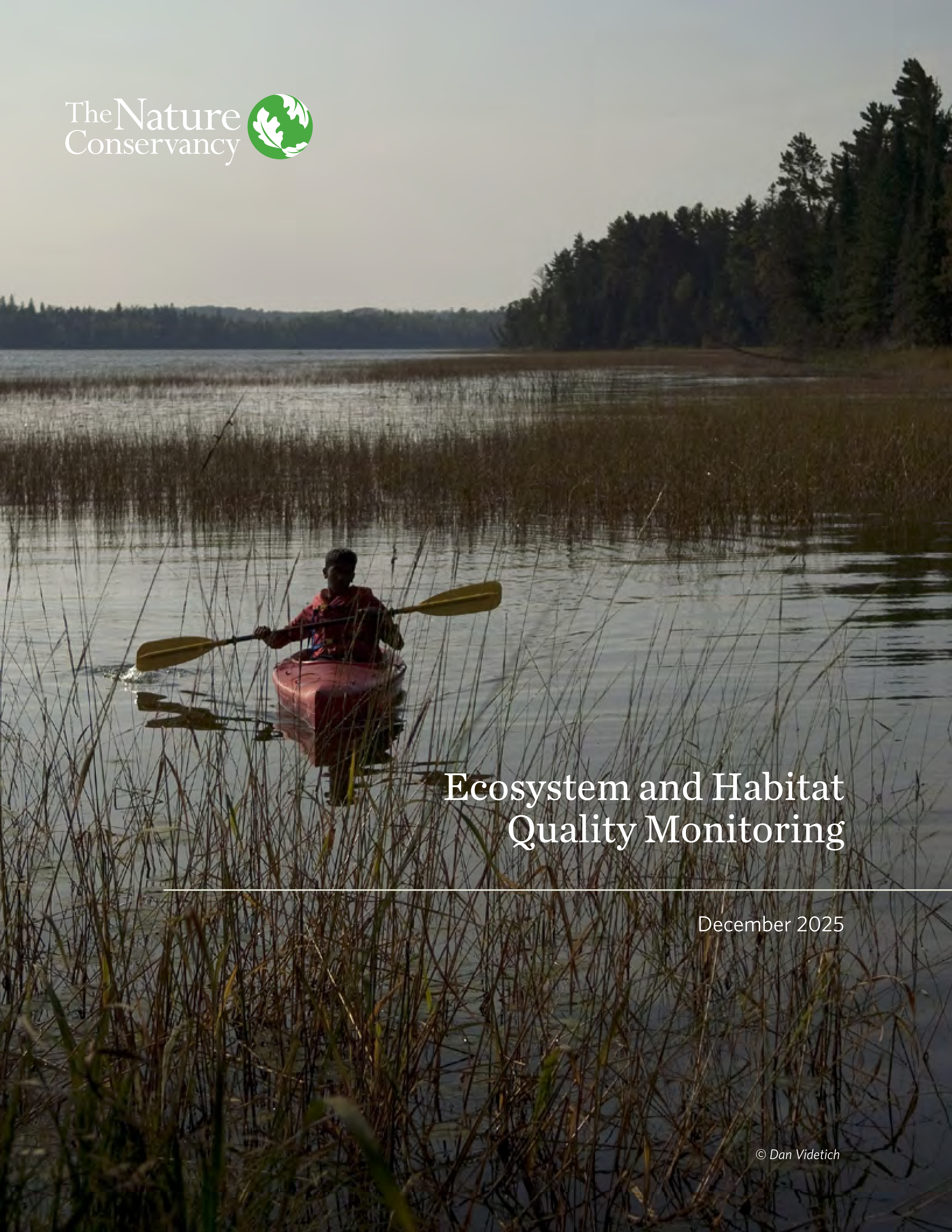

Ecosystem and Habitat Quality Monitoring

December 2025

GOAL:

To obtain consistent, comparable information on current conditions and future trends in ecosystem health and habitat quality to understand how changes in climate, land-use, and landscape management affect the Mississippi River, major tributaries, distributaries, and the Gulf of America to inform and assess actions to improve ecological condition.

The Nature Conservancy with contributions from partners listed in Table 2

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Ecosystem and Habitat Quality Monitoring Technical Design Report

1.0 Introduction

The Nature Conservancy (TNC), in partnership with federal, state, regional and nonprofit organizations, has undertaken an ambitious project to create a fully funded, constructed and staffed monitoring system across the Mississippi River watershed in the next five years. Enhancing the capacity and consistency of existing monitoring programs across the watershed is critical to improving the quality and safety of commercial navigation, supporting the health of our lands and waters, and maintaining the quality of our communities. This more comprehensive approach to monitoring will improve the nation's ability to make informed decisions that impact vast natural systems and human activity in an area spanning 1.2 million square miles and over 100,000 tributaries—approximately 41% of the contiguous United States.

Scientists working on this initiative have identified four monitoring priorities: (1) water quality and flow, (2) flood and drought resilience and management, (3) navigation safety, and (4) ecosystem and habitat quality. In 2023, TNC published a report, based on recommendations from a team of scientists, urging the augmentation of existing federal monitoring efforts in order to gather and share more accurate, timely and accessible data related to the first three priorities.[1] This "Sentinel System" builds upon current infrastructure to manage costs while filling key gaps along the Mississippi mainstem and major tributaries and distributaries to monitor water quality, navigation safety and flood and drought impacts.

In 2024, a second team of scientists undertook the task of identifying criteria for improved monitoring of ecosystem and habitat quality along the Mississippi River and its tributaries, spanning an even greater geographic area within the watershed. The goal was to obtain consistent, comparable information on current condition and future trends in ecosystem health and habitat quality. This information is necessary to understand how extreme weather events and changes in land use and landscape management affect the Mississippi River, its major tributaries, its distributaries and the Gulf of America. The results may be used to inform and assess actions to improve how people use the river and its lands and ultimately, to improve the river's ecological condition.

This report summarizes the findings and recommendations from that project.

2.0 Situation Analysis

2.1 The Importance of the Mississippi River Watershed

As mentioned in the 2023 report, *Building a Comprehensive "Sentinel" Monitoring System for the Mississippi River*, the Mississippi River, along with its tributaries and distributaries, crosses 31 U.S. states and two Canadian provinces, and forms the world's fourth largest river basin. This basin, herein referred to as a watershed, covers approximately 41% of the land mass of the contiguous United States. Approximately 70 million people live in the watershed—roughly a quarter of the population of the United States. And approximately 20 million people depend on the Mississippi River watershed for safe drinking water.[2] This complex network of river systems supports agriculture, commercial transportation, recreation and fisheries—providing food, jobs and economic security to millions of Americans. For example, 60% of all grain that the United States exports is shipped on the Mississippi River through the Port of New Orleans and the Port of South Louisiana.[3]

1 The Nature Conservancy et al. 2023. Building a Comprehensive "Sentinel" Monitoring System for the Mississippi River.
2 The Nature Conservancy. Mississippi River Basin. https://www.nature.org/en-us/about-us/where-we-work/priority-landscapes/mississippi-river-basin/
3 Mississippi River Facts. U.S. National Park Service.

Estimates of the annual amount of cargo transported up and down the Mississippi River varies. The river was estimated to carry more than 500 million short tons of imports, exports and domestic freight in 2019.[4] Various other sources estimate the annual volume of goods transported as anywhere from 589 to more than 650 million tons (actual tonnage varies due to factors affecting river transportation, including periods of drought, as occurred in 2023). For example, the Arkansas Farm Bureau Ag Insider report from October 2022 estimated that 589 million tons of freight is moved on the Mississippi River annually, a volume of cargo worth more than $150 billion.[5]

2.2 Threats to the Watershed

Threats to the watershed are having devastating impacts on the river, communities, commerce, and habitats and ecosystems.

> Gulf dead zone causes **$82 million** in annual losses for the seafood and tourism industries.

- Weather and climate extremes.
  - Periods of higher intensity flooding across the watershed damage agricultural lands, harm farming livelihoods, and destroy public and private property. From 2015 to 2022, approximately $10 billion was spent on crop insurance payments for rain and flood damage.[6] In addition, episodic droughts caused lower crop yields, even though annual rainfall increased.[7]
  - Periods of drought, such as in 2022, increased hazards for agriculture, recreation and commercial transportation along the Mississippi River and its tributaries. Experts predicted that the economic damage and supply chain impact from the historically low water levels in the Mississippi River would be around $20 billion in 2022.[8] Drought conditions persisted in 2023 and 2024, impacting water levels and flow and consequently affecting commercial barge traffic.
  - Commercial maritime allisions (collisions between vessels and stationary objects) on the Mississippi and its tributaries over the last ten years have caused millions of dollars of damage to river control structures and bridges, river communities, and the commercial maritime industry.

