Upper Mississippi River Restoration Program

Science in Support of Restoration and Management
FY20 SOW

Enhancing Restoration and Advancing Knowledge of the Upper Mississippi River

Addressing the FY2015–2025 UMRR Strategic Plan

Developing and Applying Indicators of Ecosystem Resilience to the UMRS (FY19-FY21)

Ecological resilience can be 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 exhibiting 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 is currently 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 adapted the Resilience, Adaptation and Transformation Assessment Framework, which includes three major elements: 1) a system description, 2) assessment of resilience, and 3) adaptive governance and management. A resilience working group, made up of individuals across the UMRR partner agencies, provides guidance and feedback on the direction and specifics of the assessment.

The goal of the UMRS system description was to simplify a complex system 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. 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. The system description has been published in a peer-reviewed journal (Bouska et al. 2018).

In the second element of the assessment, assessing the resilience of the system, there are two complementary assessments that occur. The evaluation of general resilience focuses on understanding properties of a 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. 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. *In Press*) that was used to develop the Habitat Needs Assessment II (McCain et al. *In Press*) to support the inclusion of resilience in restoration planning. Further a manuscript has been written and submitted to a peer-reviewed journal.

The second evaluation of the assessing the system element focuses on specified resilience in the context of alternative regimes. A draft manuscript describing plausible alternative regimes is currently underway with accompanying state-and-transition models that characterize biological conditions of the regimes, drivers of transitions, and feedback mechanisms that act to stabilize regimes. The state-and-transition models will be used to identify information gaps that will be compiled into a research framework. Evaluation of trends in driving variable provides information on the range of conditions the system has experienced over monitored time periods and the direction the system is moving and could be incorporated into the third status and trends of the UMRS. The specified resilience assessment will summarize our current state of understanding of the resilience of key ecological resources to changes in controlling variables and develop a framework for evaluating management-relevant relationships for potential thresholds of concern. Given the numerous major resources and controlling variables identified in the system description conceptual models, we plan to identify and evaluate relationships with greatest priority (and data) and focus on one analysis to complete during FY19.

To manage for resilience in a restoration program, an understanding of the effects of various restoration actions on the resilience of the ecosystem is needed. We will build on the existing conceptual models to explore how different types of HREPs likely influence controlling variables or general resilience indicators. This information could substantially inform the selection, design and evaluation of restoration projects within each floodplain reach to affect the coping capacity of the system in the face of future disturbances.

OBJECTIVES (*Note: Objective 4 (bold text below) will be the emphasis during FY2020*)

This project will be the primary responsibility of a post-doctoral scientist 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.
    - ***b)*** Description of the current general resilience of multiple reaches of the UMRS.

    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 regimes

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 submitted for publication in FY19

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 will soon be published to the LTRM A-Team Corner site online

c) Specified resilience analyses derived from UMRR LTRM data

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?**

WORKPLAN AND DELIVERABLES

In FY20, the focus will be on developing and completing two specified resilience analyses that use UMRR LTRM data to understand and explore the implications for the resilience of the UMRS. Following these analyses, we will begin to synthesize findings and implications of the broader resilience assessment of the UMRS.

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
2020R1	Updates provided at quarterly UMRR CC meeting and A team meeting	Bouska, Houser	Various
2020R2	Submit fish regime manuscript for peer-review publication	Bouska	30 December 2019
2020R3	Submit aquatic vegetation resilience manuscript to RWG	Bouska	30 September 2020
2020 R4	Submit draft outline of resilience assessment synthesis to RWG	Bouska	30 September 2020
Intended for Distribution			
Manuscript: Bouska, K. L., J. N. Houser, N. R. De Jager, D. C. Drake, S. F. Collins, D. K. Gibson-Reinemer, and M. A. Thomsen. *In Review.* Conceptualizing alternate regimes in a large floodplain-river ecosystem. Journal of Environmental Management, Responding to review comments			

Assessing recent rates of sedimentation in the backwaters of Pools 4, 8, and 13 to support river restoration and the Habitat Needs Assessment-II (FY17-18)

In a previous LTRM study between 1997 and 2001, annual bed elevations were measured along a set of backwater transects in Pools 4, 8 and 13 of the Upper Impounded Reach of the UMRS (Rogala et al. 2003). These survey data provided basic information on rates of backwater sedimentation across a gradient of depth and among backwaters that varied in their hydraulic connectivity with channels.

This study will use the same sampling design and survey methodology used in the 1997-2002 study (Rogala et al. 2003).

Conditions were again not suitable for surveys in Pool 13 in the winter of 2018/2019. We will attempt the surveys again in 2019/2020. If surveys cannot be completed in 2019/2020, the completion report will only include analysis of data from Pools 4 and 8.

Products and Milestones

Tracking number	Products	Staff	Milestones
2018ST1	Reestablishment of horizontal and vertical temporary benchmarks, and a data base for horizontal and vertical benchmarks (Continuation of 2017ST1)	Rogala, Moore, Kalas, Bierman	30 March 2020
2018ST2	Open-water nearshore surveys completed and a database (Continuation of 2017ST2)	Rogala, Moore, Kalas, Bierman	31 December 2019
2018ST3	Over-ice surveys completed and a database (Continuation of 2017ST3)	Rogala, Moore, Kalas, Bierman	30 March 2020
2018ST4	Draft completion report on sedimentation rates along transects (Continuation of 2017ST4) If surveys in Pool 13 cannot be completed in 2019/2020, the completion report will only include analysis of data from Pools 4 and 8.	Rogala, Moore, Kalas, Bierman	30 March 2020

Literature Cited:

Rogala, J. T., P. J. Boma, and B. R. Gray. 2003. Rates and patterns of net sedimentation in backwaters of Pools 4, 8, and 13 of the Upper Mississippi River. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. An LTRMP Web-based report available online at:
http://www.umesc.usgs.gov/data_library/sedimentation/documents/rates_patterns/rates_patterns.pdf

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.

Products and Milestones

Tracking number	Products	Staff	Milestones
2020L1	Geospatial analyses in support of the Forest Gap project	De Jager	30 August 2020
2020L2	Analysis; Evaluating effects of alternative flooding scenarios on forest succession in the UMRS. Potential manuscript in 2021	De Jager	30 September 2020
2020L3	Analysis; Developing a state and transition model for reed canarygrass invasion on the Upper Mississippi River floodplain. Potential manuscript in 2021	De Jager	30 September 2020
On-Going			
2016L3	Draft Manuscript: Review of Landscape Ecology on the UMR	De Jager	30 September 2020

Reference

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

Eco-hydrologic Research

Flooding is believed to be a key driver of form and function of the Upper Mississippi River System (UMRS). Understanding the role of inundation in driving dynamics in both aquatic and terrestrial ecosystems is essential for improving the health and resilience of the UMRS through informed management practices. Only recently, however, have inundation dynamics been characterized and mapped systematically in ecologically meaningful ways. The characterizations of flooding, 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 forest patterns (composition, structure) and processes (dispersal, regeneration, succession) across multiple spatial and temporal scales.

The goal of this research is to leverage 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 to contribute to the improved health and resilience of the UMRS by developing concepts, maps, and models relevant to management activities.

Specific Activities for FY2020:

Component 1 – UMRS inundation model completion and support: LTRM will maintain some level of expertise to provide basic model archiving and assistance using the UMRS inundation model. In FY2020, we will:

1a. Facilitate the inundation modelling framework's long-term curation by creating an accessible platform for its distribution
1b. Provide technical assistance on accessing model outputs and the proper use of model outputs
1c. Assist partner agencies on the development of additional uses for the 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 floodplain forests 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

Products and Milestones

Tracking number	Products	Staff	Milestones
2020EH01	Submit manuscript of UMRS inundation diversity for peer review	Van Appledorn, De Jager, Rohweder	30 September 2020
2020EH02	Submit manuscript of temporal patterns in UMRS inundation regimes for peer review	Van Appledorn, De Jager, Rohweder	30 September 2020
2020EH03	Analysis of UMRS floodplain forest diversity and development of forest typology	Van Appledorn	30 September 2020

On-Going

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; split into two manuscripts. Additional manuscript is 2020EH01)

Development of UMRS inundation model query tool; Van Appledorn, Fox, Rohweder, De Jager; 2019EH03

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 seperate 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.


RGB image NIR image CIR image

Figure 1. Phase One iXU-RS 1000 RGB and 1000 Achromatic digital cameras with co-registration base plate for generating 4-band aerial imagery.

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.

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,

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[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.

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 and Milestones

Tracking number	Products	Staff	Milestones
2020LCU1	Imagery Acquisition	Dieck, Hop	Late Aug. Sept. 2020
2020LCU2	Image processing, stereo model development, orthorectification, pool-based mosaicking, image interpretation, QA/QC, and serving of 2020 LCU datasets for Pools 4, 8, 13, 26, La Grange, and an estimated 80% of the Open River South	Dieck, Hop	September 2021
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, the Alton Pool of the Illinois River, and Pools 9-12	Dieck, Hop	September 2022
2020LCU4	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	Dieck, Hop	September 2023

ATTACHMENT A

LTRM 31-class general classification for floodplain vegetation (version 2.0), with crosswalk to LTRM LCU dataset classification and U.S. National Vegetation Classification (USNVC 2017).

MAP CODE*	MAP-CODE DESCRIPTION*	DATASET CODE**	DATASET-CODE DESCRIPTION**	HYDRO CODE	HYDRO-CODE DESCRIPTION	USNVC CODE	USNVC-CODE DESCRIPTION
OW	Open Water	Ow	Open water	1	Permanently Flooded Non-Forest	N/A	Non-USNVC; Default to Anderson Classification
SV	Submersed Vegetation	Sv	Submersed aquatic vegetation	1	Permanently Flooded Non-Forest	5.B.2.Na.1.a	Eastern North American Freshwater Aquatic Vegetation Group
RFA	Rooted Floating Aquatics	Rf	Rooted floating aquatics	1	Permanently Flooded Non-Forest	5.B.2.Na.1.a	Eastern North American Freshwater Aquatic Vegetation Group
DMA	Deep Marsh Annual	Dma	Deep marsh annual	2	Semipermanently Flooded Non-Forest	2.C.4.Nd.2.a	Eastern North American Freshwater Marsh Group
DMP	Deep Marsh Perennial	Dmp	Deep marsh perennial	2	Semipermanently Flooded Non-Forest	2.C.4.Nd.2.a	Eastern North American Freshwater Marsh Group
SMA	Shallow Marsh Annual	Sma	Shallow marsh annual	3	Seasonally Flooded Non-Forest	2.C.4.Nd.3.b	Eastern North American Wet Shoreline Vegetation Group
SMP	Shallow Marsh Perennial	Smp	Shallow marsh perennial	3	Seasonally Flooded Non-Forest	2.C.4.Nd	Eastern North American Temperate & Boreal Freshwater Marsh, Wet Meadow & Shrubland Division
SM	Sedge Meadow	MwSe	Sedge meadow	4	Temporarily Flooded Non-Forest	2.C.4.Nd.2.d	Midwest Wet Prairie & Wet Meadow Group
WM	Wet Meadow	Wm	Wet meadow	5	Saturated Soil Non-Forest	2.C.4.Nd	Eastern North American Temperate & Boreal Freshwater Marsh, Wet Meadow & Shrubland Division
DMS	Deep Marsh Shrub	Dms	Deep marsh shrub	6	Semipermanently Flooded Shrubs	2.C.4.Nd.2.b	Eastern North American Shrub Swamp Group
SMS	Shallow Marsh Shrub	Sms	Shallow marsh shrub	7	Seasonally Flooded Shrubs	2.C.4.Nd.3.a	Eastern North American Riverine Wetland Vegetation Group
WMS	Wet Meadow Shrub	Wms	Wet meadow shrub	8	Temporarily Flooded Shrubs	2.C.4.Nd.3.a	Eastern North American Riverine Wetland Vegetation Group

MAP CODE*	MAP-CODE DESCRIPTION*	DATASET CODE**	DATASET-CODE DESCRIPTION**	HYDRO CODE	HYDRO-CODE DESCRIPTION	USNVC CODE	USNVC-CODE DESCRIPTION
SS	Scrub-Shrub	Ss	Shrub/scrub	9	Infrequently Flooded Shrubs	2.B.2.Nc.90.a	Eastern North American Ruderal Meadow & Shrubland Group
WS	Wooded Swamp	Ws	Wooded swamp	10	Semipermanently Flooded Forest	1.B.3	Temperate Flooded & Swamp Forest Formation
FF	Floodplain Forest	Ff	Floodplain forest	11	Seasonally Flooded Forest	1.B.3.Na.1.a	Silver Maple - Green Ash - Sycamore Floodplain Forest Group
PC	*Populus* Community	PoCm	Populus community	11	Seasonally Flooded Forest	1.B.3.Na.1.a	Silver Maple - Green Ash - Sycamore Floodplain Forest Group
SC	*Salix* Community	SxCm	Salix community	11	Seasonally Flooded Forest	2.C.4.Nd.3.a	Eastern North American Riverine Wetland Vegetation Group
LF	Lowland Forest	Lf	Lowland forest	12	Temporarily Flooded Forest	1.B.3.Na.1.a	Silver Maple - Green Ash - Sycamore Floodplain Forest Group
AG	Agriculture	Ag	Agriculture	14	Infrequently Flooded Non-Forest	7.B	Herbaceous Agricultural Vegetation Cultural Subclass
CN	Conifers	Cn	Conifers	13	Infrequently Flooded Forest	1.B.2.Na.90.a	Eastern North American Native Ruderal Forest Group
PN	Plantation	Pn	Plantation	13	Infrequently Flooded Forest	7.A	Woody Agricultural Vegetation Cultural Subclass
UF	Upland Forest	Uf	Upland forest	13	Infrequently Flooded Forest	1.B.2.Na	Eastern North American Forest & Woodland Division
DV	Developed	Dv	Developed	14	Infrequently Flooded Non-Forest	7.C	Agricultural & Developed Vegetation Cultural Class
GR	Grassland	Gr	Grassland	14	Infrequently Flooded Non-Forest	2.B.2	Temperate Grassland & Shrubland Formation
LV	Levee	Lv	Levee	14	Infrequently Flooded Non-Forest	7.C	Herbaceous & Woody Developed Vegetation Cultural Subclass
PS	Pasture	Ps	Pasture	14	Infrequently Flooded Non-Forest	2.B.2	Temperate Grassland & Shrubland Formation
RD	Roadside	Rd	Roadside	14	Infrequently Flooded Non-Forest	7.C	Herbaceous & Woody Developed Vegetation Cultural Subclass

MAP CODE*	MAP-CODE DESCRIPTION*	DATASET CODE**	DATASET-CODE DESCRIPTION**	HYDRO CODE	HYDRO-CODE DESCRIPTION	USNVC CODE	USNVC-CODE DESCRIPTION
MUD	Mudflat	Md	Mud	3	Seasonally Flooded Non-Forest	2.C.4.Nd.3.a	Eastern North American Riverine Wetland Vegetation Group
SB	Sand Bar	Sb	Sand bar	4	Temporarily Flooded Non-Forest	2.C.4.Nd.3.a	Eastern North American Riverine Wetland Vegetation Group
SD	Sand	Sd	Sand	14	Infrequently Flooded Non-Forest	2.B.2.Nc.90.a	Eastern North American Ruderal Meadow & Shrubland Group
NC	No Coverage	Nc	No coverage		N/A	N/A	N/A

*Classification codes and names from Table 1–1 in “General Classification Handbook for Floodplain Vegetation in Large River Systems”, Techniques and Methods 2—A1, Version 2.0, November 2015 (Dieck and others).

