Upper Mississippi River Restoration Program

Science in Support of Restoration and Management
FY22 SOW

Enhancing Restoration and Advancing Knowledge of the Upper Mississippi River

Addressing the FY2015–2025 UMRR Strategic Plan

Operationalizing Ecosystem Resilience Concepts in the UMRS (2022-2024)

Ecological resilience is defined as the ability of an ecosystem to absorb disturbance and still maintain its fundamental ecological processes, relationships, and structure. The concept of ecological resilience is based on the understanding that most ecosystems can exist in multiple alternative states rather than a single equilibrium state to which it is always capable of returning. For example, shallow lakes have been shown to exist in either a clear-water heavily vegetated condition, or a turbid condition with little or no vegetation. The magnitude of disturbance (e.g., change in nutrients or turbidity) a lake in either state could sustain and remain in that state is the ecological resilience of that system.

To support the U.S. Army Corps of Engineers Upper Mississippi River Restoration (UMRR) Program's vision for a "healthier and more resilient ecosystem that sustains the river's multiple uses," the UMRR partnership has been undertaking an ecological resilience assessment. Broadly, the purpose of the assessment is to gain a deeper understanding of ecosystem dynamics to inform the planning and design of restoration projects. More specifically, the resilience assessment provides insight into how resilience is created, maintained, or broken down within a system and how restoration projects and management actions might influence those processes. In assessing the resilience of the Upper Mississippi River System (UMRS), we have focused on three major elements: 1) describing the system, 2) assessing resilience, and 3) managing resilience. A resilience working group, made up of individuals across UMRR partner agencies, provides guidance and feedback on the direction and specifics of the assessment.

The goal of the system description was to simplify the complex UMRS to identify the fundamental characteristics of the system. In doing so, we reviewed the relevant historical context that has shaped the current state of the UMRS, recognized valued uses of and services provided by the UMRS, and identified key ecological resources that are needed to support those valued uses and services. Further, we identified the major controlling variables that are known to influence key ecological resources (Bouska et al. 2018). Because the resilience assessment is intended to inform restoration decisions and a system description is considered the foundation for a resilience assessment, we engaged UMRR partner agencies throughout the development process, thereby gaining broad acceptance of the completed system description.

In the second element of the assessment, there were two complementary assessments of resilience that occurred. The evaluation of general resilience focused on understanding properties of the system that support its ability to cope with anticipated as well as unforeseen disturbances and changes. More specifically, three properties have been recognized to support the coping capacity of ecosystems to disturbances: 1) diversity and redundancy, 2) connectivity, and 3) slow variables and feedbacks. We applied these principles of general resilience to our understanding of how the UMRS functions (derived from the UMRS system description), to develop broad-scale indicators of general resilience (Bouska et al. 2019). These indicators provide information about the general adaptive capacity of the river at a floodplain reach scale from which restoration actions can be identified that, in theory, would bolster resilience to future disturbances. Many of these indicators have been integrated into the Indicators of Ecosystem Structure and Function (De Jager et al. 2018) that was used to develop the Habitat Needs Assessment II (McCain et al. 2018) to support the inclusion of resilience in restoration planning.

The second approach to assessing resilience focused on specified resilience – the resilience of particular ecological resources to specific disturbances. A critical step in this part of the assessment was the conceptualization of potential alternate regimes for the UMRS. Conceptual models were used to synthesize and communicate what we currently know or hypothesize regarding how particular components of an ecosystem can shift from desirable to undesirable conditions. We conceptualized three sets of alternate regimes based on initial discussions at the UMRR resilience workshop in 2016: 1) a clear water and abundant vegetation regime vs. a turbid water and sparse vegetation regime in lentic, off-channel areas, 2) a diverse native fish community regime vs. an invasive-dominated fish community regime, and 3) a regime characterized by a diverse and dynamic mosaic of floodplain vegetation types vs. one characterized as a persistent invasive wet meadow monoculture (Bouska et al. 2020). For each of these examples, we reviewed known or hypothesized controlling variables and feedback mechanisms and summarized restoration pathways. The conceptual models provide a foundation for quantitatively testing hypotheses contained in the models (see Bouska 2020). Unanswered research questions derived from these models are described in the Resilience Research Framework (Bouska 2019).

The third phase of the assessment is referred to as managing for resilience. In FY21, we developed guidance for how to synthesize what we've learned from our assessment into management implications. This manuscript will be submitted in FY22 for peer review publication. In FY22, we also plan to publish an overview of the UMRS resilience assessment process as a case study for how to apply a resilience assessment. This publication will review our approach to assessing resilience in the UMRS, describe the insights gained and the lessons learned from applying a resilience perspective to the understanding, restoration and management of the UMRS. This publication will also outline future directions to advance the science and application of resilience concepts in the UMRS and large floodplain-river ecosystem more generally. We will also publish and distribute an accompanying USGS fact sheet tailored to the UMRR partnership that more explicitly describes how the resilience assessment can inform and improve the management of the UMRS. We are also looking at opportunities to learn how restoration effects the river's resilience by studying HREPs.

OBJECTIVES (*Note: Objectives 4 and 5 will be the emphasis during FY2022*)
This project will be the primary responsibility of a research ecologist collaborating with scientists at the U.S. Geological Survey, Upper Midwest Environmental Sciences Center (UMESC) and scientists and managers throughout the UMRR partnership. The objectives are:

1) Establish a resilience working group to capitalize on the diversity of expertise and perspectives that comprise the UMRR partnership. This working group will be substantially involved in the formulation and conduct of this project.
   A Resilience Working Group was assembled in FY15.
2) Develop a clear conceptual understanding and definition of ecological resilience as applied to the UMRS.
   a) Small working group will develop a draft ("strawman") conceptual model of ecological resilience in the UMRS.
   b) Convene workshop to discuss and refine this model. Participants will be determined by resilience working group.
   c) Small working group will refine conceptual model based on input from workshop
   Working Draft Conceptual models of UMRS in support of the resilience assessment were completed in FY16. Given the iterative nature of a resilience assessment. These models will continue to be refined throughout the project.
3) Use principles of general resilience to guide:
   a) Development of indices of general resilience for the UMRS using data from the UMRR-LTRM.
   Indicators of general resilience were developed in FY17 and published in FY18.
4) Use the conceptual model to guide:
   a) Development of state and transition models that detail the drivers and responses of potential alternative regime
   b) Identification of knowledge gaps in our understanding of alternative regimes
   Conceptualizations of alternate regimes in the context of aquatic vegetation, fish communities, and floodplain vegetation communities were developed and published in FY20. A resilience

research framework based off alternate regime conceptualizations and our assessment of general resilience was developed and reviewed by the UMRR A-Team in FY19, and published to the LTRM A-Team Corner site online. We will continue to pursue answering research questions in this framework.

c) Specified resilience analyses derived from UMRR LTRM data

A manuscript that documents evidence for alternate regimes in fish communities using LTRM fisheries data was published in Biological Invasions in FY20. A manuscript detailing changes in aquatic vegetation communities at the contiguous floodplain lake-scale was published in Freshwater Science in FY21.

d) Evaluation of the factors contributing to the resilience of the UMRS

i) Where the UMRS is in a desirable state, what contributes to the resilience of that state and what management actions might maintain or increase that resilience?

ii) Where the UMRS is in a less desirable state (e.g., lack of vegetation in the lower impounded reach), what contributes to the resilience of that state and how might management actions overcome that resilience?

A manuscript was developed in FY21 to be submitted in FY22 describing management implications of the UMRS Resilience Assessment.

5) Evaluate the effects of HREPs on the resilience of the UMRS

a) Conceptually: Expand conceptual models to specifically describe what aspects of resilience may be affected by HREPs

b) Empirically: Use LTRM data and additional data collected at HREPs to evaluate observed effects

c) Collaborate and provide technical assistance to UMRR scientists and managers on developing approaches to learn from HREPs, thus improving our ability to put resilience into practice

WORKPLAN AND DELIVERABLES

In FY22, we plan to submit three manuscripts, provide a resilience perspective in the LTRM implementation planning process, co-lead the development of proposals on wild celery resilience and Lower Pool 13 HREP during the 2022 UMRR Science Meeting. The first manuscript to be submitted will detail the management implications of the UMRS resilience assessment by developing guidance for using understanding of desirability of current conditions, proximity to thresholds, and general resilience to navigate a recently developed resist-accept-direct framework. The guidance will be applied to aquatic vegetation, floodplain vegetation, and fish communities across the Upper Mississippi River System. We will also produce a manuscript that documents our resilience assessment process, lessons learned & challenges, and future directions in river restoration and management. We will also publish a USGS Fact Sheet on the resilience assessment synthesis with an emphasis on the relevance to the UMRR program. Lastly, we will develop a manuscript that asks whether one of the general resilience indicators, fish functional diversity and redundancy (Bouska 2018), is effective at detecting regime shifts in the fish community (Bouska 2020).

Results of these efforts will be communicated to the partnership via a seminar or workshop and presentations at various UMRS meetings. We will communicate results to a national and international audience via presentations at scientific conferences and in peer-reviewed publications.

Products and Milestones

Tracking number	Products	Staff	Milestones
2022R1	Updates provided at quarterly UMRR CC meeting and A team meeting	Bouska, Houser	Various
2022R2	Submit manuscript that investigates associations between general and specified resilience for peer review publication	Bouska	30 September 2022
On-going			
2021R3	Submit resilience assessment synthesis manuscript for peer review publication	Bouska	30 September 2022
2021R4	Submit resilience assessment synthesis fact sheet for USGS peer review	Bouska	30 September 2022
2021R5	Submit management implications manuscript for peer review publication	Bouska	31 December 2021

Landscape Pattern Research and Application

The goal of landscape pattern research on the Upper Mississippi River System is to develop concepts, maps and indicators that provide both regional-level decision makers and local-level resource managers with information needed to effectively manage the UMRS.

As described in the UMRR Landscape Pattern Research Framework (De Jager 2011), landscape pattern research on the UMRS focuses on linking decisions made at regional scales with restoration actions carried out at local scales. While regional program managers and decision makers are concerned with improving the overall ecological condition of the entire UMRS, local resource managers work to address site specific habitat and resource limitations. Landscape ecology, which focuses on the linkages between patterns visible at broad scales and ecological patterns and processes that occur at local scales, can help to integrate these two scale-dependent management activities. (Strategic Plan Outcome 2, Output 2.2, Outcome 4)

Objectives

1) To develop broad-scale indicators of habitat amount, connectivity and diversity for the purposes of a) identifying areas for ecosystem restoration across the entire system and b) to track status and trends in habitat area, diversity and connectivity.

2) To connect broad-scale landscape pattern indicators with local-scale ecological patterns and processes critical to restoration project development.

New Products

2022LP2-3: Reed canary grass (*Phalaris arundinacea*) can be an invasive species in riparian ecosystems. In the Upper Mississippi River floodplain, invasion of reed canary grass in forest understories can inhibit forest regeneration when gaps in the overstory form. Knowledge of where reed canary grass is likely to occur in the forest understories could help inform management actions to limit its spread or identify areas where forest regeneration may be inhibited by reed canary grass following gap formation. We will use species and habitat suitability modeling to predict the likelihood of occurrence of reed canary grass in forest understories throughout Pools 3-13. We will use reed canary grass presence/absence data from the US Army Corps of Engineers Phase II Forest Inventory dataset and select an ecologically relevant set of predictors from additional spatial UMRR LTRM datasets including 1890s landcover, 2010/11 landcover, and floodplain inundation attributes. We will also explore how each of the predictors used in our analysis relates to predictions of reed canary grass presence/absence. The primary output will be a map product that shows the probability of occurrence of reed canary grass in forest understories across the floodplain (Pools 3-13) that can be used to identify invasion hot spots, summarize invasion probabilities by area, or be overlayed with other map products such as layers depicting forest gap formation.

Products and Milestones

Tracking number	Products	Staff	Milestones
2022LP1	Data Analysis: 2020 Land Cover Change	Rohweder and De Jager	30 September 2022
2022LP2	Data Analysis: Reed canary grass habitat suitability modeling using forestry data, flood inundation metrics, and landscape patterns.	Delaney and Rohweder	30 September 2022
2022LP3	Draft Report: Reed canary grass habitat suitability modeling using forestry data, flood inundation metrics, and landscape patterns.	Delaney, De Jager, Van Appledorn, Bouska, Rohweder	30 September 2022
On-Going			
Manuscript: Review of Landscape Ecology on the UMR 2016L3; in draft			

Reference

De Jager, N.D. 2011. Scientific Framework for Landscape Pattern Research on the Upper Mississippi and Illinois River Floodplains. Available online:
https://www.umesc.usgs.gov/ltrmp/ateam/landscape_patterns_research_framework_final_june2011.pdf

Eco-hydrologic Research

Hydrology is a key driver of form and function of the Upper Mississippi River System (UMRS). Understanding the role of hydrology, including floodplain inundation, in driving geomorphic and ecological dynamics in aquatic and terrestrial ecosystems is essential for improving the health and resilience of the UMRS through informed management practices.

Recent work to develop robust, well-documented and systemic datasets of historic daily water surface elevations for 157 gaging locations and inundation dynamics is essential to characterizing the UMRS's hydrologic and flooding regimes. The characterizations of hydrology and inundation patterns, together with existing geospatial datasets of physical and ecological attributes developed through the UMRRP, offer abundant new opportunities to understand biophysical relationships in the UMRS, especially regarding the role of inundation in shaping ecological patterns (composition, structure) and processes (dispersal, regeneration, succession) across multiple spatial and temporal scales. They also can aid in understanding changes in the geomorphology of the UMRS, including off-channel backwater areas, and the potential changes in the amount and distribution of aquatic and terrestrial habitats.

The goal of this research is to leverage hydrologic data, including the inundation model, along with other existing UMRR datasets to learn about patterns of floodplain-river connectivity throughout the UMRS, to understand how these patterns may influence ecosystem dynamics and habitat distributions, and to contribute to the improved health and resilience of the UMRS by developing concepts, maps, and models relevant to management activities.

Specific Activities for FY2022:

Component 1 – UMRS hydrologic database and inundation model support: LTRM will maintain some level of expertise to provide basic data and model archiving and assistance using the UMRS hydrologic database inundation model.

In FY2022, we will:

- 1a. Facilitate the inundation modelling framework's long-term curation by completing an accessible online platform for its distribution
- 1b. Provide technical assistance on accessing data and model outputs and their proper use
- 1c. Assist partner agencies on the development of additional uses for the data and model in HREP project planning

Component 2 – Understanding eco-hydrologic patterns and processes: It is a goal of the UMRS management community to restore and sustainably manage aquatic and terrestrial ecosystems to serve as a vital resource for future generations. Ongoing forest management is informed by inventory and monitoring programs that summarize current species distributions and forest conditions. Data from the programs also have the potential to provide novel insights into how and at what spatial and temporal scales forest structure and composition are influenced by environmental conditions (e.g., flooding dynamics, soils, climate), land use history, biotic factors (e.g., dispersal, competition), and their interactions. Research is needed to gain an integrative understanding of how abiotic and biotic factors structure UMRS floodplain forests and to identify environmental conditions suitable for supporting healthy, resilient forest ecosystems.

This research will:

2a. Examine inundation model outputs for spatial and temporal trends in different aspects of flooding regimes that may have impacts on important biophysical patterns and processes
2b. Describe compositional and structural patterns of floodplain forest diversity and how they may vary across space and through time
2c. Integrate flood inundation model outputs with vegetation data to better understand how multiple aspects of flood regime shape vegetation communities and their dynamics
2d. Identify opportunities to apply a better understanding of flood-vegetation interactions at the HREP scale

In addition, new research will be developed to address management issues related to non-forested areas as well. This research will:

3a. Examine the role of hydrology in non-forested floodplain areas and in relation to invasive herbaceous vegetation (e.g., Reed Canary Grass)
3b. Examine geomorphic changes in off-channel backwater habitats through time

New Products
2022EH1 - Geomorphic changes in the Upper Mississippi River System have been a concern of agencies charged with maintaining and restoring riverine habitat, including changes to backwater habitats. Here, we will use empirical data from repeated transect surveys of backwater bed elevation to develop spatial models of geomorphic change in backwaters from Pools 4 and 8 over time, including projections of future change. Results from these models will be used in future analyses to support as assessment of backwater vulnerability to in-filling and habitat provisioning.

2022EH2 - Reed canary grass is an herbaceous invader of forest understories and is believed capable of transitioning forested areas into non-forested habitats. As such, they are a management concern in the Upper Mississippi River System. These analyses support work to develop habitat suitability models for predicting the likelihood of reed canary grass occurrence in the UMRS floodplain by describing the inundation regime for two sets of field vegetation surveys, the Phase II USACE forest inventory plots and riparian bird survey plots collected by E. Kirsch. Custom characterizations using the UMRS Inundation Model include intervening time between vegetation sampling and the most recent flooding event, inundation duration within a 30 day window prior to vegetation sampling, and summaries of long-term inundation regime.

Products and Milestones

Tracking number	Products	Staff	Milestones
2022EH1	Spatial analyses of backwater sedimentation patterns through time to support vulnerability modeling effort	Van Appledorn, Rohweder, DeJager	30 September 2022
2022EH2	Characterization of hydrologic/flooding regimes of non-forested areas to support eco-hydrologic modeling efforts	Van Appledorn	30 September 2022
On-going			
2020EH02	Submit manuscript of temporal patterns in UMRS inundation regimes for peer review	Van Appledorn, De Jager, Rohweder	30 September 2023
2021EH01	Draft manuscript of temporal and spatial trends of large wood in the UMRS and potential eco-hydrologic drivers	Van Appledorn, Jankowski	30 September 2022
2021EH02	Draft manuscript of UMRS floodplain forest classification	Van Appledorn, De Jager	30 September 2022
2021EH03	Spatial analyses of UMRS geomorphic channel and/or delta features (e.g., slope, width, complexity, geomorphons, shoaling, etc.) to understand	Vaughan, Van Appledorn	31 March 2022

	hydrogeomorphic constraints on river form and function		

Intended for distribution
Manuscript: Modeling and mapping inundation regimes for ecological and management applications: a case study of the Upper Mississippi River floodplain, USA; Van Appledorn, De Jager, Rohweder, Jason. (In revision with J Hydrology)
Development of UMRS inundation model query tool; Van Appledorn, Fox, Rohweder, De Jager; 2019EH03

FY2020-2025 Scope of Work: Acquisition and Interpretation of Four-Band Imagery for Production of 2020 UMRS Land Cover/Land Use Data and Pool-Based Orthomosaics

Introduction

The U.S. Army Corps of Engineers Upper Mississippi River Restoration program, through its Long Term Resource Monitoring (UMRR-LTRM) element, will collect aerial imagery of the entire systemic Upper Mississippi River System (UMRS) during the summer of 2020. A Land Cover/Land Use (LCU) spatial database will be developed that is based on the 2020 aerial imagery and will provide a fourth systemic-wide database to the 1989, 2000, and 2010/11 LCU databases. While a crosswalk was used to update the 1989 LCU database (originally interpreted with a different classification system), the 2000, 2010/11, and 2020 LCU databases will share the same classification, making them directly comparable from a classification standpoint. Furthermore, protocols in addition to standard mapping methods will be explored to increase the utility of the 2020 UMRS LCU database for research monitoring when compared to 2010/11 UMRS LCU database. These map protocols will aim to reflect "true" spatial and temporal changes in vegetation polygons and classification rather than mere changes due to differences in image interpretation or image spatial positioning. However, these additional map protocols will be limited to set time frames and budgets. Once complete, the 2020 LCU database will be another resource tool for managers and researchers to assess the year 2020 state of floodplain vegetation and evaluate the long-term vegetation trends and habitat changes over the past 30 years.

Objective

The objective is to develop and distribute LCU spatial datasets and orthoimages (frames and mosaics) from aerial imagery collected in summer of 2020 of the systemic UMRS of navigable pools (the stretch of river between locks and dams) and reaches. These pools and reaches include Pools 1 through 26, the Open River Reach, the entire Illinois River, and the navigable portions of the Minnesota, St. Croix, and Kaskaskia Rivers. The data products will be primarily for resource managers and researchers to make assessment and evaluation of current (2020) vegetation components and long-term vegetation trends within the UMRS.
To achieve this objective, four-band digital aerial imagery will be collected during peak biomass in the summer of 2020. The acquired 2020 aerial imagery will be processed for stereo viewing, which image interpreters (mappers) will view on computer workstations to map and classify features based on the aerial imagery to develop LCU datasets by navigation pools and reaches. The standard LTRM classification will be applied in mapping. The 2020 aerial imagery will be developed into orthoimages and mosaicked by navigation pools and reaches. The LCU datasets will overlay their respective orthoimage mosaic using Geographic Information System (GIS) software. The orthoimagery will display in natural color or color infrared (CIR) to provide visual context to the 2020 LCU database and to any previous year LCU database. The LCU database will provide a general classification description to mapped features. Each LCU dataset and orthoimage will be served online to access and download for viewing and making analysis using a GIS. Resource managers, scientists, and the public will have access to the 2020 LCU datasets and orthoimages in ScienceBase (with a link from the UMRR LTRM's data download website).

