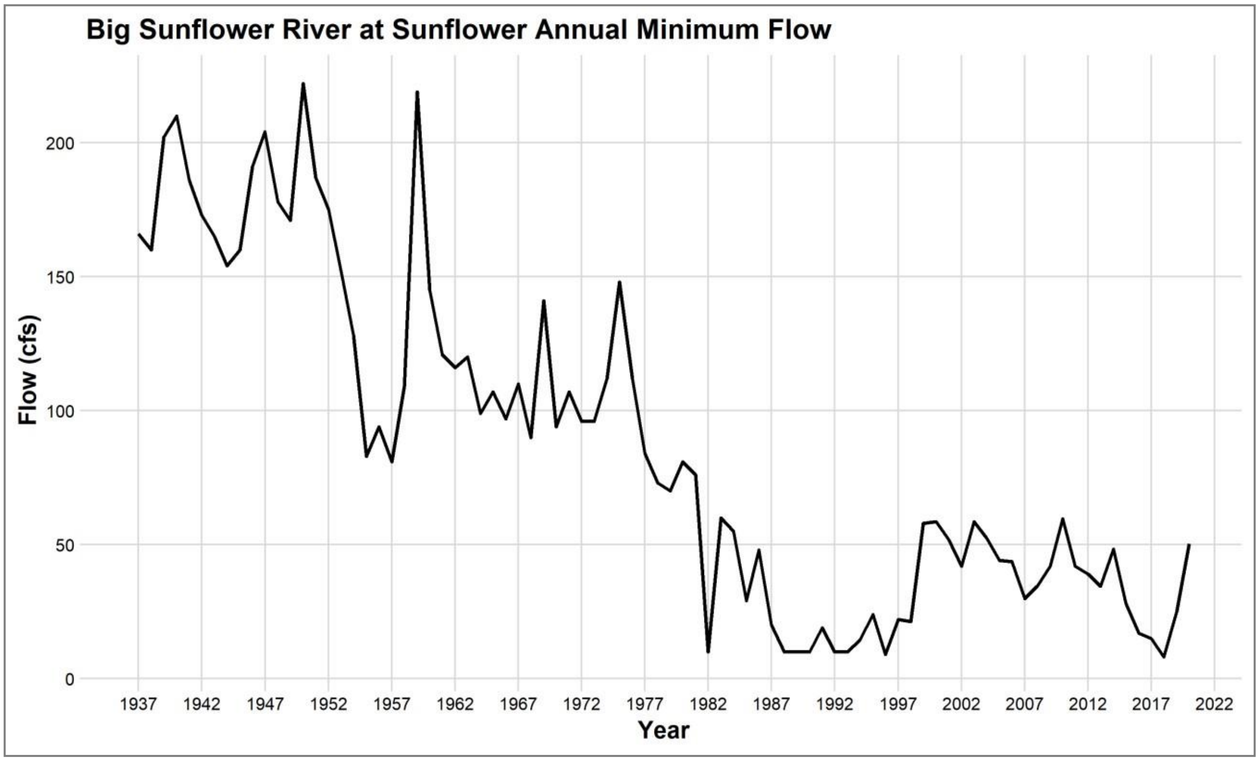

Figure 2. Annual minimum flow at the Big Sunflower River at Sunflower from 1937 through 2019.

Figure 3. Mussel beds below the Big Sunflower Lock and Dam that have been dewatered due to low environmental flow. Photo credit: KJ Killgore, ERDC

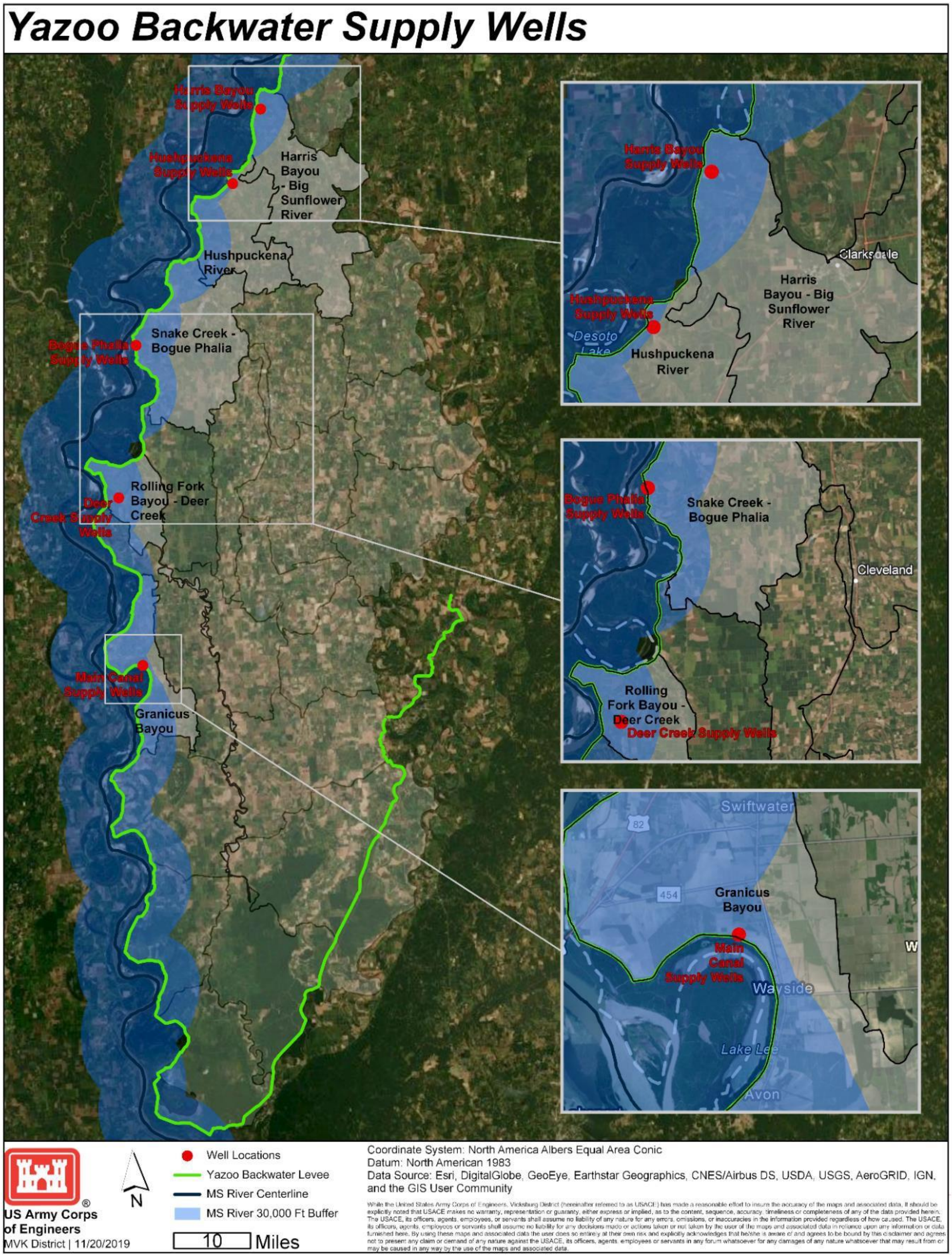

Figure 4. Favorable locations for SLFG wells were based on close proximity to the Mississippi River and residing on the east side of the Yazoo Backwater Levee.