**Classification codes and names as depicted in LTRM LCU database sets; “CLASS_31” for codes and “CLASS_31_N” for names.

VEGETATION MODIFIERS

Density A = 10-33% B = 34-66% C = 67-90% D = 91-100%

Height* 1 = 0-6 meters 2 = 6-15 meters 3 = > 15 meters *Trees only

ATTACHMENT B
FLIGHT PLANS FOR 2020 UMRS SYSTEMIC AERIAL IMAGERY ACQUISITION

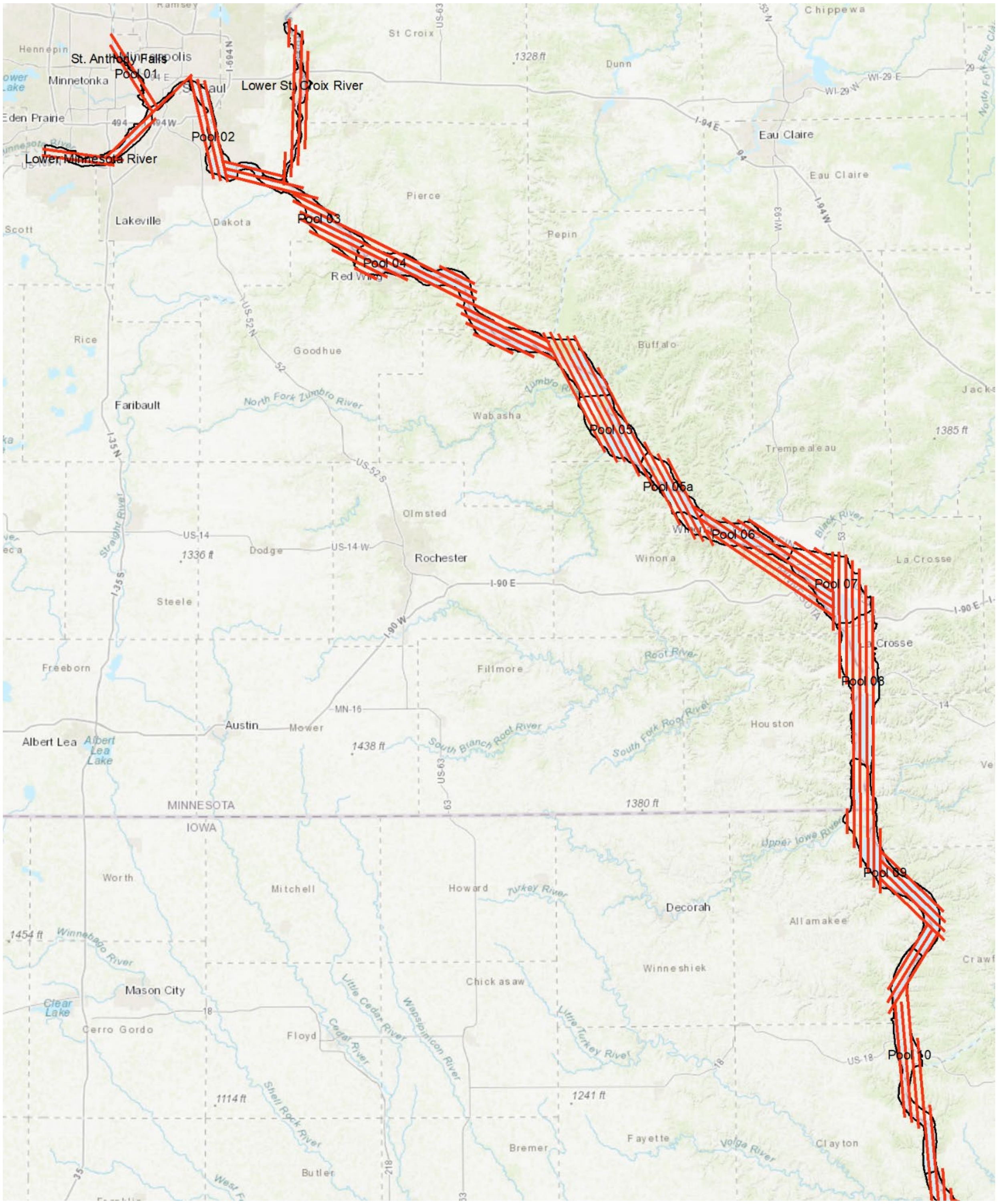


Figure 1. Flight lines for Pools 1 through 10 and the St. Croix and Lower Minnesota Rivers.

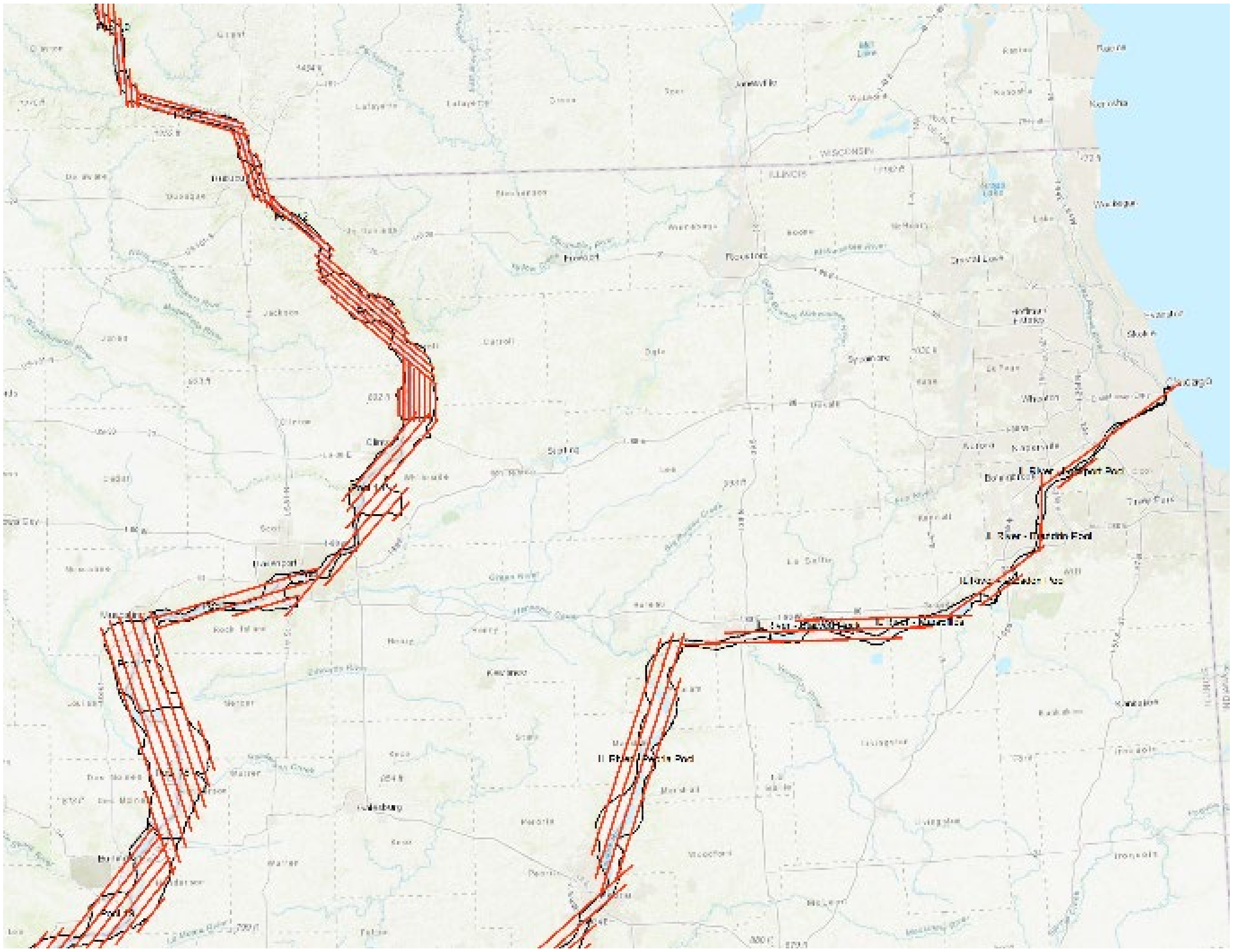


Figure 2. Flight lines for Pools 11 through 18 and the Peoria through Lockport Pools of the Illinois River.

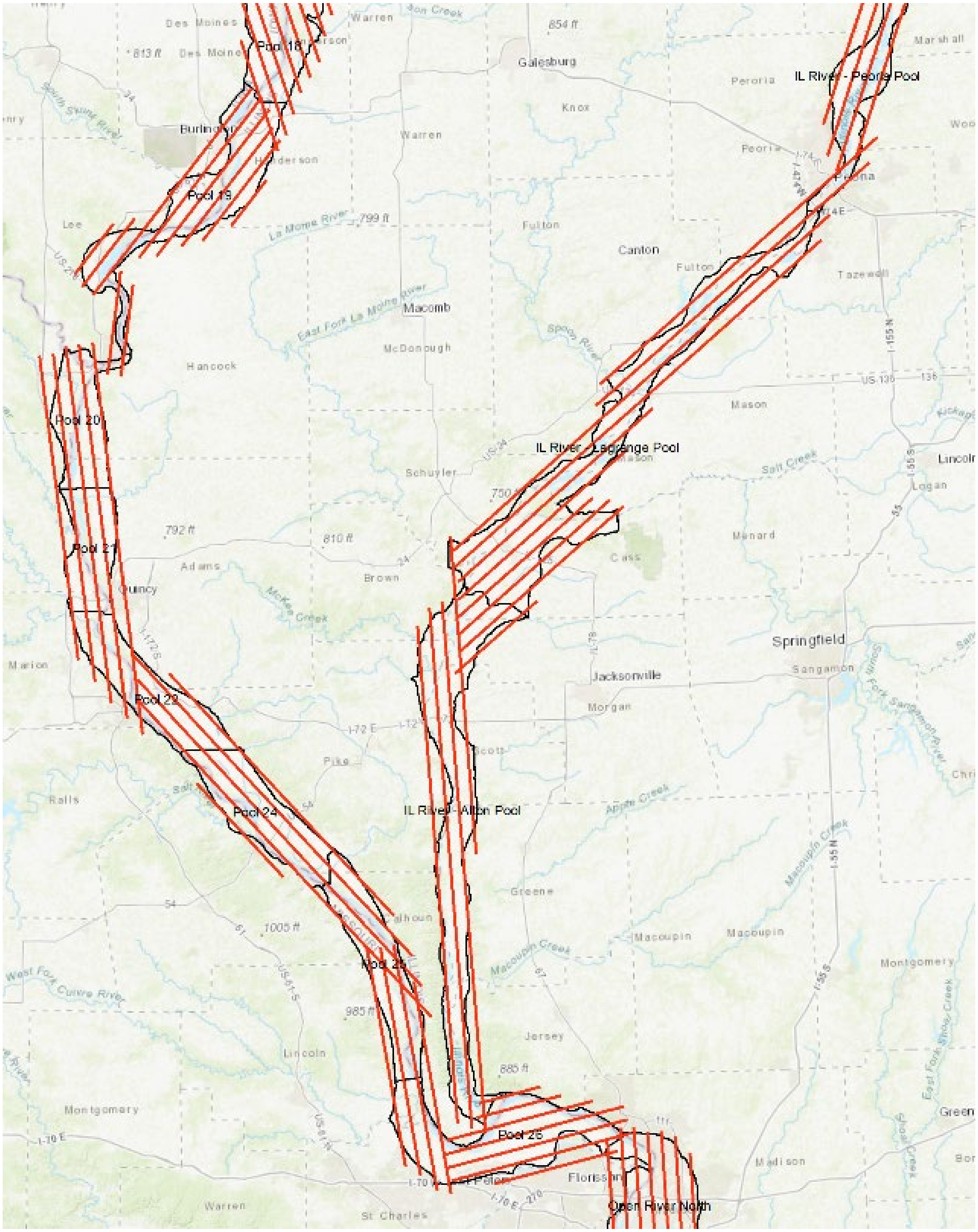


Figure 3. Flight lines for Pools 19 through 26 and the Alton and La Grange Pools of the Illinois River.

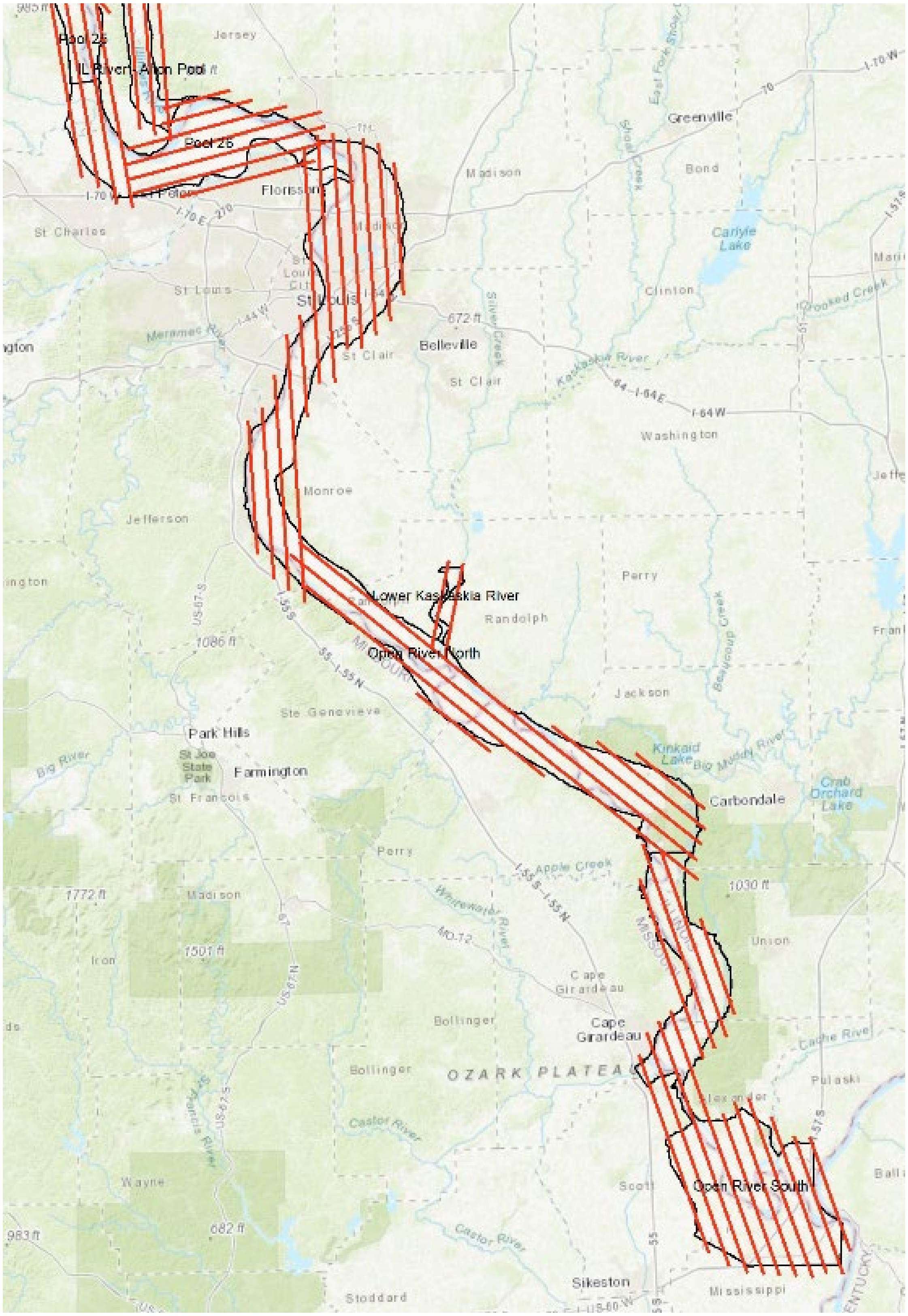


Figure 4. Flight lines for Open River North and South and lower Kaskaskia River.

Aquatic Vegetation, Fisheries, and Water Quality Research

Products and Milestones

Tracking number	Products	Staff	Milestones
On-Going			
Fisheries			
2020B12a	Final LTRM Completion Report: Developing a biochronology of smallmouth buffalo growth for the Upper Mississippi and Illinois Rivers (tied to 2018SMBF4)	Ickes with Solomon	30 July 2020
2019B13	Draft Manuscript: Evidence of functionally defined non-random fish community responses over 25 years in a large river system (replacing 2015B17 and 2016B17)	Ickes	28 February 2020
2016B14	Draft completion report: Exploring Years with Low Total Catch of Fishes in Pool 26	Gittinger, Chick	30 July 2020
2020BF1	Iowa Walleye Management Plan 2019; incorporation of LTRM data	Bowler	30 November 2019
Water Quality			
2019D13	Draft manuscript: Ice and snow cover affect winter limnological conditions differently across a connectivity gradient in a large floodplain river (replacing 2018D13)	Jankowski, Rogala, Houser	30 July 2020
Intended for Distribution			
Burdis, Rob. Manuscript: 'Ecological shift in backwater lakes of a large floodplain river: Upper Mississippi River'. (2015D16; submitted to Aquatic Sciences, accepted for publication) Working title: Decadal trends and ecological shifts in backwater lakes of a large floodplain river: Upper Mississippi River			

Statistical Evaluation

Statistical support for the UMRR LTRM provides guidance for statistical analyses conducted within and among components, for contributions to management decisions, for identifying analyses needed by the Program, for developing Program-wide statistical projects, and for reviewing LTRM documents that contain statistical content. The statistician is also responsible for ensuring that newly developed statistical methods are evaluated for use by LTRM. Guidance for management includes assistance with modifications to program design and with standardizing general operating procedures.

The statistical component will help identify useful analyses of data within and across components, ensure analytical methods are appropriate and consistent, and, when possible, coordinate multiple analyses to achieve larger program objectives regardless of which group (UMESC, field stations, USACE, etc.) conducts analyses. The statistician is also responsible for reviewing LTRM documents that contain substantial statistical components for accuracy, and for ensuring that quality of analyses is consistent among products. A primary goal of statistical analyses is to draw appropriate conclusions to inform effective management actions. Appropriate statistical analysis and interpretation is critical to making proper inferences from LTRM data. This, in turn, is critical for distinguishing between natural variation and human effects and in evaluating the long-term effects of management actions, such as HREPs, water level manipulations, or increases in navigation.