Method

Aerial Imagery Acquisition

Four-band digital aerial imagery (red/green/blue, or RGB, and near infrared, or NIR) of the systemic UMRS will be collected during peak biomass in August of 2020 at 0.2 meters (8 inches)/pixel for Pools 1 through 13 and navigable portions of the Minnesota and St. Croix Rivers where complex aquatic vegetation requires greater detail, and at 0.4 meters (16 inches)/pixel for Pools 14 through 26, Open River Reach, navigable portions of the Kaskaskia River, and the Illinois River (Attachment A). (These are the same image-resolution parameters

and locations as the 2010/11 imagery acquisition.) The four-band imagery will be capable of displaying as natural color or CIR by selecting different bands. These display options will aid the mapper in their interpretation of features on the aerial imagery.
To capture complete stereo-view coverage of the systemic UMRS, the imagery will be collected with at least a 60% forward lap and 30% side lap. To capture proper exposures of the systemic UMRS, the time acquisition window each day will be between 9:00 am and 4:00 pm.
Traditionally CIR aerial imagery was collected for UMRR-LTRM since CIR highlights small differences in chlorophyll concentration in plants, making it easier to distinguish and identify similar vegetation types. Along with the CIR aerial photographs collected for the 1989 and 2000 systemic UMRS efforts, RGB aerial photographs were also collected. Natural color images are often used for viewing orthoimages, publications, and display since they can be readily understood by viewers not familiar with CIR viewing. The 2010/11 imagery was collected in CIR only since a separate systemic aerial flight mission would have been required to acquire a RGB set of imagery. The 2020 aerial imagery acquisition will be the first systemic UMRS collected with four bands of spectrum layers.

The 2020 imagery collection will use mapping-grade Phase One digital aerial cameras. The 2020 digital imagery will have identical resolutions to the 2010/2011 digital imagery. However, sensor technology and digital-image detail have improved considerably since the time when analog aerial photographs were collected. As a result of improvements in remote sensing technology, particularly the direct georeferencing of digital aerial imagery, it is not uncommon for the analog-based aerial imagery in 1989 (1:15,840 scale) and 2000 (1:24,000 scale) to have off sets with each other or with the digital-based aerial imagery in 2010/11 and 2020. Consequently, the LCU data based on these analog photographs and digital imagery reflect those disparities. The 2020 digital imagery will be similarly collected and processed to the 2010/11 digital imagery, and imagery alignment between those two years will be closer to each other than when compared to the 1989 and 2000 imagery. Again, the 2020 UMRS LCU data will imitate this closer alignment to the 2010/11 UMRS LCU.

The Phase One digital aerial cameras are the 100-megapixel iXU-RS 1000 (RGB) and iXU-RS 1000 Achromatic (NIR) co-mounted in a Somag SSM270 3-axis gyro-stabilized mount that isolates the cameras from plane-induced vibration (Figure 1). The SSM270's camera mount ensures that four-band images are precisely co-registered, almost perfectly vertical, and smear-free.

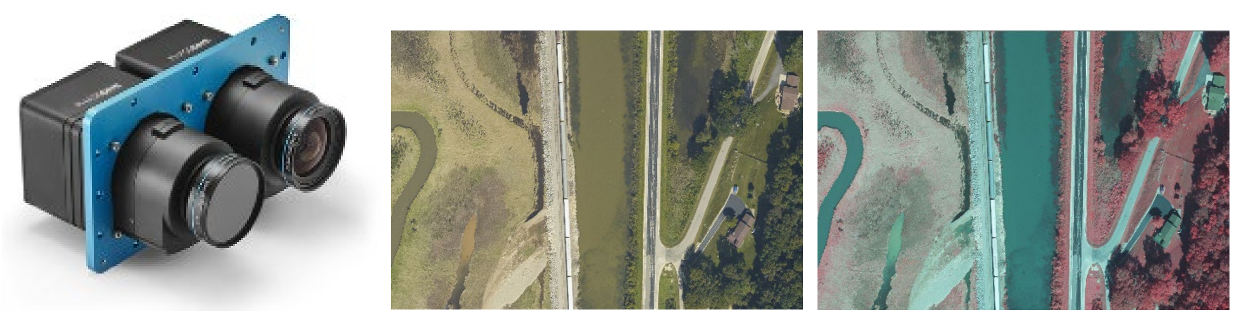

Figure 1. Phase One iXU-RS 1000 RGB and 1000 Achromatic digital cameras with co-registration base plate for generating four-band aerial imagery that can be displayed as natural color or color infrared.

The target window of dates to collect the systemic UMRS digital aerial imagery in 2020 is August 10 to September 4. For comparison, listed below are previous systemic UMRS collections aerial photographs/images.

- 1989 Collection—August 29 to October 7
- 2000 Collection—August 7 to September 5
- 2010 Collection—August 13 to September 1
- 2011 Collection—August 9 to September 7

To help maximize a uniform capture of peak aquatic, emergent, and terrestrial vegetation growth across the UMRS, the 2020 imagery acquisition will begin at the Open River Reach near Cairo, Missouri in the southern end of the UMRS where peak growth occurs earliest. The imagery acquisition will proceed northward to conclude at Pool 1 in Minneapolis, Minnesota. All imagery collection is expected to be complete prior to aquatic vegetation senescence.

As with the 2010/2011 systemic UMRS imagery collection, water levels will be monitored, and the 2020 imagery collection adjusted accordingly. For example, in 2010 the Mississippi River southward from the Quad Cities area had sustained high-water levels during the summer making for inadequate ground conditions for quality LCU database and orthoimage products. Therefore, the imagery acquisition from Pool 13 through the Open River Reach was completed in 2011. If the USACE determines any portions of the UMRS are too flooded for accurate vegetation classification in 2020, aerial imagery of those areas will be acquired the following summer.

Aerial Imagery Processing

All 2020 digital aerial images that are required for LCU mapping will have stereo model files developed for three-dimension (3D) viewing by mappers using computer workstations to develop the LCU database. With the imagery collected with a forward lap of 60%, stereo models align the common area between two adjacent images and allow for 3D viewing using specialized computer software, monitors, and glasses.
Likewise, all aerial images that are required for orthoimage mosaicking will be individually orthorectified and processed into GIS-ready orthoimage mosaics. Orthoimage mosaics will be made for each navigable pool or reach of the systemic UMRS and usable in GIS to overlay, view, and compare with existing and future LCU data or orthoimagery.

LCU Mapping

The 2020 LCU database will be prepared by or under the supervision of competent and trained professional staff using documented standard operating procedures at UMESC and will be subject to rigorous quality control (QC) assurances. To maintain classification consistency to other systemic UMRS LCU databases (2000 and 2010/11, except 1989[1]), the "LTRM 31-class general classification for floodplain vegetation" (Attachment B) will be used to map and develop the 2020 LCU database.
Standard mapping practices of interpretation, polygon delineation, and classification common to the UMESC Geospatial Sciences and Technologies Branch will be applied according to the 'General Classification Handbook for Floodplain Vegetation in Large River Systems' developed for the UMRR program LTRM element. However, for the 2020 UMRS LCU development, additional mapping protocols will be explored to support monitoring efforts by promoting consistency with the 2010/11 UMRS LCU polygon and classification. These additional mapping protocols will be developed prior to mapping by a working group exploring various scenarios. These protocols will be adjusted accordingly as difficulties arise during the mapping process.

[1] A crosswalk was developed by UMESC and field station vegetation specialists for the 1989 data to make the vegetation classification as compatible as possible with the 2000 dataset and all subsequent systemic datasets.

Prior to mapping, image interpreters will conduct field work to visit vegetation types and discern their appearances in the aerial imagery. The mappers will compare, with the aid of weatherized field computers, the ground conditions to vegetation signatures (appearances) on the newly acquired 2020 UMRS digital aerial imagery.

To map the 2020 LCU, four-band aerial images will be viewed by interpreters to classify and map LCU features using computer workstations, which includes viewing imagery in 3D using specialized computer software, monitors, and glasses. With these 3D mapping systems, the image interpreters can then identify features using color, form, texture, height, and location on the landscape. A minimum mapping unit (MMU; smallest unit mapped) of 0.5 hectare will be applied to the 0.2-meter/pixel imagery. An MMU of 1.0 ha will be applied to the 0.4-meter/pixel imagery. These are the same MMU standards that were applied to the 2010/11 LCU database. The MMU standard applied to the 2000 LCU database was 1.0 hectare. There was no MMU standard applied to the 1989 LCU database.

The trend pools and reaches (Pools 4, 8, 13, 26, Open River South, and the La Grange Pool of the Illinois River) will be prioritized in FY2021 to map and develop into LCU datasets for use in GIS. The non-trend pools and reaches will be mapped and developed into LCU datasets in FY2022–25. All pools and reaches will be completed to be served online by mid-2025.

Data Distribution

All 2020 LCU data and orthoimage products will be served on ScienceBase with a link from LTRM’s data download website. The products will be served by navigation pool or reach.

Products & Milestones

Data products include orthoimages (individual frames and mosaics) and LCU spatial map layers. Data products will be hosted on UMESC servers. Data products are supported with metadata documentation. Map graphics, presentation posters and talks, and/or reports are all potential when opportunities exist for meetings and conferences.

The expected deliverables by fiscal year (FY) are:

FY2020

Acquisition of four-band imagery for the entire UMRS in late summer of 2020 (mid-August to early-September). Catalog of all imagery by location and date collected. Field reconnaissance to support FY2021 LCU mapping. If time permits, additional field reconnaissance to support FY2022-25 LCU mapping.

FY2021

Image processing, stereo model development, orthorectification, pool-based mosaicking, image interpretation, automation, QA/QC, and serving of 2020 LCU datasets for Pools 4, 8, 13, 26, La Grange, and an estimated 50% of the Open River South (approximately 2,200 frames). If not already completed, field reconnaissance to support FY2022 LCU mapping. If time permits, additional field reconnaissance to support FY2023-25 LCU mapping.

FY2022

Image processing, stereo model development, orthorectification, pool-based mosaicking, image interpretation, automation, QA/QC, and serving of 2020 LCU datasets for remaining 50% of Open River South, Pools 9, and 12. If not already completed, field reconnaissance to support FY2023 LCU mapping. If time permits, additional field reconnaissance to support FY2024-25 LCU mapping.

FY2023

Image processing, stereo model development, orthorectification, pool-based mosaicking, image interpretation, automation, QA/QC, and serving of 2020 LCU datasets for Pools 1-3, 5-7, the St. Croix and lower Minnesota Rivers, and the Peoria Pool of the Illinois River (approximately 1,650 frames). If not already completed, field reconnaissance to support FY2024 LCU mapping. As time permits, additional field reconnaissance to support FY2025 LCU mapping.

FY2024

Image processing, stereo model development, orthorectification, pool-based mosaicking image interpretation, automation, QA/QC, and serving of 2020 LCU datasets for Pools 20-25, the Open River North, the lower Kaskaskia River, and the Starved Rock through Lockport Pools of the Illinois River (approximately 1,700 frames). If not already completed, field reconnaissance to support FY2025 LCU mapping.

FY2025

Image processing, stereo model development, orthorectification, pool-based mosaicking image interpretation, automation, QA/QC, and serving of 2020 LCU datasets for Pools 14-19, and project wrap-up (approximately 900 frames).

Products and Milestones

Tracking number	Products	Staff	Milestones
2020LCU3	Image processing, stereo model development, orthorectification, pool-based mosaicking, image interpretation, automation, QA/QC, and serving of 2020 LCU datasets for remaining 50% of Open River South, Pools 9, and 12	Dieck, Strassman	September 2022

Aquatic Vegetation, Fisheries, and Water Quality Research, and Statistical Evaluation

Products and Milestones

Tracking number		Staff		Milestones
Aquatic Vegetation				
Intended for distribution				
Manuscript: Annual summer submersed macrophyte standing stocks estimated from long-term monitoring data in the Upper Mississippi River. (2020A8; USGS review; Drake, Lund, Bales, Kreiling; IP-122160; accepted by journal)				
On-Going				
Fisheries				
Manuscript: Evidence of functionally defined non-random fish community responses over 25 years in a large river system (Ickes; 2019B13 replacing 2015B17 and 2016B17; Resubmitted to Hydrobiologia)				
Water Quality				
Intended for Distribution				
Manuscript: The ecology of ice across the river continuum (New tracking number 2021RC1) Sharma, S., Meyer, M.F., Culpepper, J., Yang, X., Hampton, S., Berger, S.A., Brousil, M.R., Fradkin, S.C., Higgins, S.N., Jankowski, K.J., Kirillin, G., Smits, A.P., Whitaker, E.C., Yousef, F., Zhang, S. 2020. Integrating Perspectives to Understand Lake Ice Dynamics in a Changing World. Journal of Geophysical Research: Biogeosciences. https://doi.org/10.1029/2020JG005799.				
Manuscript: Warmer winters increase phytoplankton biomass in a large floodplain river. Jankowski, K. J., J. N.Houser, M. D. Scheuerell, and A. P. Smits. 2021. Warmer winters increase the biomass of phytoplankton in a large floodplain river. Journal of Geophysical Research: Biogeosciences. Volume 126, Issue 9. https://doi.org/10.1029/2020JG006135. Data available at: https://umesc.usgs.gov/data_library/water_quality/water_quality_page.html				
Statistical Evaluation				
Intended for Distribution				
Manuscript: Inferring decreases in among- backwater heterogeneity in large rivers using among-backwater variation in limnological variables (2010E1; IP-027392; Gray; in journal review)				
Manuscript: How well do trends in LTRM percent frequency of occurrence SAV statistics track trends in true occurrence? (2016E2; IP-123221; Gray; in journal review)				
Manuscript: Model selection for ecological community data using tree shrinkage priors; Gray, Hefley, Zhang, Bouska; (2017FA2; IP-111931; in revision with Ecological Applications)				

Pool 12 Overwintering HREP Adaptive Management Fisheries Response Monitoring

Fisheries Population Monitoring (FY2006-Present)
This is a continuous project that builds on several years of pre-project fisheries monitoring for the Pool 12 Overwintering HREP. We have been performing pool-wide electrofishing in Pool 12 since 2006. We have also been performing fyke netting in backwater lakes that will be rehabilitated, as well as other backwaters in Pool 12 that will not be rehabilitated (as a control). We also perform otolith extraction from bluegills from the lakes we net in to obtain aging, sexing, and mortality information.

Questions still exist as to the most effective longitudinal spacing of fisheries overwintering HREP projects. The Pool 12 Overwintering HREP is unique because four backwater lakes (Sunfish, Stone, Tippy, and Kehough - in order of construction) are being rehabilitated in the same navigation pool (all within roughly eight river miles of each other), in the same window of time, and as part of the same HREP.

Products and Milestones

Tracking number	Products	Staff	Milestones
2022P13d	Age determination of bluegills	Kueter	1 February 2022
2022P13e	In-house project databases updated	Kueter	31 March 2022
	On-Going		
2021P13f	Made available to program partners via Fish Mgmt. State report (2021B4)	Kueter	30 June 2022

Pool 4 - Peterson Lake HREP Water Quality Monitoring – Pre and Post-Adaptive Management Evaluation (FY17-present)

The Peterson Lake HREP (Habitat Rehabilitation and Enhancement Project) was constructed in 1995 to maintain the lake as a productive backwater resource by reducing the loss of barrier islands to erosion and sand sedimentation in the lake (USACE 1994). One of the specific objectives of the initial project was to create a winter fish refuge in the upper portion of the lake, despite concerns of possible negative effects on summer water quality due to the reduction of flow into the area. While a small area of upper Peterson Lake does currently support a winter fish refuge the project objectives for current velocity (< 1 cm/sec) and water temperature (> 1^{o} C) were considered unsuccessful (USACE 2011). In an effort to increase the area suitable for winter fish use a proposal to shut off a major inlet into the upper lake and partial closures of two other inlets is being proposed. Pre and post water quality monitoring of upper Peterson Lake would determine if this adaptive management strategy is successful. Based on construction work in Winter 2018.

Products and Milestones

Tracking number	Products		Staff		Milestones
2022PL1	Summary letter: Describing 2022 monitoring and future work		Burdis, Lund		31 December 2022

References

United States Army Corps of Engineers (USACE). 1994. Upper Mississippi River System Environmental Management Program, Definite Project Report/Environmental Assessment (SP-16), Peterson Lake (HREP). US Army Corps of Engineers, St. Paul District.

United States Army Corps of Engineers (USACE). 2011. Peterson Lake Pool 4 Mississippi River (HREP) Project Evaluation Report. Environmental Management Program for the Upper Mississippi River System. US Army Corps of Engineers, St. Paul District.

UMRR Science Coordination Meeting

The objective of the meeting is to develop a set of research projects in support of the restoration and management of the UMRS for the UMRR Program. Past planning documents will be revisited while developing a framework to assist in the development of research projects to improve the effectiveness of our research and monitoring – integrating state agency science needs into regional science and monitoring objectives. The results of these integrated research efforts will provide critical insights and understanding regarding a range of key environmental management concerns, including how the basic condition of the ecosystem is changing; interactions and associations of hydrogeomorphology with biota and water quality, and ecosystem structure and function.

Products and Milestones

Tracking number	Products	Staff	Milestones
2022N1	UMRR Science Coordination Meeting	All	Feb. 8-11

A-Team and UMRR-CC Participation

USGS-UMESC and Field Station staff are often called upon to participate at quarterly A-Team (http://www.umesc.usgs.gov/ltrmp/ateam.html) and UMRR-CC (https://www.mvr.usace.army.mil/Missions/Environmental-Stewardship/Upper-Mississippi-River-Restoration/Partnership/Coordinating-Committee/) meetings. The field station team leaders, component specialists, and UMESC LTRM management staff are expected to participate in the A-Team meetings, if possible. Additional staff may participate as appropriate. Participation at UMRR CC meetings will be by request only. This participation could include sharing of scientific knowledge and/or presentations on current projects. Any participation by LTRM staff at A-Team and/or UMRR CC meetings will be listed in the quarterly activity products.

LTRM Implementation Planning

The Water Resources Development Act of 2020 (WRDA 2020) included an increase in allocation for the Long Term Resource Monitoring (LTRM) element of the UMRR from $10.42M to $15M. Additional funds, if appropriated, would present an opportunity to expand our understanding of the UMRS and better inform restoration and management. The LTRM Implementation Planning team Team (IPT), comprising UMRR partner agencies, was convened to identify information needs that could be addressed with additional funding. Ultimately, the IPT will evaluate options for building programmatic capacity to address priority information needs.

Evaluating the LOCA-VIC-mizuRoute hydrology data products for scientific and management applications in the UMRS

Previous LTRM project: This project directly builds on work from the UMRR Future Hydrology Meeting series (funded 2020 SSR proposal). Milestones: 2021HH4, 2021HH5, and 2021HH6. Final report is in progress.

Name of Principal Investigators:
Lucie Sawyer, Civil-Hydraulic Engineer
USACE Rock Island District (MVR), Rock Island, IL | 309-794-5836, lucie.m.sawyer@usace.army.mil
Coordinate and oversee project; oversee USACE ECB-2018-14 compliance; write reports

Molly Van Appledorn, Ecologist
USGS UMESC, La Crosse, WI | 608-781-6323, mvanappledorn@usgs.gov
Coordinate and oversee project; write reports; oversee data management & metadata development

John Delaney, Biologist
USGS UMESC, La Crosse, WI | 608-781-6323
Coordinate and oversee project; write reports

Collaborators (Who else is involved in completing the project):
Chris Frans, Civil Engineer
USACE Seattle District, Seattle, WA | 206-764-6701 christopher.d.frans@usace.army.mil
Coordinate evaluation; oversee data transfers, analysis, and interpretation; contribute to data management & metadata development

Chanel Mueller, Hydraulic Engineer
USACE St. Paul District (MVP), St. Paul, MN | 651-666-0224, chanel.mueller@usace.army.mil
Coordinate evaluation; data interpretation

Leigh Allison, Hydraulic Engineer
USACE St. Paul District (MVP), St. Paul, MN | 651-290-5617, leigh.a.allison@usace.army.mil
Lead computer scripting for evaluation; evaluation analysis; contribute to data management & metadata development

USACE district computer scripters
Assist computer scripting for evaluation; evaluation analysis; contribute to data management & metadata development

Randal Goss, Research Geographer
USACE ERDC CRREL, Hanover, NH | 603-404-4691, randal.s.goss@erdc.dren.mil
Lead website development and query tool creation for data dissemination and curation

Introduction/Background:
The hydrologic regime is a fundamental driver of ecosystem patterns and processes in the Upper Mississippi River System (UMRS). Inter- and intra-annual variability in flow influences the nature of longitudinal and lateral connectivity, controlling variables that enable exchanges of materials and energy throughout the system (Bouska et al. 2018, 2019). There is evidence that climatic changes in precipitation regimes interact with land use changes to contribute to shifts in the hydrologic regime (Zhang and Schilling 2006). Increases in the frequency and intensity of precipitation events (Zhang and Villarini 2021), flooding (Mallakpour and Villarini 2015), and baseflow (Ayers et al. 2019) have been observed across the Midwest in recent decades. Similar observations have been made specifically for the UMRS where recent episodes of longer duration spring events and late season flood events and increases in average annual discharges (Van Appledorn, *in review*) raise questions about the potential for such conditions to be the "new normal," how such conditions may influence biota and habitats of the UMRS, and how best to design and implement resilient management actions.