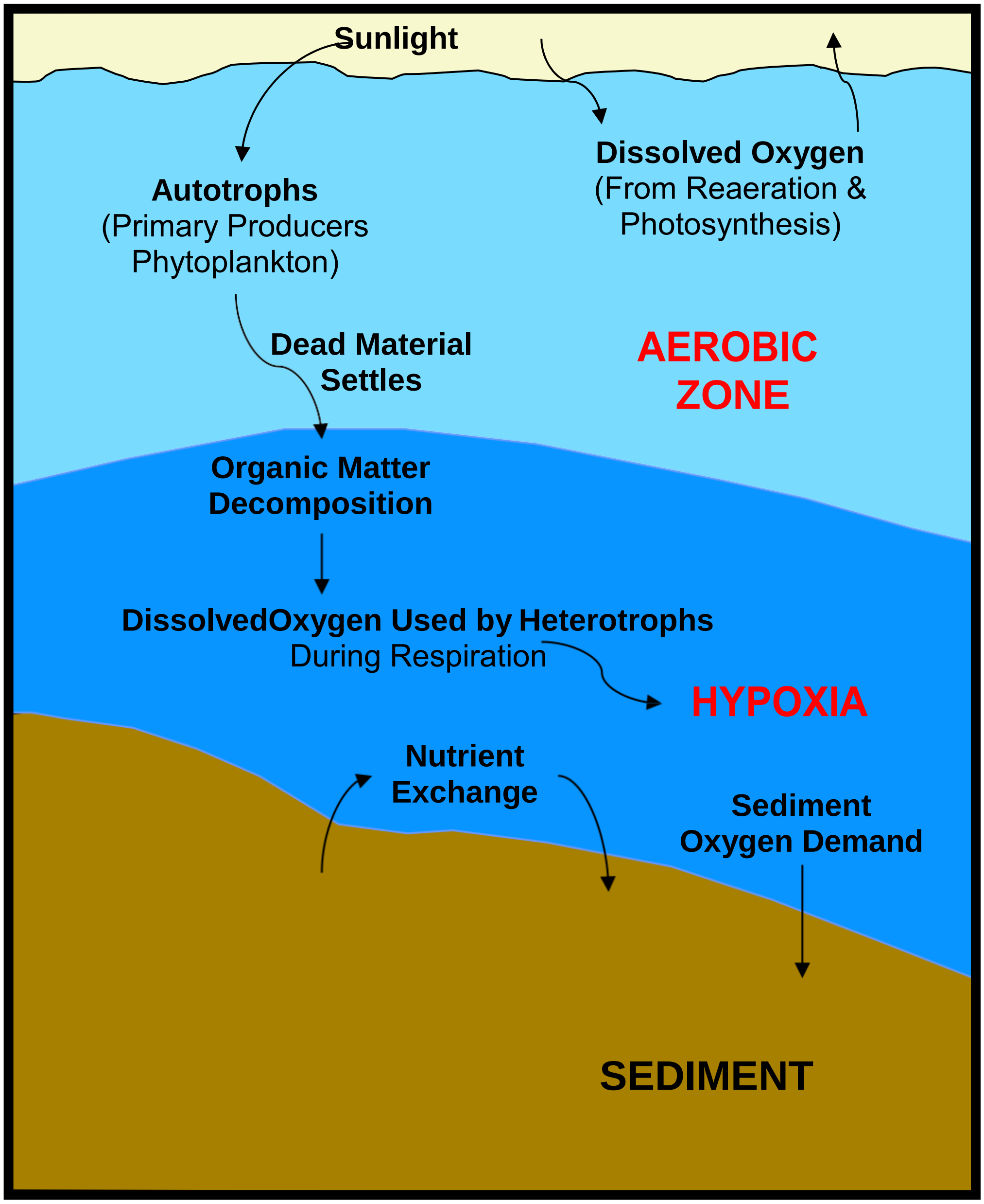

Figure 5. Generalized oxygen dynamics at various strata in the water column (boundary between aerobic and hypoxic zones can vary widely).

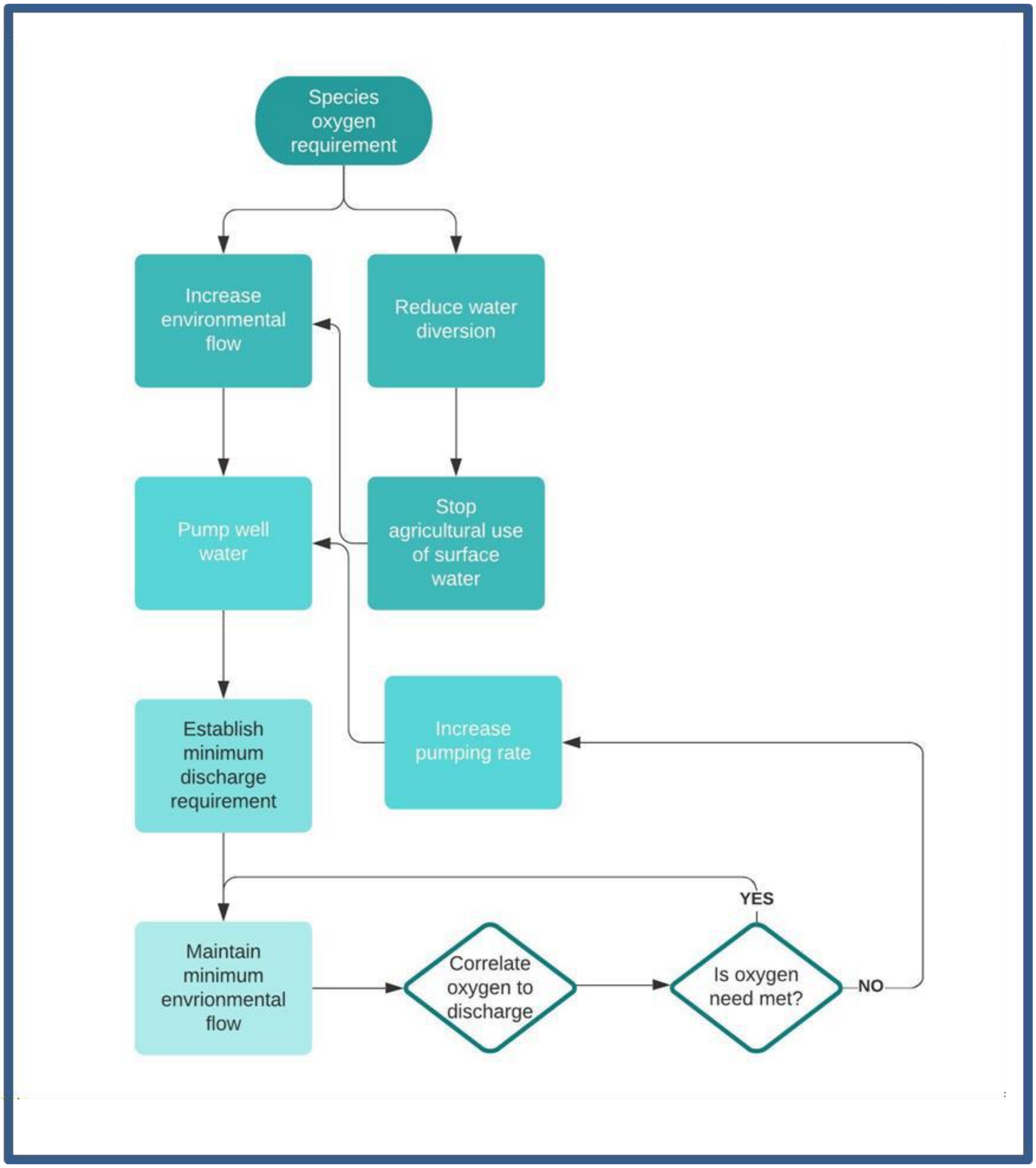

Figure 6. Design model for operating pumps to maintain minimum requirements for dissolved oxygen.