While seasonal periods of high and low flow are normal and are good for ecosystems, the increased frequency and intensity of extreme flooding and drought events in both the upper and lower Mississippi River basins are negatively impacting the health and resilience of ecosystems, leading to reductions in biodiversity and ecosystem services. Damage to ecosystems leads to other risks, such as fragmented habitats and pollution. Fluctuating periods of extreme flooding and drought lead to a loss of natural vegetation and forest cover in floodplains, as well as changes in water levels and shifts in sedimentation that fragment wetlands and aquatic habitats, particularly in the Mississippi River Alluvial basin.[9]

- Commercial maritime allisions. These collisions between vessels and stationary objects on the Mississippi and its tributaries over the last 10 years have caused millions of dollars of damage to river control structures and bridges, river communities and the commercial maritime industry.
- Pollution. Massive amounts of nitrogen and phosphorus from aging sewage treatment plants, agriculture and other sources run off into the river that cause health hazards to people and wildlife, higher water treatment costs and an annual "dead zone" that costs the Gulf of America seafood and tourism industries more than $82 million a year.[10]

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4 Mississippi River Watershed with Major Tributaries and Major Ports. May 19, 2021. Bureau of Transportation Statistics. https://www.bts.gov/modes/maritime-and-inland-waterways/mississippi-river-and-waterborne-freight

5 Agriculture, Shipping Industries Prepare for Uncertainty on Mississippi River in the Future. Waterways Council, Inc. November 9, 2023. https://waterwayscouncil.org/media/in-the-news/article/2023/11/agriculture-shipping-industries-prepare-for-uncertainty-on-mississippi-river-in-the-future

6 Milks, Jason. 2022. Markets for Floodplain Reforestation in the Delta. The Nature Conservancy.

7 Dryfoos, Delaney. November 29, 2023. Climate Report Indicates Dire Future for Mississippi River Basin, Which Is Already Feeling Impact. The Lens.

8 Sorvino, Chloe. October 28, 2022. Drought Expands East To The Mississippi River, Where It's Really Messing Things Up, Chloe Sorvino, citing AccuWeather experts. Forbes.

9 U.S. Global Change Research Program. 2024. *The Fifth National Climate Assessment*.

10 Rabotyagov, S.S., C.L. Kling, P.W. Glassman, et al. 2014. The economics of dead zones: causes, impacts, policy challenges, and a model of the Gulf of Mexico hypoxic zone. Review of Environmental Economics and Policy 8: 58–79.

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- Infrastructure. Human constructions such as levees, navigation channels, locks and dams, and diversions alter natural floodplain function. Historical clearcutting of mature forest stands for agriculture, an expanding human footprint, and changes in land use fragment natural habitat and degrade the natural ability of historic floodplains to mitigate the effects of extreme flooding and drought.
- Invasive species. These species degrade habitat in and around the Mississippi watershed, displace native species and impact aquaculture economies across the basin.
  Rising seas and sinking land. These changes create a need for strategic water and sediment management to sustain coastal wetlands and fisheries.

Decision-makers in government, communities, industry and academia need accurate scientific information from a consistent, integrated, unbiased and transparent monitoring system. Unfortunately, the current system is piecemeal, with substantial investment and robust systems in some areas (e.g., the Long Term Resource Monitoring System element of the Upper Mississippi River Restoration Program) and substandard investment and systems in other areas (e.g., in the Lower Mississippi River). Without equal investment and systemwide integration and expansion to consider new threats, critical information will not be available to protect communities, clean the water and restore critical habitats.

2.3: Tackling the Challenge

Monitoring in the watershed is conducted by numerous federal, state, regional, academic and local groups across the watershed. A lot of monitoring is being done to meet regional or state objectives but there is no set of standardized parameters and measures employed across the watershed by all organizations on an annual or more frequent basis. The sheer diversity and complexity of biological and other factors across ecosystems and habitat types makes monitoring across a vast geography inherently challenging. Among federal, regional and state monitoring, there are differences in what is monitored and the methods used. Further, there are different criteria used by state monitoring programs as well as uneven levels and frequency of monitoring. There are differences in sample design, which influence the representativeness of data and our ability to document uncertainty in water quality estimates. Some states do not regularly fund or report monitoring data at all.

Table 1 provides an overview of monitoring programs along the Mississippi River and its major tributaries.

TABLE 1

Entity	Monitoring Focus	Geographic Area
Federal Agencies		
Environmental Protection Agency (EPA)	Clean air and water standard, air and water quality, nutrient runoff, and pollutants and pollution levels with specific focus on the hypoxic dead zone in the Gulf of America through the EPA's Hypoxia Task Force.	Mississippi River Watershed in collaboration with states who participate.
United States Geological Survey (USGS)	Water quality, stream flows and levels, and invasive species.	Across the entire Mississippi River Watershed.
National Oceanic and Atmospheric Administration (NOAA)/National Weather Service (NWS)	Weather, climate, flood risk, water flow and levels, water quality, nutrient runoff and hypoxia.	Upper, Central and Lower Mississippi and Gulf of America.
United States Army Corps of Engineers (USACE)	Water quality, navigational safety, and flood risk. Support ecosystem health monitoring by the Upper Mississippi River Restoration Program (UMRR).	Across the entire Mississippi River Watershed.
U.S. Fish and Wildlife Service (USFWS)	Invasive species, water quality, threatened and endangered species, and habitat restoration.	Upper and Lower Mississippi River with greatest focus on the Alluvial Valley; Lower Mississippi River; Arkansas, White and Red River; and Tennessee-Cumberland River sub-basins.
Regional Entities/Programs		
Upper Mississippi River Basin Association (UMRBA)	Water quality through UMRBA's Interstate Water Quality Monitoring Program	Upper Mississippi River
Ohio River Valley Water Sanitation Commission (ORSANCO)	Water quality, pollution control and setting pollution standards	Ohio River basin
Long-Term Resource Monitoring (LTRM)[11] element of the Upper Mississippi River Restoration Program (UMRR)	Fish, vegetation, water quality, invertebrates, land cover and bathymetry	Upper Mississippi and Illinois Rivers
Mississippi River Basin Healthy Watershed Initiative (MRBI)[12]	Water quality, wetland and habitat restoration and resilience	12 states: Minnesota, Wisconsin, Iowa, Illinois, Indiana, Ohio, Missouri, Kentucky, Arkansas, Tennessee, Mississippi and Louisiana
State Entities		
Of the 21 states adjacent to the Mississippi River mainstem and major tributaries, all conduct some form of state-based monitoring.	Refer to attached appendix.	Mississippi River and major tributaries

11 UMRR is a federally mandated program. Research and monitoring are conducted through the LTRM. USACE provides overall program leadership responsibility and funding for the LTRM. The LTRM is implemented by USGS in cooperation with Illinois, Iowa, Minnesota, Missouri and Wisconsin. Other partners include the EPA, USFWS, U.S. Department of Agriculture Natural Resources Conservation Office, Minnesota Department of Natural Resources, Wisconsin Department of Natural Resources, Iowa Department of Natural Resources, Illinois Natural History Survey and Missouri Department of Conservation.

12 Created in 2009 and funded through the USDA's Farm Bill programs, including the Environmental Quality Incentives Program (EQIP), to help landowners participate in conservation actions.

Although a good amount of monitoring is being done in places, there are notable gaps that affect the ability to consistently monitor ecosystem and habitat quality across the entire Mississippi River watershed. For example:

- Monitoring capacity and funding are uneven across the Mississippi River watershed. One notable difference is that the Upper Mississippi River Basin has significantly greater monitoring capacity and funding than the Ohio, Missouri and Lower Mississippi River basins.
- While the EPA has established monitoring standards basin-wide through its National Aquatic Resource Surveys (NARS) in collaboration with states and Tribal nations, the national assessments are conducted every five years, and few states or Tribal nations have the capacity to augment that with more intensive sampling.
- More broadly, current monitoring is a patchwork of efforts that are mostly not coordinated across organizations and that are inadequate to address broader watershed-wide needs. Further, given the sheer scale and complexity of ecosystems and differences across habitat types, what is monitored varies across geographic areas, and data are sometimes incomplete or not collected at all.
- The initial information we have been able to get from state monitoring programs suggests that water quality and flows are monitored more comprehensively than ecosystem and habitat quality.

There are **notable gaps** that affect the ability to consistently monitor ecosystem and habitat quality across the entire Mississippi River watershed.

To tackle this set of complex challenges, scientists and technical experts from TNC and federal, regional and state organizations formed a Technical Design Team to determine whether they could define a set of standardized parameters for monitoring ecosystem and habitat quality. Starting in May 2024, they met for several multi-day workshops and developed an initial set of criteria and recommendations for integrating and enhancing existing ecosystem and habitat monitoring efforts as the fourth element of a "Sentinel System."

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3.0 Technical Design Methodology

3.1 The Goal

The Technical Design Team set forth the following goal for ecosystem and habitat quality monitoring:

To obtain consistent, comparable information on current condition and future trends in ecosystem health and habitat quality to understand how changes in climate, land-use, and landscape management affect the Mississippi River, major tributaries, distributaries, and the Gulf of America to inform and assess actions to improve ecological condition.