Regionally, studies have projected increases in flood frequency (Neri et al. 2020) and changes in seasonality of peak flows (Byun et al. 2019) in the 21st century. While these studies provide insights on projected regional patterns in hydrology, they were conducted on smaller watersheds both within and outside of the UMRS basin and did not include locations on the mainstem of the UMRS. Hydrologic data specific to the UMRS mainstem will be foundational to anticipating how the ecosystem might respond to any potential future changes in the hydrologic regime, and how to best manage for those potential conditions. The lack of quantitative information about plausible future hydrologic regimes is a roadblock to addressing an important recurring question within the partnership: how are geomorphic, hydrologic, and ecological patterns and processes likely to change in the future, and how can we best implement management practices to be resilient to these changes? Lacking quantitative projections of future hydrologic regimes hinders the ability to identify and understand their implications for the structure, function, management, and restoration of the UMRS. The primary objective of this proposed work is to fill this critical gap by producing a robust, quantitative dataset of future hydrology projections for the UMRS mainstem.

This proposal is a direct output from the UMRR Future Hydrology Meeting Series, a set of three meetings funded by the UMRR in FY2021-22. The meeting series served as an important forum for discussing how the partnership can carry out its goal of enhancing habitat and advancing knowledge for restoring and maintaining a healthier and more resilient Upper Mississippi River ecosystem in uncertain future hydrologic conditions. During Meeting #1 partnership representatives identified UMRR priorities for understanding climate changed hydrology in structured working groups which resulted in a ranked list of program needs in the themes of geomorphology, HREP/management, and ecology (Table 1). The partnership representatives were joined with technical experts at Meeting #2 to identify potential existing datasets or approaches to address the UMRR priorities from Meeting #1. Finally, at Meeting #3 a subgroup of UMRR partnership representatives and technical experts discussed in detail the workflow for developing a quantitative dataset of future hydrology that would achieve the UMRR priority needs, ultimately producing this proposal.

Table 1. Priority needs identified by UMRR partners attending the UMRR Future Hydrology Meeting Series that would ideally be addressed using a future hydrology dataset. The top three priority needs are listed by theme (geomorphic, HREP/management, and ecology).

Geomorphic	HREP/Management	Ecology
Understand how future hydrology may affect geomorphic responses	Understand changes in hydrology and hydraulics at varying spatial scales to guide river restoration designs	Understand how future hydrology may affect biological responses, ecological structure, and ecological function
Understand how natural geomorphic features and navigation infrastructure influence water conveyance across the river-floodplain under changing conditions	Understand how future hydrology can drive our vision of desired future conditions and other planning guidance	Understand how future hydrology may affect floodplain forests, aquatic vegetation, and the distribution of their suitable habitats
Assess how changing hydrology may affect backwater sedimentation	Understand whether there are opportunities for different / new restoration features that are more self-sustaining	Understand which hydrologic metrics are most influential on vegetation responses

An off-the-shelf data product was discussed as a potential resource for the partnership during the UMRR Future Hydrology Meeting Series as an alternative to new modeling efforts that would require substantially greater amount of funding and development time. The LOCA-VIC-mizuRoute hydrologic data products represent the most recent data produced by collaborators from federal agencies including Bureau of Reclamation, U.S. Army Corps of Engineers, the U.S. Geological Survey, and other collaborating academic and research institutions. The name “LOCA-VIC-mizuRoute” comes from the chain of models the data are produced from: LOcalized Constructed Analogs (downscaled Coupled Model Intercomparison Project Phase 5 global climate data; Pierce et al. 2014, Vano et al. 2020), Variable Infiltration Capacity-VIC (macroscale hydrologic model; Liang et al., 1994), and the mizuRoute hydrologic routing model (Mizukami et al. 2016). The data products themselves represent a total of 64 timeseries projections of meteorology, hydrological fluxes, and routed river discharge from 1950-2099 for the continental United States. These datasets are derived from the simulations of global weather patterns from 32 global climate models for two emissions scenarios. These two emissions scenarios, or representative concentration pathways (RCP), are a moderate emissions pathway where radiative forcing from greenhouse gas emissions level off before the year 2100 at a level of 4.5 Watts per square meter (W/m^2; RCP 4.5) and a high emissions pathway where radiative forcing continues to rise, reaching 8.5 W/m^2 by 2100 (RCP 8.5). The hydrologic projections are available for every river segment in the continental United States in the USGS’s National Hydrography Dataset. The data driving the LOCA-VIC-mizuRoute products are available at https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/ and the routed streamflow products are housed locally on USACE servers.

The LOCA-VIC-mizuRoute hydrologic data products have the desired characteristics identified in the UMRR Future Hydrology Meeting Series for an ideal dataset: discharge data at a daily time step for a minimum 50-year time horizon across the entire UMRS. However, the LOCA-VIC-mizuRoute hydrologic data products were developed for the continental United States using climate and hydrologic models not calibrated for a specific watershed such as the UMRS. This could be problematic because important processes that drive the UMRS's regional climate or basin flow regime may not be well represented, leading to unreliable projections for specific purposes. It is important, therefore, to evaluate the LOCA-VIC-mizuRoute hydrologic data products for their ability to capture important hydrological processes in the UMRS relevant to intended applications of the data. This evaluation will identify potential deficiencies and provide recommendations for the types of applications the data could reliably serve. To serve this purpose, the hydrologic data that are ultimately provided may be post-processed to reduce systematic biases and/or filtered to a reliable resolution (e.g., timestep, spatial scale).

The primary objective of this work is to produce a robust, quantitative dataset of future hydrology projections for the UMRS. To achieve our objective we will:

1. Rigorously evaluate the existing LOCA-VIC-mizuRoute hydrologic data products to establish whether they sufficiently capture the physical processes believed to drive UMRS hydrology (e.g., rainfall-runoff, groundwater, snowmelt dynamics, etc.).
2. Apply post-processing techniques to correct for any biases in the existing LOCA-VIC-mizuRoute hydrologic data products if the evaluation warrants them.
3. Develop documentation to aid in the interpretation and appropriate application of the LOCA-VIC-mizuRoute hydrologic data products for the UMRS, disseminate the data and documentation of the data, and host a webinar to educate the UMRR partnership on the data products.
4. Host a workshop in the event the existing LOCA-VIC-mizuRoute hydrologic data products are unsuitable for use in the UMRS, even with post-processing, whose goal would either be a) to identify the types of qualitative comparisons that could be made with the existing, uncalibrated LOCA-VIC-mizuRoute data projects and how to provide useful data summaries to support these comparisons to the UMRR partnership, or b) to plan for a re-calibration of the VIC hydrologic model (or other hydrologic model) to generate custom hydrologic projections for the UMRS.

Relevance of research to UMRR:
Resource managers are struggling to respond to recent changes in weather and hydrology and prepare for future changes. There are several frameworks to aid in these efforts (e.g., scenario planning [Miller et al. 2022] and RAD (resist, accept, direct) framework [Thompson et al. 2021]), but effective climate change adaptation relies upon understanding projected changes including the full range of potential trajectories. The LOCA-VIC-mizuRoute hydrologic data products, if reliable, will provide managers and researchers with a critical component needed for successful climate change adaptation planning efforts to ensure that restoration and management actions are appropriate and suitable for future conditions. For example, projections of future hydrology will be useful to HREP teams in terms of describing future without project conditions and evaluating resilience of project alternatives. For researchers, the data products could be integrated into existing quantitative models of hydrologic-ecological relationships to explore how the biota may respond to a range of potential future hydrologic conditions.

This proposal directly relates to the 2022 Science Focal Areas 1.2 ("Future discharge, hydraulic connectivity, and water surface elevation scenarios") and 1.3 ("Future hydrogeomorphology scenarios and their implications"). The LOCA-VIC-mizuRoute hydrologic data products, if they are found to be reliable for the UMRS, would be a foundational dataset for the UMRR partnership.

Any projections of future UMRS hydrology developed in this proposal will be broadly useful for scientific applications in the UMRS. Projected future hydrology data could be integrated into existing modeling frameworks to characterize potential biotic responses to future river flow conditions. Some examples of existing frameworks that may be extended in this way include those describing aquatic vegetation distributions (Carhart et al. 2021), interactions between flooding and forest succession processes (De Jager et al. 2019), ecosystem resilience (De Jager et al. 2018, Bouska et al. 2019), and eco-hydrologic relationships with LTRM monitoring datasets (e.g., Ickes et al. 2014, Houser 2016, Lund 2019). These potential applications relate to several focal areas including:

- FA 2.3 "What are the drivers of aquatic vegetation abundance, diversity, and resilience?"
- FA 2.4 "What are the main drivers of fish abundance, distribution, and community composition?"
- FA 2.5 "Consequences of river eutrophication for critical biogeochemical processing rates and habitat conditions"
- FA 2.6 "Understanding relationships among floodplain hydrogeomorphic patterns, vegetation, and soil processes, and effects on wildlife habitat and nutrient export"

Methods:
This project follows a workflow that was established during the UMRR Future Hydrology Meeting series to evaluate the existing LOCA-VIC-mizuRoute hydrologic data products (Fig. 1). The workflow begins with an assessment of data reliability (black boxes, Fig. 1), that will inform the pathway (green, blue, and red boxes; Fig. 1) for the subsequent steps. For example:

1. If the LOCA-VIC-mizuRoute hydrologic data products were found to be reliable for use in the UMRS with no further data processing necessary, we would proceed with the green pathway.
2. If the LOCA-VIC-mizuRoute hydrologic data products were somewhat reliable and could be improved for use in the UMRS through post-processes such as correcting for systematic biases or scaling applications, we would proceed with the blue pathway.
3. If reliability issues of the LOCA-VIC-mizuRoute data products could not be addressed through systematic bias correction or scaling, we would proceed down the red pathway.

It is notable that the outcome of the LOCA-VIC-mizuRoute data product evaluation is uncertain ahead of doing the actual evaluation, and as a result, there is no way to predict which workflow path the evaluation will ultimately lead. However, all components of the workflow were discussed and developed with technical experts familiar with the LOCA-VIC-mizuRoute data products, climate change analysis, and hydrologic modeling to ensure scientific best practices will be met and that the contingencies are identified and accounted for in the workflow process. Below, we detail the methodology following the workflow's color scheme from Figure 1.

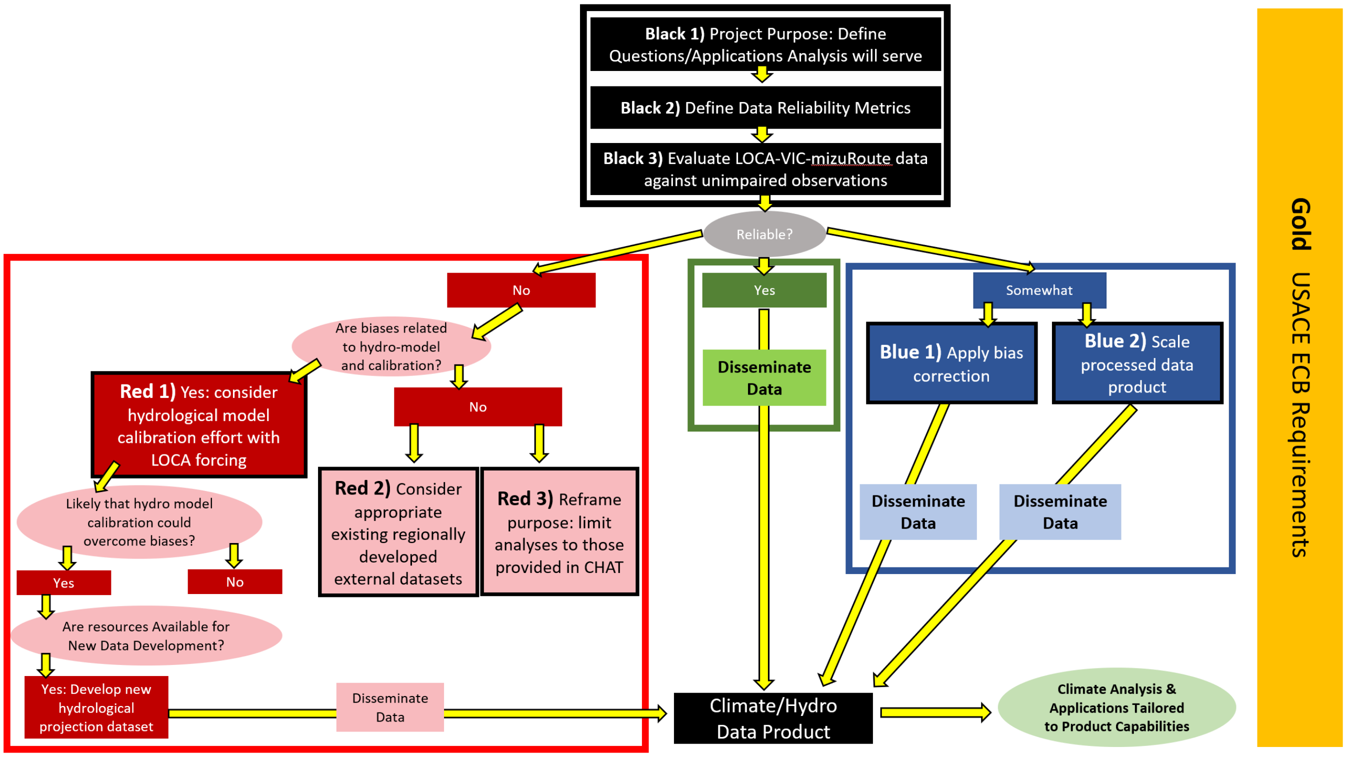

Figure 1: Workflow process for evaluating the LOCA-VIC-mizuRoute data products. Boxes are color coded to represent related sequences of activities described in the methods ("pathways").

Black boxes

The black boxes represent the starting point of the LOCA-VIC-mizuRoute data product evaluation process. The goal of the activities in the black boxes is to articulate the project's purpose (top black box, "Black 1"), identify metrics for evaluating model performance (middle black box, "Black 2"), and quantify model performance (bottom black box, "Black 3"). The activities carried out in these boxes will determine which pathway will be subsequently followed given the results of model performance.

Progress through the black boxes has already been made via the UMRR Future Hydrology Meeting Series. During the meeting series, the partnership helped identify the questions and applications for which any projected future hydrology dataset could be used and largely defined this project's purpose ("Black 1," Fig. 1). A small team of USACE district representatives, as well as project PIs, will build on the partnership discussions to refine how a projected future hydrology dataset could integrate with HREP planning and design. This document, like the partnership's prior discussions, would help guide the selection of data reliability metrics ("Black 2," Fig. 1) and inform documentation related to the data dissemination steps (green and blue boxes, Fig. 1). The activities of this proposal would largely be related to defining data reliability metrics and conducting the actual evaluation ("Black 1" and "Black 2," Fig. 1). We will assess the reliability of the LOCA-VIC-mizuRoute dataset using metrics that will be identified through literature review conducted by technical experts with input from the PIs. Metrics will be used to help identify any systematic biases in the LOCA-VIC-mizuRoute data products. Examples of systematic biases may include a poor representation of hydrologic responses to precipitation events, insufficient accounting of groundwater contributions, or snowmelt timing and dynamics. Insufficiencies like these may manifest as biases in the LOCA-VIC-mizuRoute modeled historical discharge data that can be detected when compared to observed historical discharge data using selected metrics. Based on discussions during the UMRR

Future Hydrology Meeting Series, evaluation metrics will assess annual, seasonal, and monthly flow duration, variability, magnitude and timing to understand how well low and high flows are simulated across a range of time steps. Metrics for observed and modeled historical discharge will be directly compared using the non-parametric statistics (e.g., Kolmogorov-Smirnov or Cramér-von Mises tests).

Once the metrics have been chosen, historical (1950 – 2005) modeled discharge data from the LOCA-VIC-mizuRoute data products will be compared against observed unimpaired discharges using the chosen metrics ("Black 3," Fig. 1). The comparisons will occur at USGS gaging locations selected by the technical experts to represent a range of physiographic conditions found in the basin that are not affected by upstream regulation or land use changes over the historical period. Modeled daily discharge data from the LOCA-VIC-mizuRoute products will be extracted using custom scripts. Gages that are not influenced by regulation are being mapped and historical observed unimpaired discharge datasets are being compiled as part of the Upper Mississippi River and Missouri River Flow Frequency Studies that are underway. The modeled and observed historical data will be summarized separately using the set of metrics established by the technical experts ("Black 2," Fig. 1), allowing for quantitative comparisons (e.g., non-parametric statistics) and qualitative comparisons (graphical comparisons of metrics) between the modeled and observed discharge datasets. The quantitative comparisons across multiple gage locations will offer insight as to whether the climate and/or hydrologic models underlying the LOCA-VIC-mizuRoute data products can sufficiently represent watershed processes that may vary spatially. The quantity and severity of deviations between modeled and observed metrics can indicate overall data reliability (green pathway, Fig. 1), whether there is a problematic degree of systematic biases with the modeled hydrologic data and whether they can be corrected easily (blue pathway, Fig. 1), or whether there may be insurmountable issues relating to process fidelity with the data products that necessitate looking for alternative solutions (red pathway, Fig. 1).

The outcome of the black boxes will be a quantitative analysis with data summaries in numeric and visual form that will be interpreted by a group of technical experts and the project PIs. The group will meet to discuss the results and agree on a level of data reliability which will determine the activities for the remainder of the project. The possible outcomes are: all data are reliable with no further modifications necessary (green pathway), there are indicators of reliability but the data require bias-correction or scaling post-processing (blue pathway), or the existing data appear unreliable for quantitative analysis and issues cannot be addressed through bias-correction or scaling post-processing (red pathway, Fig. 1).

Green pathway

Under the green pathway, the LOCA-VIC-mizuRoute data products would be found to be reliable for applications in the UMRS without any additional post-processing and the project team would proceed with disseminating the LOCA-VIC-mizuRoute data products. The spatial resolution at which resulting streamflow projections will be made available cannot be determined in advance of the evaluation ("Black 3," Fig. 1). However, providing projections of streamflow will be prioritized for locations along the mainstem Upper Mississippi River and ILWW and major tributaries, where long term streamflow observations exist. At each location we would intend to serve the modeled daily discharge values from 1950 – 2099 for both emissions scenarios and 32 global climate models, resulting in a total of 64 time series per location.

Data products will be made publicly available through a website with features to help users navigate, explore, and interpret the large amount of data. Website construction will be lead by Randal Goss (USACE ERDC), who has completed a similar project for the Columbia River Basin. Features will likely include: data queries by map and location list, graphical summaries of aggregated projection results across the entire period of record (1950-2099) at each location, and graphical summaries of projections by season for each location. Data will be made available to download via the website by individual locations or groups of locations. All 64 time series datasets will be served at each location to allow for maximum flexibility for end users, but website visualization tools will summarize aggregate patterns across all datasets for interpretability and clarity to allow users to explore the model outputs before downloading the packaged datasets for their desired location(s). The project team will develop documentation to help describe the data and their appropriate uses. Documentation will accompany the data products on the website and will likely summarize the models underlying the LOCA-VIC-mizuRoute hydrologic data products, the emissions scenarios, and issues with uncertainty. Strengths and limitations of the data will be discussed at length to assist stakeholders in understanding how best to interpret and use the data.

Finally, the PIs will host a webinar for the UMRR partnership to showcase the results of the project. The goal of the webinar would be to educate attendees on how to access, interpret, and use the data. Topics that will be discussed would likely include the results of the evaluation, an introduction to the data themselves and how to access them on the website, an overview of the documentation and review of best practices for use (including appropriate time scales of analyses), a discussion of uncertainty in modeled hydrologic data, and a Q&A session to address specific concerns from the partnership.

Blue pathway

The blue pathway would be followed in the event the LOCA-VIC-mizuRoute data products were found to adequately represent the hydrological processes in the UMRS but still display some systematic underlying biases that would limit the intended interpretations and applications. In this pathway, the effects of these systematic biases could be reduced by applying a bias-correction technique or scaling the intended applications of the processed data product.

Bias correction ("Blue 1," Fig. 1) is a statistical adjustment of the data to correct for the systematic biases that arise during a model simulation. Examples of correctable systematic biases include consistent underestimations of annual peak flows, underestimates of low flows, or misrepresentation of flow conditions during a certain season. There are several bias correction methods. Different methods are used to correct for different types of biases. There are several steps to apply a bias correction technique. First the systematic biases that require correction would be identified by the technical experts reviewing the results of the data product evaluation. Then, the technical experts would identify the most appropriate bias correction method to use given the biases present. Third, the bias correction method would be applied to the data products, including cross-checks that the bias has been corrected to an acceptable degree.

When the results from the evaluation look good overall but indicate that the data may not be suited for all intended data applications, then some constraints for application must be defined. This outcome is referred to as "scale processed data product" ("Blue 2," Fig. 1). In this situation, quantitative analysis using the LOCA-VIC-mizuRoute hydrologic data products would be limited to a certain time interval (duration) or to certain locations. The outcome of this scenario is either a list of appropriate uses for the data products, or a filter of the data to certain locations for which the data are most appropriate. If the former is necessary, results from the evaluation would be shared with a larger group of UMRR partners to gain consensus on which applications are most appropriate for the data.