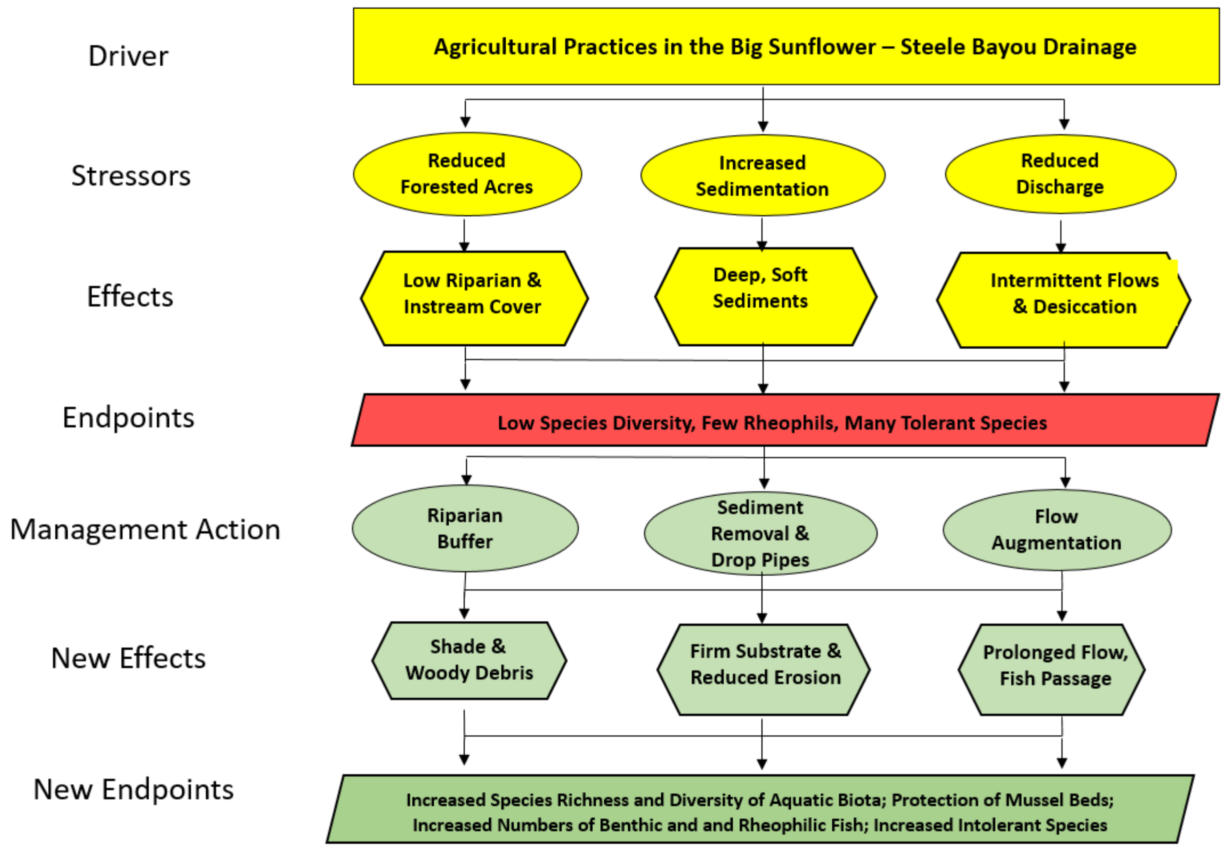

Figure 7. A conceptual model of the effect of agricultural practices and flood control in the Big Sunflower - Steele Bayou drainage on fish communities, along with management options and the endpoints of restoration or mitigation activities (Adapted from Hoover et al. 2008, Killgore et al. 2008).

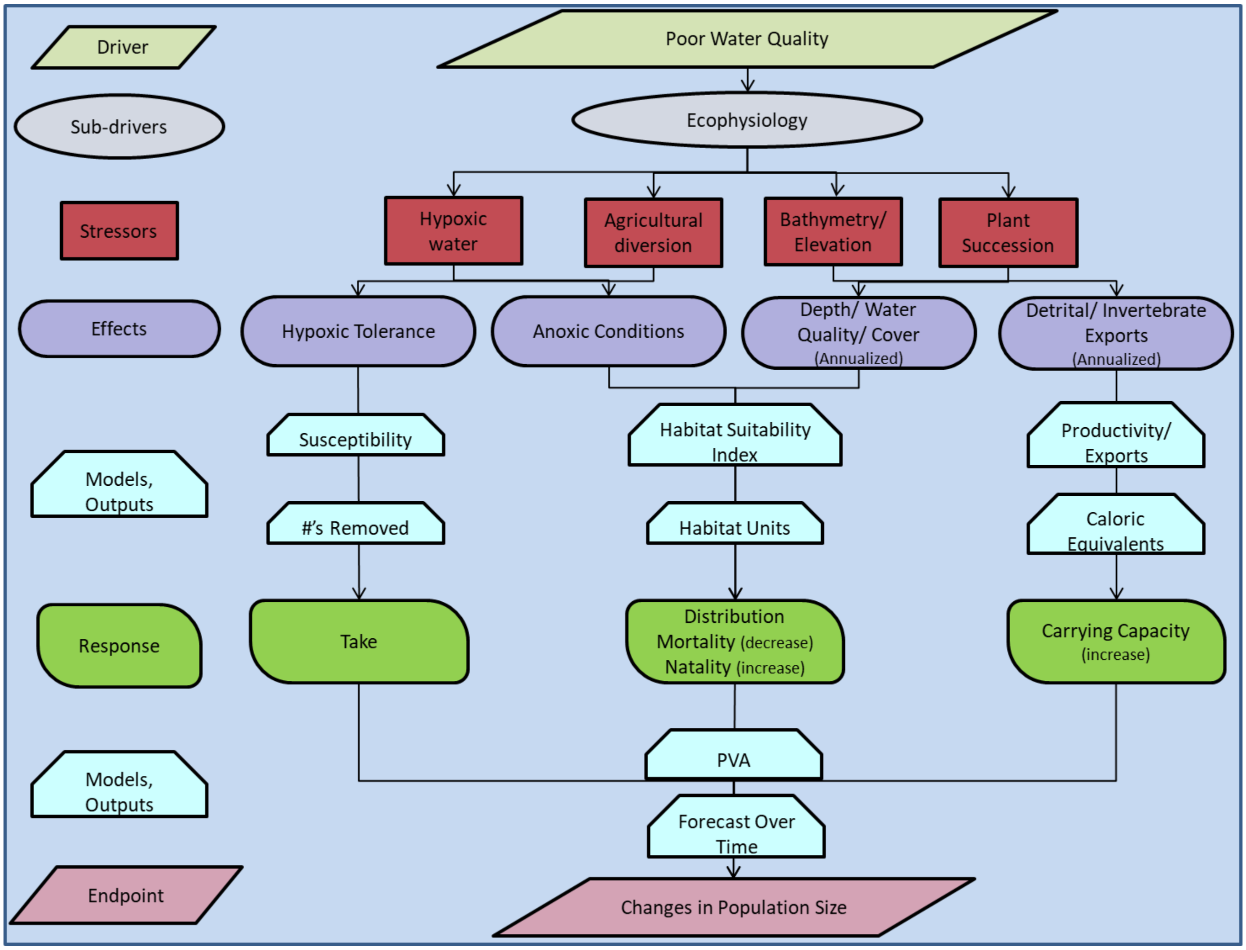

Figure 8. Conceptual model of sources, impacts and adverse effects/response related to water quality and aquatic habitat conditions.