3.2 Who Will Benefit

Ecosystem and habitat monitoring will provide benefits to a diverse array of commercial, environmental and community audiences, including:

1. Policymakers to inform regulations and policies related to land use, pollution control and species protection, based on monitoring data.
2. Scientists who use monitoring data to study ecological trends, identify threats to habitats and evaluate the effectiveness of conservation efforts.
3. Local communities to gain insights into the health of their local ecosystems, which can impact their access to clean water, recreation and tourism opportunities.
4. Businesses that rely on natural resources, who need to access data to understand potential risks to their operations from environmental changes and make informed decisions about sustainability and investment.
5. Agency restoration partners working with landowners to prioritize restoration within agricultural landscapes.
6. Conservation practitioners aiming to restore habitats and species in an efficient and cost-effective manner.
7. The public, who will benefit from healthier natural areas that support recreational activities and protect communities from extreme flooding and drought.

3.2 Organizations We Engaged

Scientists and technical experts from the following organizations participated in the Technical Design for ecosystem and habitat quality monitoring. In addition to this core group, the Technical Design Team has reached out to state experts from across the watershed for their input on the monitoring they are doing.

TABLE 2

Partner Organizations	Technical Experts
• The Nature Conservancy • America's Watershed Initiative • Upper Mississippi River Basin Association • Upper Mississippi River Conservation Committee • Lower Mississippi River Conservation Committee • Environmental Defense Fund • Mississippi Interstate Cooperative Resource Association • Ohio River Basin Alliance • Ohio River Valley Water Sanitation Commission • Tulane University	• U.S. Environmental Protection Agency • U.S. Geological Survey • U.S. Fish and Wildlife Service • U.S. Army Engineer Research and Development Center • Louisiana Department of Wildlife and Fisheries

3.4 Technical Design Process: Ecosystem and Habitat Quality Monitoring

From May 2024 through January 2025, a cross-disciplinary team of scientists and technical experts worked together to shape the technical design for ecosystem and habitat quality monitoring as part of the broader design of the Sentinel System for the Mississippi River watershed, completed in June 2023.

The team kicked off its work at a multi-day workshop sponsored by TNC in July and August 2024. The objectives of the workshop were to develop a shared understanding of current monitoring efforts throughout the Mississippi River watershed, identify priority indicators for river-wide habitat and ecosystem health, and identify gaps and needs in current monitoring. In these sessions, the Technical Design Team identified five foundational elements of the technical design.

1. The goal and geographic scope for monitoring.
2. A set of "primary interests," or optimal determinants of ecosystem and habitat quality.
3. A set of stressors, or factors that have direct, negative impacts on primary interests and are the main detriments to ecosystem and habitat health.
4. Criteria to identify priority stressors, which are a means to focus on the most serious threats and monitoring activities that are attainable within a 10-year timeframe. This is considered a sufficient time span to incorporate major variations in the hydrology and weather events influencing the rivers and streams.
5. A set of indicators that can be measured to understand the state of stressors.

3.5 Design Criteria

Over the course of three workshops, the Technical Design Team defined each of the five elements of the foundational technical design.

Geographic Scope

First, the scientists and technical experts participating in the workshops engaged in a robust discussion about the scale at which ecosystem and habitat quality monitoring should be conducted to provide effective data on conditions and trends. The discussion revolved around two core questions:

1. "Given the sheer geographic scale of ecosystems and habitats within 1.245 million square miles, what can be realistically measured?"
2. "What diversity of river and terrestrial habitats would provide an optimal measurement of ecosystem and habitat health and trends?"

Given the enormous geography of the entire watershed, the team adopted the sub-basin structure of the Mississippi River watershed used by the Mississippi Interstate Cooperative Resource Association (MICRA), as depicted in Figure 1 (page 10). To begin with a more manageable area of waters within the watershed, the Technical Design Team recommended initially focusing within waterways and battures[13] including surrounding floodplains and smaller watersheds, within the Mississippi River mainstem and the six sub-basins along the mainstem.

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13 A batture is the alluvial land between a river at low-water stage and a levee or bluff, typically referring to land between the levees along the lower Mississippi River.

FIGURE 1

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Primary Interests

Next, the team identified four primary interests of ecosystem and habitat quality.

1. Habitat connectivity—how and to what degree distinct areas of habitat are connected, which can influence the distribution, genetic diversity and health of aquatic, terrestrial and avian plant and animal species.[14]
2. In-stream flows—the amount of water needed in a stream or river to adequately provide for aquatic habitat, riparian vegetation, water quality and healthy wetlands, in addition to human uses such as navigation, recreation and hydropower.[15]
3. Diversity, abundance and distribution of habitat types—a measure of the array of different habitats in a particular ecosystem, with multiple habitats having distinctive physical attributes, functions and species. In short, the number of habitat types and their condition within an ecosystem.
4. Species abundance and distribution—the number and distribution of species within a habitat, including species of special conservation concern.

14 NOAA. What Is Habitat Connectivity and Why Is It Important? https://oceanexplorer.noaa.gov/ocean-fact/habitat-connectivity/
15 North Carolina Department of Environmental Quality. Instream Flow Unit. https://www.deq.nc.gov/about/divisions/water-resources/water-planning/basin-planning/instream-flow-unit

Stressors

Third, the Technical Design Team asked the question: "What detriments negatively impact primary interests across the five sub-basins?" To answer it, the team identified a wide range of stressors from which they selected 14 that have a high impact on the four primary interests.

1. Longitudinal and lateral connectivity
2. Altered hydrograph and water quantity
3. Altered sediment regime and sedimentation
4. Agriculture and urban land use competing with natural land cover
5. Decreased duration of flooding
6. Invasive species (plants)
7. Water pollution and contaminants
8. Water quantity and groundwater recharge
9. Groundwater recharge
10. Climate change altering hydroperiods and flood regimes
11. Diversions of the Mississippi River
12. Artificial drainage (e.g., tile drains), increase in slope and stream power
13. Invasive species (animals)
14. Abundance of wetlands, floodplains and riparian vegetation

Working with these 14 stressors, the team developed criteria to reduce the number of stressors to create a more focused and achievable scope for monitoring, given the sheer diversity and scale of the landscape and the patchwork of existing monitoring programs. To do this, the team identified five criteria for selecting the highest priority stressors.

- The stressor represents a serious threat to an ecosystem or habitat.
- It can be measured.
- We can do something about it.
- There is a high likelihood of correlation to biotic diversity.
- Change can be detected within a 10-year timeframe.

Priority Stressors

Applying the above criteria, the team decided on the following seven high priority stressors:

1. Longitudinal and lateral connectivity
2. Altered hydrograph and water quantity
3. Altered sediment regime and sedimentation
4. Water pollution and contaminants
5. Groundwater recharge
6. Invasive species (animals)
7. Abundance of wetlands, floodplains and riparian vegetation

3.6 Indicators

For the final step in the design workshop, the team defined a set of measurable indicators that can be used to understand the state of each priority stressor.

TABLE 3

Priority Stressors	Indicators
Longitudinal and lateral connectivity	• Linear distance of streams protected by riparian vegetation • Presence of floodplain habitat • Obstructions to flow within floodplain (e.g., Hatchie-Loosahatchie study)
Altered hydrograph and water quantity	• Decreased base flow to streams • Flashiness of flow • Increased discharge • Changes in frequency, direction, timing, or magnitude of inundation of floodplain
Altered sediment regime and sedimentation	• Changes in frequency, direction, timing, or magnitude of inundation of floodplain • Changes in bathymetry • Extreme changes (loss and accumulation) in sedimentation in stream and river channels
Water pollution and contaminants	• Nutrient (N and P) concentration and loading • Number and type of agriculture conservation practices • Dissolved oxygen concentration
Groundwater recharge	• Change in key hydrologic metrics • Groundwater reduction • Change in base flow
Invasive species (animals)	• Distribution and abundance of invasive animal species
Abundance of wetlands, floodplains and riparian vegetation	• Distribution and abundance of each (wetlands, floodplains and riparian vegetation)

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3.7 Additional Research and Considerations: Current State of Monitoring

Following the design workshops, the Technical Design Team determined that it needed additional information to test the hypotheses developed in the workshops and to help identify trends and gaps in monitoring across the watershed. Those questions and the additional research fell into five categories.

1. What monitoring is being done by federal and regional organizations, and how does that align with or differ from the stressors and indicators identified in the design sprints? Source: Presentations by the Environmental Protection Agency (EPA), U.S. Army Corps of Engineers, Engineer Research and Development Center (ERDC), Ohio River Valley Water Sanitation Commission (ORSANCO), Upper Mississippi River Restoration Program Long-Term Resource Monitoring (LTRM) program and consultations with points of contact in these organization to better understand their respective monitoring programs.

2. What monitoring is being done by states in the watershed, focusing on those along the Mississippi River mainstem and major tributaries (Missouri, Ohio, Tennessee-Cumberland and Red/White/Arkansas Rivers). Source: A survey of monitoring programs in 16 states along the Mississippi River mainstem and four major tributaries based on the seven priority stressors and indicators identified by the Technical Design Team.

3. How are regional monitoring programs in the Upper Mississippi and Ohio Rivers structured, and what are their strengths and challenges? Source: Review of regional monitoring organizations, such as LTRM (Upper Mississippi River) and ORSANCO (Ohio River), as models for establishing companion monitoring programs in other sub-basins, such as the Lower Mississippi River Basin, to address gaps in monitoring across the watershed.