After completion of either Blue 1 or Blue 2 boxes (Fig. 1), the resulting datasets would be packaged up for dissemination. Data dissemination would largely follow the dissemination steps described in the green pathway above. If the scaling processed data product methods are undertaken ("Blue 2," Fig. 1), then any limitations would be communicated through the data documentation.

Red pathway

The red pathway would be followed if the comparisons of the LOCA-VIC-mizuRoute dataset to observed hydrological datasets ("Black 3," Fig. 1) indicated that no post-processing could rectify the data. If the evaluation results also indicated that the data had significant deficiencies in representing key hydroclimatic processes in the basin, the "Red 1" (Fig. 1) pathway would be followed. Under this scenario we would conduct a quantitative evaluation of the likelihood that a re-calibration of the VIC model could overcome these biases. The results of the evaluation would then be shared in a virtual workshop format among project PIs, CPR CoP members and UMRR participants who attended Meeting #3. The purpose of the workshop would be to discuss the calibration evaluation results, implications for meeting UMRR priorities, and to scope an appropriate modeling effort for generating projected UMRS hydrology if the results indicated likely success of this pursuit.

It is possible that data issues could not be improved through systematic bias-correction, scaling of applications, or hydrologic modeling and calibration. Under this scenario, the project team would first consider the availability, strengths, and limitations of existing regionally developed datasets that may meet some of the UMRR's priority needs for understanding future UMRS hydrology ("Red 2," Fig. 1). During Meeting #3, it was acknowledged that there may be efforts within the region to develop regional downscaled climate and hydrologic products. These products would need to be identified and evaluated for their suitability in the UMRS. Evaluation of any regionally-developed streamflow product would follow the same process used for evaluation of the LOCA-VIC-mizuRoute data products ("Black 3," Fig. 1) and finish with an update to the LTRM project management team to determine appropriate next steps.

If alternative downscaled products tailored for the region are not available, then we would reframe the project purpose and limit use of the existing LOCA-VIC-mizuRoute hydrology to qualitative comparisons such as those shown in the Climate Hydrology Assessment Tool (CHAT; "Red 3," Fig.1). CHAT summarizes metrics at the HUC 08 scale and currently has annual-maximum of the average monthly in-channel routed runoff (additional metrics forthcoming). The project team would host a virtual workshop for the UMRR partnership (attendance list similar to the UMRR Future Hydrology Meeting Series) to introduce partners to the CHAT and identify how it could be utilized in research and management.

Gold box

"Gold" (Fig. 1) represents fulfillment of ECB-2018-14, "Guidelines for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects," requirements and would begin in advance of or concurrent with the LOCA-VIC-mizuRoute evaluation ("Black 3," Fig. 1). This effort involves coordination with the Climate Preparedness and Resilience Community of Practice (CPR CoP), which has been ongoing and was initiated during the early scoping of the UMRR Future Hydrology Meeting Series. The qualitative assessment of climate change required by ECB-2018-14 will be conducted by a PI and includes a literature review of observed and projected trends in climate change, trend analysis and nonstationarity detection in observed hydrology and relevant climate variables. The CHAT will be used to evaluate trends in the projected annual maximum of average-monthly streamflow at the 8-digit HUC scale for the Upper Mississippi River (HUC 07) and Missouri River (HUC 10) watersheds and a watershed vulnerability assessment will be conducted at the 4-digit HUC scale using the Vulnerability Assessment Tool (VAT). Recent qualitative assessments completed for both the Upper Mississippi River and Missouri River Flow Frequency updates will be leveraged to support the qualitative assessment proposed herein. As a result of this existing body of work, the primary focus of this effort will be to provide consistency, particularly in the use of the CHAT tool, between the Mississippi River and Missouri River analyses that were conducted independently. Updates to the vulnerability assessment will be required for the Ecosystem Restoration business line.

Data management procedures: Original LOCA-VIC-mizuRoute data products are currently housed on internal USACE servers; data will be extracted from the servers and analyzed by the project team. Subsequent data that are approved for release will be stored for long-term preservation on USACE servers and made publicly available through a custom web portal as described in the "Green Pathway" section above. Any data approved for dissemination will be accompanied with documentation that includes information on appropriate uses and limitations.

*Date listed is latest potential date for activities associated with multiple workflow pathways (Fig. 1).

References

Ayers, J. R., G. Villarini, C. Jones, and K. Schilling. 2019. Changes in monthly baseflow across the U.S. Midwest. Hydrological Processes 33:748-758.

Bouska, K. L., J. N. Houser, N. R. De Jager, and J. Hendrickson. 2018. Developing a shared understanding of the Upper Mississippi River: The foundation of an ecological resilience assessment. Ecology and Society 23:art6.

Bouska, K. L., J. N. Houser, N. R. De Jager, M. Van Appledorn, and J. T. Rogala. 2019. Applying concepts of general resilience to large river ecosystems: A case study from the Upper Mississippi and Illinois rivers. Ecological Indicators 101:1094–1110.

Byun, K., C.-M. Chiu, and A. F. Hamlet. 2019. Effects of 21st century climate change on seasonal flow regimes and hydrologic extremes over the Midwest and Great Lakes region of the US. Science of The Total Environment 650:1261–1277.

Carhart, A. M., J. E. Kalas, J. T. Rogala, J. J. Rohweder, D. C. Drake, and J. N. Houser. 2021. Understanding constraints on submersed vegetation distribution in a large, floodplain river: The role of water level fluctuations, water clarity and river geomorphology. Wetlands 41:57.

De Jager, N. R., J. T. Rogala, J. J. Rohweder, M. Van Appledorn, K. L. Bouska, J. N. Houser, and K. J. Jankowski. 2018. Indicators of ecosystem structure and function for the Upper Mississippi River System. 134 p. Open-File Report, U.S. Geological Survey.

De Jager, N. R., M. Van Appledorn, T. J. Fox, J. J. Rohweder, L. J. Guyon, A. R. Meier, R. J. Cosgriff, and B. J. Vandermyde. 2019. Spatially explicit modelling of floodplain forest succession: Interactions among flood inundation, forest successional processes, and other disturbances in the Upper Mississippi River floodplain, USA. Ecological Modelling 405:15–32.

Houser, J. N. 2016. Contrasts between channels and backwaters in a large, floodplain river: Testing our understanding of nutrient cycling, phytoplankton abundance, and suspended solids dynamics. Freshwater Science 35:457–473.

Ickes, B. S., J. S. Sauer, N. Richards, M. Bowler, and B. Schlifer. 2014. Spatially-explicit habitat models for 28 fishes from the Upper Mississippi River System (AHAG 2.0). A Program Report submitted to the U.S. Army Corps of Engineers' Upper Mississippi River Restoration-Environmental Management Program from the U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. January 2014. LTRMP Program Report 2014-P001. 26 pp. + Appendixes A–B.

Liang, X., D. P. Lettenmaier, E. F. Wood, and S. J. Burges. 1994. A simple hydrologically based model of land surface water and energy fluxes for general circulation models. Journal of Geophysical Research 99:14415.

Lund, E. 2019. Time lag investigation of physical conditions and submersed macrophyte prevalence in Upper Navigation Pool 4, Upper Mississippi River. U.S. Army Corps of Engineers' Upper Mississippi River Restoration Program Long Term Resource Monitoring Element Completion Report LTRM-2015A8, 23 p.

Mallakpour, I., and G. Villarini. 2015. The changing nature of flooding across the central United States. Nature Climate Change 5:250–254.

Miller, B. W., G. W. Schuurman, A. J. Symstad, A. N. Runyon, and B. C. Robb. 2022. Conservation under uncertainty: Innovations in participatory climate change scenario planning from U.S. national parks. Conservation Science and Practice 4:e12633.

Mizukami, N., M. P. Clark, K. Sampson, B. Nijssen, Y. Mao, H. McMillan, R. J. Viger, S. L. Markstrom, L. E. Hay, R. Woods, J. R. Arnold, and L. D. Brekke. 2016. mizuRoute version 1: A river network routing tool for a continental domain water resources applications. Geoscientific Model Development 9:2223–2238.

Neri, A., G. Villarini, and F. Napolitano. 2020. Statistically-based projected changes in the frequency of flood events across the U.S. Midwest. Journal of Hydrology 584:124314.

Pierce, D. W., D. R. Cayan, and B. L. Thrasher. 2014. Statistical downscaling using localized constructed analogs (LOCA). Journal of Hydrometeorology 15:2558–2585.

Thompson, L. M., A. J. Lynch, E. A. Beever, A. C. Engman, J. A. Falke, S. T. Jackson, T. J. Krabbenhoft, D. J. Lawrence, D. Limpinsel, R. T. Magill, T. A. Melvin, J. M. Morton, R. A. Newman, J. O. Peterson, M. T. Porath, F. J. Rahel, S. A. Sethi, and J. L. Wilkening. 2021. Responding to ecosystem transformation: Resist, accept, or direct? Fisheries 46:8-21.

Van Appledorn, M. *In review.* Hydrologic Indicators, *In:* Ecological Status and Trends of the Upper Mississippi River System from 1993 to 2019, J. Houser and J. Sauer, eds. Open-File Report 2022-XXXX.

Vano, J., J. Hamman, E. Gutmann, A. Wood, N. Mizukami, M. Clark, D. W. Pierce, D. R. Cayan, C. Wobus, K. Nowak, and J. Arnold. 2020. Comparing downscaled LOCA and BCSD CMIP5 climate and hydrology projections - Release of downscaled LOCA CMIP5 hydrology. 96 p.

Zhang, W., and G. Villarini. 2021. Greenhouse gases drove the increasing trends in spring precipitation across the central USA. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 379:20190553.

Zhang, Y.-K., and K. E. Schilling. 2006. Increasing streamflow and baseflow in Mississippi River since the 1940s: Effect of land use change. Journal of Hydrology 324:412–422.

Products and Milestones

Tracking number	Products	Staff	Milestones
2023Hydro1	LOCA-VIC-mizuRoute data product evaluation	Sawyer and Van Appledorn	31 June 2023
2023Hydro2	LTRM project management team update on evaluation results	Sawyer and Van Appledorn	31 June 2023
2023Hydro3	ECB 2018-14 compliance completion	Sawyer and Van Appledorn	30 September 2023
2023Hydro4	Annual update: Year 1	Sawyer and Van Appledorn	31 December 2023
2023Hydro5	UMRS projected hydrology data and documentation release	Sawyer and Van Appledorn	30 September 2024
2023Hydro6	UMRR webinar on UMRS projected hydrology data release	Sawyer and Van Appledorn	31 December 2024
2023Hydro7	Virtual workshop or LTRM project team update for red pathway outcomes	Sawyer and Van Appledorn	31 March 2024 30
2023Hydro8	Draft LTRM completion report	Sawyer and Van Appledorn	September 2024 30
2023Hydro9	Final LTRM completion report	Sawyer and Van Appledorn	December 2025

Assessing Forest Development Processes and Pathways in Floodplain Forests along the Upper Mississippi River using Dendrochronology

Previous LTRM project: None

Name of Principal Investigator(s):
Dr. Marcella Windmuller-Campione, Lead PI, Assistant Professor of Silviculture, Dept. of Forest Resources, University of Minnesota, 612-624-3699 (office), 847-772-5458 (cell), mwind@umn.edu, serve as the supervisor for the post-doc that will be hired for this project, supervise and manage data summarization, statistical analysis, and writing of reports and peer-reviewed articles.

Dr. Molly Van Appledorn, Co-PI, Ecologist, US Geological Survey, Upper Midwest Environmental Sciences Center, 608-781-6323, mvanappledorn@usgs.gov, assist with logistics related to project funding, coordinate analysis and use of hydrologic and environmental data sets, interpretation of results and linking to broader projects within the UMR, writing and review of products.

New Hire, Post-doctoral Scientist, Dept. of Forest Resources, University of Minnesota, primary individual responsible for data analysis and summarization as well as writing of reports and peer-reviewed articles, primary responsibility for data processing, quality control, meta-data development, data management and preservation.

Andy Meier, Lead Forester, USACE, St. Paul District, 651-290-5899, Andrew.R.Meier@usace.army.mil, collaboration in defining specific questions for analysis, interpretation of results, ensuring relevance to management on the UMRR, providing additional USACE forest data as it is relevant to informing analysis, writing and review of products.

Collaborators (Who else is involved in completing the project):
Ben Vandermyde, Lead Forester, USACE, Rock Island District, PO Box 534, Pleasant Valley, IA 52767, 309-794-4522, ben.j.vandermyde@usace.army.mil, defining specific questions for analysis, providing context for future integration of MVR and MVS dendrochronology data, review of outputs; **in kind support (~20 hrs/year)**

Brian Stoff, Lead Forester, USACE, St. Louis District, 301 Riverlands Way, West Alton, MO 63386, 636-899-0064, brian.w.stoff@usace.army.mil, collaboration in defining specific questions for analysis, providing context for future integration of MVR and MVS dendrochronology data, review of outputs; **in kind support (~20 hrs/year)**

Greg Edge, Silvicultrist/Forest Ecologist, Wisconsin Department of Natural Resources, 3550 Mormon Coulee Road, La Crosse, WI 54601-6768, 608-498-6512, Gregory.Edge@wisconsin.gov, collaboration in defining specific questions for analysis, review of outputs; **in kind support (~20 hrs/year)**

Paul Dubuque, Silviculture Program Consultant, Minnesota Department of Natural Resources, 500 Lafayette Road, St. Paul, MN, 55155, 651-259-5294, paul.dubuque@state.mn.us, collaboration in defining specific questions for analysis, review of outputs; **in kind support (~20 hrs/year)**

Mike Reinikainen, Silviculture Program Coordinator, Minnesota Department of Natural Resources, 500 Lafayette Road, 55155, 651-259-5270, mike.reinikainen@state.mn.us, collaboration in defining specific questions for analysis, review of outputs; **in kind support (~20 hrs/year)**

Michelle Martin, Central Region ECS Specialist, Minnesota Department of Natural Resources, 1200 Warner Road, St. Paul, MN, 55106, 651-259-5836, michelle.martin@state.mn.us, collaboration in defining specific questions for analysis, review of outputs; **in kind support (~20 hrs/year)**

Introduction/Background:
Floodplain forest ecosystems of the Upper Mississippi River (UMR) have been influenced by anthropogenic management for generations, resulting in large declines in forest cover from the time of European settlement (Theiling et. al 2000). Extensive land clearing for timber and agriculture significantly altered the landscape prior to the establishment of the 9-foot navigation channel. The installation of the lock and dam system in the 1930s

led to further loss of forest and alteration of forest dynamics (Theiling et al. 2000), while hydrologic changes currently occurring within the UMR have continued to exacerbate declines in forest. There has been extensive research exploring the influence of the lock and dam system on many ecological processes within the UMR, but most of this work has focused on aquatic habitats and communities. Our understanding of terrestrial UMR habitats and indicators of resilience within those habitats remains very basic, with almost no long-term data. As an example, a 1988 index to the Annual Proceedings of the Upper Mississippi River Conservation Committee includes 17.5 pages of citations for “fish” and “fishing,” ranging from 1947 to 1988, but only a single citation for “forest” (UMRCC 1988). The only available review of UMR floodplain forest literature includes 68 citations, but only two references to analyses specifically conducted in UMR forests (Romano 2010).

Recent work has expanded our knowledge base to a certain extent. There has been research documenting landscape level patterns in UMR floodplain forests (Yin et al. 1997) and establishing relationships between large-scale forest dynamics and hydrologic conditions (De Jager et al. 2012, De Jager et al. 2019). However, basic local-scale, long-term developmental patterns that influence forest communities in the UMR are not well established. Understanding stand development patterns is critical for designing stand-level management prescriptions needed for effective on-the-ground restoration because it is the interaction of trees with other vegetation and the environment in their local neighborhoods that ultimately sets the long-term direction of forest establishment and growth. In effect, landscape-level analyses identify the problems and broad-scale drivers of change, but local-level analyses are essential to developing management solutions and altering long-term, state-altering trajectories in UMR forests.

With limited local-scale, long-term data available, management decisions related to habitat rehabilitation and enhancement of floooplain forests are generally made based on current conditions and observations of short term dynamics. In these degraded systems, many of the trees present on the landscape today regenerated at a time period for which there is no recorded forest data and very sparse anecdotal information. Given that floodplain forests continually rank as a top restoration priority (see next section) and that these forests are continuing to disappear, more detailed information of long-term dynamics at the local scale is critical for development of viable restoration strategies for floodplain forests.

Dendrochronology is a tool that can be used to assess historic forest conditions by relating tree age and the width of annual growth rings to environmental conditions such as flooding or drought in associated years. In addition to broad-scale environmental factors, tree ring analysis can also identify local-scale tree mortality events associated with factors such as the natural death of old trees or windthrow. In upland systems, these local canopy mortality events create canopy gaps which often result in the establishment or release of understory trees from competition – an important forest development process that leads to species and structural diversification. However, in the UMR floodplain, the 2018 UMRR-Science in Support of Restoration (UMRR-SSR) project assessing systemic forest canopy gap dynamics (Guyon et al., in prep) has indicated that current forest canopy gaps may not be regenerating back to forest as expected. Recent work in Rock Island and St. Louis Districts funded through the UMRR-SSR program used dendrochronology to demonstrate both broad-scale impacts of flooding and drought on forest dynamics as well as the importance of local release events in the persistence of individual trees (King et al. 2021). Given the variability between districts in floodplain topogpraphy, hydrology, and tree species, it is important to assess these patterns in St. Paul District pools as well.

The current proposal will fill the data gap within the St. Paul District in UMR tree ring data by utilizing tree cores collected as part of a Cooperative Ecosystem Studies Unit (CESU) agreement between the University of Minnesota and the USACE – St. Paul District, funded from 2018-22 with operational Environmental Stewardship funding. The orginal CESU funding focused on quantifying current forest dynamics (Windmuller-Campione et al. *in review).* The proposed study would leverage the field-based analysis of current inventory data by incorporating detailed tree ring analysis of the already-collected trees cores to answer three main questions:

1. What is the current age structure of floodplain forest sites, and how does the age structure vary within sites and among sites in the context of local scale environmental variation and regional scale hydrologic patterns?
2. What is the disturbance history of floodplain forest sites, what role do tree- or gap-level disturbance play in forest structuring relative to flooding events, and how is species composition influenced by disturbance history relative to flooding?
3. What is the persistence of different species in understory conditions in floodplain forest sites, and are there thresholds at which management actions would most effectively influence the development of more resilient forest conditions?

Relevance of research to UMRR:
Over the last few years, floodplain forest have become a higher and higher priority for restoration for all agencies involved in UMR management, and numerous HREPs have identified floodplain forest restoration as a top priority. A number of active HREPs (Reno Bottoms, Pool 12 Forest, Green Island) and HREPs with approved fact sheets (Black River Bottoms, Pool 8 Forestry) have landscape-scale forest management as key components.

The analysis proposed in this project will be directly applicable to HREP planning and design in a number of ways. First, it will help in initial project planning and selection of management areas by allowing for the development of relationships between current forest conditions and historic stand development, which, in turn, will allow for prioritization of management based on potential for long-term resilience. In addition, data from this analysis may be used to improve inputs to the long-term forest modeling frameworks to aid in site selection. For the design of forest management actions within HREPs, this project will also help to identify forest canopy density threshholds that may merit canopy thinning actions, or identify tree species with low long-term persistence under dense canopies which would benefit from release. It will also help to identify environmental conditions associated with early forest establishment and growth that will allow for the design of management prescriptions that replicate those conditions. All of these planning and design improvements will ultimately result in more cost-effective forest restoration efforts in the UMR.

Though the current project will utilize data from the St. Paul District, all of the tree species and most of the forest community types that occur within St. Paul District also occur lower in the UMR and along the Illinois River, so patterns identified in this project can be applied to management decisions elsewehere in the river. Data from St. Paul District may also be integrated with dendrochronology data collected for the earlier UMRR project in Rock Island and St. Louis districts to develop regional assessments of long-term forest dynamics.

This research will directly address Focal Area 2.6 “Understanding relationships among floodplain hydrogeomorphic patterns, vegetation and soil processes, and effects on wildlife habitat and nutrient export” because it will characterize forest stand dyanmcis and how they relate to river hydrogeomorphology. Specially it will address Focal Area 2.6.b.5: “What are the successional histories of local-scale regeneration processes that control transitions from seeds to saplings?” by analazying annual tree growth over a period of multiple decades in selected study stands. These data will provide a picture of conditions within the stand in the past, and those conditions will be related back to processes associated with initial tree seedling and sapling growth in those stands. In addition, the research will address components of and provide insights for additional floodplain focal area questions, in particular: 2.6.b.2, 2.6.b.8, 2.6.b.9.

Methods:
This proposed study leverages forest inventory data and tree cores collected from a 2018-22 CESU study. The initial study focused primarily on describing current forest conditions and how those conditions differed based on intra- and inter-site variability in forest condition and environmental drivers. Below we describe the sampling design and datasets of the initial study as context for our new proposed work.