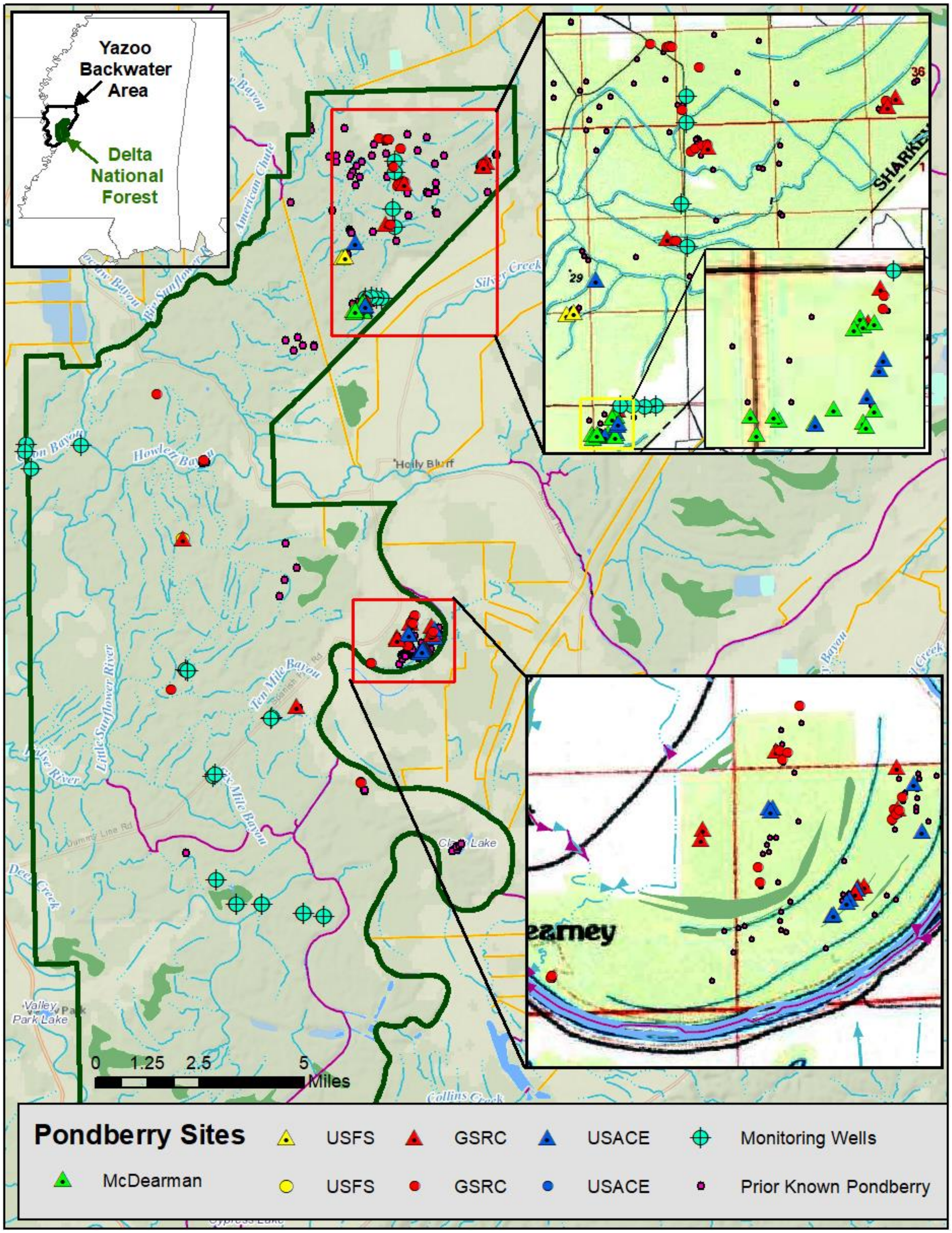

Figure 9. Location of pondberry colonies in relation to existing monitoring wells.

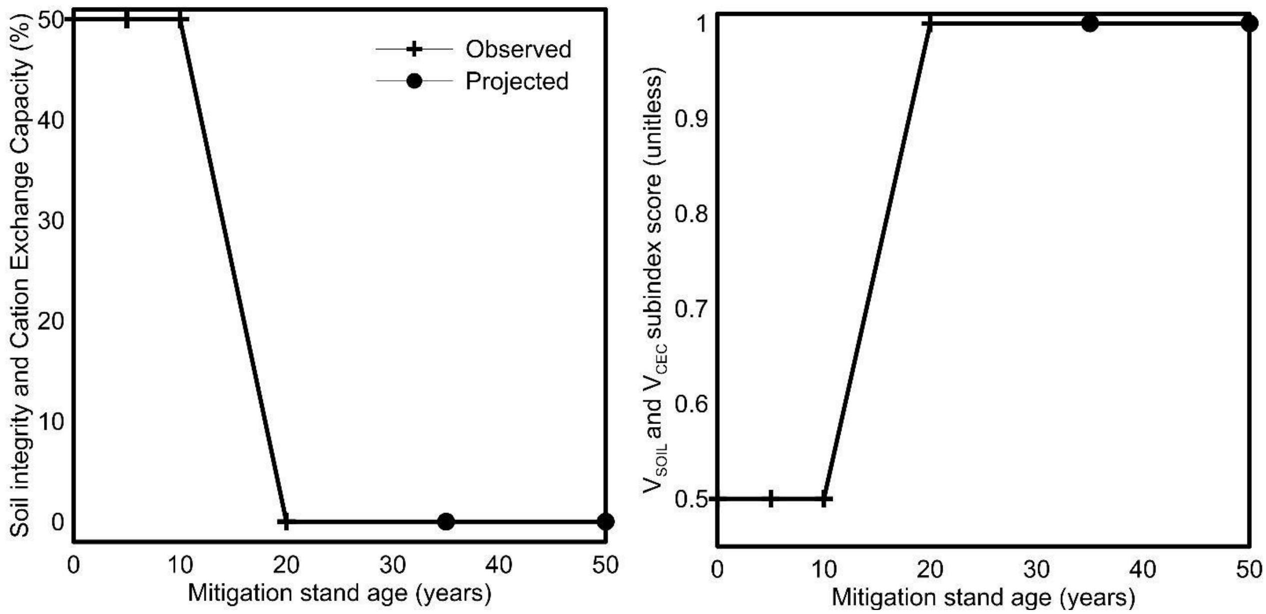

Figure 9. Compensatory mitigation milestones for V_{SOIL} and V_{CEC} HGM variable metric values (left panel) and subindex scores (right panel) over the period of analysis.

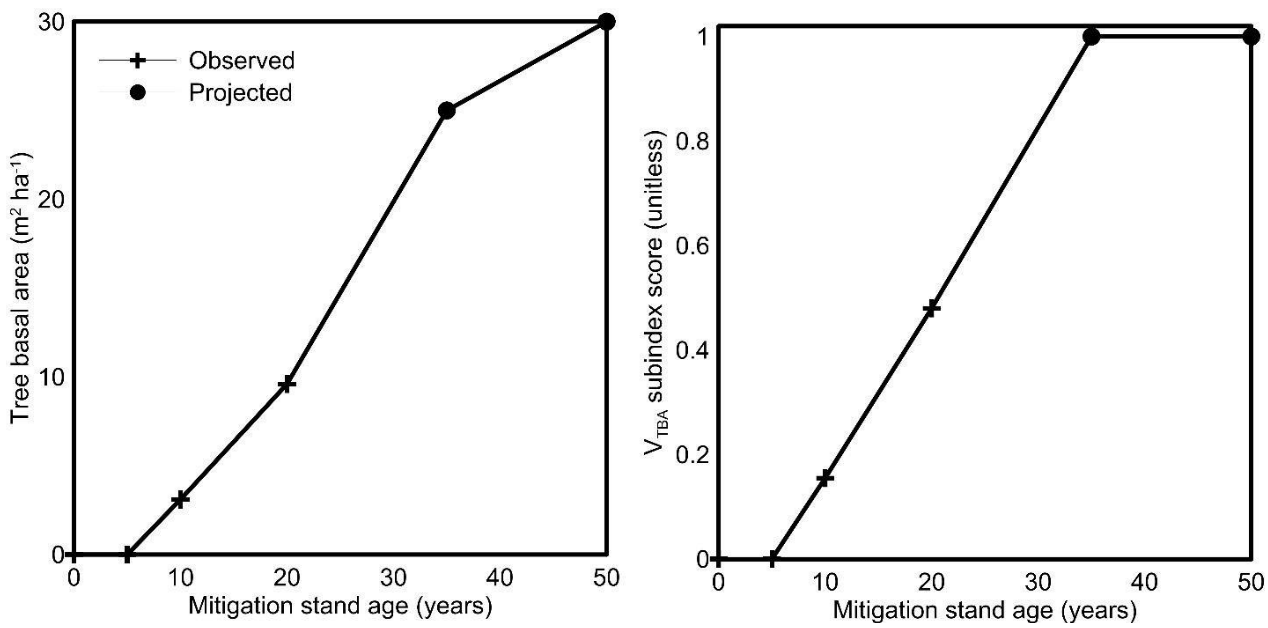

Figure 10. Compensatory mitigation milestones for V_{TBA} HGM variable metric values (left panel) and subindex scores (right panel) over the period of analysis.