4. What are scientists telling us about the current state of monitoring in the Mississippi River watershed? Source: Review of academic papers about ecosystem and habitat monitoring in the watershed.

5. Given the sheer scale of monitoring across extensive miles of waterways and millions of acres of land, should an integrated ecosystem and habitat quality monitoring system be created using a subset of the stressors and indicators identified in the sprint workshops? Is there sufficient understanding of different habitat types to design an integrated approach? What technology can be used to monitor over such a large landscape? Source: Companion research by The Nature Conservancy and the Environmental Defense Fund (EDF) and additional discussions among ERDC, Tulane University, TNC, and EDF Technical Design Team members on priority indicators, the need to refine habitat types that comprise the watershed, and the efficacy of using remote sensing to expand monitoring across large-scale systems.

Following are selected highlights of monitoring work being done for which the team has gathered and evaluated information.

3.8 Federal Monitoring: A Focused View

The EPA, via its National Aquatic Resource Surveys (NARS), works in collaboration with federal partners, states, and Tribes to "to assess the quality of the nation's coastal waters, lakes and reservoirs, rivers and streams, and wetlands using a statistical survey design."[16] NARS surveys and assessment reports include four sets of indicators: biological (e.g., benthic macroinvertebrates, fish populations, wetland vegetation), chemical (e.g., dissolved oxygen, nutrients such as nitrogen and phosphorus, sediments), physical (e.g., riparian vegetative cover, habitat complexity, water clarity), and human or recreational (e.g., contaminants that are harmful to people and fish).[17]

16 United States Environmental Protection Agency. National Aquatic Resource Surveys. https://www.epa.gov/national-aquatic-resource-surveys
17 United States Environmental Protection Agency. Indicators Used in the National Aquatic Resources Surveys, Suite of Indicators. https://www.epa.gov/national-aquatic-resource-surveys/indicators-used-national-aquatic-resource-surveys

The assessments face a variety of challenges. Across the Mississippi River watershed, states and Tribes participate in NARS to support the national and regional scale assessment on a five-year rotating cycle. EPA provides $8 million in funding for sampling and lab work to states and Tribes, though many opt for contract support to monitor the NARS sites that fall within their jurisdiction. While these assessments use nationally consistent and regionally relevant methodologies, only a few states have integrated the NARS rivers and streams protocols into their state monitoring programs. Most state and Tribal monitoring programs are driven by historical practices, resource constraints and a need to address local protection and restoration priorities. While the field and assessment methods support individual state and Tribal needs, the variation in these methods does not support watershed-wide, regional or national assessments.

Although it is not a monitoring program in itself, the EPA's Mississippi River/Gulf of America Hypoxia Task Force is a broad federal, regional, state and Tribal partnership that establishes goals and strategies for reducing the Gulf's coastal hypoxic zone (through state nutrient reduction in the Mississippi River mainstem and tributaries). It has also established goals for restoring and protecting waters within the 31 states and Tribal Lands across the watershed for ecological, economic and community well-being.[18]

ERDC conducts engineering and scientific research and development that support monitoring of civilian and military infrastructure and installation operations, flood control and mitigation, navigational safety, and the environment in technical areas such as habitat remediation and restoration, land planning and management, endangered species, environmental impact analysis and water quality.

The overarching challenge of assessment is that, given the sheer size of the watershed and the diversity across entities doing monitoring, the watershed lacks an effective, integrated methodology and tools to monitor ecosystem and habitat conditions at scale. A working group within the Technical Design Team asked the following question: "How might remote sensing technologies be effectively deployed to monitor habitat and ecosystems conditions across large-scale landscapes and diverse habitat types?" This question is addressed further in the recommendations section of this report.

3.9 State Monitoring: A High-Level Overview

The majority of states along the Mississippi River mainstem and major tributaries conduct varying levels and types of monitoring. Monitoring is often driven by state-specific priorities, funding and structures. States contribute to federal programs, such as the EPA's NARS, using a consistent set of criteria and strategies; however, indicators of ecosystem and habitat stressors still vary at the individual state program level. Most states adjacent to the Mississippi River or one of its major tributaries have a lead agency, such as a Department of Natural Resources or equivalent, that plays a key role in monitoring. In large part, most states work in collaboration with other state or federal agencies to conduct monitoring, and to a lesser extent with academic institutions, nonprofit organizations and citizen groups.

To gather more information about state monitoring programs, the Technical Design Team tasked a working sub-group to design and distribute a survey in the form of a questionnaire to 17 states[19] along the Mississippi River and major tributaries. The survey was based on indicators for each of eight original priority stressors that the Technical Design Team identified (subsequently revised to seven). It included questions about what states were monitoring (according to the priority stressors and indicators), the frequency of monitoring, reporting periods, and gaps in and strengths of each state's programs.

At the time of publication, eight states had responded to the survey instrument: Arkansas, Illinois, Indiana, Louisiana, Minnesota, Missouri, Pennsylvania and Wisconsin. It is important to note that various agencies do different monitoring within a number of the states. The information in Table 4 is preliminary and deserves additional review, as not all states fully reported monitoring activities among all agencies. The table indicates whether states do or do not monitor the stressors being studied.

18 United States Environmental Protection Agency. Mississippi River/Gulf of America Hypoxia Task Force. https://www.epa.gov/ms-htf

19 The survey questionnaire was sent to contacts identified by EPA District heads for monitoring in the states of Alabama, Arkansas, Illinois, Indiana, Iowa, Louisiana, Minnesota, Mississippi, Missouri, Kansas, Kentucky, Nebraska, Ohio, Pennsylvania, Tennessee, West Virginia and Wisconsin.

TABLE 4

Stressors/Indicators	**AR**	**IN**	**IL**	**LA[20]**	**MN**	**MO[21]**	**PA**	**WI**
Longitudinal and lateral connectivity								
Linear distance of streams	N	N	N	N	Y	Y - RAM	N	N
Presence of floodplain habitat	N	N	N	Y (C)	Y	Y - RAM	N	Y
Obstructions to flow within floodplain	N[22]	N	N	Y (C)	N	Y - RAM	N	N
Altered hydrograph								
Decreased base flow in streams	N	Y	N	N	Y	Y-RAM	N	Y
Flashiness of flow	N	Y	N	N	Y		N	Y
Increased discharge	N	Y	N	N	Y		N	Y
Obstructions to flow within floodplain	Y - USGS	N	N	N	N		N	N
Altered sediment regime and sedimentation								
Changes in frequency, direction, timing, or magnitude of inundation of floodplain	N	N	N	Y (C)	Y		N	Y
Changes in bathymetry	N	N	N	N	Y		N	Y
Water pollution and contaminants								
Nutrients (N and P)	Y	Y	N	Y (C)	Y	Y – LTRM, Y - RAM	Y	Y
Agriculture conservation practices	N	Y	N	N	Y		Y	N
Low dissolved oxygen	Y	Y	N	Y (C&D)	Y	Y - LTRM	Y	Y
Water quantity and groundwater recharge								
Groundwater studies	N	N	N	N	Y		Y	N
Altered biotic communities								
Distribution and abundance of key species or functional classes	Y	Y	Y	Y (C&D)	Y	Y - RAM	Y	Y
Fish community sampling	Y	Y	Y	Y (C&D)	Y	Y – LTRM, Y – benthic trawling	Y	Y
Changes in fish population health indices	Y	Y	Y	Y (D)	Y	Y - RAM	Y	N
Invasive species								
Distribution and abundance of invasives	Y	N	Y	Y (C&D)	Y	Y - LTRM	Y	Y
Abundance of wetlands/floodplains/riparian vegetation								
Distribution and abundance of each	N	N	N	Y (C&D)	Y		N	Y

20 Louisiana's Coastal Protection and Restoration Authority (CPRA) and Department of Wildlife & Fisheries (DFW) do different monitoring noted by (C) and (D) in the chart above.

21 Data provided by Missouri indicate where monitoring is done by either the USGS Long-Term Resource Monitoring Program or Missouri's Department of Conservation resources, assessment, and monitoring (RAM) program.

22 Not within floodplain.

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From these data and additional information provided by the states, we drew the following observations:

- Minnesota and Wisconsin appear to have the most comprehensive monitoring coverage across all eight priority stressors and their respective indicators. Neither state monitors obstructions to flow for longitudinal and lateral connectivity or altered hydrograph.
- Monitoring of longitudinal and lateral connectivity is uneven among the eight states that provided data. Louisiana, Minnesota and Wisconsin monitor the presence of floodplain habitat, whereas the other five states do not.
- Indiana, Minnesota and Wisconsin have the most comprehensive coverage in monitoring altered hydrograph, with Arkansas and Missouri each monitoring one different indicator.
- Five of the eight states monitor abundance of wetlands, floodplains and riparian vegetation.
- All states but one monitor water pollution and contaminants (nutrients and low dissolved oxygen).
- Arkansas, Louisiana, Indiana and Illinois have established monitoring programs, although none reported monitoring longitudinal or lateral connectivity, altered sediment regimes and sedimentation, or water quantity and groundwater recharge.
- All eight states monitor the majority of indicators for altered biotic communities.
- Seven of the eight states monitor invasive species.
- Of these eight states, only three monitor abundance of wetlands/floodplains: Louisiana, Minnesota and Wisconsin.