Completed Field Study – Field Data for Current Proposal
For the initial 2018-22 CESU study, plot level forest inventory data were collected at 13 silver maple- (*Acer saccharinum* L.) dominated or mixed-silver maple forest sites in the St. Paul District (Figure 1) covering a wide longitudinal gradient (between sites) and hydrogeomorphic gradient (with sites). Study sites were chosen to span elevation gradients, inundation dynamics, and the potential range of associate species in silver maple forest ecosystems, with some potential sites eliminated due to access limitations. Although silver maple was the dominant overstory species at the study sites, other commonly occurring species were hackberry (*Celtis occidentalis* L.), bitternut hickory (*Carya cordiformis* (Wangenh.) K. Koch), swamp white oak (*Quercus bicolor* Willd.) and American basswood (*Tilia americana* L.). Within the sites, forest composition ranged from almost complete overstory dominance by silver maple to mixed forest communities with no live silver maple present in the plot.

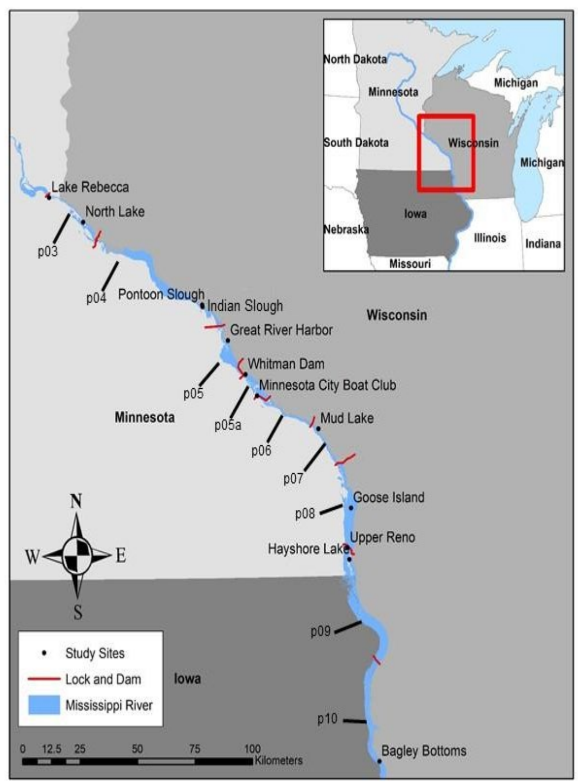

Figure 1: Location of study sites (black dots), locks and dams (red lines), and navigation pools (p03-p10) within the St. Paul District section of the UMR.

Overstory forest inventory data were collected using 400 m^2 fixed radius plots during the 2018, 2019, and 2020 growing seasons. Plots were systematically distributed through each study site to achieve a sampling density of 1 plot per 10 hectares with a minimum sampling number of 4 plots and a maximum of 15 plots per site. The goal was to broadly cover the site with plot samples while accommodating logistical concerns (e.g., accessibility, flooding). Tree species, height, diameter at breast height (dbh), health status (live or dead), canopy class (dominant, co-dominant, intermediate, suppressed), and plot canopy cover were recorded for each overstory tree in a plot.

All overstory trees > 12 cm at dbh within each plot were cored with an increment borer in two perpendicular directions, resulting in the collection of over 1,100 cores (Table 1). For each tree core, there is therefore an associated diameter, height, species, health status, canopy position, and percent canopy cover. Each individual tree was mapped within the plot to document their exact location, enabling detailed assessments of local-scale conditions related to tree age and growth. Cores were dried in an oven before being mounted and prepared using standard dendrochronology methods (Stokes & Smiley 1968).

In addition to the data collected through the inventory, data were compiled for five important environmental variables at each site: elevation, relative elevation, inundation frequency, inundation duration, and inundation depth. All variables were derived from publicly available geodatasets. Elevation was summarized using the UMR topobathymetric dataset, which combines terrestrial LIDAR products with bathymetric surveys to form a seamless terrain at the 2m X 2m scale (USACE, 2016). Relative elevation, defined as the elevation above a minimum river surface elevation, was summarized by detrending the topobathymetric dataset of down-river slope as described by Van Appledorn et al. (2021). The three inundation variables were summarized using a geospatial model of inundation dynamics described by De Jager et al. (2018) and Van Appledorn et al. (2021) and are indices of long-term inundation conditions. Because plots at Lake Rebecca were located outside the inundation model domain, inundation attributes and relative elevations for Lake Rebecca were substituted from adjacent areas with similar ranges of absolute elevation using the same inundation and relative elevation models mentioned above. Van Appledorn et al. (2021) provide full details of inundation variable calculations. The five environmental variables (elevation, relative elevation, inundation frequency, inundation duration, and inundation depth) were summarized to characterize average conditions of the plot using mean values and within-plot variability using the range and standard deviation observed within the plot boundaries.

Initial analyses of current conditions on the study sites indicated high levels of variability in composition and structure between plots at individual sites that was only partially driven by environmental variables (Windmuller-Campione et al., *in review*; Nielsen, 2020), indicating that long-term stand dynamics are likely an important driver of current stand conditions.

Dendrochronology – New Data Analysis for Proposed Study

The proposed study will utilize >1,100 tree cores that were collected as part of the initial field study to assess historic conditions, filling a critical gap of any long-term forest data in the UMR preceding the early 2000s. For the current proposal, mounted tree cores will be scanned and tree ring widths will be measured using a novel digital approach for tree core measurement that allows for recording and managing data in a digital, easily shareable format (Figure 2; https://dendro.elevator.umn.edu/). Annual tree growth and the year at the center of the tree will be calculated from the ring widths for each tree. These data will then be related back to plot-level field data collected in the previous project to describe plot-level forest conditions. Indicator years related to canopy or environmental conditions will be derived from the variation in tree ring width, and these will be used to determine whether the wide variability in current forest conditions as observed and reported from the field data (Windmuller-Campione et al., in review; Nielsen, 2020) are driven by historic conditions and whether those historic conditions are better indicators of long-term forest resilience than current conditions.

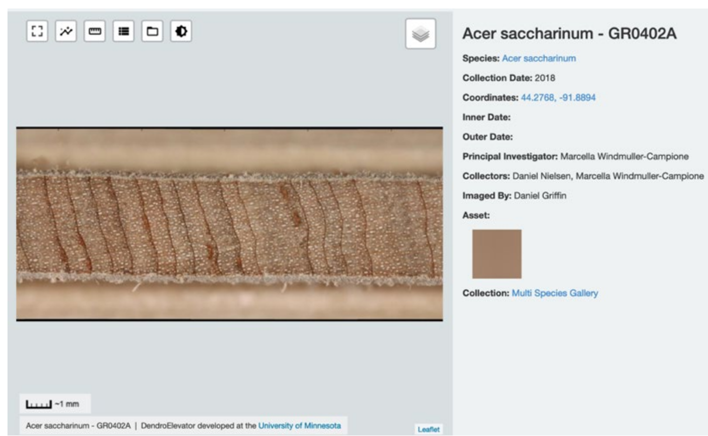

Figure 2. Example of processed tree cores that are scanned and measurements occur within an open source software platform allowing for more flexibility, quality control, and greater ability to share results across institutions, disciplines, and organizations

Following the initial summaries of existing stand conditions (Windmuller-Campione et al., *in review*), tree cores from the Lake Rebecca site (Pool 3) were used for a preliminary investigation of the relationships between tree age and annual growth rates and the relationship of age and growth to long term forest dynamics (Crawford et al., 2020). For example, ring-width chronlologies at Lake Rebecca show distinctive patterns of growth variability prior to the 1980s that likely represent the development of an even-aged canopy that was relatively open with competition for light as the primary factor driving growth; canopy closure appeared to occur in the mid-1980s. Multiple synchronous growth events are also evident in this chronology (Figure 2). Based on the age of the inntermost ring on the site, it is clear that cottonwood established on the site first, with silver maple establishing later (Figure 3), with little establishment after 1960. From this case study that only used a subset of cores for two species, there is evidence of very promising results that could be expanded to the 12 remaining sites to provide critical information on long-term, local tree growth dynamics for individual species and for forest communities. All of the background field and environmental data that were used to develop the pilot Lake Rebecca dendrchronology analysis will be applied to the analysis of tree core data for the current proposal in ways that will directly answer the three main study questions, as described below.

The next section will cover the methods for each of the three questions outlined in the introduction.

Table 1. Tree cores available for analysis by site and tree species for the current study. Other species are species with less than 10 total cores and includes bitternut hickory, hawthorn, black walnut, black locust and American basswood

Pool	Study Site	Tree Species										Total Cores
		silver maple	green ash	Am. elm	cotton-wood	river birch	hack-berry	swamp white	black oak	box-elder	other	
3	Lake Rebecca	51	17	9	24	0	0	0	0	2	0	***103***
3	North Lake	75	10	14	17	0	3	0	0	3	0	***122***
4	Pontoon Slough	34	4	2	2	4	0	2	0	0	0	***48***
4	Indian Slough	23	9	1	1	7	13	2	0	0	0	***56***
5	Gr. Riv. Harbor	25	8	1	4	0	0	0	1	2	3	***44***
5A	Whitman Dam	79	17	31	0	6	5	20	0	0	8	***166***
5A	Mn City Boat Club	37	10	5	14	0	3	0	0	12	2	***83***
5A	McNally Landing	0	17	2	0	0	7	0	0	0	0	***26***
7	Mud Lake	29	3	8	0	0	0	5	0	0	0	***45***
8	Goose Island	10	24	2	5	28	5	6	12	1	4	***97***
9	Upper Reno	64	20	13	1	2	10	22	0	0	0	***132***
9	Hayshore Lake	70	8	7	2	0	1	6	0	0	0	***94***
10	Bagley Bottoms	111	7	20	3	3	1	4	0	0	0	***149***
	Grand Total	*608*	*154*	*115*	*73*	*50*	*48*	*67*	*13*	*20*	*17*	***1165***

Question 1 – Methods: What is the current age structure of floodplain forest sites, and how does the age structure vary within sites and among sites in the context of local scale environmental variation and regional scale hydrologic patterns?

To address this question, we will quantify the forest age structure at the time of sampling and annual tree growth in the years prior to sampling using tree core data. In forest management, age structure (even-aged vs. uneven-aged) is one of the key factors considered when developing forest management prescriptions; regeneration of even-aged forests requires large-scale, high-intensity disturbance, while uneven-aged forest can generally be managed with a range of disturbance intensities.

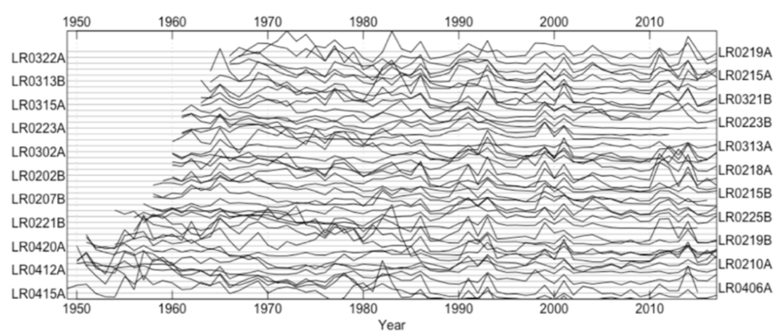

Figure 2. Ring-width chronologies for silver maple at Lake Rebecca in Pool 3. Each line represents an individual tree and the height of the line indicates the amount of annual growth (from Crawford et al. 2020).

Figure 3. Year of silver maple (top) and cottonwood (bottom) recruitment to a 4.5 foot tall height at Lake Rebecca in Pool 3.

The age structure of UMR floodplain forests is not well understood, and it is not clear for many tree species whether they require high intensity disturbance to regenerate or whether they persist in uneven-aged systems. By comparing actual age structure and annual growth rates for individual species, and relating those data to current forest composition and structure and to environmental variables, we will be able to characterize the ability of individual tree species to persist within aging forests. In addition, relationships between the year of tree establishment and environmental and forest conditions at the time of establishment will allow us to describe natural patterns of forest regeneration in the context of river dynamics. Site-level age structure will be related back to environmental variables to assess whether there are discrete associations between known disturbance events and tree establishment. These insights will provide critical information for determining future trajectories of floodplain forests and whether the species currently present on the site are likely to persist. They will also help to define key periods in forest development at which management interventions may be necessary to ensure long-term forest health and reduce potential for invasive species establishment.

To accomplish this, annual ring widths will be recorded for each tree and statistically cross-correlated using COFECHA (Holmes 1983) to verify the accuracy of each ring's assigned calendar year. Various established techniques for cross-dating will be used to ensure accurate dates for rings (Griffin et al. 2011). We will then develop cross-dated tree ring chronologies to compare relationships at the stand level, species level, and potentially based on hydrologic classes. Standaridization of the chronologies will be completed in the dplR package in R (Bunn 2008). To account for the presence of trees in the dataset whose growth has been primarily influenced by competition, thus reducing the potential of a "strong environmental signal" (Schulman 1954) in ring widths, we will use a minimum interseries correlation threshold of 0.3 for the chronologies to maximize the common environmental signals while still including as many individual trees as possible.

Chronologies will be compared both statistically and visually during the time periods when chronologies demonstrate the highest interannual variability. A Kruskal-Wallis test will be used to determine if growth patterns vary among stands or species; a Dunn-Bonferroni post-hoc test will be used to confirm differences when applicable. We will also test whether there are differences among chronologies when they are grouped by flood frequency and flood duration classes using Kruskal-Wallis with Dunn-Bonferroni post-hoc tests. For each chronology that is developed, we will utilize linear regression to compare annual growth patterns to hydrologic variables.

Question 2 – Methods: What is the disturbance history of floodplain forest sites, what is role do tree- or gap-level disturbances play in forest structuring relative to flooding events, and how is species composition influenced by disturbance history relative to flooding?

Within forest communities, fine-scale disturbances or gap dynamics can greatly influence forest structure, composition, and function. Disturbance reconstruction from dendrochronological data can be accomplished using the TRADER package (Altman et al. 2014) in R. It detects "releases," or increases in annual growth rate compared to some set of previous years, which indicates disturbance. There are three different techniques that we will use to test for potential releases, as these methods have not yet be utilized in these floodplain forest species. The three techniques are: the radial-growth averaging criteria (Nowacki and Abrams 1997), the boundary-line methods (Black and Abrams 2003), and a technique which combines radial growth averaging and boundary-line techniques, hereafter the "Splechtna method" (Splechtna et al. 2005).

The growth-averaging method (or radial-growth averaging) is one of the most common techniques for growth release and was intended to be used on dominant and co-dominant trees. This method uses the average radial growth, comparing the previous ten years of growth to the next ten year of growth to determine if there are releases. Moderate releases are described as a 25 - 50% increase in growth and a major relase is > 50% release. This method can be utilized on small sample sizes which can allow us to detect releases on less common species, such as hard mast species (e.g., oak, hickory) in our dataset.

Given that the growth-averaging method was designed for co-dominant and dominant trees, Black and Abrams (2003) developed the boundary-line growth method by accounting for how tree growth changes over a tree's lifespan without a distrubance (negative exponential growth response), allowing it to be used on intermediate and suppressed trees. However, to utilize this method, there is a minimum threshold of at least 5,000 ring width measurements (Black et al. 2014), for example, 50 cores with an average age of 100 years or 100 cores with an average age of 50 years. This method can be used for more common species including green ash and American elm that are typically intermediate or suppressed tree species in the UMR floodplain.

Finally, to better account for differences in shade tolerance in the growth rate of tree species, Splechtna et al. (2005) used aspects from both Nowackie and Abrams (1997) and Black and Abrams (2003) that resulted in a more conservative estimate of release or disturbance events. A release is identified when there is at least a 50% change in growth; this change accounts for the negative exponential nature of tree growth.

Because we cannot go back in time to verify a disturbance event, we can examine the potential range of release events detected by each method. We would interpret release events detected by multiple methods as strong evidence for a true historical release event and thus a fine-scale distrurbance to the local forest community. Additionally, given the range of silvics of the species within our study, we can account for the potential differences in growth and thus release by utilizing different methodological techniques.

We will construct a timeline of potential disturbance events using the release information for each stand (see additional information in Question 3). We will overlay the timing of releases with hydrologic data to quantify if there are direct relationships between metrics of flooding (or drought) and release events. These events may be lagged; we will quantify any temporal trends through linear and non-linear statistical methods.

Question 3 – Methods: What is the persistence of different species in understory conditions in floodplain forest sites, and are there thresholds at which management actions would most effectively influence the development of more resilient forest conditions?

Question 3 builds from Questions 1 and Question 2, to explore how the above data can be utilized for restoration and forest management practices. For example if we utilize Lake Rebecca prelimary data as an example (Figure 2 and 3), we observed limited establishment of silver maple or cottonwood in the last 40 years and that growth is rather stable across overstory trees. Pairing the chronology data with the forest inventory, we can see that average density (509 (±74.4) TPH) at Lake Rebecca was extremely high, the densest of all the sites. From this information, we see that the overstory trees are actively growing (and not declining) and with the current density underplanting would likely be unsuccessful unless thinning was implemented. However, the story at other sites may be very different.

By pairing data collected in Questions 1 and 2 with previously collected forestry inventory data (including stem mapped plots), we will be able to explore and outline different successional pathways and also indentify different opportunities for management intervention. For example, if overstory growth was declining at Lake Rebecca, this may be an early sign that overstory mortality may happen or could signal that thinning is required to increase resources. After the thinning, there could be an opportunity for underplanting in the newly formed gaps. We may also be able to see periods of increased growth which was likely caused by a gap (Question 2), by having a better understanding of the frequency of gap events, regeneration efforts could be planned to more closely coincide with potential opportunities for regeneneration. Additionally, as HREPs are planned and implemented and increased understanding of age structure (Question 1) and growth dyanmics (Question 2) can allow for greater opportunities in regenerating a diverse forest structure. For example, a species like swamp white oak may naturally establish on a site decades after the earliest cottonwood and willow; however, that establishment maybe due to an opening in the canopy. The combination of tree cores and stem mapped data can allow us to explore these complex dynamics for swamp white oak and other hard mast species which provide multiple ecosystem services. This information can be used to develop management guidance.

As we explore the timing and developmental pathways within this question, we will host a series of virtual meetings or listening sessions with natural resource managers and foresters. We expect to host three to five meetings (in-kind support has been listed for many of the individuals that we would be targeting for these meetings). Prior to the first meeting a short summary of results would be shared with the group to facilitate an engaging and productive discussion. An example of information that might spark discussion: if there are certain environmental conditions which are more likely to have two-aged cohorts (Question 1) and we detect that a release occurs around 40 years (hypothetical finding from Question 2), could we use artificial regeneration to increase species and structural diversity? What species might you consider? Have you tried underplanting under canopy position? By pairing the data with the managers, we can begin to develop and explore potential proactive restoration to decrease the potential for invasive terrestrial plants to establish while maintaining forest resilience. This collaborative approach to developing management recommendations will include a collaboratively written report. Within this report, we will use our data on different successional models of forest development create a series of stand development models which can be utilized for management. The discussion and writing of the report will also allow for the development of future research projects to inform management.

Data management procedures
All data have been collected for the proposed project. Tree cores are currently being stored in Dr. Windmuller-Campione's lab on the Saint Paul Campus at the University of Minnesota. We are utilizing an open source platform (DendroElevator - https://dendro.elevator.umn.edu/) for the measurement, storage, and sharing of data. Data will be stored through the University of Minnesota Data Repository (DRUM) (https://conservancy.umn.edu/handle/11299/166578) which we have previously used for long-term data storage and sharing for a previous CESU agreement.

References

Altman, J., Fibich, P., Dolezal, J., & Aakala, T. (2014). TRADER: a package for tree ring analysis of disturbance events in R. *Dendrochronologia*, *32*(2), 107-112.

Black, B. A., & Abrams, M. D. (2003). Use of boundary-line growth patterns as a basis for dendroecological release criteria. *Ecological applications*, *13*(6), 1733-1749.

Black, B.A., Griffin, D., van der Sleen, P., Wanamaker, A.D., Speer, J.H., Frank, D.C., Stahle, D.W., Pederson, N., Copenheaver, C.A., Trouet, V., Griffin, S., Gillanders, B.M., 2016. The value of crossdating to retain high-frequency variability, climate signals, and extreme events in environmental proxies. Glob. Change Biol. 22(7), 2582-2595.

Bunn, A. G. (2008). A dendrochronology program library in R (dplR). *Dendrochronologia*, *26*(2), 115–124. Schulman, E. (1954). Longevity under Adversity in Conifers. *Science, 119*(3091), 396-399.

Crawford, D., Griffin, D., Windmuller-Campione, M.A., Reuling, L.F., Van Appledorn, M.V., Nielsen, D.M., Meier, A.R. (2020). Dendrochronology to inform management of floodplain forests in the Upper Mississippi River basin. Hydrology and Aquatic Resources Conservation Webinar Series

De Jager, N.R., M. Thomsen and Y. Yin. (2012). Threshold effects of flood duration on the vegetation and soils of the Upper Missississippi River floodplain, USA. Forest Ecology and Management 270: 135-146.

De Jager, N.R., M. Van Appledorn, T.J. Fox, J.J. Rohweder, L.J. Guyon, A.R. Meier, R.J. Cosgriff, and B.J. Vandermyde. (2019). Spatially explicit modelling of floodplain forest succession: interactions among flood inundation, forest successional processes, and other disturbances in the Upper Mississippi River floodplain, USA. Ecological Modeling 405: 15-32.