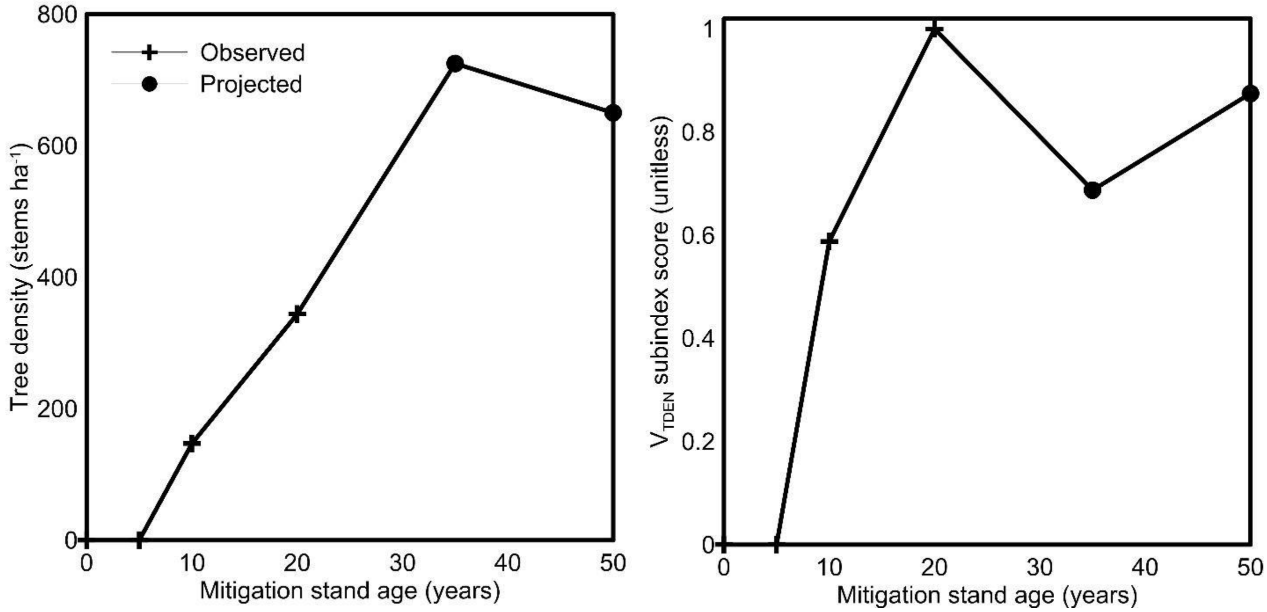

Figure 11. Compensatory mitigation milestones for V_{TDEN} HGM variable metric values (left panel) and subindex scores (right panel) over the period of analysis.

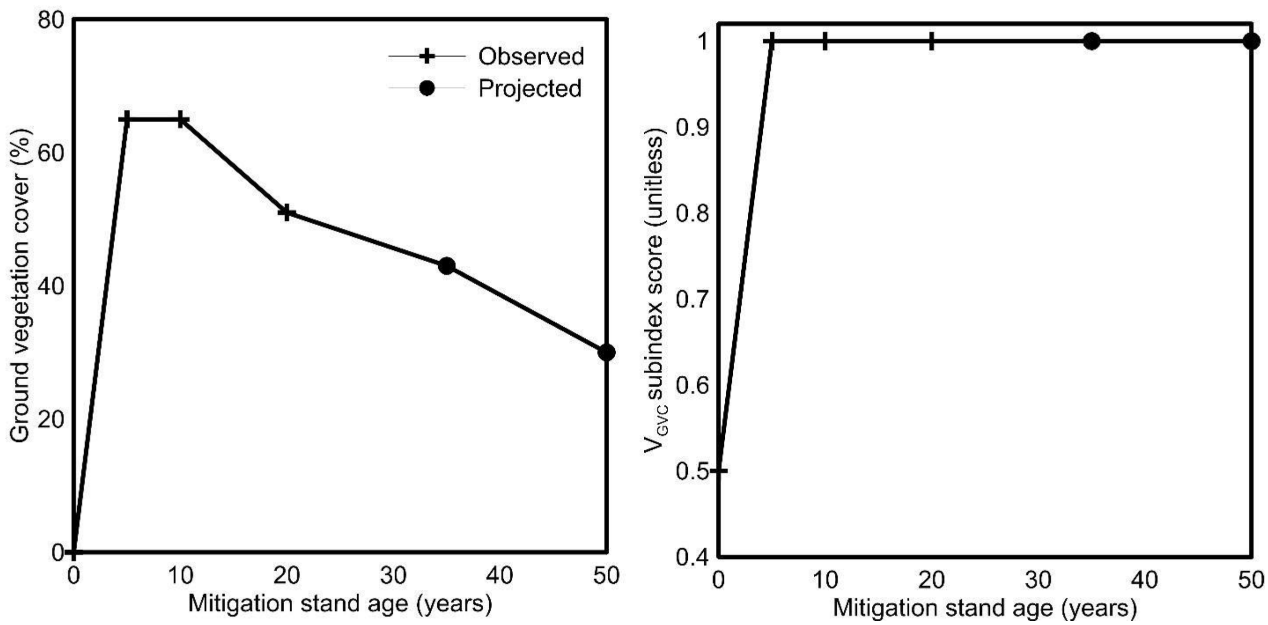

Figure 12. Compensatory mitigation milestones for V_{GVC} HGM variable metric values (left panel) and subindex scores (right panel) over the period of analysis.

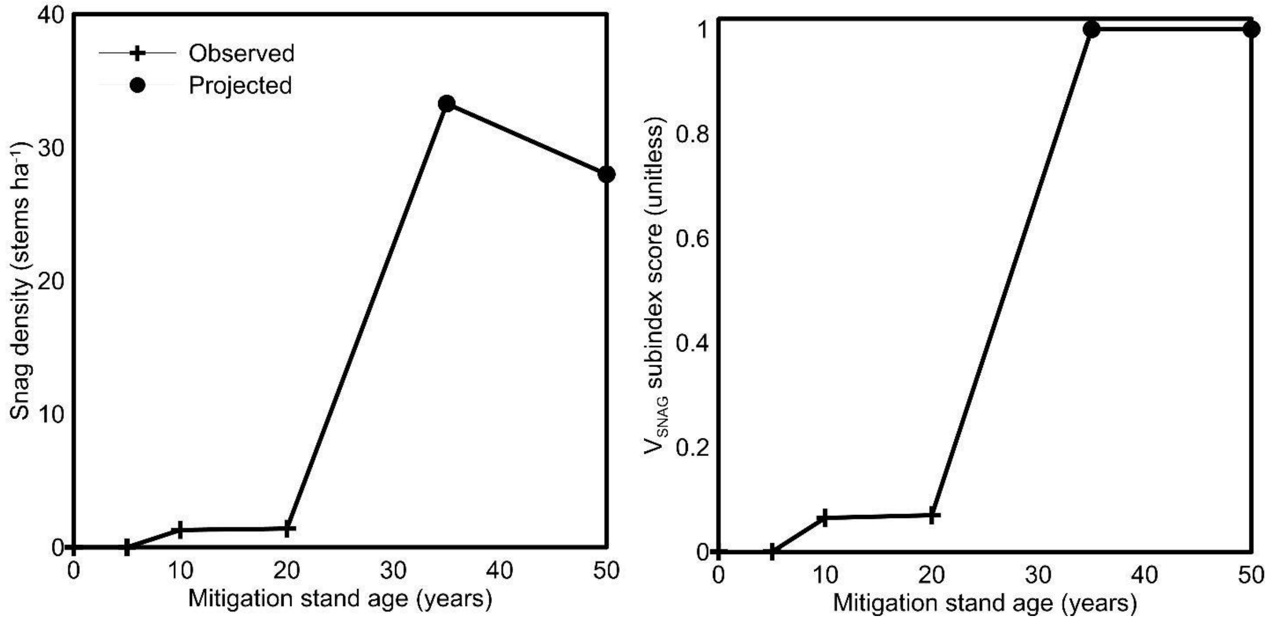

Figure 13. Compensatory mitigation milestones for V_{SNAG} HGM variable metric values (left panel) and subindex scores (right panel) over the period of analysis.