The frequency of monitoring varies across states depending on what is being monitored. The frequency ranges from monthly and seasonally to annually or every 3 to 5 years. Similarly, there are variances in the duration of data collected. The full set of data submitted by these eight states can be found here.

For states that have not yet responded to the survey, the working group collected high-level data from state monitoring agency websites. The following high-level trends were identified:

While a good deal of monitoring is being done, states are using **different parameters and criteria.**

- States in the Upper Mississippi River Basin have some similarities in what they monitor but also have different established monitoring goals and strategies, programs, networks and assessments.
- Overall, state monitoring priorities are largely driven by state-specific strategies, goals and legislation.
- About half the states we researched appear to monitor linear distance of streams protected by riparian vegetation (but this needs to be confirmed by individual states). A greater number appear to monitor the presence of floodplain habitat and obstructions to flow within floodplains, although the parameters for monitoring vary among states.
- Most states along the Mississippi River and major tributaries monitor (either directly or through regional entities) nutrients such as nitrogen and phosphorus, as well as dissolved oxygen.
- Most of the states monitor altered biotic communities, in particular, aquatic species—including fish populations.
- Most of the states monitor invasive plant and animal species, although species vary by geography. The most commonly cited invasive animal species monitored are zebra mussels and invasive carp.
- Not all states monitor the distribution and abundance of wetlands, floodplains and riparian vegetation. Site selection is largely driven by individual state goals and strategies.
- While a number of states monitor longitudinal and lateral connectivity and abundance of wetlands, floodplains and riparian vegetation, further research is needed to determine the degree to which consistent or comparable indicators are employed at sites across a larger geography.
- Where regional monitoring or governance bodies exist, our research shows that there is a greater degree of consistent collaboration across state monitoring priorities and efforts.
- Some states monitor a greater number of waterways and land areas of a larger geography than other states.

In sum, while a good deal of monitoring is being done, the initial review of monitoring across the states we researched indicates that the states are using different parameters and criteria to conduct the monitoring. While this is primarily due to the diversity across the landscape, it is also a factor of different state priorities and localized needs.

At the time of publication, further information should be gathered about state-based monitoring in each of the 17 states surveyed along the Upper and Lower Mississippi River basins and the river's major tributaries.

3.10 Regional Monitoring in the Ohio River and Upper Mississippi Basins

ORSANCO, established in 1948, is an interstate compact agency for the Ohio River basin. It represents eight states and the federal government, and its mission is to protect the water quality of the Ohio River and its tributaries so that these waterbodies can continue to be used as a source of drinking water, industrial supply, and recreation, and so that they can support healthy and diverse aquatic communities. ORSANCO provides water quality monitoring and assessment, spill detection and emergency response services and is also involved in setting Ohio River pollution discharge control standards through policy engagement and public involvement.

ORSANCO receives approximately $1.5 million in federal funds (primarily through the EPA Clean Water Act, Section 106) and $1.5 million in state funds annually. It is governed by a commission made up of governor-appointed commissioners, which meets three times a year. In addition, ORSANCO uses standing and advisory committees that include stakeholders and technical experts to discuss relevant issues and challenges in the Ohio River basin. The organization has approximately 24 staff, half of which are technical staff.

ORSANCO's monitoring activities are largely within the Ohio River and its tributaries. The majority of monitoring activities center around water quality and include bimonthly sampling at 17 fixed sites on the Ohio River and 16 fixed sites on tributaries. In addition, ORSANCO conducts metal tests and bacteria monitoring for contact recreation and monitors harmful algal blooms. The agency also has an organics detection system for emergency spill response monitoring. ORSANCO monitors fish and macroinvertebrate assemblages in each of the 19 navigation pools in the Ohio River every five to seven years and collects samples to inform fish consumption advisories. Finally, ORSANCO staff support the U.S. EPA's National Rivers and Streams Assessment program through monitoring sites in several basin states.

One challenge to monitoring is that over the past 15 years, there has been little change in annual funding, and it has been difficult to keep pace with inflation. There have been efforts to adjust the organization's authorizing language regarding ORSANCO's ability to accept additional funds. ORSANCO is currently working with non-government organizations (NGOs) and USACE to draft the Ohio River Restoration Plan to enhance opportunities to improve habitat in the Ohio River basin.

The keys to long-term success for ORSANCO are regular communication and coordination among partners and stakeholders. Committees provide an in-person venue for issues to be discussed and settled among partners and for on-the-ground technical representation to inform monitoring parameters, methods and design. These committee meetings promote trust and collaboration among committee members.[23] Also key to ORSANCO's long-term success in the Ohio River basin has been the dedication of caring staff.

The Upper Mississippi River Restoration (UMRR) program is federally funded and was first authorized in the 1986 Water Resources Development Act (WRDA). In its authorization, Congress acted on a recommendation of the Upper Mississippi River Basin Commission to sustain the river as both a transportation corridor and a vital ecosystem by funding construction of a lock and dam and a restoration and monitoring program. In 1986, WRDA stated "...it is hereby declared to be the intent of Congress to recognize that system as a nationally significant ecosystem and a nationally significant commercial navigation system."[24]

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There are two elements within the UMRR: the Habitat Rehabilitation and Enhancement Project and Long-Term Resource Monitoring (LTRM). Within LTRM, annual monitoring includes water quality, aquatic vegetation and fish communities in six study reaches (Pool 4, Pool 8, Pool 13, Pool 26 and portions of the open river in the Upper Mississippi River and the La Grange Pool of the Illinois River).[25] In addition to annual monitoring, LTRM has analyzed decadal landcover (1989, 2000, 2010 and 2020) and has provided systemic topo-bathymetric data.

In the 2020 Water Resources Development Act, annual authorization for LTRM was increased from $10 million to $15 million. In 2024, base monitoring funds were $7.8 million. The base monitoring program includes collection of the long-term data as well as support for research scientists to analyze long-term data and conduct associated research. Currently, a base level of roughly $8.5 million or $9 million covers basic field collections, some basic data serving, equipment refreshment, and a limited number of analyses, reports and publications. However, additional LTRM funding through "science in support" dollars is enhancing LTRM's capacity to produce more cutting-edge, impactful research informing management on the river. LTRM is supported through

23 Argo, Ryan. ORSANCO. January 2025.

24 U.S. House of Representatives. 33 U.S. Code 652: Upper Mississippi River Management, subsection (a)(2). 1986. https://uscode.house.gov/view.xhtml?req=(title:33%20section:652%20edition:prelim)#:~:text=(2)%20To%20ensure%20the%20coordinated,;%20and%20Kaskaskia%20River%2C%20Illinoi

25 De Jagar, Nathan, James T. Rogala, Jason J. Rohweder, et al. 2018. Indicators of Ecosystem Structure and Function for the Upper Mississippi River System. U.S. Department of the Interior. U.S. Geological Survey.

a partnership among the U.S. Geological Survey (USGS), USACE, U.S. Fish and Wildlife Service (USFWS), EPA, the U.S. Department of Agriculture (USDA) and the Natural Resources Conservation Service (NRCS). Funds are distributed to six state-led field stations, with partner agencies being the Minnesota Department of Natural Resources, Wisconsin Department of Natural Resources, Iowa Department of Natural Resources, Illinois Natural History Survey and Missouri Department of Conservation. Each field station has between four and eight full-time staff and seasonal employees. Funds beyond base monitoring support complementary research projects that are identified through biennial partner science meetings and other partnership venues.

When LTRM began in 1988, monitoring occurred at a selected sample of fixed sites. In 1993, a stratified random sampling design was implemented and most of the fixed sites were discontinued. The stratified random sampling design was adopted to detect patterns and trends at broad spatial (e.g., navigation pool and strata) and temporal (e.g., annual, decadal) scales. Approximately 450 sites are sampled for aquatic vegetation annually within Pools 4, 8 and 13. Water quality is monitored quarterly with approximately 120–150 samples per reach each season. An additional 9–19 fixed sites within and surrounding each of the six key pools are monitored annually for water quality. Fish monitoring is conducted at approximately 200–300 sites annually using a multi-gear approach (e.g., day electrofishing, hoop nets, fyke nets). Select habitat variables (e.g., vegetation cover, sediment type, woody debris) are measured at each site under the different monitoring components. All components have standardized sampling procedures, and field staff meet regularly to ensure consistency.

Regarding challenges with the program, early on, a decision was made to switch from fixed sites to a stratified random sampling design to better make inferences at the strata and pool scale. The first five years of fixed site monitoring are rarely used in comprehensive analyses but have been useful in trend and local habitat evaluations. However, the design-based inferences made possible by the stratified random sampling design provide insights and understanding at scales that would not have been possible with the initial fixed site sampling design. Over the years, there have been fluctuations in funding, requiring reductions in sampling (especially around 2003, when overall sampling effort across components was reduced and the macroinvertebrate component was discontinued). In recent years, funding has increased, and the macroinvertebrate component has resumed. One of the fundamental challenges with a long-term monitoring program that is funded through annual appropriations is maintaining a sustainable, long-term, base monitoring effort while maintaining the flexibility to do additional work in years with additional funding beyond the base cost.