Griffin, D., Meko, D. M., Touchan, R., Leavitt, S. W., & Woodhouse, C. A. (2011). Latewood Chronology Development for Summer-Moisture Reconstruction In the US Southwest. *Tree-Ring Research*, *67*(2), 87–101.

Guyon, L., A. Oines, A. Meier, A. Strassman, M. Thomsen, S. Sattler, N. De Jager, E. Hoy, B. Vandermyde, and R. Cosgriff. In prep. Forest canopy gap dynamics: quantifying forest gaps and understanding gap-level forest regeneration on the Upper Mississippi River.

Holmes, R. L. (1983). Computer-assisted quality control in tree-ring dating and measurement. *Tree-Ring Bulletin*, *43*, 69–78.

King, D.J., G.L. Harley, J.T. Maxwell, K.J. Heeter, B.J. Vandermyde, and R.J. Cosgriff. (2021). Floodplain forest structure and the recent decline of *Carya illinoinensis* (Wangenh.) K. Koch (northern pecan) at its northern latitudinal range margin, Upper Mississippi River System, USA. Forest Ecology and Management 496: 119454.

Nowacki, G. J., & Abrams, M. D. (1997). Radial-growth averaging criteria for reconstructing disturbance histories from presettlement-origin oaks. *Ecological monographs*, *67*(2), 225-249.

Romano, S.P. (2010). Our current understanding of the Upper Mississippi River System floodplain forest. *Hydrobiologia, 640:115-124.*

Splechtna, B. E., Gratzer, G., & Black, B. A. (2005). Disturbance history of a European old-growth mixed-species forest—A spatial dendro-ecological analysis. *Journal of Vegetation Science*, *16*(5), 511-522.

Stokes, M. A. & Smiley, T. L. (1968). An introduction to tree-ring dating. University of Chicago Press, Chicago, Illinois, USA.

Theiling, C.H., C. Korschgen, H. De Haam, T. Fox, J. Rohweder, and L. Robinson. (2000). Habitat needs assessment for the Upper Mississippi River System: Technical Report. US Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. Contract report prepared for the US Army Corps of Engineers, St. Louis District, St. Louis, Missouri. 248 pp. + Appendixes A to AA.

UMRCC. (1988). Index to the Annual Proceedings of the Upper Mississippi River Conservation Committee.

Windmuller-Campione, M.A., Reuling, L.F., Van Appledorn, M.V., Nielsen, D.M., Meier, A.R. In Review. What is a stand? Assessing the variability of composition and structure in floodplain forest ecosystems across spatial scales in the Upper Mississippi River. Forest Ecology and Management

Yin, Y., J.C. Nelson, and K.S. Lubinski. (1997). Bottomland hardwood forests along the Upper Mississippi River. Natural Areas Journal 17(2): 164-173.

Products and Milestones

Tracking number	Products	Staff	Milestones
2023dendro1	Finalize the scanning of 1,100 tree cores uploaded into DendroElevator	Windmuller-Campione	30 November 2023
2023dendro2	Annual summary	Windmuller-Campione and Van Appledorn	31 December 2023
2023dendro3	Coordination and scheduling for three to five virtual meetings; Meetings will address current objectives outlined in Activity 3 and future directions	Windmuller-Campione and Van Appledorn	1 March — 31 May 2024
2023dendro4	Draft manuscript — Age data of floodplain forests of the Upper Mississippi River	Windmuller-Campione and Van Appledorn	30 May 2024
2023dendro5	Draft Manuscript — Growth dynamics of silver maple of the Upper Mississippi River	Windmuller-Campione and Van Appledorn	30 September 2024
2023dendro6	Final report writing, edits on manuscript, and completion of all data storage	Windmuller-Campione and Van Appledorn	30 November 2024

Assessing long term changes and spatial patterns in macroinvertebrates through standardized long-term monitoring

Previous LTRM project:
This is a systemic project that builds on and refines the LTRM macroinvertebrate component that was discontinued in 2004. The macroinvertebrate component sampled all six LTRM sampling pools for various periods of time from 1992-2004. The proposed project is adapted from the historic design to preserve the ability to make comparisons with historic data and improve precision around abundance estimates through strata-specific effort reallocations. Beyond inferences made through historic sampling, this proposed framework will also allow us to target additional important, but poorly characterized macroinvertebrate communities and establish baseline contaminant levels in mayflies across the program.

Name of Principal Investigators:
Dr. Jim Lamer
Director, Illinois River Biological Station, Illinois Natural History Survey, Prairie Research Institute, University of Illinois
(309) 543-6000
lamer@illinois.edu
Jim will be involved in project coordination, analysis, writing, and execution

Molly Sobotka
Systems Ecologist
UMRR - Long Term Resource Monitoring Supervisor
Big Rivers and Wetlands Field Station
Missouri Dept. of Conservation
Cape Girardeau, MO
573-290-5858 ext. 4483
Molly.Sobotka@mdc.mo.gov
Molly will be involved in project coordination, analysis, writing, and execution with special focus on rock bag/plate sampler communities

Levi Solomon
Illinois River Biological Station, Illinois Natural History Survey, Prairie Research Institute, University of Illinois
(309) 543-6000
soloml@illinois.edu
Levi will be involved in project coordination, sampling, and writing

Kris Maxson
Illinois River Biological Station, Illinois Natural History Survey, Prairie Research Institute, University of Illinois
(309) 543-6000
Kmaxs87@illinois.edu
Kris will be involved in project coordination, sampling, and writing

Shawn Giblin
Mississippi River Water Quality Specialist
Wisconsin Department of Natural Resources
(608) 785-9995
shawn.giblin@wisconsin.gov
Shawn will be involved in project coordination, analysis, and writing

Steve DeLain
Fisheries Biologist
Minnesota Department of Natural Resources
(651) 299-4019
steve.delain@state.mn.us
Steve will be involved in project coordination, sampling, analysis, and writing

Scott Gritters
Fisheries Biologist
Iowa Department of Natural Resources
(563) 872-4976
scott.gritters@dnr.iowa.gov
Scott will be involved in project coordination, analysis, and writing

Ross Vander Vorste
Assistant Professor, Biology
University of Wisconsin- La Crosse
(608) 785-6978
rvandervorste@uwlax.edu
Ross will be involved in project coordination, analysis, and writing

Collaborators (Who else is involved in completing the project):

Christine Custer, United States Geological Survey, La Crosse, WI
Matt Henderson, United States Environmental Protection Agency, Athens, GA

Introduction/Background:

Macroinvertebrates are a key component of aquatic ecosystems, providing the predominant trophic base for a wide variety of fish and waterfowl species (Hoopes 1960, Thompson 1973). Through nutrient cycling and transfer of organic material, macroinvertebrates are a substantial driver of river ecosystem change and structure and constitute the primary consumer biomass of the UMR (Reice and Wohlenberg 1992). Recognizing the ecological significance of this group of organisms, the UMRR LTRM program conducted benthic macroinvertebrate sampling, beginning in 1991, across main channel, backwater, side channel, and impounded geomorphic strata in Pool 4, Pool 8, Pool 13, Pool 26, and Open River Reach of the Mississippi River and La Grange Reach of the Illinois River. Mayflies, midges, and fingernail clams were the primary benthic taxa quantified, although zebra mussels and Asiatic clams were added to the component soon after its start. The component was discontinued for the Open River reach in 2001 due to the lack of suitable soft-substrate habitats and despite its importance in river food web dynamics, it was discontinued for the remaining reaches after 2004 due to funding restrictions. Although the component was discontinued, its importance for answering questions regarding our river resources remains.

Changes in spatial and temporal trends in macroinvertebrate abundance reflected in the LTRM historic sampling and the mechanisms responsible not only inform macroinvertebrate abundance from this span of time, but also offers a baseline to make future comparisons in response to system-wide stressors. Despite LTRM macroinvertebrate sampling ending in 2004, the need for macroinvertebrate trend data remains to understand the impact of not only drivers of fish functional diversity and nutrient cycling, but past and new biotic and abiotic changes to the system. For instance, invasive carp began reaching high densities in the Illinois River, and portions of the UMR in the mid 2000's and some evidence suggests their high densities and resulting egestion can enrich the benthos and promote increases in benthic macroinvertebrate abundances (Yallaly et al. 2015, Collins et al. 2017). Inferences made from continued benthic sampling can help explain historic and future waterfowl use and abundance. Furthermore, in order to address a growing concern over *Hexagenia* spp. decline in response to pesticide compounds such as neonicotinoids and pyrethroids, comparison of new and historic samples will help determine the extent of decline (Bartlett et al. 2018, Moran et al. 2017, Stepanian et al. 2020). Additionally, reinstatement of the systemic macroinvertebrate component will further provide the infrastructure to conduct targeted contaminant water, sediment and tissue analysis, and genus-level tolerance values as indicators of resilience and environmental change (Steingraber and Wiener 1995, Sauer 2004), and species-level resolution for comprehensive taxonomic assessment.

The LTRM benthic macroinvertebrate component was a powerful program to detect spatial and temporal trends in macroinvertebrate abundance, but continuation of the component allows us to revisit and reevaluate sampling design and component objectives for the betterment of the component while still preserving the ability to make comparisons to historic samples. One limitation of the previous LTRM protocol was the sole focus on soft-substrate and benthic taxa, which was limiting or difficult to sample in the Open River Reach compared to the other reaches. This prevented system-wide comparisons, and although benthic communities are important, have limited mobility, and react quickly to environmental change, other macroinvertebrate communities are also important and can be assessed system-wide. The EPT (Ephemeropterans, Plecopterans, Trichopterans) and amphipod taxa are adapted for life in deep, fast-moving turbid rivers (McCain et al. 2015), critical prey sources for aquatic organisms and integral to aquatic food webs and trophic structure but are poorly understood and inadequately captured in historic sampling. The addition of rock bag samplers to the LTRM framework (main channel) would allow for the detection of systemic changes in this unique community type across all 6 LTRM study reaches. Additionally, since the historic LTRM macroinvertebrate sampling design relied only on the best estimated sampling size and strata allocations in the absence of previously collected long-term macroinvertebrate data in the system, a need to understand the power to detect changes as related to sample size and design was needed (Bartsch et al. 1998). This proposal is meant to adaptively apply what we have learned and modify historic protocols to make sampling more efficient, systemic, capable of serving as a baseline to address more targeted research questions, all while still allowing direct comparisons to historic data.

This proposal's suggested baseline infrastructure accomplishes this the following ways:

1. Power analysis - Power analysis was conducted (Ickes unpublished) to identify sample sizes required to detect <25% annual change in abundance for the three major benthic macroinvertebrate taxa groups (mayfly nymphs, fingernail clams, midge larvae; in that order) and identify and eliminate pool-specific strata (mainly non-soft substrates) where sampling effort required to detect significant change would exceed what would feasible for sampling crews (i.e., would far exceed historic levels of sampling). This allows for re-allocation of those sites in non-informative strata to increase precision on abundance estimates in other strata while still maintaining a similar level of historic sampling effort.

2. Systematism – To overcome omission of the Open River reach from benthic sampling due to lack of suitable or sampleable substrates and allow for project-wide data comparisons on an important, but poorly quantified community of macroinvertebrate taxa, this proposal adds rock bag samplers. The samplers can be deployed in main-channel habitats throughout all LTRM reaches to make temporal and spatial comparisons possible program-wide. Many of the organisms that will colonize rock bag samplers serve diverse functional roles in the UMR to complement those served by those living in the soft-substrate benthos.

3. Project coordination - The infrastructure to support the historic project coordination is no longer in place so this proposal would fund personnel to not only coordinate system-wide sampling efforts, but also provide field and lab support to all LTRM macroinvertebrate field crews. A postdoctoral researcher or equivalent would be responsible for coordinating sampling site allocation, logistical support for data entry and curation, coordinating specimen preservation and archiving, source for to coordinate targeted research objectives among various researchers (e.g., finer taxonomic resolution, contaminant analysis, genetic analysis, diet analysis), coordinate laboratory identification, continual adaptive management, data analysis and writing to synthesize and evaluate historic and new data. This proposal also would have technicians dedicated to the project to assist all field crews with benthic and rock bag sampling as needed, assist with sample transport and laboratory coordination and sample processing.

This continuation of historic data collection and modifications to add efficiency, additional important macroinvertebrate communities, and systematism will be an important source of long-term macroinvertebrate data to further our understanding of environmental stressors and functional processes that have occurred in the Mississippi River system over the past 30+ years and into the future.

Primary objectives include:

1. LTRM macroinvertebrate sampling to detect spatial and temporal changes in macroinvertebrate abundance and allow for strata-specific comparisons to historic LTRM macroinvertebrate (1991 – 2004) trend data. This would be a 3-year initial trial with possibility of continuation after the initial evaluation period to extend into at least a 5-year program to evaluate trends. Macroinvertebrate sampling protocols and data will be assessed annually to adaptively improve design and implementation. Additionally, this component structure and sampling design can serve to address current and future research objectives and questions, such as *Hexagenia* radar validation, effects of invasive carp benthic enrichment, waterfowl trends in abundance, macroinvertebrate response to climate change, improving water quality, geomorphic changes and sedimentation, and effects of pesticides on benthic macroinvertebrate communities.

2. Add a systemic component (rock bag samplers/plate samplers) to sample main-channel colonizer communities (predominantly EPT and amphipods) allowing for data collection on this important but poorly characterized community and to allow for program-wide comparisons to complement the historic benthic sampling.

3. Provide systemic species-level taxonomic resolution for the first year of the study to develop macroinvertebrate biological indices that can be beneficial to characterize the community and its current status and resilience to system degradation.

4. Determine contaminant levels of polycyclic aromatic hydrocarbons (PAHs), neonicotinoids, pyrethroids and other current-use pesticides in burrowing mayfly tissue during years one and two of the study.

Relevance of research to UMRR:

The proposed work would support multiple goals and objectives of the UMRR and partnering agencies including:

This is a systemic program including all 6 LTRM reaches and partially fills a critical gap in our understanding of Mississippi River ecology.

1. This project will fill information gaps identified in the Focal Areas document under subarea 5.2: *Better understand the mechanisms behind observed changes in fish populations and implications for UMRS ecosystem and management.* This project also supports overall LTRM goals to "*Develop a better understanding of the Upper Mississippi River System and its resource problems*" and to "*Monitor resource change*" (e.g., comparison of 1992-2000 data to 2019-2021 data). As part of the ongoing UMRR resilience assessment, a draft manuscript has been developed as part of the resilience assessment that describes alternative regimes that are thought to occur in the UMRS. One set of regimes describes transitions between a diverse, native fish community and an invasive-dominated fish community (Bouska et al. *in prep*). Further, feedbacks that are thought to maintain the regimes are described. One of the types of feedback that is hypothesized to maintain an invasive-dominant fish community involves the role of bigheaded carp in altering trophic pathways. Based on observations from experimental studies, it is hypothesized that a bigheaded carp dominance may have resulted in a shift in the abundance of benthic invertebrates in the lower Illinois River consistent with results outlined by Yallaly et al. (2015) and Collins and Wahl (2017). Results provided by this proposed work will help inform whether the mechanisms observed in experimental studies play out in a complex and dynamic river system. Specifically, this project aims to answer the question: have bigheaded carp led to a shift from pelagic planktonic food resources to benthic food resources resulting in the potential benefit of benthic macroinvertebrates? As conceptual models concerning ecosystem resilience and regime shifts are developed, having scientifically valid data to support and validate ecological mechanisms is of vital importance.

2. Provide critical information needed to better understand the functional diversity of the system by including a critical, but largely absent trophic base (i.e. benthic and colonizing macroinvertebrates) and their resulting ecological impact that would be beneficial for a multitude of agencies (including but not limited to: INHS, IL DNR, MDC, IA DNR, MN DNR, WI DNR, USGS, FWS, USACE) to help make informed decisions about our river resources.

Methods:

Benthic sampling:

The LTRM macroinvertebrate component protocols outlined by Thiel and Sauer (1999) would be introduced on the La Grange Reach from May 1 – June 14 for upper three reaches and April 1 – June 1 for Pool 26 and La Grange) from 2023-2025 (three-year initial trial with annual evaluation and adjustment as needed). The protocol would be modified to include only pool-specific, soft-substrate strata that are capable of detecting a <25% annual change based on reasonable and similar sampling effort that was conducted in 2004 (~120+ sites). These strata vary between reaches, consisting of backwater and impounded strata in the upper three reaches, main-channel and backwater in the La Grange Reach, and impounded and side channel in Pool 26 (Table 1). Alternative sampling strategies for Open River reach will be explored. All other methods outlined in Thiel and Sauer (1999) will followed to maintain consistency with historic LTRM sampling.

The number and allocation of benthic samples would vary between reach and strata (Table 1). Using a Ponar Grab sampler, benthic samples would be collected from the substrate, excess substrate and debris cleared and macroinvertebrates then picked from the sample and jugged in the field with no identification or enumeration conducted in the field, but all other data recorded following methods outlined by Theil and Sauer (1999). This is a deviation from methods used in historic LTRM macroinvertebrate collections as all sample picking and enumeration was conducted in the field during that component. This modification would alleviate excessive field processing but should have no impact on comparisons to historic sampling.

Table 1. Benthic and rock bag sampler effort across RTA and strata. Sample sizes established to detect <25% annual change in mayfly abundance.

	BW	IMP	SC	MC	Total sites	MC (rock bags/paired Hester Dendy)
Pool 4	57	64	0	0	121	25
Pool 8	43	66	0	0	109	25
Pool 13	72	46	0	0	118	25
Pool 26	0	60	51	0	111	25
Open River	0	0	0	0	0	25
La Grange	69	0	0	50	119	25

New macroinvertebrate collections would allow for direct comparisons between existing LTRM data (1992-2002) and newly collected data (2023-2025) to assess long-term spatial and temporal trends in macroinvertebrate abundance. The benthic samples will primarily focus on changes in burrowing mayfly nymphs, fingernail clams, and midge larvae abundance. Results will better inform UMRR Resilience efforts.

Rock bag samplers:

Rock bag/paired plate samplers (see McCain et al. 2015) will be deployed at randomly generated sites (n=25 per pool) in main-channel border strata of all 6 RTAs. Samplers will be deployed according to McCain et al. (2015) in the month of May and will remain submerged at each site for approximately 6 weeks. Upon retrieval of the samples, all organisms will be rinsed from rocks on sieve and sluice table using methods similar to Theil and Sauer (1999). All organisms will be preserved in 70% ethanol unless other downstream research objectives require special collection (e.g., genomic or contaminant analysis) and returned to the Illinois River Biological Station for further processing. The first two years, species-level taxonomic resolution will be pursued to develop a comprehensive species assessment of the UMR macroinvertebrate biological index to assess system health and resiliency. Sample identification and enumeration will be performed by Rithron Associates, Inc. and/or UW-La Crosse ($50,000 per year) during first year. After initial one year of species-level resolution, abundances will be sorted by coarser informational taxonomic groups Family/Genus) and be conducted by dedicated Illinois River Biological Station technicians.

Screening level mayfly tissue analysis:

Upon the conclusion of the benthic sampling effort of the first study year, the five sites with the greatest abundance of burrowing mayflies will be identified. The most abundant mayfly sites will be chosen to optimize capture efficiency and collect sufficient numbers of mayflies required for contaminant analysis. Among these five sites, three sites will be selected to represent the largest geographic distribution within each pool for tissue analysis. A suction dredge will be utilized at these three sites per pool to collect burrowing mayflies (25-30 g) for screening level mayfly tissue contaminant analysis. Mayflies will be frozen until delivery for laboratory analysis. Mayfly tissue will be analyzed to quantify body burden of PAHs, current use pesticides and neonicotinoid insecticides at SGS AXYS Analytical Services Ltd. ($45,414 in year one). Post-extraction tissue samples will be split at SGS AXYS and 0.5 of the extract will be sent to US EPA (Athens, GA) for quantification of additional analytes. Following year one screening level analysis, more focused mayfly tissue analysis, for compounds of interest, will be conducted in year two based on the screening level analysis conducted in year one ($20,000 in year two).

Data management procedures

All SRS sampling locations will be generated by USGS-UMESC (Jason Rohweder), and field data will be collected through the macroinvertebrate database app produced USGS-UMESC (Ben Schlifer). All field stations will send data through exported database app to project coordinator at the Illinois River Biological Station. Database app entries will be completed at the Illinois River Biological Station after all samples have been processed. Data and associated metadata will be preserved in the Illinois River Biological Station database and be archived and made available directly to field stations involved in the collection. After internal and external QA of data, data will be archived and made publicly available through UMESC LTRM server.

References

Bartlett, A. J., Hedges, A. M., Intini, K. D., Brown, L. R., Maisonneuve, F. J., Robinson, S. A., ... & de Solla, S. R. 2018. Lethal and sublethal toxicity of neonicotinoid and butenolide insecticides to the mayfly, *Hexagenia* spp. Environmental Pollution. 238: 63-75.

Bartsch, L. A., W. B. Richardson, and T. J. Naimo. (n.d.). 1998. Sampling Benthic Macroinvertebrates in a Large Flood-Plain River: Considerations of Study Design, Sample Size, and Cost:15. Environmental Monitoring and Assessment. 52:425-429

Collins, S. F. and D. H. Wahl. 2017. Invasive planktivores as mediators of organic matter exchanges within and across ecosystems. Oecologia. 184: 521-530.