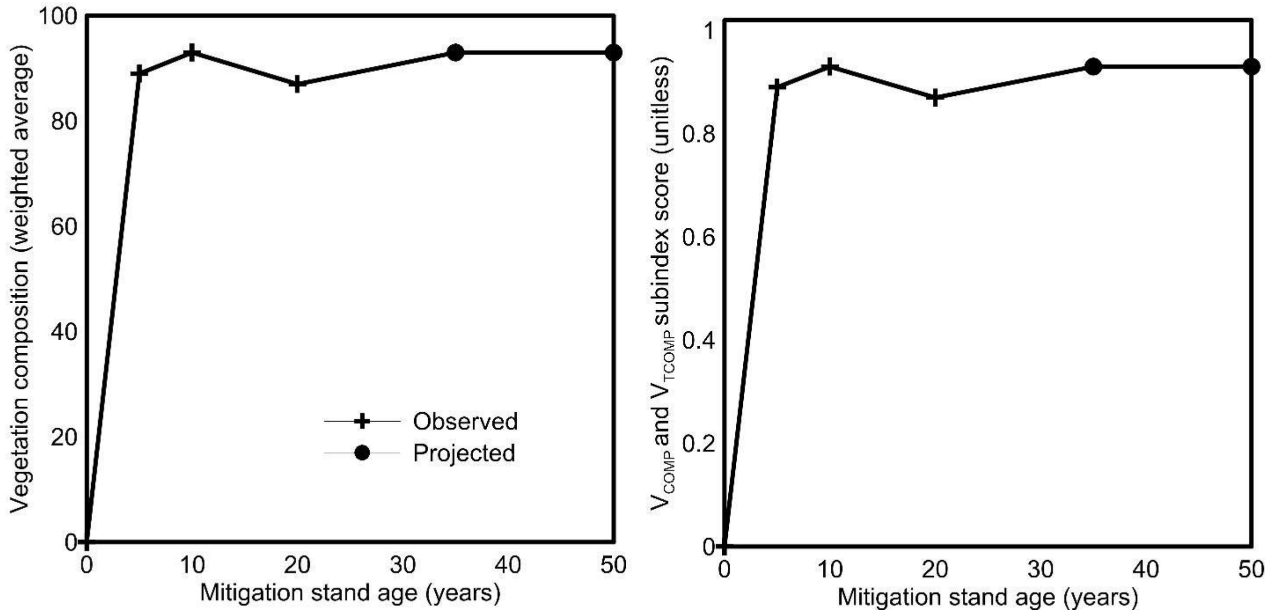

Figure 14. Compensatory mitigation milestones for V_{COMP} and V_{TCOMP} HGM variable metric values (left panel) and subindex scores (right panel) over the period of analysis.

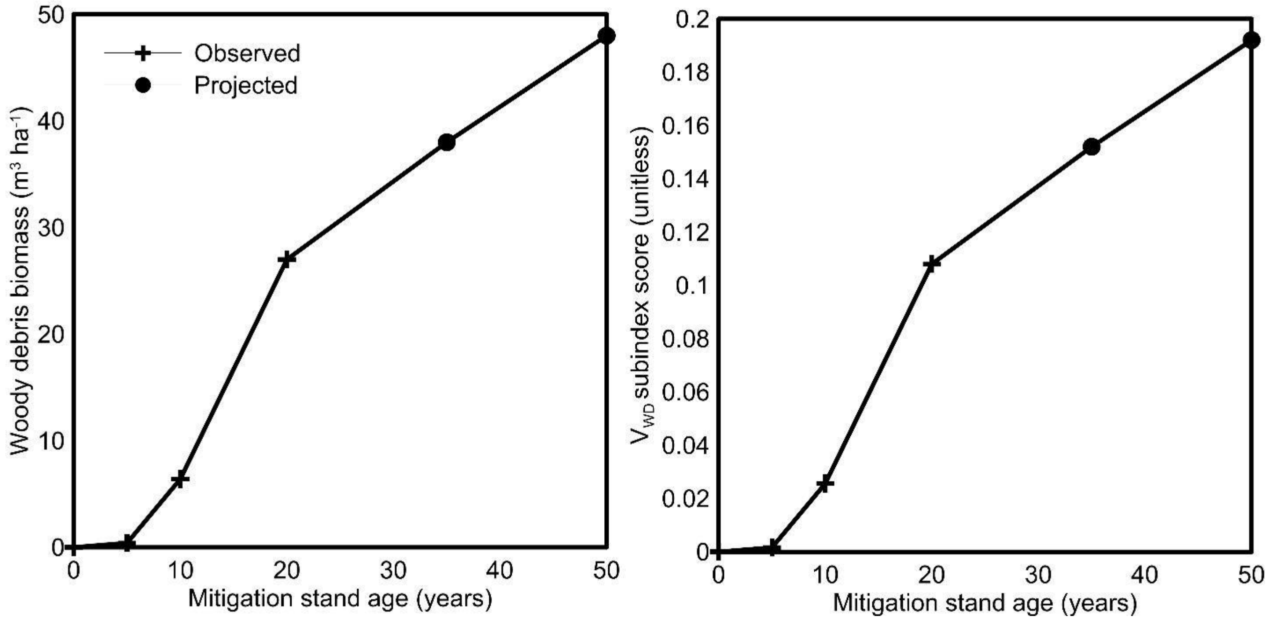

Figure 15. Compensatory mitigation milestones for V_{WD} HGM variable metric values (left panel) and subindex scores (right panel) over the period of analysis.

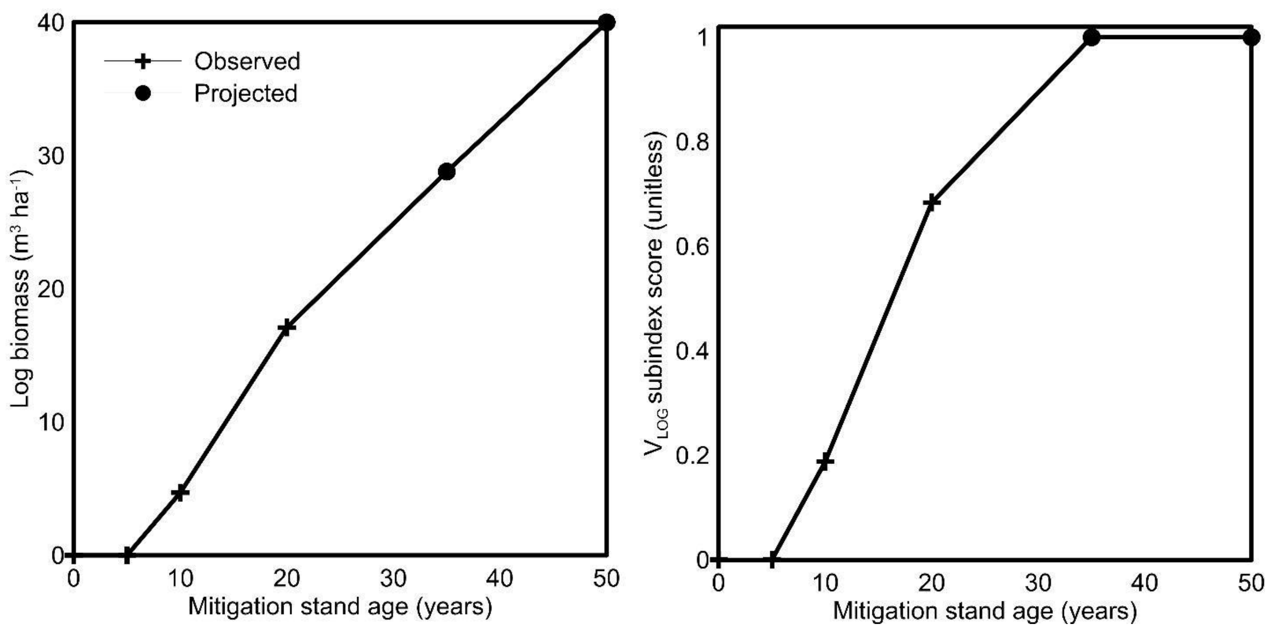

Figure 16. Compensatory mitigation milestones for V_{LOG} HGM variable metric values (left panel) and subindex scores (right panel) over the period of analysis.