Product Description

2020E1: LTRM estimates of submersed aquatic vegetation percent frequency of occurrence will often be low. This issue reflects that the LTRM may miss a species when the species is present at a sampling site but is not present at any of the six rake locations within that site or that we may fail to detect a species at a rake location when it is, in fact, present ; the latter errors are often termed 'detection errors.' We suspect that the probability of detection errors will decrease with abundance. One approach used in a similar setting but with animals is to let probabilities of detection increase with the number of animals present. This product addresses the utility of this method for use with LTRM rake data, and specifically when numbers of organisms (plants in this case) are either not practical to count or are better replaced by plant volume or biomass. Product: draft manuscript.

Products and Milestones

Tracking number	Products	Staff	Milestones
2020E1	Draft manuscript. Detection errors	**Gray**	30 September 2020

Intended for distribution
Manuscript: Inferring decreases in among- backwater heterogeneity in large rivers using among-backwater variation in limnological variables (2010E1). Rogala withdrew the paper from a journal after it had been with the journal for 18 months; paper to be resubmitted in FY19 by Gray.
Draft manuscript: How well do trends in LTRM percent frequency of occurrence SAV statistics track trends in true occurrence? Gray 2016E2; in journal review
Manuscript: Model selection for ecological community data using tree shrinkage priors; Gray, Hefley, Zhang, Bouska; (2017FA2; 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
2020P13a	Collect annual increment of pool-wide electrofishing data	Bowler	1 November 2019
2020P13b	Collect annual increment of fyke netting data from backwater lakes	Bowler	15 November 2019
2020P13c	Perform otolith extraction from bluegills for aging	Bowler	1 December 2019
2020P13d	Age determination of bluegills collected in Fall 2019	Bowler and Kueter	1 February 2020
2020P13e	In-house project databases updated	Bowler	31 March 2020
2020P13f	Summary letter compiled and made available to program partners	Bowler	30 September 2020

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
2017PL3	Collection of post-construction winter water quality data	Burdis, DeLain, Lund, Dawald	February 2020
2017PL4	Collection of post-construction summer water quality data	Burdis, DeLain, Lund, Dawald	August 2020
2017PL5	Summary letter: Tabular and graphical summary of water quality data	Burdis, Lund, Moore	December 2020

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 LTRM 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	Product		Staff		Milestone
2020N1	Science Planning Meeting; UMESC		All LTRM		Week Jan. 13, 2020

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 (www.mvr.usace.army.mil/Missions/EnvironmentalProtectionandRestoration/UpperMississippiRiverRestoration/Partnership/CoordinatingCommittee.aspx) 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.

FY20 Funded Science in Support of Restoration and Management Proposals

Mapping Potential Sensitivity to Hydrogeomorphic Change in the UMRS Riverscape and Development of Supporting GIS Database and Query Tool

Name of Principal Investigator(s):
Jayme Strange, Biologist/GIS Lab Manager, U.S. Geological Survey – Upper Midwest Environmental Sciences Center, 608-781-6290, jstrange@usgs.gov – Project oversight with geospatial expertise and oversight of GIS technicians who will provide the analyses and data/metadata management, journal and report writing.

Faith Fitzpatrick, Research Hydrologist, U.S. Geological Survey – Upper Midwest Water Science Center, 608-821-3818, fafitzpa@usgs.gov – Project oversight with geomorphology expertise, hiring of post-doc to complete analyses, journal and report writing.

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

Fluvial geomorphologist – new USGS hire – Assist principle investigators in project geomorphology expertise, further develop and interpret hydrogeomorphic change classification, lead writing on hydrogeomorphic change descriptions for the UMRS. Assist other UMRR science studies that need hydrogeomorphic change context and technical expertise.
Molly Van Appledorn - USGS – UMESC, mvanappledorn@usgs.gov – assist in mapping decision, develop terrain model for identification of floodplain hydrogeomorphic units, interpretation with journal and report writing.
GIS Student Interns – USGS – UMESC – assist in mapping and data management.
USACE Core Team:

- **Jon Hendrickson** - U.S. Army Corps of Engineers – St. Paul District, jon.s.hendrickson@usace.army.mil - UMMR-LTRM Hydrogeomorphic Working Group support and hydraulic engineer advice.
- **Lucie Sawyer** - U.S. Army Corps of Engineers – Rock Island District, lucie.m.sawyer@usace.army.mil – UMMR-LTRM Hydrogeomorphic Working Group support and hydraulic engineer advice.
- **Michael Dougherty** – U.S. Army Corps of Engineers – Rock Island District, michael.p.dougherty@usace.army.mil – USACE GIS support and advice.
- **Kara Mitvalsky** – U.S. Army Corps of Engineers – Rock Island District, kara.n.mitvalsky@usace.army.mil – USACE HREP support and advice.

Introduction/Background:
Understanding the processes and causes for short- and long-term hydrogeomorphic changes along the UMRS has been important for scientific studies and management decision on ecological rehabilitation associated with the UMRR. These changes represent the interactions of hydrology, hydraulics, and sediment dynamics at a variety of spatial and temporal scales along the UMRS, including continued adjustments associated with reworking of flows and sediment in inter-dam areas. From 2018-20 a core team of USGS and USACE scientists and engineers developed a draft framework for a conceptual model (Figure 1) and hierarchical classification system for hydrogeomorphic change (Figure 2) in the UMRS. The model and classification were developed after a review of relevant previous studies, geographic information system-based data sets, and the broader literature on diagnostic-style process-based classification systems (Fryirs, 2003; Brierley and Fryirs, 2005; Buffington and Montgomery, 2013; Montgomery and Buffington, 1993). The UMRS Cumulative Effects Study (WEST Consultants, Inc., 2000) served as the springboard for understanding the drivers important for hydrogeomorphic change throughout the previously established management units of four floodplain and 12 geomorphic reaches The core team's activities were guided by the technical assistance and expertise of a 14-member panel consisting of geomorphologists, ecologists, engineers, and managers from the USACE, USGS, state agencies and universities throughout the UMRS. A description of the development of the framework for the draft model and classification system based on results from a panel workshop, is in Fitzpatrick et al (in prep).

The draft conceptual model provides a context for the major factors that contribute to hydrogeomorphic change and help communicate and link changes over time in one area of the river with changes in another area. The previous work by Jacobson et al. (2015) for development of a conceptual ecological model for Pallid sturgeon in the Missouri River provided a relevant example the building blocks of a conceptual model. Drivers of change at the broad conceptual level for the UMRS include upstream hydrology and flow conditions, tributary flows and sediment loads, water level changes, and local velocity variations that contribute to erosion and deposition. The type and potential for hydrogeomorphic change is mediated by local variations in vegetative roughness, proximity to tributaries and dams, valley slope and width, and hardened structures added over the years for navigation and rehabilitation.

An important objective of the 2018 project was to explore and update the UMRR GIS database and query tools. The GIS query tool developed for the first and second Habitat Needs Assessment (HNA; Theiling et al., 2000; DeHaan et al., 2000; McCain et al., 2018) formed the basis for a needed expansion and application to map and classify hydrogeomorphic units and potential hydrogeomorphic change linkages across floodplain and aquatic environments. Hydrogeomorphic units describe the origin of the landform, potential processes affecting the form, and the type of expected change and sensitivity to change. These changes can be abrupt to gradual, slow or fast, depending on the level hydraulic energy required to initiate the change. The attempt of the 2018-20 core team for grouping process-based linkages of hydrogeomorphic units into associations, or catenae, is perhaps the most useful, yet difficult part of the development of the classification system. Many of the typical processes related to change are depositional and include channel bed aggradation and lateral migration, island head erosion, floodplain sedimentation, backwater filling, and delta/fan/bar growth. The more detailed process-based classification is possible because of the available new higher resolution river-wide data sets for topobathy and gradient (USACE, 2016) and terrain/landform modeling tools, basin-wide quantitative models on tributary sediment loads (USGS Sparrow Model; Robertson and Saad, 2019; https://sparrow.wim.usgs.gov/sparrow-midwest-2012/), and flood inundation maps (Van Appledorn, et al., 2018).

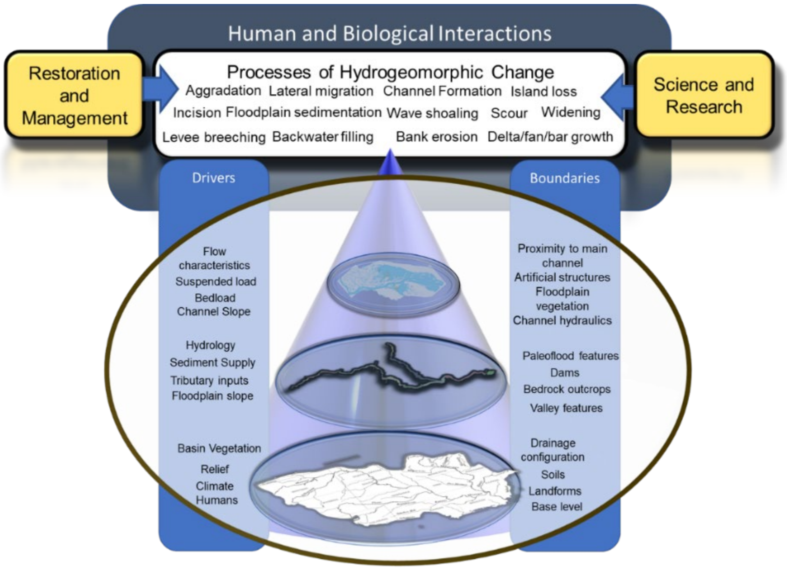


Figure 1. Draft conceptual model for hydrogeomorphic change in the UMRS

In large river systems like the UMRS, most of the hydrogeomorphic processes can be related to spatial and temporal variations in the delivery of water and sediment from surrounding tributaries and how the river rearranges sediment in the valley bottom over time. In the impounded reaches and tributary mouths of the UMRS, depositional processes can be spatially distinguished based on proximity to the dam and water levels. There are also multiple areas within impounded reaches that show shifts in river competency and capacity. Recently, UMRR studies completed maps of planform and side channel changes in the river system. The planform change study identified the most likely cause and location for these changes (Rogala et al., 2020 in review), many of which are depositional and delta-like features where flowing waters enter backwaters or impounded waters upstream of dams. Hydrogeomorphic change identified by Rogala et al. (in review) included tributary delta deposition, crevasse delta deposition, barrier island erosion, island expansion, island erosion, island migration, channel widening, and channel migration. In 2018, the Hydrogeomorphic Change working group began a project that surveyed UMRS side channels and did a quick study of geomorphic change in those side channels. In 2020, the side channel working group will be using that data to create products that will provide a biological context of what hydrogeomorphic change means in a side channel. The hydrogeomorphic working group and side channel working group will collaborate to share products and help expand off current research questions in the future.

The hydrogeomorphic catenae level helps to explain how some hydrogeomorphic features are connected by erosion and deposition processes along a continuum of inundation, velocity and slope combinations. The extension of the catena concept to fluvial processes follows its original application in soils by Geofrey Milne for describing distinct arrays or series of soils and their position along a slope linked by erosion and deposition processes (Milne, 1935; Birkeland, 1984).

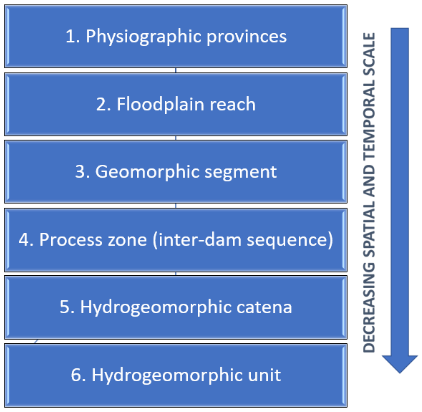


Figure 2. Hierarchical classification system developed from existing framework and literature.

Our goals for this 2020-2022 project are to map potential hydrogeomorphic change characteristics for hydrogeomorphic unit and catena levels and provide a more fully developed and vetted GIS-based database and query tool that would be available to both scientists and engineers working on UMRR studies and HREP planning and design. These goals will be met through the following objectives : 1) acquire and assemble existing spatial data layers related to the hydrogeomorphic change hierarchical classification system, 2) generate additional and new characteristics that are needed to describe the common processes potentially causing hydrogeomorphic change, 3) provide maps and interpretive analyses on the spatial distribution and causes for erosion and deposition responsible for changing hydraulic distributions, landform characteristics, ecology, and water quality in the UMRS, and 4) provide a query-based GIS tool for use in scientific studies and HREP plans. In order to complete these goals an on-site geomorphologist is necessary to be able to provide the close attention and guidance needed for the GIS database development team.

Relevance of research to UMRR:

The 2020-22 project proposed here provides relevance to Focal areas in Theme 1 from the 2020 UMRR Science Meeting “understanding ongoing and likely future changes in the hydrology and geomorphology of the UMRS and implications for the future distribution and abundance of aquatic areas” and Theme 2, “understanding how geomorphology, hydrology and biotic interactions affect the distribution and abundance of biota in the river and on the floodplain”. The GIS query tool of hydrogeomorphic change will be particularly useful for HREP projects. Understanding the potential physical and ecological dynamics of an area before placing a project will allow designers to predict future maintenance and placement cost.

- Focal area 1.1 “Recent and ongoing geomorphological changes and their implications for future conditions”: Mapping hydrogeomorphic units in the UMRS is a first step to detecting geomorphological changes in the UMRS and understanding the context and implications of such change. How does hydrogeomorphic setting and potential for change influence relate to post-project sediment dynamics for HREPs?
- Focal area 1.2 “Future discharge, hydraulic connectivity, and water surface elevation (WSE) scenarios”: This work will assist scientists to better understand the geomorphic setting that increases the potential for levee breaches and new side channels to form.
- Focal area 1.3 “Future hydrogeomorphology scenarios and their implications”: The classification could be used to help determine which areas of the river will most likely be affected by more hydrogeomorphic change due to changes in flood inundation and sediment loads.
- Focal area 2 The products from the GIS database and analysis will allow future research study the spatiotemporal scale, physical character, and spatial distribution of river hydrogeomorphic models influence biotic communities, ecosystem metabolism, nutrient movement and processing, and possible sensitivity to anthropogenic disturbances (Williams et al. 2013).

Methods:

Many geospatial datasets have already been identified and compiled in a prototype database at the USGS Upper Midwest Environmental Science Center and were used to develop the framework for the classification from the 2018-20 project. This project will make those datasets publicly available if they are not already. The project requires the onsite presence of an experienced fluvial geomorphology to work side-by-side with the GIS analysts. The GIS-based query tool will allow users to view the GIS database and query the data that helped define the UMRS classification and conceptual model. Users could even download data on their study area of interest if they so choose. Completing an online spatial query tool is important for communicating the linkages to river managers and HREP projects in-regard to hydrogeomorphology and future changes of the UMRS. The project involves the following tasks:

1) Obtain more geomorphological expertise -- Hire a fluvial geomorphologist to take the lead on fleshing out and testing the initial conceptual model and hierarchical classification. Keep the 2018-20 core team active and engaged in technical guidance, review, and application.
2) Build and ensure a publicly available GIS database for current and future spatial information. Compile all the existing GIS data for all hierarchical levels (Figure 2). If some of those datasets (e.g., layers from the CES such as landform sediment assemblages) are not publicly available, they will be made public on Science Base following USGS standards for data review and management. The data layers include landform sediment assemblages and longitudinal profiles.
3) Determine hydrogeomorphic units on the floodplain from terrain modeling and positioning algorithms (Figure 3) of floodplain elevation data, flood inundation maps, and landform assemblage and land cover maps (Jasiewicz and Stepinski, 2013). GIS-based pattern recognition tools will be used to classify and map landform features using digital terrain models as data inputs by assessing distributions of elevations within defined areas and their relationships to each other. Once an initial distribution of landforms has been identified and mapped using the pattern-recognition tool, the landforms will be interpreted based on their relationships with other relevant variables such as land cover, inundation dynamics, and positioning. The expected outcome of these analyses is a map layer of landform features with potential interpretation of the biophysical associations they represent.
4) Conduct quality checks and comparison analyses of aquatic and floodplain derived hydrogeomorphic change units. Create a seamless map of hydrogeomorphic units that includes aquatic and floodplain environments.
5) Use geomorphic expertise to expand draft list of hydrogeomorphic change related catena. Compile additional information on hydrology, hydraulics, water levels, and sediment loads. Conduct GIS analyses to relate the positioning of the hydrogeomorphic units relative to large tributary sediment loads (Figure 4).
6) Compare maps to information from systemic and non-systemic studies of measured change.
7) Identify longitudinal process zones attributed with water surface elevation, open water, impounded, fetch, etc. in navigation pools and along the 12 geomorphic reaches.
8) Map and describe hydrogeomorphic units and catenae by UMRS reaches that are sensitive to hydrogeomorphic change. Describe differences in potential hydrogeomorphic change characteristics for hydrogeomorphic units among the 12 reaches. Identify, if possible, causes for spatial variations.
9) Build a publicly available GIS-based spatial query tool in ArcGIS Online that pulls data from the UMESC GIS server (Figure 5). A handful of the systemic datasets are already available (Example shown through the UMRS Systemic Spatial Data Viewer). The query tool will be published in the USGS Science Base.
10) Conduct web meetings early on and at least one face-to-face meeting with expert panel and UMRR scientists to communicate development of GIS database, vetting of hydrogeomorphic catenae, and testing the application of classification. Conduct web or face-to-face meeting early on to familiarize the new geomorphologist with the core team and expert panel and introduce the development of the conceptual model and classification.
11) Write annual project update summaries.
12) Write journal articles(s) and report. In addition to at least one journal article on the classification system, we also anticipate a peer-reviewed manuscript that describes the floodplain hydrogeomorphic units and their distribution and relationships with floodplain forest communities in the UMRS.