UMRR has made partnership a **central component** of its organizational structure and invested in partner relationships.

A fundamental key to the long-term success of UMRR is that it is operated in a true spirit of partnership. Multiple federal and state agencies and several NGOs committed to collaborating in a partnership approach to long-term monitoring and river restoration, which provides the program with the ability to do things that no individual agency would be able to do on its own. UMRR has made partnership a central component of its organizational structure and invested in partner relationships. Communication and coordination among partners are enabled through different river teams that work on a wide range of issues beyond the UMRR program, as well as a Coordinating Committee that is specific to the UMRR program.

In addition, success is fostered by both the original intent of Congress—to manage the river for both ecosystem health and commercial navigation purposes—and by the five states' commitment to achieving that dual-purpose goal. That commitment was codified in 1981 by state executive orders establishing the Upper Mississippi River Basin Association (UMRBA). When the joint federal–state UMR Basin Commission was terminated in 1981 by presidential executive order, the governors of Illinois, Iowa, Minnesota, Missouri and Wisconsin signed a joint resolution calling for "the continuation of an interstate organization to maintain communication and cooperation among the states on matters related to water planning and management." Each governor then issued an Executive Order establishing membership in the association. The UMRBA subsequently worked with Congress and federal agencies to implement recommendations from the 1981 UMR Basin Commission Master Plan, including the establishment of an ecosystem restoration and monitoring program (i.e., UMRR LTRM) and construction of a second lock at L&D 26. The five states' continued prioritization of ecosystem management and commercial navigation is expressed through UMRBA's work, thereby contributing significantly to the longevity of the UMRR LTRM.

An important component of the long-term success of LTRM is its commitment to and support of substantial research based on the long-term data. That is, the data are used extensively, and results are published and presented widely. Substantial effort goes into extracting information and understanding the long-term data and complementary data sets. Biennial science meetings serve as a forum for all partner agencies to contribute to the decisions regarding what research to prioritize and how to approach it. In addition, the UMRR's Habitat Rehabilitation and Enhancement Project actively uses LTRM data to inform past and current habitat rehabilitation projects, and there is a trajectory of increased integration of the two program elements.

All of the LTRM data are shared publicly in several forms.[26] Full data sets can be downloaded or used in "graphical data browsers" where users can select a parameter of interest and see summary graphs showing how that parameter has changed through time in the different study reaches and the different strata within those reaches. The stratified random sampling design and LTRM field methods have been adopted and applied in other river systems; in particular, fish sampling in the Illinois River has expanded to other reaches as part of a multi-agency monitoring program for invasive carp.

In recent years, UMRR has also increased its emphasis on communication and outreach. One example is the joint USGS/USACE press release that accompanied the 2022 Ecological Status and Trends of the Upper Mississippi and Illinois Rivers report. These press releases and presentations in various venues resulted in substantial press coverage of that report and the larger program.[27]

In summary, ORSANCO and LTRM are already working across states to monitor a good portion of the indicators that were identified as important by the Technical Design Team. These two programs are good examples that show it is possible to work across multiple states and across larger landscape scales to conduct ecosystem and habitat quality monitoring.

3.11 Monitoring Ecosystem and Habitat Quality at Scale

One of the most challenging issues to designing a comprehensive monitoring approach for ecosystem and habitat quality across the Mississippi River watershed is the complexity of ecosystems and habitat types over an enormous and geographically diverse area. For example, there are approximately 30 Level III ecoregions in the Mississippi River watershed and over 100,000 tributaries ranging from Strahler stream order 1 to 10. The Technical Design Team identified three important questions that were discussed and may require further research:

1. What indicators are a reasonable subset to launch a comprehensive monitoring effort across the watershed's vast geography?
2. How do we classify habitat types and their species across the watershed to consistently measure ecosystem and habitat conditions and changes in health over time?
3. What methods are available to monitor conditions both accurately and in a timely manner to provide valid data about ecosystem and habitat quality at scale?

Currently, ecosystem and habitat quality assessments are largely conducted at the state level, with only a couple of successful regional efforts. This is likely because funding has historically been intended to "promote restoration of historic ecosystem conditions."[28] Therefore, it is reasonable to speculate that state-based monitoring evolved from historic guidance, such as the Clean Water Act of 1972, to use data to restore ecosystem conditions to previously determined values. However, this focus on local ecosystem restoration may no longer be a viable outcome for habitat and ecosystem health, given the large scale and duration of negative impacts from human needs and the impacts of extreme weather events in the watershed. For example, in response to the Clean Water Act, a multi-billion-dollar industry has developed to promote stream, wetland and river restoration—but with its emphasis on restoring geomorphic form, it has not, in general, led to improved water quality or recolonization of "restored" streams and rivers by desired biota.[29]

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26 USGS, Upper Mississippi River Restoration Program, Long-Term Resource Monitoring. https://umesc.usgs.gov/ltrm-home.html
27 Bouska, Kristen. As reported by UMRR and LTRM, January 2025.
28 McLellan, E.L., K.M. Suttles, K.L. Bouska, et al. 2024. Improving ecosystem health in highly altered river basins: a generalized framework and its application to the Mississippi-Atchafalaya River Basin. Frontiers in Environmental Science 12. https://doi.org/10.3389/fenvs.2024.1332934.
29 Bernhardt, E.S., and M.A. Palmer. 2021. River restoration: the fuzzy logic of repairing reaches to reverse catchment scale degradation. Ecological Applications 21 (6): 1926–1931. https://doi.org:10.1890/10-1574.1.

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It may be time to shift from an emphasis of restoring systems to historic conditions to a more adaptive approach, in which the goal is not re-creation of historic condition, but rather restoration and/or enhancement of ecological processes that support biodiversity.[30,31,32] To do this, McLellan et al., a Whole River Collaborative Science Team led by the Environmental Defense Fund (EDF), proposed a generalized framework for improving ecosystem health and applied that framework to the Mississippi-Atchafalaya River basin. This framework identified a set of priority stressors and both leading and lagging indicators for measuring impacts of stressors on ecological processes and functions. Leading indicators are forward-looking, directly related to management actions and can be used to predict future changes in ecosystems, whereas "lagging" indicators are retrospective, showing how the ecosystem has responded to past changes.[33] McLellan et al. proposed a set of 20-year goals, targets and indicators for measuring trends in the conditions of ecosystems and habitat quality at the scale of the Mississippi River basin.

Building upon the recommendations in McLellan et al., EDF led a collaborative scientific exercise to extract a set of goals, targets and indicators that could be readily gathered and/or potentially monitored with remote sensing approaches, so that action could commence quickly. In the *Whole River Goals and Targets Final Report* produced by EDF, the authors recommend the following ecological and social goals, targets and indicators for ecological monitoring at scale. Additional criteria added by scientists reviewing this report are indicated with an asterisk (*).

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30 Beechie, T.J., D.A. Sear, J.D. Olden, et al. 2010. Process-based principles for restoring river ecosystems. BioScience 60: 209–222 https://doi.org/10.1525/bio.2010.60.3.7

31 Palmer, M.A., and A. Ruhi. 2019. Linkages between flow regime, biota, and ecosystem processes: implications for river restoration. Science 365 (6459): eaaw2087. https://doi.org:10.1126/science.aaw2087.

32 Palmer, M.A., K.L. Hondula, and B.J. Koch. 2014. Ecological restoration of streams and rivers: shifting strategies and shifting goals. Annual Review Ecology, Evolution, and Systematics 45: 247–269. https://doi:10.1146/annurev-ecolsys-120213-091935.

33 Whole River Collaborative Science Team (Environmental Defense Fund: Will McDow, Allie Olsonoski, Eileen McLellan, Kelly Suttles; National Audubon Society: Shubham Datta, Tara Hohman, Erik Johnson, Nat Miller; National Wildlife Federation: Jessica Espenshade, Alisha Renfro; The Nature Conservancy: Shamitha Keerthi, Nick Ohde, Bryan Piazza; Theodore Roosevelt Conservation Partnership: Jamelle Ellis). December 2024. Whole River Collaborative Goals and Targets.

TABLE 5

Ecological			
Category	**Goal (Direction)**	**Target in 20 Years**	**Measurement**
Water Quality	The chemical, physical, and biological condition of streams, rivers and lakes in the basin has improved to support better **ecological functioning** (e.g., reduced eutrophication).	N and P loads are reduced by the amount specified by the Gulf Hypoxia Task Force by 2050. Increased number of stream and river segments and lakes that meet Clean Water Act aquatic life uses.	N and P loads are measured each year by the Gulf Hypoxia Task Force. Increase or decrease in riparian buffer area is from the USFS dataset. The extent of river and stream miles in the watershed in good condition comes from NARS biological condition indicators.*
Water Quantity	Water availability is adaptively managed to meet the **needs of wildlife and landscape** in the right amount at the right place, and right time.	Increased water storage, reduced impervious surfaces, increased infiltration in the landscape.	
Habitat	The physical and biological condition and amount of plant and animal habitat in the basin has improved.	Maintained and expanded amount of habitat.	Changes in natural land cover.