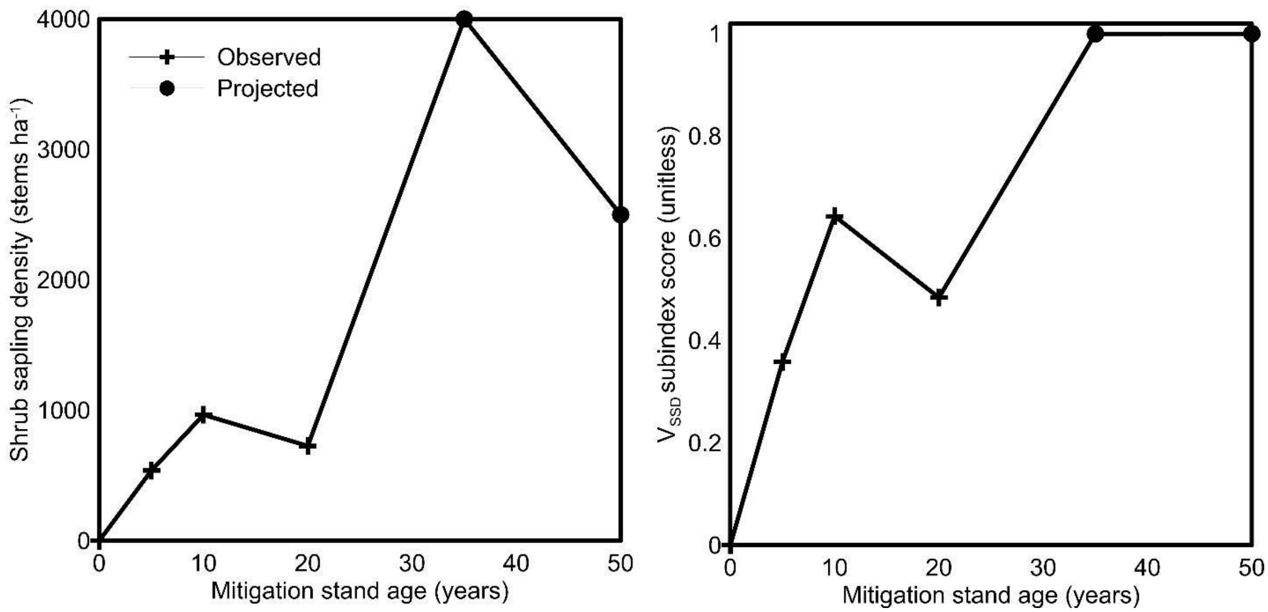

Figure 17. Compensatory mitigation milestones for V_{SSD} HGM variable metric values (left panel) and subindex scores (right panel) over the period of analysis.

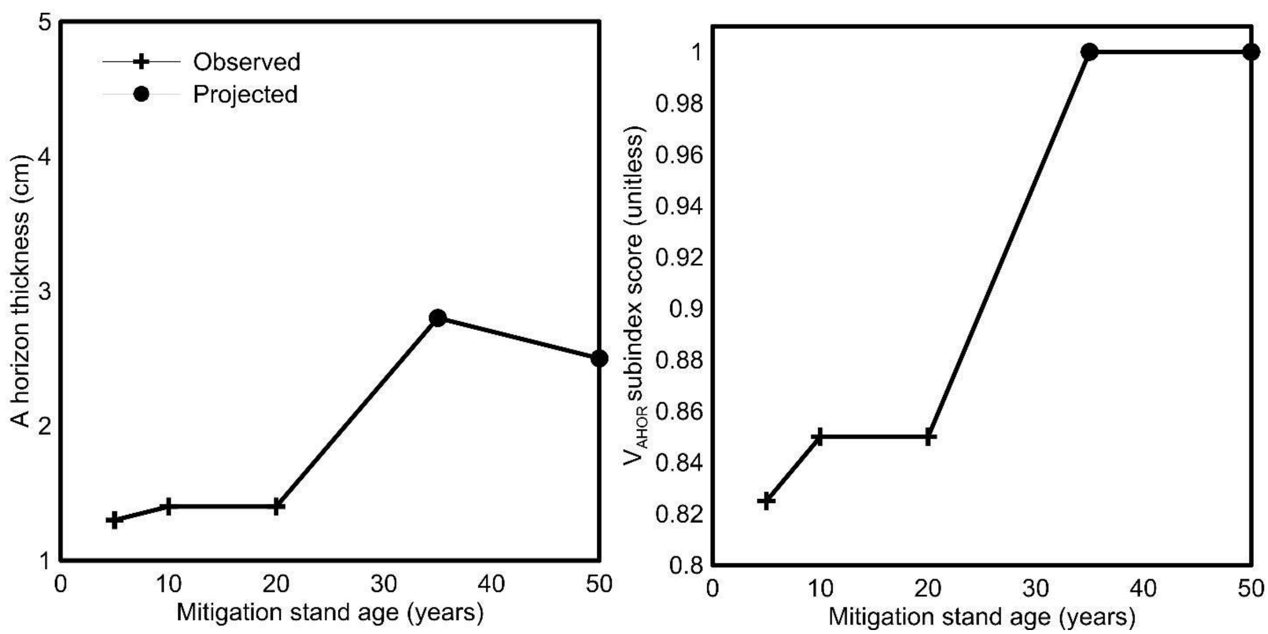

Figure 18. Compensatory mitigation milestones for V_{AHOR} HGM variable metric values (left panel) and subindex scores (right panel) over the period of analysis.

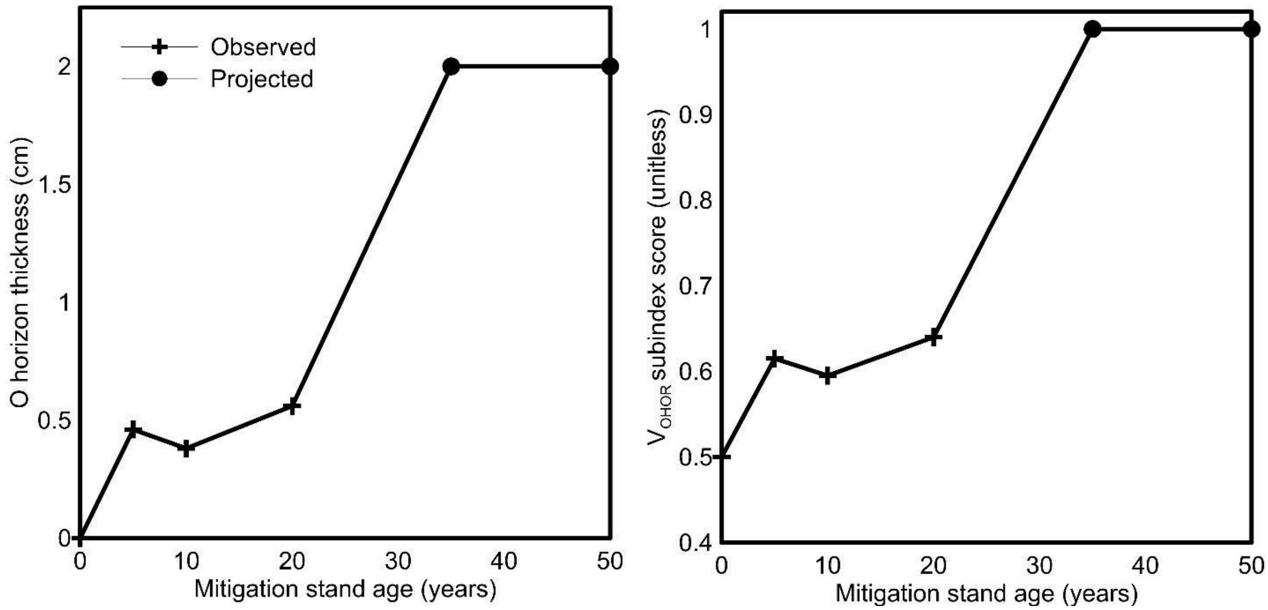

Figure 19. Compensatory mitigation milestones for V_{OHOR} metric values (left panel) and subindex scores (right panel) for over the period of analysis.