Create a USGS narrative or story map or other web product that promotes the use of the classification.

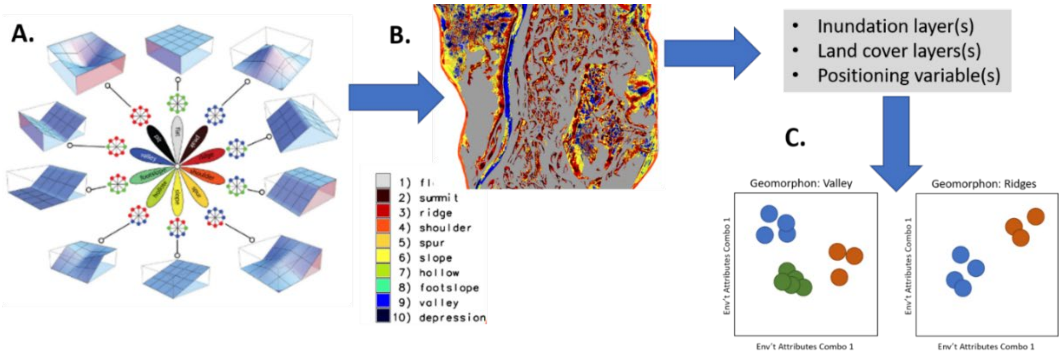


Figure 3. Processing steps involved in terrain modeling-based mapping of floodplain hydrogeomorphic units: A) pattern-recognition algorithms, B) identification of unique floodplain hydrogeomorphic units, and C) attributing of units with flood inundation, land cover, and positioning relative to other hydrogeomorphic change influencing features.

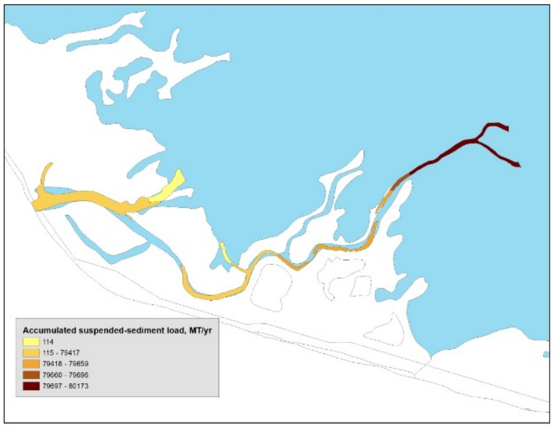
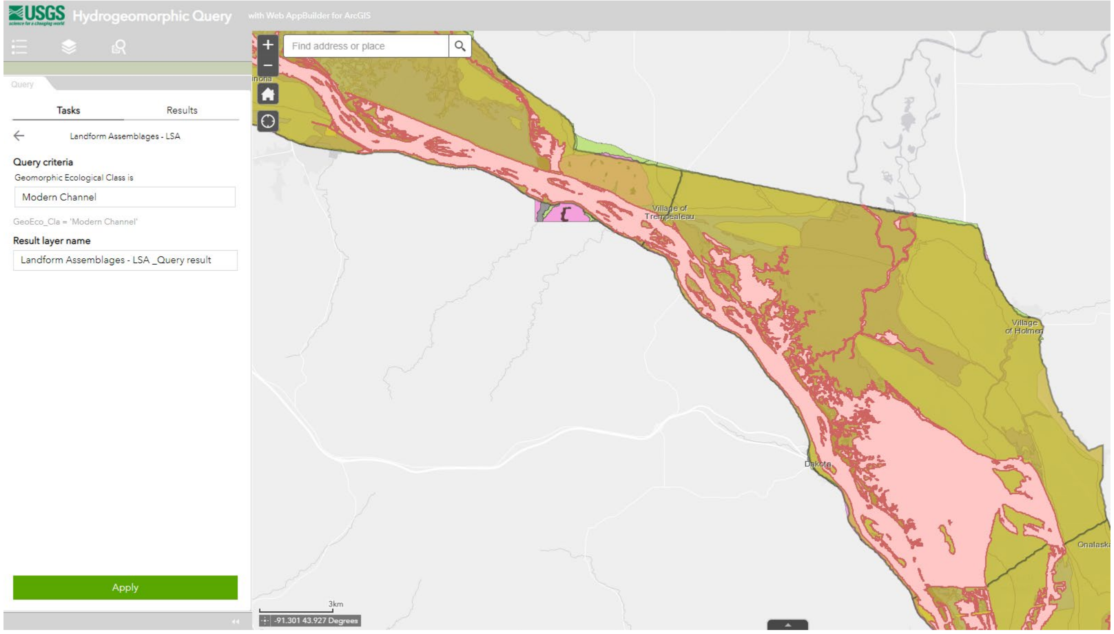


Figure 4. Example of UMRS Sparrow model (Robertson and Saad, 2019) results for accumulated tributary suspended sediment loads attributed to affected aquatic-based hydrogeomorphic units.



Landform Assemblages - LSA

Query criteria

Geomorphic Ecological Class is

Modern Channel

GeoEco_Cla = 'Modern Channel'

Result layer name

Landform Assemblages - LSA _Query result

Figure 5. Example of spatial data query tool for the hydrogeomorphic change GIS database.

Timeline and project schedule (Figure 6) for expected milestones and products [with completion dates]:

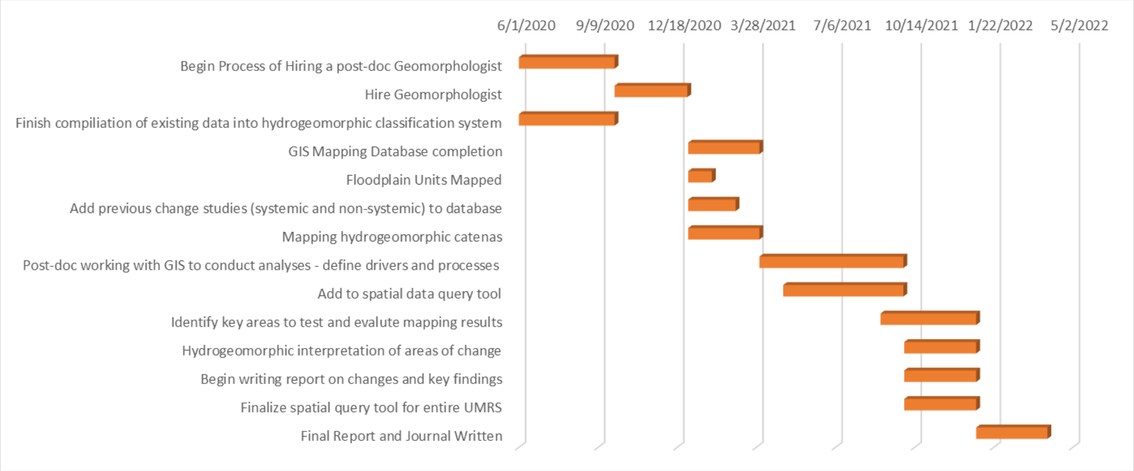


Figure 6. Timeline and project schedule for expected milestones and products.

Below is a breakdown of what products could be generated and how the information will be used.

Tracking number	Products	Staff	Completion Date
	GIS compilation of existing datasets	Strange, GIS staff	30 September 2020
	Complete annual project summary	Strange, Fitzpatrick	31 December 2020
	Conduct web meeting with core team and panelists, introduce new geomorphologist	Geomorphologist, Strange, Fitzpatrick, all attend	30 January 2021
	GIS compilation of hydrogeomorphic units and catena	Strange, Fitzpatrick, Geomorphologist, Van Appledorn	30 March 2021
	Conduct web meeting for presentation of results from hydrogeomorphic change classification interpretation, checking, testing, and application	Geomorphologist, Strange, Fitzpatrick, all attend	30 November 2021
	Complete annual project summary	Strange, Fitzpatrick	31 December 2021
	Submit draft LTRM Completion report on hydrogeomorphic change GIS database and query system	Geomorphologist, Strange, Fitzpatrick, Van Appledorn, USACE core team	31 December 2021
	Submit Final LTRM Completion report on hydrogeomorphic change GIS database and query tool.	Geomorphologist, Strange, Fitzpatrick, Van Appledorn, USACE core team	30 March 2022

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Improving our understanding of historic, contemporary, and future UMRS hydrology by improving workflows, reducing redundancies, and setting a blueprint for modelling potential future hydrology

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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). Anthropogenic factors such as land-use changes, navigational infrastructure, protective levees, and active water level management have contributed to high flow conditions outside of the historic spring flood pulse period (Yin et al., 1997; Sparks et al., 1998; Zhang and Schilling 2006; Theiling & Nestler, 2010), and in certain areas, dam operations can cause higher water levels during summer and drier conditions during the spring and fall (Sparks et al., 1998). There is also evidence that climatic changes in precipitation regimes interact with land use changes to contribute to shifts in the hydrologic regime (Zhang and Schilling 2006). Recent episodes of longer duration spring events and late season flood events (Figure 1) and increases in average annual discharges (Figure 2) raise questions about the potential for such conditions to be the "new normal," and how such conditions may influence biota and habitats of the UMRS. It remains important therefore to assess whether and to what degree the hydrologic regime has changed through time, and what potential hydrologic changes we might anticipate in the future, in order to better understand the implications for the biota and how to manage the UMRS.

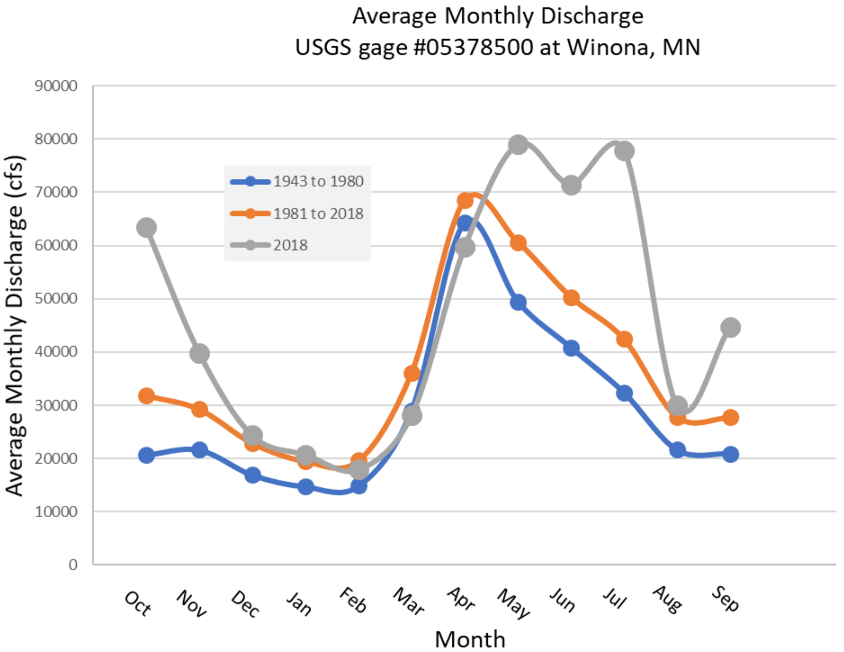

Figure 1. Patterns in average monthly discharge differ across two periods of record show an increase in values across all months in water years 1981 to 2018 (orange) compared to 1943 to 1980 (blue). The greatest increases occurred in May, June, and July. In 2018 (grey), monthly discharge was exceptionally high in May, June, and July despite having early season discharges lower than or similar to historic trends.

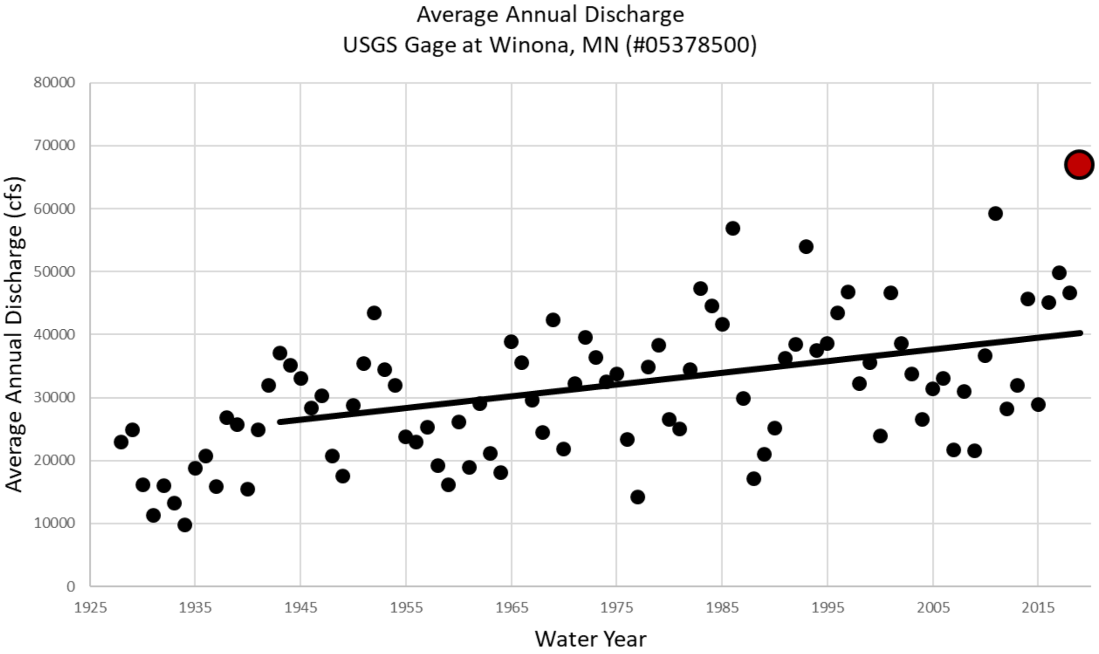

Figure 2. Average annual discharge at the USGS gage at Winona, MN increases through time. In 2019 (red point), average annual discharge was 66,880 cfs, much higher than the period from 1943 to 1980 (average of 29,000 cfs) or 1981 to 2018 (average of 36,700 cfs).

Hydrologic data are necessary for describing historical environmental conditions, contextualizing contemporary conditions, projecting future conditions, conducting scientific research on aquatic and floodplain organisms and processes, assessment of existing and future without project conditions as required for restoration projects, and many other applications. Hydrologic data are foundational to anticipating how the UMRS ecosystem might respond to any potential future changes in the hydrologic regime, and how to best manage for those potential conditions. Exploring the implications of potential changes relies on 1) models of eco-hydrologic relationships that link hydrologic data of past and contemporary regimes to datasets such as the Long Term Resource Monitoring's (LTRM) fish, water quality, and aquatic vegetation data, and 2) applying such models to hydrologic data that represent what the conditions may look like based on plausible future scenarios. A substantial body of work exists describing eco-hydrologic relationships in the river and ongoing projects further expand our understanding. For example, time series of water surface elevations and/or discharge from US Army Corps of Engineers (USACE) gaging locations are used to drive simulations of aquatic vegetation distribution (Carhart et al., *in prep*), inundation dynamics (Van Appledorn et al., *in review)*, interactions between flooding and forest succession dynamics (De Jager et al. 2019), establish eco-hydrologic relationships with LTRM monitoring datasets (e.g., Ickes et al., 2014, Houser 2016, Lund 2019), and quantify indicators of resilience throughout the UMRS (De Jager et al., 2018, Bouska et al., 2019). Models relating hydrology to successful habitat distribution are used by Habitat Restoration and Enhancement Project (HREP) teams to plan and design restoration projects. UMRS hydrologic data are also used to investigate fish passage through navigation dams (Montenero et al. 2018), Asian carp spawning (Larson et al. 2017), forest communities (Guyon and Battaglia 2018), and other topics.