Social/Community			
Category	**Goal (Direction)**	**Target in 20 Years**	**Measurement**
Water Quality	The chemical, physical and biological condition of streams, lakes and wetlands in the basin has improved to better support **human and community needs** (e.g., drinking water, food) **and uses** (e.g., recreation).	All stream and river segments and lakes meet CWA contact recreation and public water supply uses by 2050.	Number of streams that meet CWA standard. Extent of river and stream miles in the watershed in good condition for NARS recreational indicators.*
Water Quantity	Water availability is adaptively managed to meet the **needs and uses of humans and community** in the right amount at the right place, and right time.	Fewer people are vulnerable to flooding. More people have access to adequate water supplies.	Reference the FloodPop dataset as source for measures.[34] *
Habitat	The condition and amount of plant and animal **habitat in the basin has improved to better support human and community needs and uses** (recreational, health, aesthetic, economic, social).		

34 Gold, A.C., and I. Steinberg-McElroy. 2025. High-resolution estimates of the US population in fluvial or coastal flood hazard areas. Nature: Scientific Data 12, Article number 1377. https://www.nature.com/articles/s41597-025-05717-y.

In The Nature Conservancy's 2023 report, *Building a Comprehensive "Sentinel" Monitoring System for the Mississippi River*, a team of scientists and technical experts established specific metrics for monitoring water quality as part of three elements identified for creating a comprehensive monitoring approach: water quality, flood and drought resilience and management, and navigation safety. Their recommendations for monitoring nitrogen and phosphorus levels in key waterways are consistent with the *Whole River Goals and Targets Final Report.* Based on the volume and importance of waterways across the watershed, the Technical Design Team determined that water quality and quantity (in-stream flows) should also be considered measures of ecosystem and habitat quality.

Another important body of work is *Status and Trends of Wetlands in the Conterminous United States 2009 to 2019, U.S. Fish and Wildlife Service Report to Congress*. Published in 2024, it is the sixth in a series of congressionally mandated reports over 70 years that provide scientific estimates of wetland areas in the contiguous United States, as well as wetland changes and recommendations to reduce wetland loss. The study showed a significant increase (nearly 50%) in net wetland loss since 2009, a net annual loss of vegetated wetland that increased by nearly 50% (compared to annual losses in the prior study period) and a net increase in non-vegetated wetlands. The study data show an overall increase in the proportion of non-vegetated wetlands at the expense of vegetated wetlands, which has a significant impact on the health of habitats and habitat species and the communities that reside in and near them.[35]

3.12 Key Indicators to Start Measuring at Scale

Drawing on the recommendations of these bodies of work, and evaluating the complexity of ecosystem and habitat monitoring at scale, the Technical Design Team proposes focusing on a sub-set of indicators and the use of remote sensing technologies that would help launch more integrated and comprehensive monitoring across multiple habitat types.

The four primary interests identified by the Technical Design Team are (1) habitat connectivity; (2) in-stream flows; (3) diversity, abundance and distribution of habitat types; and (4) species abundance and distribution. As it is not feasible at this point to monitor all the indicators for the seven priority stressors identified by the Technical Design Team (see page 9 of this report), the team suggests anchoring habitat and ecosystem monitoring on the following two primary stressors:

- Longitudinal and lateral connectivity
- Abundance of wetlands, floodplains and riparian vegetation

In conjunction with monitoring water quality and quantity, focusing on these two primary stressors will provide a solid foundation for understanding habitat and ecosystem changes and health over time.

Classification and Selection of Habitat Types

There are approximately 30 Level III ecoregions in the Mississippi River watershed and over 100,000 tributaries, as mentioned previously. Given the vast diversity of habitat types, comprehensive monitoring will be improved by a better classification of habitat types and their species than currently exists so that it will be possible to use remote sensing to estimate the extent and change in habitats and corresponding species. Given the vast geography, we need to meet two specific needs in order to do this. The first is a better classification of habitat types, using the following assumptions:

- Agree on a hierarchical habitat classification for the basin (e.g., macro, meso, micro)
  - Impounded vs. free flowing
  - Rivers – channel width, channel sinuosity, slope, riparian
  - Floodplains – width, vegetation, waterbodies (defined)

35 Lang, M.W., J.C. Ingebritsen, and R.K. Griffin. Status and Trends of Wetlands in the Conterminous United States 2009 to 2019. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 2024. 43 pp. https://www.fws.gov/sites/default/files/documents/2024-04/wetlands-status-and-trends-report-2009-to-2019_0.pdf.

- Focus on habitat complexity using remote sensing. Assume that habitat type dictates known fish/invertebrate assemblages validated by selective field studies.
- View rivers as a spatially heterogenous scene, not disjunct reaches.

The second need is a standardized, accepted linkage of species to habitat types across the entire watershed, following a key biological assumption that the type of habitat dictates the abundance and diversity of aquatic communities. As it is not feasible to sample every habitat over such a large geography, using remote sensing will require a standardized field data collection protocol done across a sampling of habitats across states in the watershed to link species to specific habitats. With that linkage, we can use remote sensing to evaluate biotic indicators and trends basin-wide. A field data collection effort like this would require a collaborative effort among state and federal partners to establish those relationships so that we can employ a remote sensing approach at scale.

Use of Remote Sensing at Scale

Remote sensing can address the two primary indicators recommended by the Technical Design Team.

However, there are outstanding questions of how remotely sensed variables can be used to assess abiotic variables like altered sediment regime, sedimentations, in-stream flow variables, water quantity, and groundwater recharge on a basin-wide scale. In 2021, Scanlon et al. published an article on sustainability of water resources using remote sensing.[36] There are replicable examples of using remote sensing to identify and classify both abiotic and biotic habitat variables. For example, in 2016, an article published in *Geomorphology* provides baseline information for conducting remote sensing at large scales in water habitats.[37] Remote sensing has also been useful at both small scales and larger basin-wide scales. For example, the use of high-resolution, low-elevation airborne imagery is useful for mapping primary fluvial variables (e.g., river bathymetry, substrate grain size, water temperature) and inferred hydraulic variables (e.g., flow velocity). However, for surveys over larger river networks, these flights may prove too costly. When aerial imagery is cost prohibitive, commercially available satellite imagery with submeter resolution (panchromatic) and 2-m resolution (multi-spectral), such as that provided by WorldView, Geoeye, and Quickbird, can be used. Satellites can cover hundreds of river kilometers at submeter resolution at a much lower cost than airborne or boat-based surveys, particularly in remote regions with poor or no access that are not near airfields.

Another example of using remote sensing for monitoring longitudinal and lateral connectivity and abundance of wetlands, floodplains and riparian vegetation could be scaled for monitoring across the watershed. In *Identification of Artificial Levees in the Contiguous United States*, the authors "tested different geomorphic, land cover and spatial variables" developed from national datasets and global information system models to locate over 182,000 kilometers of undocumented artificial levees in the 100-year floodplain along the Mississippi and Missouri River sub-basins. The authors used seven diverse eight-hydrologic unit code basins for their case study.[38]

Finally, in the Hatchie-Loosahatchie Mississippi River Ecosystem Restoration Study conducted by the USACE, engineers and scientists used remote sensing technology to gather data on "aquatic habitat, floodplain forests, and scarce vegetative communities" correlated with biotic indicators to make restoration recommendations for the Hatchie-Loosahatchie River along miles 775–736. The Corps used remote sensing technology to inventory habitat conditions across 11 ecological geographic complexes based on the geomorphology and hydrology of the floodplain.[39]

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36 Scanlon, B.R., A. Rateb, D.R. Pool, et al. 2021. Effects of climate and irrigation on GRACE-based estimates of water storage changes in major US aquifers. Environmental Research Letters 16: 094009. https://iopscience.iop.org/article/10.1088/1748-9326/ac16ff.

37 Hugue, F., M. Lapointe, B.C. Eaton, et al. 2016. Satellite-based remote sensing of running water habitats at large riverscape scales: Tools to analyze habitat heterogeneity for river ecosystem management. Geomorphology (Amsterdam, Netherlands) 253: 353–369. https://ui.adsabs.harvard.edu/abs/2016Geomo.253..353H/abstract.

38 Knox, R.L., R.R. Morrison, and E.E. Wohl. 2022. Identification of artificial levees in the contiguous United States. Water Resources Research 58: e2021WR031308. https://doi.org/10.1029/2021WR031308.

39 U.S. Army Corps of Engineers, Mississippi Valley Divisions, Regional Planning and Environmental Division South. February 2023. Hatchie-Loosahatchie Mississippi River Ecosystem Study Mile 775-736, TN and AR. https://www.mvm.usace.army.mil/Portals/51/docs/missions/Hatchie/00%20Loosahatchie%20Files/Main%20Report%20DIFR-DEA.pdf.