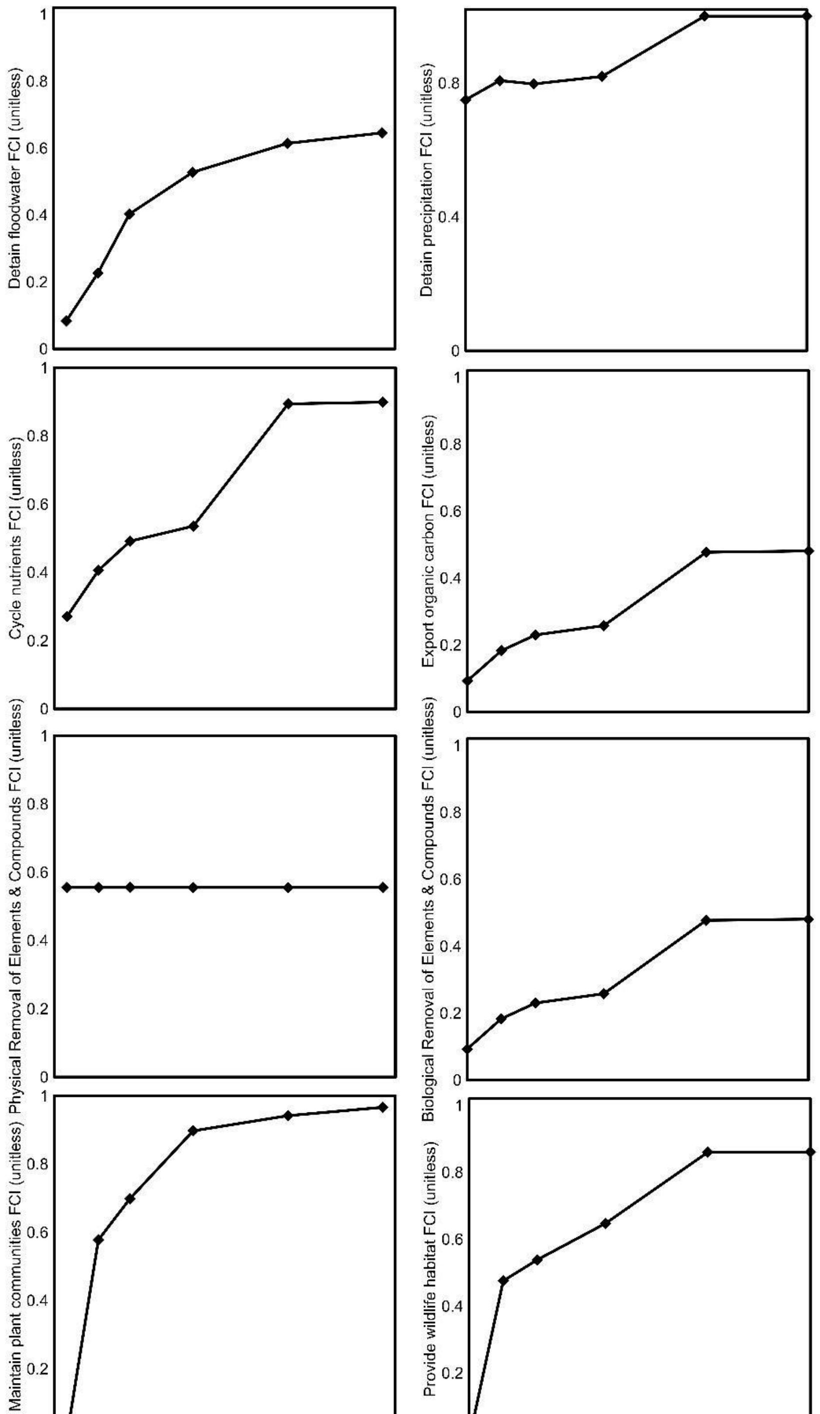

Figure 20. Compensatory mitigation milestones for HGM functions over the period of analysis.

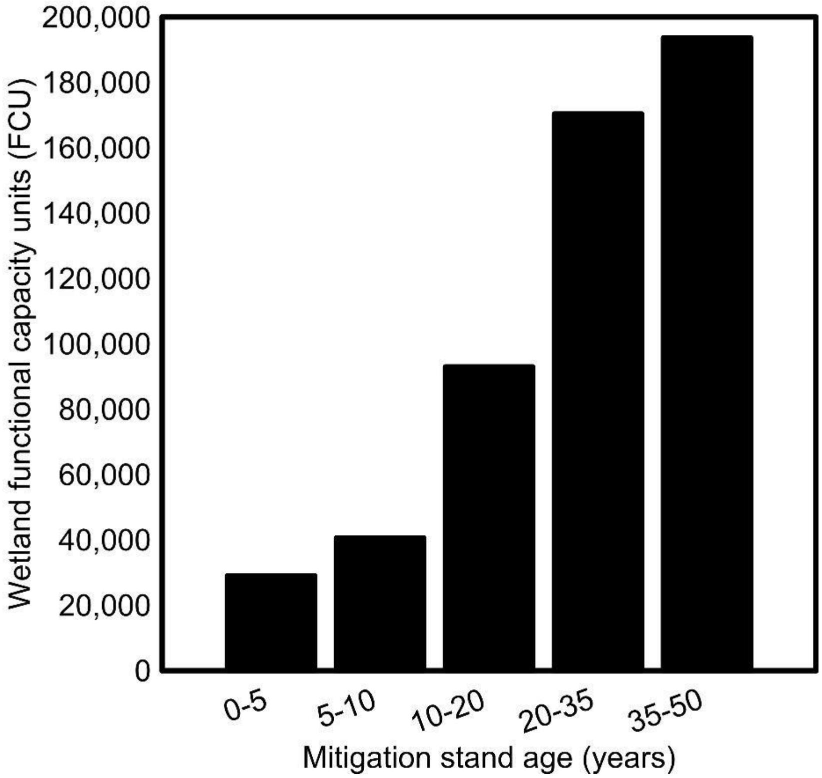

Figure 21. Compensatory mitigation milestones for AAFCUs over the period of analysis.

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
Rollling 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	Rollling Fork Bayou – Deer Creek
Main Canal	Granicus Bayou

Table 3. Examples of water quality parameters, which support monitoring objectives 1 and 2, may be applied during application of the monitoring protocol (includes *in-situ* and laboratory analysis). Parameters may be adjusted based on historic data collection, identification of data gaps, initial monitoring and M&AM Plan iterative process, and applicability to management objectives. If ion-specific probes are available (e.g., Nitrate/Nitrite Nitrogen), the measurement may be made in the field.

		Analysis	
Parameter	**Units**	***In-situ***	**Lab**
Air Temperature*	Degrees Celsius	✓	
Water Temperature*	Degrees Celsius	✓	
pH*	Standard Units	✓	
Redox Potential	mV	✓	
Dissolved Oxygen*	mg/L	✓	
Dissolved Oxygen Saturation*	Percent	✓	
TDS	mg/L (calculated from Conductivity)		
Specific Conductance*	μS/cm	✓	
Turbidity*	NTU	✓	
Fecal Coliform/E.coli	MPN/100mL		✓
5-Day BOD[1]	mg/L		✓
COD	mg/L		✓
Total Suspended Solids	mg/L		✓
Total Phosphorus	mg/L		✓
Ortho-Phosphate	mg/L		✓
Ammonia Nitrogen	mg/L		✓
Nitrate/Nitrite Nitrogen	mg/L		✓
Total Kjeldahl Nitrogen	mg/L		✓
ICP Metals Scan	μg/L		✓
Cadmium[2]	μg/L		✓
Copper[2]	μg/L		✓
Lead[2]	μg/L		✓
Zinc[2]	μg/L		✓
Mercury	μg/L		✓
Filtration	as required		✓
Alkalinity	mg/L as $CaCO_3$		✓
Total Hardness	mg/L as $CaCO_3$		✓
Chlorophyll A	mg/L		✓
Note: All stream samples and laboratory analysis should be handled in accordance with USEPA approved methods that are given in Title 40 of the Code of Federal Regulations (40 CFR).			

Table 4. 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 5. 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
Amphitude	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 6. 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 7. 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 8. Example of performance metrics for fishes in the Lower Mississippi River Basin including the Big Sunflower River and reference sites. 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.

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 Orangespotted 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

9.0 REFERENCES

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