USACE maintains a systemic network of gaging locations throughout the UMRS to monitor river conditions. Records of water surface elevations and discharges, among other environmental variables, are available for most active gaging locations and have been integral to UMRS research and management (e.g., Carhart et al., in prep; Van Appledorn et al., in review, De Jager et al., 2018, Bouska et al., 2019). Acquiring, cleaning, compiling, documenting, and storing hydrologic data used in ecological analyses and management activities has been and continues to be a major challenge. Hurdles include redundant efforts to obtain and clean data, little incorporation of contemporary data, poor documentation, and limited data accessibility. Over time, Upper Midwest Environmental Sciences Center (UMESC) scientists have compiled a database of daily water surface elevations from the USACE network for largely internal use; there are no compilations of discharge data. The database represents the most comprehensive data source on systematic UMRS water surface elevations and is integral to many past and current LTRM research projects, UMRR initiatives, and other research on the UMRS. However, there are limitations inherent with the database: the data have gaps, thorough documentation is lacking, access is limited, and for most gage locations in the database, data are only current through 2015. Together, these issues create substantial, additional work for any research or restoration project conducted by LTRM scientists, UMRR partners, and HREP teams that require water surface elevation data.

In addition, no hydrologic data representing potential future conditions exist. The lack of quantitative information about plausible future hydrologic regimes is a road block to addressing an important recurring question within the partnership: how are geomorphic, hydrologic, and ecological patterns and processes likely to change in the future? Lacking quantitative predictions about future hydrologic regimes hinders the ability to identify and understand their implications for the structure, function, management, and restoration of the UMRS.

There is a fundamental need, therefore, for:

1) a comprehensive, well-documented, standardized, and accessible database of USACE-derived hydrologic data for the UMRS for scientific, management, and restoration applications;
2) a concise and accessible synthesis of the observed trends describing whether the hydrologic regime has changed over the period of record, where any changes may have occurred, and the nature of the changes.; and
3) a blueprint for modeling future hydrologic regimes as a necessary first step toward generating broadly useful, quantitative output for scientific, management, and restoration applications.

The goal of this proposal is to address the need for historic, contemporary, and future hydrologic data via two related efforts. First, we aim to develop a database of historic and contemporary hydrologic data as a collaboration between the USGS and USACE, and summarize the major trends observed in that data. Second, we propose to scope a hydrologic modeling effort that would apply existing models to generate broadly useful hydrologic datasets for understanding potential future conditions. Together, the complementary efforts of developing a hydrologic database of historic and contemporary data and the scoping of a modeling effort to generate quantitative predictions of future hydrologic conditions will address a fundamental need for comprehensive, well-documented, standardized, and accessible hydrologic data for the UMRS. These efforts will allow the partnership to pursue answers to two important questions in the future:

1) Where, and in what ways, has the hydrologic regime of the UMRS changed over time?
2) What are likely future changes in UMRS hydrology, if any, given plausible climate change and land use scenarios?

Relevance of research to UMRR:
Our proposal directly relates to the theme of the 2020 UMRR Science Meeting, “identifying and understanding plausible future for the hydrology and geomorphology of the UMRS and implication regarding the structure, function, and management and restoration of the river-floodplain ecosystem,” by developing two important products. First, the comprehensive database of historic and contemporary hydrologic data will provide the needed context for interpreting future hydrologic patterns and assessing the potential implications for the biota and habitats. Second, our proposed work will generate a blueprint for modeling potential future UMRS hydrology. This proposal also directly relates to the following focal areas: FA1.1 (recent and ongoing geomorphologic changes and their implications for future conditions), FA1.2 (future discharge, hydraulic connectivity, and water surface elevation scenarios), and FA1.3 (future hydrogeomorphology scenarios and their implications).

The products developed in this proposal will be broadly useful for scientific applications in the UMRS. For example, historic and contemporary hydrologic data can be used to update existing eco-hydrologic models such as the aquatic vegetation model (Carhart et al., in prep), develop maps of contemporary flooding conditions using the UMRS surface-water inundation model (Van Appledorn et al., in review), or validate other existing models. New statistical relationships can be assessed and tested more easily with an accessible, centralized and query-able hydrologic database by LTRM scientists and UMRR partners. LTRM field station teams will be able to make custom data queries that can be post-processed and incorporated into reports and used in statistical analyses for other special projects. These types of potential applications that could stem from the work developed here are related to several focal areas, including FA2.3 (aquatic vegetation distributions), FA2.4 (main drivers of fish dynamics), FA2.5 (eutrophication and habitat conditions), FA2.6 (floodplain inundation patterns), and FA2.7 (floodplain vegetation dynamics).

This proposed work will support scientifically informed management and restoration practices in the UMRS. Eco-hydrologic relationships are directly useful for the planning and design of HREP features (i.e. floodplain forest with topographic diversity features, aquatic vegetation features, aquatic overwintering features, and mussel habitat impact assessment). In addition, generating a set of plausible future hydrologic conditions supports HREP teams in assessing future without project conditions, and provides information needed for designing resilient restoration features that perform throughout the 50-year project life.

Methods:
The overall goal of this project is to support science, management, and restoration activities in the UMRS by streamlining the process of acquiring historic and contemporary hydrologic data from USACE gages and by generating a blueprint for modeling plausible future hydrologic conditions. These efforts provide the necessary first steps to allowing the partnership to pursue answers to – and implications of –important questions about the historic, contemporary, and future hydrologic regime of the UMRS.

Q1: Where, and in what ways, has the hydrologic regime of the UMRS changed over time?
The necessary first step to answering Question 1 is to develop a comprehensive, easily accessible database of hydrologic data from USACE gaging locations throughout the UMRS. Such a database will act as a central repository, streamline the process of acquiring historic and contemporary hydrologic data for UMRR partners, and ensure consistency in data quality.

Steps to develop a database of historic and contemporary data require collaborations between USACE and USGS personnel (see Timeline below), including the following actions:

1) District Water Control Chiefs will coordinate an inventory of historic hydrologic data within each USACE district. The inventory will summarize basic information for gage locations throughout the UMRS (see Table 1 at the end of this document) such as data availability (e.g., water surface elevation data, discharge data, rating curves), gage status, and gage documentation.
2) USACE will document QA/QC methods the have been implemented for historic data within districts (mainly for pre-2004 data) and across districts (mainly post-2004 data). The documentation will be provided to USGS UMESC and will be used to understand any existing data quality issues and how to address them.
3) The USACE will develop its own .DSS database of historic water surface elevations. Upon completion, the database will be transferred to USGS UMESC scientists who will review contents for consistency.
4) The LTRM database manager will develop a web-based, front-end hosting application to allow for custom queries of the hydrologic database. The historic data received from USACE will then be made available along with documentation.
5) To keep the hydrologic database current, USGS UMESC scientists will develop and implement a semi-automated scripting process in collaboration with USACE to extract contemporary hydrologic data from the Corps Water Management System (CWMS) Database, a repository of hydrologic data that has undergone a standard QA/QC process. Extractions will take place annually and data will be integrated with existing compiled data.

The result of these steps is a central, standardized, current, and accessible database of hydrologic data and associated meta-data for the entire UMRS (see Table 1 and end of proposal). At a minimum, the database will include daily water surface elevations for all gage locations. Discharge data may also be included for the trend pools based on an assessment of data quality and consistency (Step 2 above).

A final report describing the development process for the database, query tools, database functionality, and the data and documentation itself will be written. The report will include quantitative summaries of hydrologic trends such as annual max/min/mean water surface elevations, annual hydrographs, and seasonal patterns through time. These summaries will give insights into whether the hydrologic regime has changed over the period of record, where any changes may have occurred, and the nature of the changes. In doing so, we aim to create a reference document that will give context for interpreting future hydrologic conditions or exploring potential implications for biota and habitats.

Q2: What are likely future changes in UMRS hydrology, if any, given plausible climate change and land use scenarios?
Developing a dataset of potential future hydrologic conditions for the UMRS is a substantial investment in time, personnel, and financial resources, and any hydrologic modeling efforts require advanced and thorough planning to ensure any output is broadly applicable for the partnership. To address the lack of information about potential future hydrologic conditions we propose a scoping effort rather than a full investment into hydrologic modeling. Scoping is a necessary first step because 1) modeling climate-changed hydrology at the scale of the UMRS is non-

trivial, 2) consideration of existing models is prudent and requires detailed examination, 3) any quantitative analyses need to meet different agencies' guidance requirements, and 4) discussion is required among UMRR Program partners to ensure any resulting datasets are broadly useful.

Scoping would be accomplished through a workshop involving USACE Climate Preparedness and Resilience (CPR) Community of Practice (CoP) leads, USACE climate change subject matter experts (SME), UMRS CWMS hydrologic and hydraulic modeling SMEs, USGS scientists, and UMRR Program partners. The goal of the workshop is to identify plausible scenarios (i.e., global climate model meteorological output, land use scenarios, etc.) that would guide future efforts to apply an existing hydrologic model of the UMRS watershed, likely the USACE's CWMS HEC-HMS hydrologic model, to generate potential future hydrologic conditions of the UMRS (Figure 3). These future conditions could then be routed through an existing UMRS hydraulic model (the CWMS HEC-RAS model) to produce potential future water surface profiles and stage time series at USACE gage locations that drive LTRM statistical models, aquatic vegetation models, and inundation models to make predictions about ecological responses to hydrologic change.

During the workshop, future scenarios of interest would be identified (including climate, land-use, and/or river management scenarios); existing hydrologic models (particularly the UMRS CWMS HEC-HMS model), current modeling capabilities and limitations, and best-practices would be discussed; and logistics coordinated (e.g., identification of personnel, modeling timelines, budgets). Decision points about how climate change should be represented may include discussions on appropriateness of global climate circulation models, regional climate models, emissions scenarios, and downscaling methods, and how these pieces may integrate with existing hydrologic modeling frameworks for the UMRS (Figure 3). The workshop will also account for specific needs of ecologists and HREP teams which may benefit from coupled hydrologic and hydraulic modeling of future scenarios (e.g., CWMS HEC-HMS and CWMS HEC-RAS), which may impact parameterization decisions and desired model outputs. Although no modeling work is proposed in this effort, the discussions of the workshop will be essential to ensuring that any future modeling will meet the needs of the partnership. The workshop could also help identify opportunities to leverage other sources of funding. Ideally, the workshop would be led by a trained moderator to ensure the discussion is productive and results in a clear path toward hydrologic model development.

The outcome of the workshop would be a final report that would serve as a blueprint for using an existing modeling framework to simulate potential future hydrologic conditions in the UMRS. The report would summarize decision points, key resources identified including existing UMRS hydrologic models and parameterizations, climate-change guidance among the UMRR partnership, and background information on modeling climate-changed hydrology. The report would also include a cost estimate for completing the proposed modeling for the UMRS, should the partnership undertake such an effort in the near future.

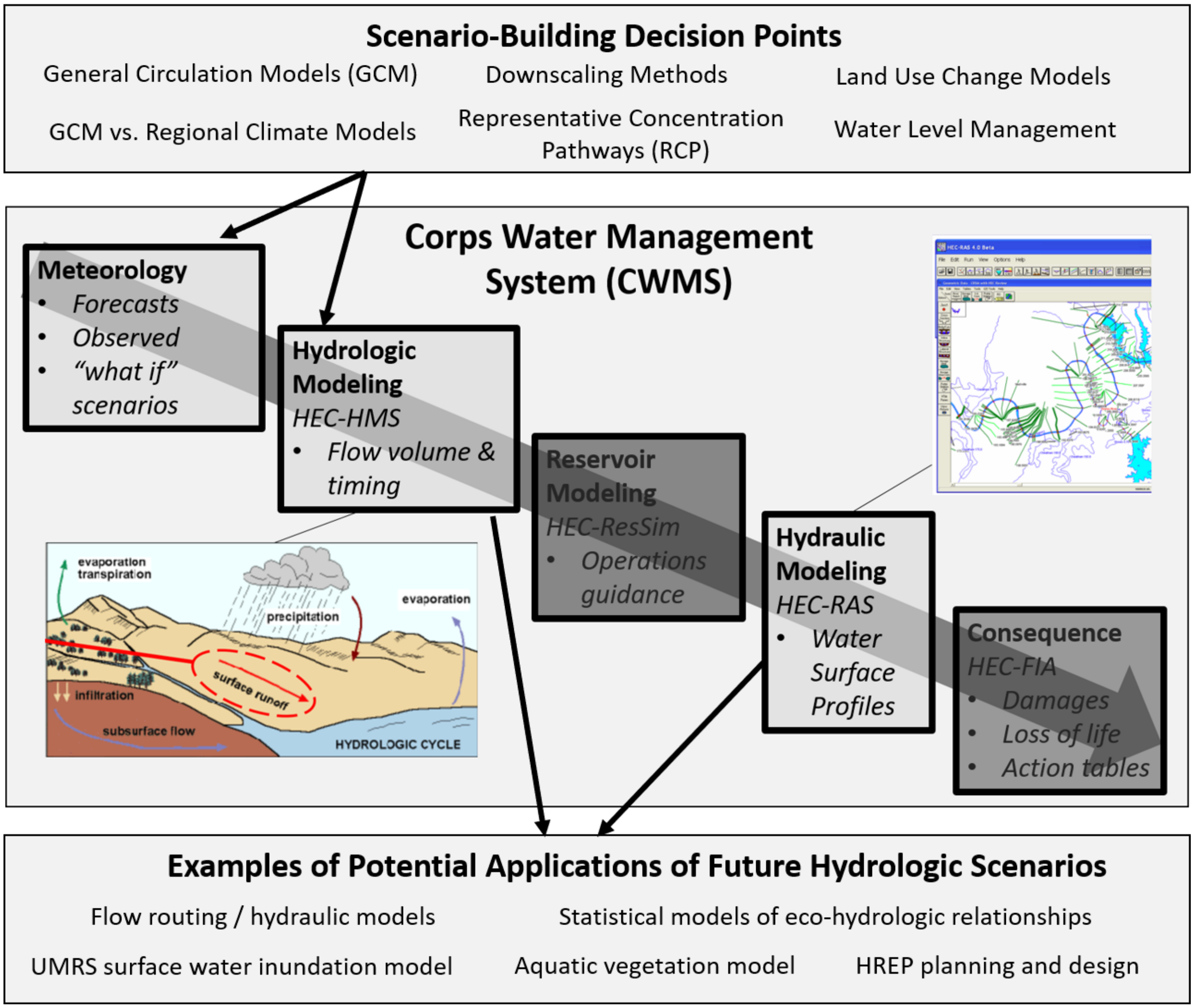

Figure 3. Conceptual map of how decisions made during the workshop (top box) will inform modeling of potential future conditions as carried out via the USACE's CWMS modeling suite (middle box), especially as they relate to intended ecological and restoration applications (bottom box). Future hydrologic and hydraulic modeling efforts will likely be performed using the CWMS models and represent a separate effort not pursued in this proposal. CWMS model components (e.g., meteorology, hydrologic model, etc.) are integrated but may be executed individually; Reservoir Modeling and Consequence inquiries are not relevant to workshop discussions or potential applications of the UMRS CWMS for this proposal. Decision points about how to best simulate climate change scenarios, and whether land use change or water level management decisions should also be simulated, will be informed by CWMS model capabilities. Outputs of modeling efforts such as annual peak flow distributions or water surface elevations (hydraulic modeling output) can be used for a range of potential scientific, management, and restoration applications.

Milestones and products:

Tracking number	Products	Staff	Completion Date
	Historic and Contemporary Hydrologic Database Release and Documentation		30 September 2021
	Draft LTRM Completion Report: document database and documentation development steps, database capabilities, and quantitative summaries of the hydrologic regime through time.		

	Final LTRM Completion Report: document database and documentation development steps, database capabilities, and quantitative summaries of the hydrologic regime through time				31 March 2022
	Developing Future Hydrologic Scenarios Workshop: 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 that utilizes best-practices in order to ensure any quantitative model output is broadly useful.				
	Draft LTRM Completion Report (Scenarios): This report will serve as the blueprint for modeling future hydrology to be undertaken with future funding opportunities.				
	Final LTRM Completion Report (Scenarios): This report will serve as the blueprint for modeling future hydrology to be undertaken with future funding opportunities.				31 March 2022

Timeline:

	FY21				FY22			
	Fall	**Winter**	**Spring**	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**
	Part 1: Historic and Contemporary Database							
USACE Water Control Chiefs Summarize Data Availability, Status, and Gage Documentation by District	X							
USACE Identify and Document Consistent QA/QC Methods across the 3 Districts	X	X						
USACE Develops .DSS database of historic water surface elevations		X	X					
USACE Data Documentation / USGS Metadata development		X	X	X				
USACE transfer historic data to USGS				X				
USACE and USGS develop script for semi-automated contemporary data acquisition	X	X						
Transfer contemporary data to USGS		X						
USGS Data & Documentation Review			X	X	X			
Front-end database development		X						
Data compilation, integration, and serving				X	X			
Report draft				X	X			
Final report					X	X		
	Part 2: Future Hydrologic Scenarios							
Develop workshop goals and agenda	X							
Generate list of potential workshop attendees & moderator	X							
Invitations and date selection		X						
Workshop			X	X				
Workshop notes distributed				X				
Workshop report draft				X	X			
Workshop final report					X	X		

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Table 1. Summary of USACE gaging locations on which efforts to compile historic and contemporary water surface elevations will focus. Estimates of the first year where recorded daily water surface elevations are available are based on previous data acquisition efforts. * indicates all or a portion of the data for the period of record were published by Montenero et al. (2018).