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Whatever technique is used, remote sensing can provide standardized information on a range of abiotic and biotic habitat variables that are important to understanding changes across the watershed:

- Channel area, channel widths, island area, sinuosity and floodplain widths using LiDAR-derived terrain maps, aerial imagery, and maps
- Indices—sinuosity, river braiding index, hydromorphological index of diversity (HMID) of floodplains
- Connectivity—hydrologic connectivity of floodplain waterbodies using satellite imagery, stream gauge data, and geospatial information
- Possible method—Group on Earth Observations Biodiversity Observation Network (GEO BON), an international method to monitor habitat using remote sensing.

Whatever technique is used, **remote sensing** can provide standardized information on a range of abiotic and biotic habitat variables that are important to understanding changes across the watershed.

To make a final recommendation on approach, it will be necessary to convene a scientific team consisting of ecologists, remote sensing and GIS experts who can finalize the best approach for application in the Mississippi River watershed.

4.0 System Design Recommendations

While we have made great progress in defining an ecosystem and habitat monitoring approach, further research and testing are needed to definitively determine what capacity and gaps exist in monitoring across the watershed and to propose the best methodologies for comprehensive ecosystem and habitat monitoring. The work of the Technical Design Team has laid the foundation for further design work. In this phase of work, the Technical Design Team encountered several key problems in defining technical design criteria for an integrated system to monitor ecosystem and habitat quality:

1. There is no cooperative management body that sets and uses a common set of indicators for monitoring fisheries.
2. State monitoring activity is disparate and focused on state-specific needs rather than on ecosystem or basin-wide habitat processes and health.
3. Monitoring capacity varies throughout the watershed and there is a general lack of capacity beyond the Upper Mississippi River. There is scarce coordination of monitoring across sub-basins.
4. The sheer scope and scale of monitoring ecosystems and habitat across the watershed will likely require significant investments in monitoring technology, coordination and capacity over time.

To address these problems and make tangible progress in the remaining design and implementation of a Comprehensive Mississippi River Monitoring System, the Technical Design Team proposes the following recommendations.

4.1 Champion and Fund Efforts to Create Shared Management Goals for the Watershed

Support the following two current efforts to create and fund cooperative management bodies to develop a comprehensive science strategy to support ecosystem management, enhance interjurisdictional fisheries management and set ecosystem management goals for the watershed. Once goals are established, it will then be possible to create a comprehensive monitoring system with shared targets and indicators.

(a) In 2025, U.S. Senator Roger Wicker, R-Miss., introduced the *Mississippi River Basin Fisheries Commission Act of 2025*, a bill designed to enhance fisheries management and environmental quality throughout the Mississippi River basin. Representatives Mike Ezell, Mississippi, and Troy Carter, Louisiana, also introduced this bill in the U.S. House of Representatives. The legislation would establish a federally funded commission to establish cooperative management for interjurisdictional fisheries management across the watershed. The commission would receive federal funding to support fisheries management, restoration projects, conservation initiatives and research. It would also reinforce existing partnerships among agencies with interjurisdictional fisheries management responsibility across the watershed.

(b) Support and help fund the America's Watershed Initiative to create a partnership with a set of focused goals and objectives for broader Mississippi River watershed action to remedy poor water quality, the impacts of flood and drought, aging infrastructure, degraded and disconnected habitat, and inequitable access to recreational opportunities. During the collaboration's June 2024 workshop in St. Louis, Missouri, there was clear interest in taking a more comprehensive approach to monitoring, which was perceived to have compelling value.[40]

4.2 Build and Implement Greater Shared Monitoring Capacity Across the Watershed

Ensure continued support and funding of EPA's NARS program, including compounded inflation so that it will be able to operate over the next 25 years. Funding must address any gaps in monitoring indicators and implementation to integrate the national program with a comprehensive ecosystem and habitat monitoring system for the watershed.

In addition, we should ensure that regional monitoring programs remain intact and receive required annual funding to operate and enhance capacity (e.g., LTRM, ORSANCO).

Using LTRM and ORSANCO as models, we recommend designing, developing and engaging monitoring entities in all sub-basins across the Mississippi River watershed to create a coordinated monitoring system.

40 Summary Report of Workshop Proceedings and Actions. Mississippi River Watershed Partnership Workshop. August 2024.

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4.3 Fund and Complete an Assessment of Existing Monitoring Programs Throughout the Watershed

Fund a concentrated effort to complete the identification of what state agencies are monitoring. As mentioned previously in this report, the Technical Design Team has begun this work, although completing it extends beyond the scope and timeline of this effort. Further, the Technical Design Team recommends engaging state representatives in monitoring agencies so that future work further incorporates state data, programmatic knowledge and perspectives.

4.4 Identify a Consistent Set of Monitoring Parameters for the Watershed

Fund a team of technical experts to finalize a priority subset of indicators, measures and targeted outcomes that will serve as the foundation for watershed-wide parameters for measuring ecosystem and habitat health for use by federal, state and independent monitoring entities. In addition, we recommend leveraging NARS for tracking long-term changes in consistent indicators of the health of rivers, streams, lakes and wetlands throughout the watershed. Based on EDF's work and discussions with scientists in this phase of designing a comprehensive monitoring system, the Technical Design Team recommends focusing on a sub-set of ecosystem and habitat stressors and leading and lagging indicators as a starting point. These include (1) water quality, (2) water quantity, (3) longitudinal and lateral connectivity, and (4) abundance of wetlands, floodplains and riparian vegetation) for measuring the impacts of stressors on ecological processes and functions.

4.5 Better Define Habitat Types and Associated Species in the Mississippi River Watershed

Fund a scientific team consisting of ecologists, remote sensing experts and GIS experts to finalize the best approach for application of remote sensing to track abiotic and biotic indicators in the Mississippi River watershed.

Given the geographic scope of the Mississippi River watershed, we recommend using a remote sensing approach to develop habitat maps as a first phase to create a set of consistent habitat and species conditions and criteria that can be used for widespread monitoring. Once habitat maps are developed, it may be necessary to define or locate a reference condition. For example, in some watersheds (e.g., Big Sunflower), impairment has progressed to the point where reference sites cannot be located. Using Stoddard's classification (minimally disturbed, least disturbed, best attainable), it may be possible to identify high-quality sites that serve as potential endpoints in restoration/management.

4.6 Test Remote Sensing at Two Sites in Different Habitat Types

We recommend funding additional research on existing remote sensing technologies and their potential application for comprehensive ecosystem and habitat quality monitoring in the watershed. In particular, we should fund and implement remote sensing tests at two different habitat sites to assess the efficacy of the remote sensing techniques and proposed set of indicators above.

Site selection should consider the following:

- Waterbody type, regardless of latitude, should be the primary criteria during the testing phase. Incorporate latitude and ecoregion in the site-selection criteria once the full program is initiated.
- Select sites that can be leveraged with other programs to defray costs and garner support (e.g., MR&T).

The following is a suggested list of waterbody type criteria for selecting test sites:

- Stream Order:
  - Larger rivers with Strahler stream order greater than 6 (Mississippi and Missouri rivers are a stream order of 10)
  - Medium-sized rivers with Strahler stream order 3–6
  - Smaller streams with Strahler stream order 1–2 (avoid these first-order streams initially to reduce the number of sites, as many are ephemeral)
- Impoundments:
  - For larger rivers, impounded mainstem (locks and dams, reservoirs) versus non-impounded (free-flowing)
  - For medium-sized rivers, regulated or not regulated by upstream reservoirs
- Levees:
  - With levees/without levees
  - For those with levees, presence or absence of an active floodplain between the levees

4.7 Implement a Collective Data Management System and Expand User Access through a Unified Interface

Fund the design and implementation of a shared interface of comprehensive monitoring data, with a specific focus on the proposed indicators and with information to track change in habitat quality. Please refer to The Nature Conservancy's 2023 report Building a Comprehensive "Sentinel" Monitoring System for the Mississippi River for recommendations on creating a shared user interface for watershed-wide monitoring data.

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5.0 Summary

From 2021 to 2025, our work with technical experts from across the Mississippi River watershed has clearly demonstrated both the complexity and compelling value of creating a comprehensive monitoring system. This report, and its companion published in 2023, lay the groundwork for better understanding the state of monitoring across the Mississippi River watershed and for building on existing infrastructure and programs to create a Sentinel System.

The technical design for ecosystem and habitat quality monitoring element of this Sentinel System deserves additional investigation and definition, building on the foundation of work and research done to date represented in this report. Specifically, we need to further define the ecosystem and habitat quality response indicators, gather remaining information about monitoring that is currently being done by states and determine how state programs align or differ, define distinguishing attributes of habitat types, and conduct two remote sensing tests in two different habitats. This will enable us to quantify the cost of specific recommendations for enhancing ecosystem and habitat quality monitoring around specific geographies within the watershed.

As noted in our 2023 report, the current monitoring system across federal, regional and state entities is hampered by a lack of funding and does not fully meet the needs of multiple users. By investing support and funds where gaps exist, building on existing programs and infrastructure that are effective, we believe that our nation can transform how monitoring at scale is done to create a "valuable, highly functional, and world-class monitoring network befitting our nation's most economically and environmentally important watershed."[41]

41 The Nature Conservancy et al. 2023. Building a Comprehensive "Sentinel" Monitoring System for the Mississippi River.

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