DeBoer, J. A., A. M. Anderson, and A. F. Casper. 2018. Multi-trophic response to invasive silver carp (Hypophthalmichthys molitrix) in a large floodplain river. Freshwater Biology. doi.org/10.1111/fwb.13097

Hoopes, D. T. 1960. Utilization of Mayflies and Caddis Flies by Some Mississippi River Fishes.Transactions of the American Fisheries Society 89(1):32–34.

McCain, K. N. S., R. A. Hrabik, V. A. Barko, B. R. Gray, and J. R. Bidwel. 2015. An Evaluation of Macroinvertebrate Sampling Methods for Use in the Open River Reach of the Upper Mississippi River. U.S. Army Corps of Engineers' Upper Mississippi River Restoration Program Long Term Resource Monitoring Element Completion Report 2005C2.

Moran, P. W., Nowell, L. H., Kemble, N. E., Mahler, B. J., Waite, I. R., & Van Metre, P. C. 2017. Influence of sediment chemistry and sediment toxicity on macroinvertebrate communities across 99 wadable streams of the Midwestern USA. Science of the Total Environment. *599*: 1469-1478.

Reice, S.R., and M. Wohlenberg. 1992. Monitoring freshwater benthic macroinvertebrates and benthic processes: Measures for assessment of ecosystem health. Pages 287–305 *in* D.M. Rosenberg and V.H. Resh, editors. *Freshwater Biomonitoring and Benthic Macroinvertebrates*. Chapman and Hall, New York.

Sauer, J. 2004. Multiyear synthesis of the macroinvertebrate component from 1992 to 2002 for the Long Term Resource Monitoring Program. 2004. Final report submitted to U.S. Army Corps of Engineers from the U.S. Geological Survey, Upper Midwest Environment Sciences Center, La Crosse, Wisconsin, December 2004. Technical Report LTRMP 2004-T005. 31 pp. + Appendixes A–C.

Solomon, L. E, R. M. Pendleton, J. H. Chick, and A. F. Casper. 2016. Long-term changes in fish community structure in relation to the establishment of Asian carps in a large floodplain river. Biological Invasions. DOI 10.1007/s10530-016-11808

Stepanian, P. M., Entrekin, S. A., Wainwright, C. E., Mirkovic, D., Tank, J. L., & Kelly, J. F. 2020. Declines in an abundant aquatic insect, the burrowing mayfly, across major North American waterways. Proceedings of the National Academy of Sciences. *117*: 2987-2992.

Thiel, P. A., and J. S. Sauer. 1999. Long Term Resource Monitoring Program procedures: Macroinvertebrate monitoring. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, revised May 1999. LTRMP 95-P002-2 (Revised 1999). 9 pp. + Appendixes A–H.

Thompson, D. 1973. Feeding Ecology of Diving Ducks on Keokuk Pool, Mississippi River. The Journal of Wildlife Management 37(3):367–381.

Yallaly, K. L., J. R. Seibert and Q. E. Phelps. 2015. Synergy between silver carp egestion and benthic fishes. Environmental Biology of Fishes. 98:511-516

Products and Milestones

Tracking number	Products	Staff	Milestones
2023inv1	Field collection of macroinvertebrates	State field station staff	14 June 2023
2023inv2	Laboratory identification of macroinvertebrates	TBD	30 August 2023
2023inv3	Screening level mayfly tissue analysis	Giblin	30 September 2023
2023inv4	Annual summary	Lamer	31 December 2023
2023inv5	a. Data entry completed and submission of data to USGS (Includes contaminant data)	State field station staff, Giblin	31 January 2024
2023inv6	b. Data loaded on level 2 browsers; QA/QC scripts run and data corrections sent to Field Stations	Lamer, Schlifer	15 February 2024
2023inv7	c. Field Station and contaminant QA/QC with corrections to USGS	State field station staff, Giblin	15 March 2024
2023inv8	d. Corrections made and data moved to public Web Browser	Lamer, Schlifer	30 March 2024
2023inv9	Field collection of macroinvertebrates	State field station staff	14 June 2024
2023inv10	Laboratory identification of macroinvertebrates	TBD	30 August 2024
2023inv11	Screening level mayfly tissue analysis	Giblin	30 September 2024
2023inv12	Annual summary	Lamer	31 December 2024
2023inv13	a. Data entry completed and submission of data to USGS (Includes contaminant data)	State field station staff, Giblin	31 January 2025
2023inv14	b. Data loaded on level 2 browsers; QA/QC scripts run and data corrections sent to Field Stations	Lamer, Schlifer	15 February 2025
2023inv15	c. Field Station and contaminant QA/QC with corrections to USGS	State field station staff, Giblin	15 March 2025
2023inv16	d. Corrections made and data moved to public Web Browser	Lamer, Schlifer	30 March 2025
2023inv17	Draft LTRM Completion report or manuscript on contaminant sampling	Giblin	30 September 2025
2023inv18	Field collection of macroinvertebrates	State field station staff	14 June 2025
2023inv19	Laboratory identification of macroinvertebrates	TBD	30 August 2025
2023inv20	Annual summary	Lamer	31 December 2025
2023inv21	a. Data entry completed and submission of data to USGS (Includes contaminant data)	State field station staff, Giblin	31 January 2026
2023inv22	b. Data loaded on level 2 browsers; QA/QC scripts run and data corrections sent to Field Stations	Lamer, Schlifer	15 February 2026
2023inv23	c. Field Station and contaminant QA/QC with corrections to USGS	State field station staff, Giblin	15 March 2026
2023inv24	d. Corrections made and data moved to public Web Browser	Lamer, Schlifer	30 March 2026
2023inv25	Draft LTRM Completion report or manuscript on macroinvertebrate sampling, trends, etc.	Lamer	30 September 2026

Putting LTRM's long-term phytoplankton archive to work to understand ecosystem transitions and improve methodological approaches

James Larson, USGS, 6087816268, jhlarson@usgs.gov; FlowCam project management; technician supervision, data analysis, manuscript writing and publication, budget oversight.

Kathi Jo Jankowski, USGS, 6087816242, kjankowski@usgs.gov; Phytoplankton sample project management, data analysis, manuscript writing and publication, data management and oversee database development.

Madeline Magee, WI DNR, 6083415017, madeline.magee@wisconsin.gov; Data analysis and writing, assistance with database development and publication.

Jessica Fulgoni, Kentucky Wesleyan College, Jessica.fulgoni@kwc.edu; Data analysis and writing, assistance with phytoplankton sample selection and data management.

Collaborators:

Nicole Ward, MN DNR, 651-299-4021, nicole.ward@state.mn.us; data analysis/interpretation and report/manuscript preparation.

Ashley Johnson, IA DNR 515-250-1697 ashley.johnson@dnr.iowa.gov; data analysis/interpretation and report/manuscript preparation.

Database specialist, TBD

Introduction/Background:

The increasing threats from climate change, invasive species, and land use stressors in the Mississippi River directly and indirectly alter ecosystem components (e.g., fish, vegetation, water quality) (Zhang and Schilling 2006; Tavakol et al. 2020). Feedbacks among ecosystem components drive the initiation and persistence of ecosystem regime shifts (Bouska et al. 2020). In freshwater ecosystem transitions, phytoplankton may play a disproportionately large, and perhaps overlooked, role since they serve as a key link between trophic levels (Bertani et al. 2016). Further, climate, invasive species, and land use stressors interact to directly alter phytoplankton communities and may promote increased frequency and severity of harmful algal blooms (HABs; Paerl and Huisman 2008; Michalak et al. 2013; Glibert 2017). Thus, unravelling the nuanced and interactive effects of spatially and temporally-variable stressors on phytoplankton communities will enable managers to better anticipate future ecosystem conditions. **The 25-year LTRM phytoplankton sample archive spans documented river ecosystem transformations, large inter-annual variations in discharge and temperature, and, thus, can be used to assess how phytoplankton communities respond to and shape ecosystem conditions along the longitudinal gradient of the river**.

However, the LTRM program is on the brink of losing this irreplaceable archive of samples, as the growing volume of unprocessed samples cannot remain in storage. The proposed study will process and analyze the phytoplankton archive to achieve two primary aims: **1) examine long-term phytoplankton community change along the longitudinal and lateral gradients of the river**, and **2) develop streamlined phytoplankton methodological approaches that ensure timely and cost-effective processing of phytoplankton community samples moving forward**. This study will ensure that the program does not end up with the same backlog of un-processed samples in 25 years while generating a more detailed understanding of phytoplankton community shifts and response to stressors such that we may better anticipate future ecosystem transformations and promote proactive river management.

Despite the abundance of macrophytes and terrestrial organic matter inputs to rivers, certain taxa of algae are extremely important in sustaining aquatic food webs (Hamilton et al. 1992; Brett et al. 2009). However, some phytoplankton taxa are known to produce compounds that are toxic (e.g., some species of cyanobacteria), cause foul tastes and odors, or are poor-quality food for consumers (Ahlgren et al. 2009; Brett et al. 2009; Taipale et al. 2013). In lake ecosystems, a long-standing paradigm is that increases in phosphorus drive algal communities towards cyanobacterial dominance (and high overall productivity), but this paradigm is an overgeneralization (Paerl et al. 2016; Glibert 2017; Scott et al. 2019) and has been less successful in describing flowing waters (Cloern 2001; Hilton et al. 2006). In addition to nutrients, macrophytes (Yuan 2021, Takamura et al. 2003, Gross et al. 2007), grazing pressure (Vanderploeg et al. 2001), climate and temperature (Paerl and Huisman 2008) and hydrologic regime (Giblin and Gerrish 2020) have all been identified as potential drivers of phytoplankton community composition. Physical factors (discharge, residence time, turbidity) may be more important than nutrients in driving variation in phytoplankton community composition in the Upper Mississippi River (Manier et al. 2021). However, no prior phytoplankton community analysis in the UMR has examined greater than 5 sequential years or considered the full longitudinal gradient. **The LTRM phytoplankton archive may provide the temporal and spatial scale necessary to unravel complex and interacting drivers of change in the river.**

Given the importance of phytoplankton and algae to river productivity and water quality, it is critical to identify how long-term trends occurring in the UMR have influenced phytoplankton community composition. Long-term (20+ year) increases in vegetation, shifts in the patterns of discharge, and the invasion of the UMR by non-indigenous species have all changed the system, but we have relatively limited understanding of the associations between these changes and phytoplankton communities. At present, there is an archive of samples collected across the LTRM pools from 1996 to the present. These samples can be used to test the importance of the various major ecological changes that have occurred in the UMR over the past twenty-plus years, but they are likely to be lost if no analysis begins in the next year.

In the proposed study, we aim to put the LTRM phytoplankton archive to work by 1) assessing long term changes in phytoplankton communities, and 2) developing more time and cost-efficient methods for phytoplankton community data acquisition moving forward. We hypothesize that changes that have occurred in the UMR over the past decades in the macrophyte community (Larson et al. 2022; Bouska et al. 2022), fish community (Ickes et al. 2022) and the climate (Pryor et al. 2014) are also associated with major changes in phytoplankton community composition. These changes include the increase in macrophyte abundance and diversity in the upper pools (4, 8 and 13), the invasion of bigheaded carp (Ickes et al. 2022), and climate-related shifts in temperature and discharge (Byun and Hamlet 2018; Van Appledorn et al. 2021) that have been documented to affect algal biomass (Jankowski et al. 2021). Furthermore, there is an expectation that future environmental changes will increase the frequency and severity of harmful cyanobacterial blooms (Paerl and Huisman 2008). We will use these data to identify where and under what conditions cyanobacteria appear to dominate phytoplankton communities and whether this is increasing over time. We also propose to explore the use of automated phytoplankton identification technologies (FlowCam, see methods) to replace the methods currently used to preserve, store, and identify phytoplankton samples, so that UMRR/LTRM can follow these trends through time with less effort and expense. Finally, this proposal will include the production of an LTRM phytoplankton dataset that combines data generated by this proposal with data from previous studies, which will be made publicly available on the LTRM website.

LTRM is uniquely positioned to understand environmental drivers of phytoplankton community composition, given the 25+ year archive of phytoplankton samples. However, since the phytoplankton samples are overflowing their current storage space and need to be discarded, the data will be lost if a solution is not generated for processing existing and future samples.

This proposal contains two complementary studies, with individual stage 1 and stage 2 budgets, corresponding to the following questions:

1. **How have phytoplankton communities changed through time in the Upper Mississippi River system?**
   a) How do long-term trends in phytoplankton communities and the occurrence of HABs species differ across the longitudinal and lateral gradients of the river?
   b) How sensitive are communities to changes associated with climate, hydrogeomorphic,vegetation, and nutrient/sediment trends?

2. **Are data generated using automated phytoplankton identification equipment comparable to data generated by microscopy in this large river system? (i.e., a feasible lower cost, less time-intensive method)?**
   a) Is the FlowCam effective at processing old samples and does storage time affect FlowCam results?
   b) Would using the FlowCam be an appropriate strategy for processing new samples, and what methodology is most appropriate for new samples?

Relevance of research to UMRR:

Phytoplankton community composition and abundance is often the difference between aquatic ecosystems being perceived as healthy or impacted. Habitats that become dominated by cyanobacteria impair human uses, reduce fish productivity and can create toxic and noxious conditions. Anthropogenic river modifications (e.g., HREPs) that alter water velocities, discharge, vegetation, morphology (e.g., depth) and sediment composition will influence phytoplankton, but often in ways that we are only beginning to understand. This research will aid in the development of local understanding and statistical models that could anticipate how phytoplankton community composition and abundance will respond to natural and anthropogenic changes to riverine habitats. Finally, a major goal of this project is to inform the LTRM phytoplankton sampling scheme going forward and to create a public database of phytoplankton community information. **Improving and streamlining the ability of the LTRM program to**

track, monitor, and provide phytoplankton data is a critical need, either through automated processes or through more targeted sampling associated with critical drivers and characteristics identified through exploration of archived samples.

This work directly addresses the 2022 Focal Area 2.1 (Assessing the associations between aquatic areas and biota and biogeochemistry using existing data) and adds contextual understanding to Focal Area 2.3 (What are the drivers of aquatic vegetation abundance, diversity, and resiliency). Focal Area 2.5 (Consequences of river eutrophication for critical biogeochemical processing rates and habitat conditions)

Methods:

To address research Question 1, we will compile existing phytoplankton composition datasets and process new samples from the LTRM sample archive. We estimate more than half of the samples needed for this analysis have either already been processed as part of previous studies or can be processed using matching funds (Table 1). Given the volume of additional samples that need to be processed, however, we will use an outside contractor to identify the communities. To address Research Question 2, we will evaluate the use of the automated phytoplankton identification system (FlowCam) on a a subset of the archive samples that have been fully identified as well as evaluate methods for use on newly collected samples.

Table 1 – Outline of sources of new and existing data used to address the research questions in this proposal.

Research question	Sampling approach	# Samples	Source
1a. Longitudinal patterns	New Samples: 12 years of main channel sites, SRS (4x annually), 1 fixed site (11x annual) across all reaches Existing Data:	**925*** 485	**This proposal** Mainier et al. 2021 (~87); Fulgoni et al. (~108); Jankowski (290)
1a. Lateral patterns	Existing Data Pools 8, 13; backwater/impounded; 2006-2009 Pool 4, 13, and La Grange; side channel, backwaters, impounded	~130 ~550	Manier et al. 2021 Jankowski et al., in progress
2a. Is the FlowCam effective at processing old samples?	A subset of samples processed for phytoplankton counts as above will also be processed through FlowCam.	100	Samples will be selected using a stratified random approach from the 925 samples processed in Question 1
2b. Would using the FlowCam be an appropriate strategy for processing new samples?	New samples will be collected and processed through FlowCam, with various holding times and conditions	**50***	**This Proposal**
Total Samples		**New: 975*** Existing: 1035 Total = 2010	

*** Indicates samples funded by this proposal**

Question 1a: **Long-term longitudinal and lateral trends.** Our *longitudinal analysis* of phytoplankton community composition will focus on main channel habitats because they are the most comparable among reaches (pools; Manier et al. 2021). To optimize cost-effectiveness of samples analyzed, we will select 12 years between 2000-2020 by crossing flow and air temperature conditions (e.g., high-flow, warm year; low-flow, warm year; high-flow, cool year;

low-flow, cool year). Temperature and discharge are known to be critical variables for many ecosystem processes, so our year-selection approach will ensure that we capture the range of observed conditions. Within each year selected, we will analyze 3 main channel samples from each river reach from all four seasonal SRS episodes. In addition, we will analyze one sample from a main channel fixed site in each reach for all 11 fixed-site sampling events each year. This combination of SRS and fixed site samples will give us a higher resolution look at spatial variability within the main channel at least 4 times of the year (SRS), which we will complement with the more high-resolution temporal changes captured by fixed site sampling episodes that occur two weeks - monthly. Including fixed site sampling will also allow us to capture phytoplankton dynamics during periods of the year that can be particularly important in phytoplankton community development (e.g., March – June).

Our *lateral analysis* of phytoplankton community composition will address the degree to which any identified main channel patterns are associated with changes occurring in backwaters and impounded areas. To achieve this aim, we will augment the longitudinal sampling scheme in Pools 4, 13 and the La Grange reach with ~700 samples that have been previously identified for other projects (Table 1).

Question 1b: Driver response. Data from the long-term longitudinal and lateral analysis (**1a**) will be paired with LTRM water quality, vegetation, and other environmental data to identify potential drivers of variation in phytoplankton community composition. From these samples, we will then use a variety of univariate and multi-variate analytical techniques (e.g., MARSS, structural equation modeling, multi-level models) to identify associations between the phytoplankton community data and the existing LTRM water quality and vegetation datasets, in addition to other environmental data available from these locations.

Questions 2a-b: Method development. The Ecological Sciences Branch at the Upper Midwest Environmental Sciences Center currently has an automated particle imaging device named the FlowCam Cyano (Yokogawa Fluid Imaging). We will evaluate the viability of FlowCam rapid identification of both archived and new phytoplankton samples. FlowCam is an automated particle imaging system that can process approximately 5,000-10,000 particles in 6 minutes. Once particle images of particles are generated, the user identifies a subset of the images to generate an algorithm (or "library") for automatic identification of the remaining images and an iterative software process to continually improve the image processing algorithm. Although the FlowCam has many time- and cost-efficiency advantages over traditional microscopy, it is unlikely to provide the same level of taxonomic resolution.

Method development will consist of two studies. First we will use the FlowCam to identify ~100 archived samples that are also being analyzed for microscopy as part of Q1. These samples will be selected in a randomly stratified pattern from among habitat types, season and years. Previous studies have mostly found preserved and live sample analysis with FlowCam was in good agreement with traditional microscopy (Álvarez et al. 2014; Graham et al. 2018; Hrycik et al. 2019). However, these studies occurred primarily in lentic settings. In a previous study using an earlier version of the FlowCam (Milde et al. 2017) we found that preserved Mississippi River phytoplankton often contain many detrital particles that made it difficult to identify algal particles automatically. The FlowCam Cyano can operate in 'trigger mode' whereby only particles with chlorophyll *a* or phycocyanin are imaged. The newer FlowCam also includes an updated sorting algorithm. As a result, it may be possible to use the new FlowCam to identify archived samples effectively, at a fraction of the time and cost of microscopy.

The second study is focused on newly collected samples. From recent experience, we know ‘trigger mode’ greatly improves the FlowCam’s accuracy on fresh samples and is especially good at separating cyanobacteria from other algal groups. For this study, we will collect new samples from the field and compare how different storage methods (e.g., chilled, preserved, unpreserved), holding times (e.g., <6 h, 24 h, 48 h, 1 week), and environmental conditions at the collection site (e.g., temperature, turbidity) will affect the results generated from FlowCam analysis. From these experiments, we will identify a sampling approach that provides representative results (i.e., good replication, consistency with results obtained immediately upon collection). Samples within this representative period will also be analyzed with microscopy to insure FlowCam results are consistent with microscopy. The purpose of this study is to determine A) if the FlowCam can provide information comparable to that provided by microscopy and B) the sampling protocols that would be needed to use the FlowCam for future LTRM sampling. For example, we could determine whether a single, centrally located FlowCam would be capable of processing samples from all the field stations or if multiple FlowCams would be necessary to measure trends in phytoplankton.

Data management procedures

Phytoplankton species dataset: In addition to the new sample identification proposed here, there are numerous studies that have used or are using LTRM phytoplankton samples and have generated phytoplankton community composition data (Table 1). Most of these data are already "in house” but have not been compiled and made available to others publicly (Manier et al. 2021, Decker et al. 2015, Fulgoni et al., in prep). Therefore, we will work authors of other publications to compile species and biovolume data from these previously completed projects with data generated by this proposal into a downloadable database that is served on the LTRM website. Once the project is completed, all data and metadata will be peer-reviewed by USGS, permanently archived at UMESC, and made publicly available through the LTRM website. We have included funds for a database specialist to design and create the database, and it will be updated annually with assistance from LTRM IT Specialist, Ben Schlifer, when new data are available.

FlowCam dataset: We will publish the comparative data in ScienceBase along with reports and manuscripts. If FlowCam data appears relevant to LTRM monitoring/research, we will make a recommendation on how to store and serve data making it available to the UMRR partnership.