Gage Name	Pool	Est. First Year on Record
0002A	OR	1933
0013A	OR	2001
0020A	OR	1896
0030A	OR	1933
0039A	OR	1896
0043A	OR	1934
0046A	OR	1878
0052A	OR	1896
0066A	OR	1896
0081A	OR	1885
0094A	OR	1898
0100A	OR	1933
0109A	OR	1891
0125A	OR	1891
0136A	OR	1891
0146A	OR	2001
0158A	OR	2000
0168A	OR	1892
0176A	OR	1894
0179A	OR	1861
0185A	OR	1951
0185B	OR	1951
0190A	OR	1892
0190B	OR	1976
0196A	OR	1941
0203C	P26	1990
0218A	P26	1879
0228A	P26	1930
0250A	P25	1930
0260A	P25	1939
0265A	P25	1930
0282A	P24	1873
0293A	P24	1930
AMAW3	P5	1938
BASSI	P17	1965
BLANC	P17	1968
BRDIL	LA	1879
BRNDP	BR	1933
BRNDT	DI	1933
BRWM5	P8	1930
BURLT	P19	1917

CAMAN	P14	1938
CASSV	P11	1973
CLAI4	P10	1933
CLINT	P14	1965
DAM10P	P10	1936
DAM10T	P11	1935
DAM1P	P1	2004
DAM1T	P2	2004
DAM2P	P2	1932
DAM2T	P3	1932
DAM3P	P3	1935
DAM3T	P4	1934
DAM4P	P4	1934
DAM4T	P5	1934
DAM5AP	P5A	1934
DAM5AT	P6	1934
DAM5P	P5	1934
DAM5T	P5A	1934
DAM6P	P6	1934
DAM6T	P7	1934
DAM7P	P7	1934
DAM7T	P8	1934
DAM8P	P8	1934
DAM8T	P9	1934
DAM9P	P9	1934
DAM9T	P10	1934
DKTM5	P7	1930
DM11P	P11	1937
DM11T	P12	1935
DM12P	P12	1938
DM12T	P13	1936
DM13P	P13	1939
DM13T	P14	1939
DM14P	P14	1939
DM14T	P15	1940
DM15P	P15	1934
DM15T	P16	1879
DM16P	P16	1936
DM16T	P17	1936
DM17P	P17	1939
DM17T	P18	1932
DM18P	P18	1938
DM18T	P19	1936
DM19P	P19	2016
DM19T	P20	2000
DM20P	P20	1935
DM20T	P21	2013

DM21P	P21	1938
DM21T	P22	1936
DM22P	P22	1939
DM22T	P24	1936
DM24P	P24	1939
DM24T	P25	1939
DM25P	P25	1939
DM25T	P26	1939
DM26P	P26	1938
DM26T	OR	2004
*DRSDP	DI	1934
*DRSDT	MA	1931
DUBUQ	P12	1878
FAIRP	P16	2012
FLRNC	AL	1930
FORTM	P19	2003
GORDN	P12	1976
GREGY	P20	1931
GTNBG	P10	1999
HANBL	P22	1879
HARDN	AL	1878
HAVAN	LA	1878
HENRY	PE	1869
IML32	P16	1964
KEITH	P18	2000
KINGS	LA	2011
LACW3	P8	1937
LAGRA	P21	1960
*LAGRP	LA	1937
*LAGRT	AL	1937
LECLA	P14	1972
LIVER	LA	1929
LKCM5	P4	1936
LKPTP	LP	1974
LKPTT	BR	1976
LNSI4	P9	1938
*MARDP	MA	1933
*MARDT	SR	1935
*MARLP	MA	1933
*MARLT	SR	1933
MCGI4	P10	1936
MOLIN	P15	1951
MONTP	P16	1964
MORIS	MA	1949
MPP	P26	1990
MPT	P27	1990
MRDSA	AL	1878

MRSLS	MA	1981
MUSCT	P17	1878
OQWKA	P18	1934
PEARL	AL	1878
PEORI	PE	1942
*PEORP	PE	1936
*PEORT	LA	1936
PREW3	P3	1940
PRNCE	P14	1986
QUNCY	P21	1946
SABUL	P13	1965
SPECH	P11	1975
*SROKP	SR	1933
*SROKT	PE	1933
SSPM5	P2	1931
STPM5	P2	1930
SUNST	P16	1974
VLCTY	AL	1878
WABM5	P4	1935
WARSW	P20	1964
WNAM5	P6	1878
WUPTN	P11	1975

Understanding physical and ecological differences among side channels of the Upper Mississippi River System

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Collaborators:
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Introduction/Background:

What's the issue or question?

Physical controls on side channel function are poorly understood and a variety of drivers have the potential to impact how side channels function and how biota are distributed within and between habitats. For example, man-made structures alter connectivity and velocity within a side channel. Regional water level conditions (both regulated and natural) can also impact connectivity and enhance or reduce the effect of structures. Bathymetric variation might control the presence of large wood or emergent vegetation. At broader scales, the distributions of species and ecosystem services may depend on distribution of side channel functions. Side channels become increasingly valued in reaches that lack other substantial off-channel habitats, yet our understanding of how side channels function pales in comparison to other highly valued habitats (e.g., backwaters). In this proposal, we seek to develop a reach-scale inventory of side channel classes, improve our understanding of the physical attributes that drive ecological responses within side channels, and synthesize management implications to inform HREP planning and design.

We propose to develop a classification system for side channels in LTRM study reaches utilizing physical characteristics and biological attributes. Much of this data has already been collected either by previous focused projects (i.e., recent surveys of bathymetric change) or during LTRM standard data collection. LTRM data collection occurs in a subset of side channels within the LTRM study reaches at differing levels of effort. Physical metrics have been developed for the UMRS as part of the aquatic area classification (including estimates of connectivity); however, these were not designed to account for the complexities of side channel function and must be updated to be applicable. Additional metrics will also be created for this effort. New classification metrics would address physical attributes (e.g., connectivity and sediment conditions). Response metrics will be based on biotic data and could include fish community diversity and juvenile fish abundance. Preliminary analyses will identify specific study reaches side channel classes under-represented in our datasets. Our primary objectives are to develop a functional classification of side channels based on physical habitat attributes (e.g. connectivity, sediment stability), and investigate associations between the side channel classes and ecological responses (e.g., LTRM fish and water quality data). In addition, we propose new benthic invertebrate collections to support more robust response metrics to physical differences in side channels. Finally, management implications will be synthesized to identify classification metrics that can be altered to meet restoration objectives. Side channel classes will provide information on pre-modification conditions and help managers understand how alterations will impact channel function when planning and designing HREP projects.

What do we already know about it?

The Upper Mississippi River is a complex ecosystem managed by numerous organizations to meet the needs of a variety of stakeholders. Management ranges from the creation and restoration of different habitats within the river for fish and other wildlife to maintaining the main channel for navigation. Side channels are an important riverine feature that provide a variety of services and represent the majority of off-channel habitat in certain reaches of the Mississippi and Illinois Rivers. Off-channel habitats often provide reduced depth and velocity environments vital to a variety of organisms. Side channels in the UMRS operate as flow-through systems (lotic habitats), resemble backwaters (lentic habitats), or move between those states based on river level. Certain side channels are regulated to reduce the risk of channel capture. Side channels within an LTRM study reach have been found to differ with regard to water quality, primary productivity conditions (Sobotka and Phelps 2016, 2017), and fish communities (Barko and Herzog 2003). Side channels in other large rivers experience high rates of primary and secondary production and nutrient storage and these rates have been found to be related to connectivity metrics (Hein et al. 1999, Ginders et al. 2016). Physically-based predictive models have associated mussel presence and abundance with side channel entrances and small side channels in the northern reaches of the Upper Mississippi River (Zigler et al. 2008). Among side channels of the Lower Mississippi River, macroinvertebrate diversity has been associated with connectivity and substrate type (Harrison et al. 2017).

How will the proposed work improve our understanding of the UMRS?

Anthropogenic modifications have altered the distribution and function of off-channel habitats in the Mississippi River. In the Middle Mississippi River most off-channel areas consist of flow through side channels while in the pooled reaches low velocity backwaters dominate. As sedimentation in the upper river and channelization in the unimpounded river continue, remaining off-channel areas become of increasing importance. Much effort has gone into understanding UMRS backwaters, especially in the upper pools of the UMR however research on side channels is lacking. It is likely that side channels provide different services across LTRM study reaches and those services cannot be quantified and incorporated into our larger UMRS ecological understanding until controls on side channel functions are understood. These results will also aid in understanding how past modifications to the system impacted river functions. Certain biotic communities depend on off-channel habitat and their distribution and abundance patterns will be clarified by these results.

What are the objectives or hypotheses?

1) Develop a functional classification and inventory of UMRS side channels in LTRM study reaches based on physical attributes
2) Investigate associations between physical classification and ecological responses using existing LTRM datasets and newly collected biotic data
3) Synthesize management implications of side channel classification to inform HREP planning and design

Relevance of research to UMRR:

A functional classification of side channels currently does not exist and will provide baseline conditions for HREP planning and design and future investigations of over-all river function. Improved understanding of the associations between physical characteristics and ecological responses will allow managers to better understand how modifications to side channels will impact the biota and services associated with the channel. This information would inform HREP planning and design by providing needed information on existing conditions. Currently, several existing and potential future HREPs with side channel components lack information on existing conditions. This is needed information during the feasibility study to identify the problem, understand the future with and without project conditions, and be in compliance with environmental laws and regulations. Additionally, given an understanding of what habitat attributes drive the ecological responses, HREP designs could directly manipulate that habitat attribute through constructed project features to enhance the desired ecological response meeting the management and restoration objectives and desired future conditions.

Further, side channel metrics from this proposal could provide the backbone and documentation needed to create new Habitat Suitability Index models for side channels (future effort). Results will also provide a reach-scale inventory of side channel functional diversity, which managers can use to plan projects to increase regional functional diversity, if desired.

The research proposed addresses the following focal areas:

- **Focal area 1.1 Recent and ongoing geomorphological changes and their implications for future conditions.** Products from this project will provide biological context to hydrogeomorphic change in a side channel. Together with the proposed “Development of a GIS database with additional GIS analyses, mapping and interpretation for the Upper Mississippi River System’s hydrogeomorphic classification system” project, we will have a more informed understanding of where hydrogeomorphic change occurs and what that means for biological communities in side channels.
- **Focal area 1.3 Future hydrogeomorphology scenarios and their implications.** Associations between biological communities and side channel functions and hydrogeomorphic conditions will be products of this project. Predictions of future conditions could include analysis of how the functions of individual side channels would change given a change in their classification based off changes in hydrology. Managers could use future scenarios as components of project decision making.
- **Focal area 2.1 Assessing the associations between aquatic areas (De Jager et al. 2018) and biota and biogeochemistry using existing data.** This project will use existing level 3 aquatic area classification metrics and newly created metrics as well as existing LTRM fish community and water quality data to examine associations between physical and biotic conditions within side channels.
- **Focal Area 2.2 Better understanding the critical drivers within side channels of the UMRS in order to improve side channel management and restoration.** Products will include associations between side channel classes and ecological responses. Tying physical attributes of side channels to biotic responses will allow managers to design restoration projects to meet the specific objectives of those projects. Further, this proposal will examine the spatial distribution of existing side channels. Managers will be able to identify areas lacking side channel conditions and design projects to create or increase desired ecological responses.
- **Focal area 2.4 What are main drivers of fish abundance, distribution and community composition?** Identifying biota associated with side channel functions and habitats will help explain the local and regional distributions of those species and groups. Identifying broad-scale distribution of side channel habitat diversity will help clarify over-all biotic diversity patterns.

This proposal does encompass the Piasa Island HREP boundary in Pool 26 (in design) and would provide pre-restoration conditions and a future opportunity to evaluate how changes in physical attributes associated with restoration (e.g., depth and connectivity) influence ecological responses.

Methods:
We propose a two-tiered approach to creating a classification system for UMRS side channels, with separate budgets for each tier.

Tier 1 – Classification of side channels and association with ecological responses derived from LTRM datasets

Existing and new physical attributes of side channels will be used to develop a physical classification of side channels. Existing data will include relevant metrics summarized in the Level 3 Aquatic Areas Classification (De Jager et al. 2018) and habitat data collected during LTRM sampling. New physical metrics will be derived from recent bathymetric surveys of side channels and may include sediment roughness, presence/density of large wood, topobathymetry, and depth diversity. Additional new physical metrics will be derived to describe connectivity of side channels using existing USACE structure datasets, bathymetry, and lidar. All new datasets will be made publicly available through ScienceBase. Existing and derived physical metrics will be normalized, and a cluster analysis will be conducted to group similar side channels together. Scree plots will be used to identify the appropriate number of clusters.

Existing ecological response data will be used to evaluate ecological associations with physically-derived classes of side channels. We will rely upon LTRM fish community, macroinvertebrate, and LTRM water quality datasets to derive ecological metrics that are hypothesized to respond to changes in physical attributes (e.g., fish community diversity, juvenile fish abundance, chlorophyll α concentration). Initial exploratory analyses will be conducted to determine the distribution of data across side channels to identify potential site limitations. We propose to use multivariate methods to investigate the associations between physical classifications and ecological response metrics. We will use nonmetric multidimensional scaling (NMDS) to visualize differences in biotic community compositions and associated physical characteristics. Further, we propose to investigate associations between the physical metrics and ecological response variables using an approach such as quantile regression, random forest, or classification and regression tree to better understand how the ecological metrics respond to physical metrics. Results from Tier 1 will also include recommendations for additional sampling of side channel types found to be under-represented in the dataset. Results from all analyses will be included in final UMRR reports.

Tier 2 – Association of side channel classification with benthic macroinvertebrates

Benthic macroinvertebrate metrics are excellent indicators of habitat quality and environmental change. These organisms serve as the major food source for fish and waterfowl. Thus, we propose collection of benthic macroinvertebrate community data to improve our understanding of how physical differences in side channels influence biotic assemblages. Macroinvertebrate community metrics are frequently included in assessments of aquatic systems, including the Mississippi River (UMRBA 2014). Previous studies have reported challenges in effectively sampling macroinvertebrates in large rivers (McCain et al. 2015, Harrison et al. 2018). Therefore, we propose to evaluate the effectiveness (i.e., total macroinvertebrate abundance and richness) and recovery (number of samplers lost) of three commonly recommended gear types, the benthic sled, rock baskets, and benthic Hester-Dendy colonization samplers, during the summer of 2020 (Weigel and Dimick 2011, Harrison et al. 2018). Methods evaluation will take place in Pool 8 (Vander Vorste and student) and the Open River reach (Big Rivers and Wetlands field station staff) during the summer of 2020. Hester-Dendy samplers will be made from 8 x 3-inch Masonite hardboard, fixed to a 40-lb cinder block, attached to a surface float or nearby tree, and allowed a colonization period of 6 weeks for maximum effectiveness. Upon methods evaluation (including assessment of field staff time and effort), sampling benthic macroinvertebrates will occur between May 1 and June 15, 2021. Participating LTRM field station staff and a graduate student research assistant will collect macroinvertebrate community data from a subset of side channels (n=4) per LTRM study reach. Side channels for sampling will be selected based on locations of previously collected bathymetric and LTRM data. Three replicates will be collected from each side channel. These collections will be sorted and identified to the lowest practicable taxonomic levels at the University of Wisconsin La Crosse. Macroinvertebrate community data and physical metrics will be analyzed using Indicator Species Analysis that identifies benthic invertebrates that are indicative of certain physical characteristics. Benthic macroinvertebrate community data will be made publicly available through ScienceBase.

Timeline:

Task	Summer 2020	Fall 2020	Winter 2021	Spring 2021	Summer 2021	Fall 2021	Winter 2022	Spring 2022	Summer 2022	Fall 2022	Winter 2023	Spring 2023
Tier 1												
Dataset compilation and processing	■	■										
Data analysis			■	■	■							

Manuscript and report writing						🟦	🟦	🟦	🟦	🟦		
Tier 2												
Invertebrate gear evaluation	🟦	🟦	🟦	🟦	🟦							
Invertebrate sample collection				🟦	🟦							
Invertebrate identification						🟦	🟦	🟦				
Data analysis								🟦	🟦	🟦	🟦	🟦
Thesis and manuscript writing								🟦	🟦	🟦	🟦	🟦

Milestones and products:

Tracking number	Products	Staff	Completion Date
	Annual progress summary: data collection and processing, preliminary analyses, and initial methods evaluation		30 December 2020
	Annual progress summary on side channel classification scheme, recommendations for additional sampling, analyses of side channel classes and ecological associations		30 December 2021

Dec. 30, 2020 – Annual progress summary addressing data collection and processing, preliminary analyses, and initial methods evaluation will be submitted.

Dec. 30, 2021 –Annual progress summary on side channel classification scheme, recommendations for additional sampling, analyses of side channel classes and ecological associations will be submitted. Physical metric data sets will be submitted for internal USGS review.

Sept. 30, 2022 – Final manuscript addressing classification scheme and ecological responses will be submitted for peer review. Final UMRR Report on management implications will be submitted. Results will be included in the next HREP Design Handbook Update.

May 30, 2023 – Final manuscript addressing benthic invertebrate associations with side channel physical characteristics will be submitted for peer review. Benthic invertebrate dataset will be submitted for internal USGS review.

In addition to written documents, we expect several presentations resulting from this project to be shared at regional and national professional conferences.

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Refining our Upper Mississippi River's ecosystem states framework

PRINCIPAL INVESTIGATOR:

Dr. Danelle Larson, U.S. Geological Survey, UMESC
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Danelle will be responsible for: project management (budgeting, contracts, data management plan, progress and completion reports); leading response-driver analyses and state-and-transitional modeling; writing at least 2 manuscripts and 1 technical report; and publishing online data products. She has expertise in aquatic vegetation and management, as well as ecological state theory and applications.

COLLABORATORS:

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Alicia will help with the conceptualization and study design of Objectives 1 and 2; assist with dataset compilation; assist with data interpretation and publications.

Dr. Wako Bungula, University of Wisconsin- La Crosse, Mathematics Department
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Wako will mentor an undergraduate student using topological data analysis to address Objective 1 and 2; write manuscript and present on topological data analysis results.

Mr. Jason Rohweder, U.S. Geological Survey, UMESC
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Jason will help conceptualize the study design for Objectives 1 and 2; gather and integrate the datasets for Objectives 1 and 2; conduct spatial mapping in Objective 2; assist with data management.

Dr. John Delaney, U.S. Geological Survey, UMESC
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John will lead Objective 3-vulnerability assessments and the associated products listed below. John is currently leading a climate change vulnerability assessment for the Upper Mississippi River Watershed.

INTRODUCTION/BACKGROUND:

What's the issue? What do we already know? How will this work improve our understanding of the UMRS?

A Programmatic goal is to ensure all desired ecosystem states are preserved and functioning across the riverscape and that restoration supports a resilient ecosystem. [5] The UMRS' *ecosystem states* (i.e. the set of biological and physiochemical characteristics, processes, and interactions) are not well quantified or mapped, but necessary [6]. An ecosystem states approach has been employed for over a century in many types of ecosystems under various names such as phytosociology, alternative community states, and ecological regimes and regime shifts. Restoration practitioners and river managers need an ecosystem state-and-transition modeling (STM) framework to promote multiple species, habitats, and vegetation diversity and redundancy[2,4–6].

Two distinct ecological states for the UMRS have been conceptualized and broadly demonstrated using a state-and-transition model [1,7–9]: the "clear water state" and the "turbid state." [10] The upper pools have experienced large-scale shifts from turbid to clear water in the 2000's, but it's unclear whether this change happened systemically by a principal driver, or, whether there remain eutrophic areas at smaller scales to focus our restoration and management. We also need more information about how to transition turbid reaches (pools 10 and below) to a clear-water state. The scientific and management communities plea for applying an ecosystem states framework in rivers worldwide, while acknowledging most rivers do not have sufficient data to properly evaluate [2,11,12].This proposal will use the wealth of UMRS data to identify the criteria to classify all ecosystem states and their drivers of change at multiple spatial and temporal scales.

State and transition models (STM) are effective tools for organizing and communicating ecosystem states, state transitions, and employing adaptive restoration and management.[13,14] Vegetation (abundance or species composition) and chlorophyll *a* are the primary state variables. The STM incorporates expert knowledge, stakeholder feedback, historical references, and data into a synthetic framework for shared understanding and restoration guidance. The STM first describes the vegetation that can occur at a site, and then identifies causes of state stability and transitions (including succession, disturbance, or management). An ecosystem state can display "*transient dynamics/transitions,*" [15] which are significant but temporary changes in vegetation that is reversible or naturally in flux. "*State transitions*" (also called "regime shifts") are dramatic changes in ecosystem state that are irreversible, have unacceptably long recovery times, or require significant restoration action and resources. *Drivers* are variables that cause change, and identifying the drivers is key to preventing or inducing state changes (e.g., preventing “clear-water to turbid” state shifts, or, expanding wild celery beds). Identifying driver-response relationships (Fig. 1) will inform how a state is *resistant* to changing environmental conditions, how *resilient* a state may be after a severe disturbance, and, assess *vulnerability* of state transitions. The STM will integrate information on the states, transitions (both transient and long-term), drivers, and remaining uncertainties. The STM can be an excellent framework for implementing structured decision making[14] because restoration decisions are guided by science and become more transparent when the model is used as a communication tool. Further, the STM can lead to a framework for adaptive monitoring and management[16,17]. The STM model allows “learning by doing” restorations because the model can be updated with new information, and this information can alter restoration decisions and techniques based upon the STM.

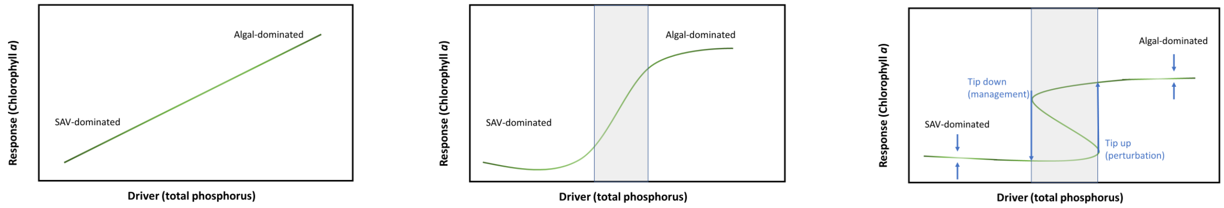

Fig. 1: Three examples of driver-response relationships. The ecosystem states are algal-dominated (high chlorophyll a) and SAV-dominated (high vegetation prevalence). The state variable is chlorophyll *a* (or conversely, SAV), and the driver is total P concentration. Each curve shows different responses to nutrient loading and provides management guidance. Panel (a) is a linear response and implies that management simply needs to reduce any amount of total P to see a decrease in chlorophyll *a*. Alternative states can exist with linear relationships, but different states and endpoints falls along a gradient. Panel (b) is a non-linear and threshold response and informs managers they must cross a threshold concentration of total P to reduce chlorophyll *a* and enter a SAV-dominated state. Panel (c) is a hysteresis-type response that suggests complexity for management intervention because alternative stable states exist. Recent hypotheses state panel (c) may occur in the UMRS [2], although panels (a) and (b) are also feasible. To best manage and restore ecosystem states, it is imperative we understand driver-response relationships and constraints.

We will build off the UMRS’ current STM, but our new STM will be refined with further information and explicitly consider vegetation species composition[18] to align with our restoration goals, like increasing wild celery or vegetation diversity[4,5]. When using a community composition approach with state theory[18], ecosystems can have 2–5+ states. Previous HREP evaluations suggest that we can restore aquatic vegetation communities [19,20], but predictable outcomes will require advanced knowledge. The UMRS’ vegetation communities change at various scales in space and time [2,19,21–23]; however, we generally don’t understand the conditions that define, create, maintain, or transition these states [7,8,24,25]. We also do not recognize which vegetation community changes are transient dynamics versus state transitions, but desire this distinction for restoration[6].

The goal of this proposal is to build off the UMRS’ existing STM of the “clear water” state and “turbid state.” Our advanced STM will identify all the UMRS’ ecosystem states that considers vegetation community composition, within-state transient dynamics, and potential causes for transitions. We will analyze LTRM and other riverine datasets using multiple techniques, as well as obtain expert knowledge from the scientific literature and during a UMRS workshop. We will synthesize all these sources of information into a STM, which will greatly improve our understanding of ecosystem states, restoration, management, and knowledge gaps.

What are the objectives, hypotheses, and associated focal areas (FA)?

The overarching goal of this proposal is to: **Create a state-and-transition model that synthesizes information about all the UMRS’ states, causes of transitions, and management implications. ** These four objectives will be the foundation of the STM:

(1) What are the various ecosystem states [including vegetation communities]? (FA 2.3 and FA 2.5)

(2) Where are the states in the UMRS and how do they vary with spatial scale (e.g., aquatic area, strata, pool, and reach)? (FA 2.1, 2.3, 2.5)?

(3) How often do the states change? What are the main drivers of transitions? What is the evidence for transient dynamics versus major regime shifts, and at what scales should those be defined? (FA 2.1, 2.3, 2.5)?

(4) Are some river reaches and backwaters more vulnerable to state transitions, or, "low-hanging fruit" for management? For example, where would a small, low cost reduction in water level maintain or expand submersed aquatic vegetation and prevent a turbid state?

Hypotheses:

We expect that distinct ecological states that can be defined by aquatic vegetation communities that are associated with specific sets of environmental covariates. There may be at least 6 distinct ecosystem states in the UMRS: (1) "clear-water" and SAV-dominated (SAV prevalence but species not considered); (2) "turbid" and algal dominated (water quality conditions prevent SAV); (3) "brown" state, where sediments hinder both SAV and chlorophyll *a*; (4) lotic-SAV dominated (wild celery); (5) lentic-SAV dominated (coontail); and (6) high vegetation diversity. We acknowledge there may be other unique states not yet known (e.g. like SAV and emergent mixed stands) and will allow the data analyses to reveal those. We suspect these states will be found throughout the UMRR, but the upper pools will exhibit a greater number and diversity of states.

State transitions can occur and be detected through LTRM at three major spatial scales: the aquatic areas scale (i.e., large, individual backwaters), strata, and pool. The states that are fluctuating frequently with seasonal water levels are transient dynamics (e.g. SAV→turbid→SAV). The states that change but do not reverse after the triggering event is likely a regime shift (e.g. SAV→turbid). We suspect that Pools 4, 8, and 13 all experienced a state transition (submergent plants <50% frequency of occurrence → submergent plants >50-95% occurrence) around year 2004 and the vegetated state is now stable (except Pool 13 may be questionable). Additionally, we hypothesize that Upper Pool 4 experienced a state transition from low vegetation species richness to high species richness around years 2008-2010. We expect that pools 13-19 are the most vulnerable to aquatic vegetation loss and state transition (pers. Comm. with partners), but it also may have the most restoration potential, as well. We provide additional testable hypothesizes in figures here:

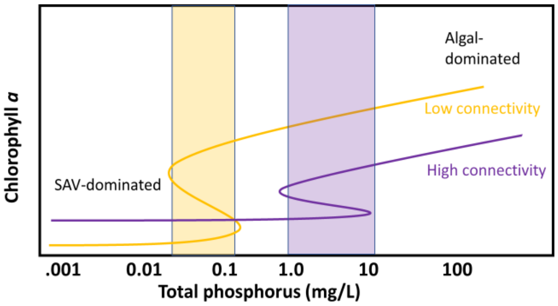

Fig. 2: We predict that the thresholds (yellow or violet bands) for state change depends on the interaction of nutrients and connectivity (measured as the "%_channel" metric[26]). Specifically, less connected backwaters are more susceptible to increased total P that causes an algal-dominated state transition. At higher total phosphorus concentrations and connectivity, algae cannot overtake established SAV due to flushing with connectivity to the mainstem.

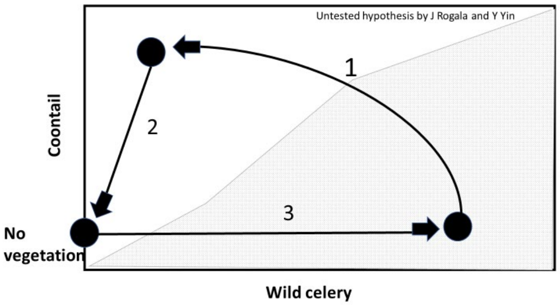

Fig. 3: Recently three ecological communities were suggested in the UMRS (black nodes: coontail, wild celery, or no vegetation[21]). Are these state transitions (long-term changes) or simple transient dynamics, and how does that influence restoration decisions? These states may transition by way of hypothesized drivers (arrows 1, 2, and 3; transitions remain untested). If wild celery dominates, transition 1 suggests that low flows can allow filamentous algae, duckweeds, and eventually coontail to displace celery, and the celery population crashes. In the coontail state, arrow 2 suggests flood scours quickly transition to an unvegetated state. In the no vegetation state, transition 3 would occur when normal to higher flows allow wild celery to recolonize, but celery establishment can take more than *8-10 years*. We will evaluate if these state transitions occur, how often and where, and estimate the thresholds to expect change (e.g., quantitatively define "low and high flows" and thresholds for scouring of vegetation). This information can help managers anticipate state transition with hydrological predictions, intervene with water level manipulation, or manage transition pathway 3 to reduce the number of years to reestablish desirable wild celery.

RELEVANCE OF RESEARCH TO UMRR:

How does this work inform river restoration and management? How will the proposed work contribute tothe selection or design of HREPs?

We need to identify the ecosystem states within the UMRR to help set realistic restoration goals (See Fig. 4, step 1), recognize the constraints to overcome (step 2) and use this information to prioritize constraints and HREPs (step 3). Collectively, our STM will address steps 1-3*.* Then, our continued LTRM vegetation monitoring and future research can evaluate actions that produce or inhibit state transitions (step 5). Our STM, in conjunction with long-term monitoring and/or adaptive management, will provide feedback to guide managers to maintain the desired state (step 6) or redefine feasible restoration goals (step 1).

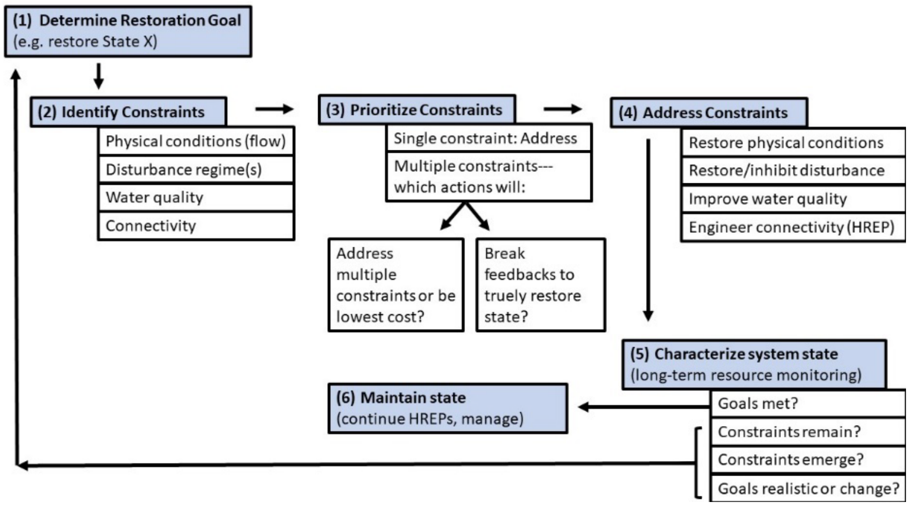

Fig. 4. Our STM will help to identify and prioritze constraints to reach restoration goals (steps 1-3). The STM will connect directly to HREP selection and adaptive management (steps 4-6) [27].

Describe how the research addresses one or more of the 2020 Focal Areas: This work encompasses three focal areas (2.1, 2.3, and 2.5). Our proposal will effectively cover >50% of the research questions outlined in FA 2.3.

If work involves an HREP, name it: The Lower Pool 13 HREP; Peterson Lake in Pool 4 (see details in Methods).

METHODS:

To achieve the 4 objectives and create an advanced STM, we will propose several different techniques that provides unique information.

(1) *Define the major states* and vegetation communities using non-metric multidimensional scaling (NMDS).
(2) *Map the states and changes* using the NMDS scores and a curve-fit approach[21,28] on the LTRM time series. We will map states at several spatial and temporal scales. This will delineate where community changes occur along the river continuum and how frequently (e.g., annual vs. decadal time steps) to help differentiate transient dynamics and state transitions. State maps can help prioritize HREP's.
(3) *Reveal distinct criteria for classifying the states* by conducting Topological Data Analysis (TDA; Fig 5).
(4) *Detect state transitions at the pool-scale* using TDA on our LTRM time series. TDA will test hypotheses that vegetation diversity abruptly arose in certain pools and time periods.
(5) *Seek drivers of transition* by graphing driver-response curves (examples in Fig. 1 and 2).
(6) *Obtain expert opinion* regarding states, transitions, and vulnerabilities during a UMRR Workshop.
(7) *Create vulnerability maps and tools* that assess where and when ecosystem states are vulnerable to undesirable changes (e.g., vegetation "crash"). Provide tools that allow users to change drivers of transition (e.g., connectivity, water quality, flow) in order to guide HREP selection and management.
(8) *Synthesize information in methods 1-7 into a STM graphic and narrative.* The STM will include the states, transient dynamics, drivers of state transitions, and remaining uncertainties. The STM is a framework for communication, prioritizing restoration, future experiments, and adaptive management.
(9) *Solicit stakeholder feedback* on the STM and improve as needed before releasing publicly.