References

Ahlgren, G., T. Vrede, and W. Goedkoop. 2009. Fatty acid ratios in freshwater fish, zooplankton and zoobenthos -- Are there specific optima?, p. 147–178. In M.T. Arts, M.T. Brett, and M.J. Kainz [eds.], Lipids in Aquatic Ecosystems. Springer.

Álvarez, E., M. Moyano, Á. López-Urrutia, E. Nogueira, and R. Scharek. 2014. Routine determination of plankton community composition and size structure: a comparison between FlowCAM and light microscopy. J. Plankton Res. 36: 170–184. doi:10.1093/plankt/fbt069

Van Appledorn, M., N. R. De Jager, and J. J. Rohweder. 2021. Quantifying and mapping inundation regimes within a large river-floodplain ecosystem for ecological and management applications. River Res. Appl. 37: 241–255. doi:10.1002/rra.3628

Bertani, I., R. Primicerio, and G. Rossetti. 2016. Extreme Climatic Event Triggers a Lake Regime Shift that Propagates Across Multiple Trophic Levels. Ecosystems 19: 16–31. doi:10.1007/s10021-015-9914-5

Bouska, K. L., J. N. Houser, N. R. De Jager, D. C. Drake, S. F. Collins, D. K. Gibson-Reinemer, and M. A. Thomsen. 2020. Conceptualizing alternate regimes in a large floodplain-river ecosystem: Water clarity, invasive fish, and floodplain vegetation. J. Environ. Manage. 264: 110516. doi:10.1016/j.jenvman.2020.110516

Bouska, K. L., D. M. Larson, D. C. Drake, E. M. Lund, A. M. Carhart, and K. R. Bales. 2022. Aquatic vegetation dynamics in the Upper Mississippi River over 2 decades spanning vegetation recovery. Freshw. Sci. 41: 33–44. doi:10.1086/717867

Brett, M. T., M. J. Kainz, S. J. Taipale, and H. Seshan. 2009. Phytoplankton, not allochthonous carbon, sustains herbivorous zooplankton production. Proc. Natl. Acad. Sci. 106: 21197–21201. doi:10.1073/pnas.0904129106

Byun, K., and A. F. Hamlet. 2018. Projected changes in future climate over the Midwest and Great Lakes region using downscaled CMIP5 ensembles. Int. J. Climatol. 38: e531–e553. doi:10.1002/joc.5388

Cloern, J. 2001. Our evolving conceptual model of the coastal eutrophication problem. Mar. Ecol. Prog. Ser. 210: 223–253. doi:10.3354/meps210223

Giblin, S. M., and G. A. Gerrish. 2020. Environmental factors controlling phytoplankton dynamics in a large floodplain river with emphasis on cyanobacteria. River Res. Appl. 1–14. doi:10.1002/rra.3658

Glibert, P. M. 2017. Eutrophication, harmful algae and biodiversity — Challenging paradigms in a world of complex nutrient changes. Mar. Pollut. Bull. 124: 591–606. doi:10.1016/j.marpolbul.2017.04.027

Graham, M. D., J. Cook, J. Graydon, D. Kinniburgh, H. Nelson, S. Pilieci, and R. D. Vinebrooke. 2018. High-resolution imaging particle analysis of freshwater cyanobacterial blooms. Limnol. Oceanogr. Methods 16: 669–679. doi:10.1002/lom3.10274

Gross, E. M., S. Hilt, P. Lombardo, and G. Mulderij. 2007. Searching for allelopathic effects of submerged macrophytes on phytoplankton – state of the art and open questions. Hydrobiologia 584: 77-88.

Hamilton, S. K., W. M. Lewis, and S. J. Sippel. 1992. Energy sources for aquatic animals in the Orinoco River floodplain: evidence from stable isotopes. Oecologia 89: 324–330. doi:10.1007/BF00317409

Hilton, J., M. O'Hare, M. J. Bowes, and J. I. Jones. 2006. How green is my river? A new paradigm of eutrophication in rivers. Sci. Total Environ. 365: 66–83. doi:10.1016/j.scitotenv.2006.02.055

Hrycik, A. R., A. Shambaugh, and J. D. Stockwell. 2019. Comparison of FlowCAM and microscope biovolume measurements for a diverse freshwater phytoplankton community. J. Plankton Res. 41: 849–864. doi:10.1093/plankt/fbz056

Jankowski, K. J., J. N. Houser, M. D. Scheuerell, and A. P. Smits. 2021. Warmer Winters Increase the Biomass of Phytoplankton in a Large Floodplain River. J. Geophys. Res. Biogeosciences 126. doi:10.1029/2020JG006135

Larson, D.M., E. M. Lund, A. M. Carhart, D. C. Drake, J.N. Houser, N. R. De Jager, K. L. Bouska, K. R. Bales, and S. M. Giblin. 2022. Chapter F: Aquatic Vegetation, In J.N. Houser, Ecological Status and Trends of the Upper Mississippi River System 1993-2019.

Manier, J. T., R. J. Haro, J. N. Houser, and E. A. Strauss. 2021. Spatial and temporal dynamics of phytoplankton assemblages in the upper Mississippi River. River Res. Appl. 37: 1451–1462. doi:10.1002/rra.3852

Michalak, A. M., E. J. Anderson, D. Beletsky, and others. 2013. Record-setting algal bloom in Lake Erie caused by agricultural and meteorological trends consistent with expected future conditions. Proc. Natl. Acad. Sci. U. S. A. 110: 6448–52. doi:10.1073/pnas.1216006110

Milde, A. S., W. B. Richardson, E. A. Strauss, J. H. Larson, J. M. Vallazza, and B. C. Knights. 2017. Spatial and Temporal Dynamics of Suspended Particle Characteristics and Composition in Navigation Pool 19 of the Upper Mississippi River. River Res. Appl. doi:10.1002/rra.3131

Paerl, H. W., and J. Huisman. 2008. Climate. Blooms like it hot. Science 320: 57–8. doi:10.1126/science.1155398

Paerl, H. W., J. T. Scott, M. J. McCarthy, and others. 2016. It Takes Two to Tango: When and Where Dual Nutrient (N & P) Reductions Are Needed to Protect Lakes and Downstream Ecosystems. Environ. Sci. Technol. 50: 10805–10813. doi:10.1021/acs.est.6b02575

Pryor, S. C., D. Scavia, C. Downer, M. Gaden, L. Iverson, R. Nordstrom, J. Patz, and G. P. Robertson. 2014. Ch. 18: Midwest. Climate Change Impacts in the United States: The Third National Climate Assessment.

Scott, J. T., M. J. McCarthy, and H. W. Paerl. 2019. Nitrogen transformations differentially affect nutrient limited primary production in lakes of varying trophic state. Limnol. Oceanogr. Lett. lol2.10109. doi:10.1002/lol2.10109

Taipale, S., M. Brett, M. Hahn, D. Martin-Creuzburg, S. Yeung, M. Hiltunen, U. Strandberg, and P. Kankaala. 2013. Differing Daphnia magna assimilation efficiencies for terrestrial, bacterial and algal carbon and fatty acids. Ecology 95: 563–576. doi:http://dx.doi.org/10.1890/13-0650.1

Takamura, N., Y. Kadono, M. Fukushima, M. Nakagawa, and B. O. Kim. 2003. Effects of aquatic macrophytes on water quality and phytoplankton communities in shallow lakes. Ecological Research 18: 381-395. https://doi.org/10.1046/j.1440-1703.2003.00563.x

Tavakol, A., V. Rahmani, and J. Harrington. 2020. Evaluation of hot temperature extremes and heat waves in the Mississippi River Basin. Atmos. Res. 239: 104907. doi:10.1016/j.atmosres.2020.104907

Vanderploeg, H. A., J. R. Liebig, W. W. Carmichael, M. A. Agy, T. H. Johengen, G. L. Fahnenstiel, and T. F. Nalepa. 2001. Zebra mussel (Dreissena polymorpha) selective filtration promoted toxic Microcystis blooms in Saginaw Bay (Lake Huron) and Lake Erie. Can. J. Fish. Aquat. Sci. 58: 1208–1221. doi:10.1139/cjfas-58-6-1208

Yuan, L. L. 2021. Continental-scale effects of phytoplankton and non-phytoplankton turbidity on macrophyte occurrence in shallow lakes. Aquatic Sciences 83. DOI: 10.1007/s00027-020-00769-1

Zhang, Y.-K., and K. E. Schilling. 2006. Increasing streamflow and baseflow in Mississippi River since the 1940s: Effect of land use change. J. Hydrol. 324: 412–422. doi:10.1016/j.jhydrol.2005.09.033

Products and Milestones

Tracking number	Products	Staff	Milestones
2023Phyto1	System-wide phytoplankton community dataset	Jankowski	30 September 2023
2023Phyto2	Draft Manuscript: Phytoplankton community composition over the past 20 years in the Upper Mississippi River: distribution of harmful taxa and relationships with environmental trends	Jankowski and others	30 May 2024
2023Phyto3	Draft Manuscript: Relating phytoplankton communities to distinct vegetation recovery trajectories in Pools 4 and 13	Jankowski and others	30 May 2024
2023Phyto4	Report: Assessment of FloCam for use on archived and fresh phytoplankton samples for LTRM sampling	Larson, James	30 March 2024
2023Phyto5	Draft Manuscript: Comparison of trends captured by microscopy and FlowCam phytoplankton community analysis	Larson, James	30 May 2024

FY18 Funded Science in Support of Restoration and Management Proposals

Detailed descriptions of the following projects can be found at
https://umesc.usgs.gov/ltrmp/documents/fy18Science_sow.pdf

FY18 Funded Science in Support of Restoration and Management Proposals						
Conceptual Model and Hierarchical Classification of Hydrogeomorphic Settings in the UMRS						
2019CM4	GIS data base and query tool	31-Dec-2019	On-going		Prototype developed	Fitzpatrick, Hendrickson, Sawyer, Strange
2019CM5	Submit draft LTRM Completion report on hydrogeomorphic conceptual model and hierarchical classification system	31-Dec-2019	30-Aug-2022			Fitzpatrick, Hendrickson, Sawyer, Strange
2019CM6	Submit Final LTRM Completion report on hydrogeomorphic conceptual model and hierarchical classification system	30-Jun-2020	30-Dec-2022			Fitzpatrick, Hendrickson, Sawyer, Strange
Water Exchange Rates and Change in UMRS Channels and Backwaters, 1980 to Present						
2019WE4	Submit Final LTRM Completion Report	30-Mar-2020	30-Dec-2021			Hendrickson
Intrinsic and extrinsic regulation of water clarity over a 950-km longitudinal gradient of the UMRS						
2019IE3	Submit Draft manuscript	30-Mar-2020	30-Mar-23	PIs determined that to move forward biomass information is needed. Will continue work once biomass model complete. Original Lead author (Drake) resigned from WDNR.		Carhart and others
Systemic analysis of hydrogeomorphic influences on native freshwater mussels						
2019FM7	Complete statistical analyses and prepare geospatial maps	30-Sep-2021	30-Sep-2022	Delayed since lead technician who was to perform most of the analyses took a new position; new hire in place		Teresa Newton, Jason Rohweder
2019FM8	Draft LTRM completion report	30-Sep-2021	30-Sep-2022			Teresa Newton
2019FM9	Final LTRM completion report	30-Jan-2023				Teresa Newton
Using dendrochronology to understand historical forest growth, stand development, and gap dynamics						
2022DD1	Draft manuscript: Floodplain forest structure and the recent decline of Carya illinoinensis (Wangenh.) K. Koch (northern pecan); Part 2	30-May-2022	TBD			Harley
Forest canopy gap dynamics: quantifying forest gaps and understanding gap – level forest regeneration						
Manuscript: Forest canopy gap dynamics: quantifying forest gaps and understanding gap - level forest regeneration in Upper Mississippi River floodplain forests (2019FG5, MEIER et al.); Gap data found at: https://www.sciencebase.gov/catalog/item/5f3299a682cee144fb30dd02						
Investigating vital rate drivers of UMRS fishes to support management and restoration						
2019VR8	Data set complete (data delivered to Ben Schlifer, physical structures delivered to BRWFS)	30-Sep-2021	30-Aug-22	Pandemic has slowed progress on many aspects of age and growth. Ageing complete, working to apply that to raw LTRM catch data in a standard and		Quinton Phelps
On-Going						
2019VR10	Submit draft manuscript (Drivers of vital rates)	31-Dec-2021	30-Sep-23			Quinton Phelps, Kristen Bouska
2019VR11	Submit draft manuscript (Microchemistry)	31-Dec-2021	31-Dec-22	Delayed by having to make several repairs to mass spectrometer; instrument down-time slowed our progress. In June completed analysis of otolith samples from all LTRM fish to be used in the project. The remaining steps data analysis and writing.		Greg Whitledge
Intended for distribution						
Manuscript: vital rates of Channel Catfish, led by Colby Gainer (MS student) in review with the North American Journal of Fisheries Management; 2019VR9						

FY19 Funded Science in Support of Restoration and Management Proposals

Detailed descriptions of the following projects can be found at
https://umesc.usgs.gov/ltrmp/documents/fy19_science_support1aug2019.pdf

Tracking number	Milestone	Original Target Date	Modified Target Date	Date Completed	Comments	Lead
FY19 Funded Science in Support of Restoration and Management						
Development of a standardized monitoring program for vegetation and fish response to Environmental Pool Management practices in the Upper Mississippi River System						
2019epm3/4	Thesis by Courtney Weldon (formerly LTRM Completion Report)	30-Jun-2021	30-Jun-22	30-Jun-22	Courtney successfully defended her thesis, and it will be deposited with the UIUC library and ACES (Department of Agriculture and Consumer Economics) library	Weldon, Chick, and Richter
Combining genetics, otolith microchemistry, and vital rate estimation to inform restoration and management of fish populations in the UMRS						
Intended for distribution						
Manuscript documenting the findings from genetic analyses of the six regional species has been accepted to the journal Molecular Ecology; Dr. Yue Shi						
Reforesting UMRS forest canopy openings occupied by invasive species						
2019ref3	Draft LTRM Completion	30-Apr-2021	30-Dec-22			Guyon and Cosgriff
2019ref4	Final LTRM Completion	30-Sep-2021	30-Jun-23			Guyon and Cosgriff
A year of zooplankton community data from the habitats and pools of the UMR						
2019zoo2	Draft LTRM Completion report on utility of zooplankton community monitoring for HREP assessment	30-Dec-2020	22-Dec-2022		Sample collection delayed because of Covid-19 state protocols; zooplankton ID delayed; Fulgoni took new position	Sobotka
2019zoo3	Final LTRM Completion report on utility of zooplankton community monitoring for HREP assessment	30-Jun-2021	30-Jun-2023			Sobotka
2019zoo4	Draft LTRM Completion report on detailing differences between pools and habitats. Report will also investigate the potential investigate the potential impacts of Asian carp on the zooplankton community.	30-Dec-2020	22-Dec-2022			Sobotka
2019zoo5	Final LTRM Completion report on on detailing differences between pools and habitats. Report will also investigate the potential investigate the potential impacts of Asian carp on the zooplankton community.	30-Jun-2021	30-Jun-2023			Sobotka
FY19 Funded Illinois Waterway 2020 Lock Closure						
Pre- and Post-Maintenance Aerial Imagery for Illinois River's Alton through Brandon Lock and Dams, 2019-2021.						
2022IWW	Complete the imagery review and reporting	30-Aug-2022				Strassman
Fish Community Response to the 2020 Illinois Waterway Lock Closure						
2022FSH1	Draft Manuscript: Fisheries and WQ	31-Dec-22				Lamer

FY20 Funded Science in Support of Restoration and Management Proposals

Detailed descriptions of the following projects can be found at
https://umesc.usgs.gov/ltrmp/documents/fy20_science_support16june2020.pdf

Tracking number	Milestone	Original Target Date	Modified Target Date	Date Completed	Comments	Lead
FY20 Funded Science in Support of Restoration and Management						
Mapping Potential Sensitivity to Hydrogeomorphic Change in the UMRS Riverscape and Development of Supporting GIS Database and Query Tool						
2021HG5	Complete annual project summary	31-Dec-2021	30-Mar-22			Strange, Fitzpatrick
2021HG6	Submit draft LTRM Completion report on hydrogeomorphic change GIS database and query system	31-Dec-2021	30-Sep-22			Vaughan, Strange, Fitzpatrick, Van Appledorn, USACE core team
2021HG7	Submit Final LTRM Completion report on hydrogeomorphic change GIS database and query tool.	30-Mar-2022	31-Dec-22			Vaughan, Strange, Fitzpatrick, Van Appledorn, USACE core team
Improving our understanding of historic, contemporary, and future UMRS hydrology by improving workflows, reducing redundancies, and setting a blueprint for modelling potential future						
2021HH1	Historic and Contemporary Hydrologic Database Release and Documentation	30-Sep-2021	30-Sep-22	Awaiting final data delivery from USACE Water Control Chiefs (2 of 3 districts have submitted historic data and documentation; 1 district has submitted documentation only); awaiting USACE hydrologic data server switch completion for accessing contemporary data		M. Van Appledorn, L. Sawyer
2021HH2	Draft LTRM Completion Report: document database and documentation development steps, database capabilities, and quantitative summaries of the hydrologic regime through time.	30-Dec-2021	31-July-2022	Dependent on data acquisition from USACE		M. Van Appledorn, L. Sawyer
2021HH3	Final LTRM Completion Report: document database and documentation development steps, database capabilities, and quantitative summaries of the hydrologic regime through time	31-Mar-2022	30-Sept-2022			M. Van Appledorn, L. Sawyer
2021HH4	Developing Future Hydrologic Scenarios Workshop: topics include identify appropriate future climate and/or land-use scenarios for use in a UMRS watershed model, existing hydrologic modeling resources and capabilities, and logistics for completing a climate-changed hydrologic modeling effort	30-Dec-2021		27-Jan-2022		M. Van Appledorn, L. Sawyer
2021HH5	Draft LTRM Completion Report (Scenarios): This report will serve as the blueprint for modeling future hydrology to be undertaken with future funding opportunities.	31-Mar-2022	31-Aug-2022	11-Aug-2022		M. Van Appledorn, L. Sawyer
2021HH6	Final LTRM Completion Report (Scenarios): This report will serve as the blueprint for modeling future hydrology to be undertaken with future funding opportunities.	30-Jun-2022	30-March-2023			M. Van Appledorn, L. Sawyer
Understanding physical and ecological differences among side channels of the Upper Mississippi River System						
2021SC3	Manuscript on side channel classification scheme submitted for peer review	30-Sep-2022				Sobotka, Strange, Bouska, McCain, Theel
2021SC4	Final report on UMRR management implications submitted for USGS review	30-Sep-2022				Sobotka & McCain
2021SC5	Manuscript on benthic invertebrate associations with side channel characteristics submitted for USGS and peer review	30-May-2023				Sobotka & Vander Vorste
Refining our Upper Mississippi River's ecosystem states framework						
2021SS8	TDA Mapper, regime shifts	1-May-2022		1-May-2022		Bungula, student, Larson
2021SS9	Draft the STM, share with stakeholders	1-Sep-2022				Larson
2021SS10	Technical report, vulnerability assessment tool, and manuscripts to IDPS for internal review	1-Sep-2022				All
Augmenting the UMRR fish vital rates project with greater species representation for genetics and otolith microchemistry						
2021VR3	Submit draft manuscript (genetics)	31-Dec-2022				Davis, Tan, Lamer
2021VR4	Submit draft manuscript (genetics - mimic/channel)	31-Dec-2022				Davis, Tan, Lamer
2021VR5	Submit draft manuscript (constructing management units)	31-Dec-2022				Bartels, Bouska, Davis, Lamer, Larson, Phelps, Tan, Whitledge
Functional UMRS fish community responses and their environmental associations in the face of a changing river: hydrologic variability, biological invasions, and habitat rehabilitation						
2021FF2	Draft manuscript: "Has large scale ecosystem rehabilitation altered functional fish community expressions in the Upper Mississippi River System?"	30-Sep-2021	30-Sep-2022		Delayed with other priorities such as S&T Report writing	Ickes and Gatto
2021FF3	Draft Manuscript: "Why aren't bigheaded carps (*Hypophthalmichthys* sp.) everywhere in the Upper Mississippi River System?"	30-Sep-2021	30-Sep-2022			Ickes and Gatto
Understanding landscape-scale patterns in winter conditions in the Upper Mississippi River System						
2021WL1	System wide spatial layers of habitat conditions	30-Sep-2022				Mooney, Dugan, Magee
2021WL2	Draft manuscript: Landscape scale controls on overwintering habitat in a large river	30-Sep-2022				Mooney, Dugan, Jankowski, Magee
2021WL3	Draft manuscript: Response of oxygen dynamics to ice and snow phenology in backwater lakes	30-Sep-2023				Jankowski, Dugan, Burdis, Kalas, Kueter
2021WL4	Draft Manuscript: Patterns in sediment characteristics and oxygen demand across a winter riverine landscape	30-Sep-2023				Perner, Kreiling, Jankowski, Giblin
Forest Response to Multiple Large-Scale Inundation Events						
2021FR3	Technical Report	1-Jun-2022	30-Mar-23		Delayed due to staffing shortages, hiring of new staff at NGREEC	Cosgriff, Guyon, De Jager