Detailed methodology for each step is provided below.

Study area:

We will incorporate information from the entire UMRR (pools 1-26 and the Illinois River) and the LTRM's 22+ years of water quality and aquatic vegetation data. To address the dichotomy of vegetation/clear-water and unvegetated/turbid states, we will use the vegetation presence/absence data collected during summer at all six LTRM water quality stations. We will also supplement with the UMRCC vegetation presence/absence data from the "out-pools" to better understand the pools hypothesized to be in a state of flux and highest potential for rehabilitation (Pools 11-19; pers. comm. with partners). We will use the LTRM aquatic vegetation community data from Pools 4, 8, and 13 to evaluate the states characterized by vegetation assemblages.

Objectives 1, 2, and 3 approaches– identifying the ecosystem states and state transitions:

First, we will integrate all necessary data. The main state variables of interest (aquatic vegetation and chlorophyll *a*) are found across two LTRM datasets. In addition, hypothesized drivers and characteristics of these states are found in at least 5 disparate datasets: LTRM vegetation and water quality, aquatic area metrics, velocity, wind fetch, and discharge. Using ArcGIS, we will summarize the hypothesized drivers (i.e. water clarity, total phosphorus, connectivity, discharge) at the aquatic area scale[26] for each year (total of 22 years).

Next, we will determine the main ecosystem states using LTRM data following the general procedure in Carhart and De Jager 2019 that used NMDS to identify lotic and lentic SAV communities. Here, the NMDS will also include a variety of vegetation life forms (SAV, floating rooted, metaphyton, emergents, and chlorophyll *a*) and hypothesized drivers.

We will map the states and state transitions using the interpolated NMDS scores and a curve-fit[28] from years 1998–2019. Curve fit will be done at multiple time scales (i.e. annual, 5-year, 10+ years) in order to differentiate between transient dynamics and regime shifts. We will use these maps to identify hotspots of specific states and how the patterns vary with scale. We will then quantify and map where the specific states are stable (i.e., high resistance), where they are frequently changing and had reversible change (i.e. high resistance) or have undergone a significant state shift (i.e, low resistance and resilience). In addition, we will examine whether a few previous and ongoing HREP case studies produced desired states by altering water levels or reducing mainstem connectivity through time (e.g., Peterson Lake in Pool 4, Lower Pool 13).

Topological Data Analysis (TDA) will further help visualize ecosystem states and transitions, as well as define the classifying criteria of each state. TDA will include a spatial component to seek differences in strata and pools and sometimes performs better than NMDS. The use of TDA for ecological data is novel and promising (Fig. 5). We will allow the ecological data to determine the distinct criteria that define the states using the TDA Mapper tool. The TDA Mapper is an algorithm that uses dimension reduction [29–31] and makes a network diagram with nodes and connections. The nodes represent sample sites of state similarity and provides information on how the state was defined; for example, a node may be classified as the "clear water state" and contain specific criteria for inclusion such as >60% submersed aquatic vegetation prevalence, <15 mg/L total suspended solids, and <15 ug/L chlorophyll *a*. We will compare the TDA Mapper diagrams to describe commonalities and differences of ecological states and criteria among pools and strata. Another TDA tool called "Persistence Homology" will use the 22-year time series to detect change points and reveal past regime shifts [32] that we hypothesized above.

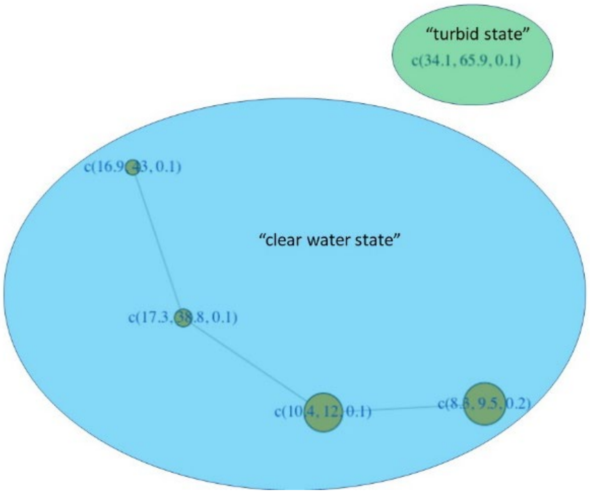

Fig. 5. Example of TDA Mapper output for pool 8 in summer 2011 using LTRM water quality data. TDA Mapper revealed two ecosystem states: a "clear water state" and a "turbid state." Each node is a collection of sampling sites with strong similarity based on the three input variables: total suspended solids, chlorophyll *a*, and total phosphorus. The size of the nodes corresponds to the relative number of sampling sites, and labels on the nodes describe the average values for each variable (sediment, chlorophyll, total phosphorus). Within the "clear water state", the connecting lines between the nodes reveals transient dynamics or expected variability within the state. The states were principally differentiated by two variables: suspended sediments and chlorophyll *a,* but not total phosphorus. The clear water state had low sediment concentrations (8-17 mg/L) and chlorophyll *a* (typically <12 ug/L but ranged 9-43ug/L). In the turbid state, suspended solids were moderately high (34 ug/L), and chlorophyll *a* was high (mean: 66 ug/L). The clear water state dominated in Pool 8, but a few sites were in the turbid state. Future TDA's will include other hypothesized variables to further refine the states, vegetation community composition, and, examine trends across space and time.

We will also examine driver-response relationships (e.g., Fig. 1 and 2) to understand drivers and thresholds of transition [13,33]. Although this information seems rudimentary, the river's ecosystem states and drivers are not yet well defined using LTRM's rich datasets. We will fit several competing models to the data to reveal the type and dominate response-driver relationships (Fig. 1, 2, and 3). We will generate many graphics like that in Fig. 2 to explore relationships and then use Akaike's Information Criterion to test which type of response curve fits the data best. The more complex responses like hysteresis will require use of differential equations. Correlation is not always causation, so we will also use good judgement to determine drivers and may recommend future experimental research in the river or UMESC's mesocosms for increased certainty.

Objective 4 approach– vulnerability assessment:

We will produce a comprehensive vulnerability assessment that uses data and expert opinions to understand which backwaters, strata, and pools are stable versus highly susceptible to undesirable state shifts. The undesirable state shifts can include: vegetated → unvegetated, wild celery → coontail, or high vegetation diversity → low diversity. We will host a 2-day workshop to gather expert opinion to develop a robust vulnerability model that is tailored to management needs. The workshop attendees will be selected to provide diverse perspectives and knowledge regarding the river's aquatic vegetation resources, threats, and management objectives. We will list and rank what are the greatest *exposures* to the established aquatic vegetation (i.e. the factors that influence state transitions or vegetation "crash"); list and rank how *sensitive* the aquatic vegetation is to each exposure (using our driver-response data and expert opinion); and list and rank the *adaptive capacity* (resiliency) of the vegetation to such exposures and discuss methods to increase adaptive capacity. Synthesized information based on literature, Mississippi River data, and expert opinion revealed during the workshop will feed a vulnerability model, where: *Vulnerability = (Exposure*sensitivity) – adaptive capacity*[34]

Our vulnerability results will be mapped to identify vulnerability hotspots, prioritize areas for restoration, and develop management strategies. We will also create an interactive, online vulnerability assessment tool. At the workshop, we'll have a tutorial and case study example to show participants the tool's capabilities so they can help us design a meaningful tool to plan HREP's and management actions. The tool will allow the user to alter potential impacts and adaptive capacities (e.g., hydrologic variables, backwater connectivity, vegetation biomass) to assess how to increase resiliency and prioritize actions.

State-and-Transition Model--- Synthesis of Results:

The highlights from previous UMRR work and discoveries from this proposal will be integrated and synthesized into a classic state-and-transition model.[14] The model will be provided as a visual graphic, like box and arrow diagrams, to show the UMRR's ecological states, transition pathways, and feedbacks. It will contain descriptions of the criteria for each state; differentiate transient dynamics/natural vegetation flux from ecosystem state transitions; describe the triggers, drivers, and response type to drivers (e.g., linear, threshold, or hysteresis) for state transitions; and reveal our remaining knowledge gaps. We will provide basic restoration guidelines for altering ecosystem states, increasing resiliency, and reducing vulnerability.

Beyond this proposal's timeframe, Larson will continually update the model using new data and stakeholder participation for shared understanding and grow the STM's utility for restoration. The STM can become a platform for structured decision making and/or adaptive monitoring and management if the partnership chooses to adopt these approaches.

Data availability: We will create a Data Management Plan that will undergo review before the data collection process, and our data products will go through an additional review before data is released. The Data Management Plan will comply with the USGS' procedures APP045.3 and APP048.0. Our manipulated data files and analyses script will be shared via ScienceBase and the LTRM website for accessibility and repeatability.

SPECIAL NEEDS: None but thank you.

BUDGET: Budget spreadsheet attached.

TIMELINE & EXPECTED MILESTONES: We will begin the project in October 2020, submit all products for internal review by September 2022, and finish a project completion report by September 2022.

Task	**Completion Date**	**Task Leads**
Data integration (gather datasets, integrate)	December 2020	Rohweder (All assist)
Identify states and transitions using NMDS approach	March 2021	Larson, Carhart
Driver-response curves	May 2021	Larson
Workshop: vulnerability assessment	May 2021	Larson, Delaney
Mentor student intern	August 2021	Bungula, Larson

Annual reporting and data management update	September 2021, 2022	Larson
Vulnerability maps	December 2021	Delaney
Spatial mapping of states and changes	December 2021	Rohweder (Carhart trains)
Vulnerability assessment tool	March 2022	Delaney
TDA Mapper, regime shifts	May 2022	Bungula, student, Larson
Draft the STM, share with stakeholders	September 2022	Larson
Technical report, vulnerability assessment tool, and manuscripts to IDPS for internal review	September 2022	All

PRODUCTS & COMPLETION DATES:

*All our products listed will first be sent to the LTRM Science Director, and then undergo a data and report review following the USGS' IDPS process. All data will be preserved and publicly available through ScienceBase and the LTRM website.

- **Maps** of the ecological states in space and time that vary in scales of interest. Select maps will be posted on the LTRM website to complement the existing "surface maps" that currently highlight places of no vegetation and vegetation. (fulfills Objective 1,2,3; completed December 2021; lead: Rohweder and others)
- **Report** on the topological data analysis outputs. This will be one of the first papers using TDA Mapper in an ecological setting, and the first paper to define multiple ecological states along a river continuum. (fulfills Objective 1,3; completed September 2022; lead: Bungula and Larson)
- **Report** on the principal drivers and the response types of key aquatic vegetation species and communities. (fulfills Objective 1,3; completed August 2021; lead: Larson and others)
- **A 2-day workshop** to review the report on driver-response relationships, and discuss expert opinion on potential impacts, sensitivity, and adaptive capacity of aquatic vegetation communities in the UMRS. This will feed the vulnerability tools and STM. The facilitator will provide a **summary report**. (fulfills Objectives 3 and 4; completed May 2021; Leads: Delaney and Larson)
- **Vulnerability maps and online assessment tool** will allow managers to manipulate the drivers of change (e.g., connectivity, sediment loads) to help determine and prioritize restoration location and action. (fulfills Objective 4; completed March 2022; lead: Delaney)
- **Publication** of aquatic vegetation vulnerability in the UMRS. This will be the first scientific inquiry into the vulnerability of aquatic vegetation (fulfills Objective 4; completed March 2022; leads: Delaney and Larson)
- **Publication** on the major ecological states and their changes across the UMRR in the past 20 years. State-and-transition modeling will describe the states and transition pathways and identify where the current knowledge gaps remain. (fulfills Objective 1,2,3; draft completed September 2022; lead: Larson)

APPENDIX 1. REFERENCED LITERATURE:

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Augmenting the UMRR fish vital rates project with greater species representation for genetics and otolith microchemistry

Principal Investigators:

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The principal investigators will coordinate and manage the project, communicating amongst the collaborators and reporting to the UMRR program, as appropriate. Duties include writing and editing the proposal, overseeing data collection, chain of custody, and transfer of samples, ensuring QA/QC procedures are followed, and assisting with data analysis, interpretation, and reporting. The PI's may be included as authors on manuscripts.

Collaborators:

Kristen Bouska, USGS UMESC, kbouska@usgs.gov, will participate in planning, analysis, and reporting results of this component of the vital rates project as it relates to previously funded portions of the project.

Dr. Mark Davis (INHS, davis63@illinois.edu), Dr. Milton Tan (INHS, miltont@illinois.edu), Postdoctoral Research Associate, and PhD student – oversee project components, conduct data analyses, write manuscripts

Dr. Greg Whitledge (SIU, gwhit@siu.edu) and PhD student – oversee project components, conduct data analyses, write manuscripts

Dr. Quinton Phelps (MSU, quintonphelps@missouristate.edu) and grad students – sample processing/curation

The following LTRM field station staff will collect and store fish specimens for the project:

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Introduction/Background:

One goal of the Upper Mississippi River Restoration (UMRR) program is to understand fish community attributes and trends, as well as the factors influencing these attributes. Catch data provide an essential backbone from which long-term trends and spatial patterns in community and population structure can be evaluated. However, interpretation of catch data is often limited by stochasticity and lag effects; limiting the spatiotemporal scales at which inferences may be drawn. Fish vital rate (VR) information can be applied to specific years, providing a more linkable and specific response to environmental disturbances or patterns. If the extent of intermixing between and among fish populations can be determined, the utility of VR data to explain fish population responses to habitat availability and disturbance can be strengthened. Thus, genetic structure and diversity of fish populations, as well as natal origins and movement patterns of the fish species of interest provide a more complete understanding of how a given fish population interacts with environmental cues and habitats over its lifetime and in a dynamic riverscape. Combining basic catch data with vital rate, population genomic, and otolith microchemistry data provide a rare opportunity to explore fish populations with great clarity and ecological understanding.

Previously, the UMRR funded a fisheries project to evaluate vital rates and otolith microchemistry on 6 species commonly found throughout the UMRS, as well as vital rates on 7 additional regionally abundant species. That project was expanded to include a genetic component for the 6 systemic species. Those two combined projects will illuminate relationships between fish life history strategies and the complex mosaic of habitats available to them throughout the UMR ecosystem. Preliminary genetics results support our initial hypotheses of varied genetic structure seemingly associated with life history traits. Bluegills from Pools 4, 8, and 13, were genetically distinct from those sampled in pool 26, the Open River reach, and the La Grange pool. In contrast, Channel Catfish were genetically similar from all reaches. Genetic structure was evident for Bullhead Minnow, as well.

This proposal expands the project to include both genetics and otolith microchemistry for 6 of the regionally abundant species, and adds one more systemic species group, Mimic/Channel Shiner, whose taxonomy remains uncertain, and whose life history strategy (opportunistic spawner) has been under-represented in the previous iterations of the project. In addition, previously collected samples from Pools 19 and 20 are available for eight of the selected species and will also be added to the project. Samples from these pools will augment understanding the role LD19 (upstream passage restricted to lock chamber) has in structuring fish communities in the UMR. This region may also be a critical transition zone for the Mimic/Channel Shiner complex and help aid in their taxonomic resolution.

These three subprojects under the larger umbrella of "vital rates" are thus, additive, and complementary. Taken individually, each has merit, but collectively, they will provide a robust framework within which numerous questions can be answered for individual species, as well as for the life history strategies they encompass. Patterns, based upon life history strategy, of genetic structure and diversity, natal origin and movement, and growth/ recruitment/ mortality should predictably occur within and among LTRM study reaches in correspondence with their habitat characteristics and location within the floodplain.

Relevance of research to UMRR:

This proposed subproject to the Fish Vital Rates project can broadly assist with answering many of the questions under UMRR Science Planning Focal Area 2.4, but specifically will inform several areas:

2.4.5 – "How do habitat connectivity and heterogeneity contribute to resource availability, recruitment dynamics and accessibility of refugia for fish assemblages?" We hypothesize that reaches with greater habitat heterogeneity should display less intermixing of lentic fish populations because they provide a more complete suite of characteristics to meet the needs of fishes at various lie history stages. Again, diversity of natal origins, patterns in locational history, and genetic structure, diversity, and effective population sizes are measures of these responses.

2.4.6 – "How do the physical template and disturbance regime structure fish communities via life-history strategies?" We expect that reaches with volatile disturbance patterns or simple physical templates should favor opportunistic spawning fishes and constrain equilibrium strategists, whereas, equilibrium spawning fishes would be favored in reaches with lower disturbance and greater complexity of habitats over periodic and opportunistic strategists. Vital rates have better potential to explain fish responses to habitat and hydrological variables than catch rates because VR are immediate and uninfluenced by gear efficiency and bias. This is particularly true if species within life history guilds display similar patterns. Genetic structure and otolith microchemistry help determine appropriate spatial scales for assessments by defining population boundaries and spatial extent of habitat utilization.

Research Questions:

- Are UMR fish populations spatially (genetically) isolated?
- Are UMR fish populations produced locally or from distant sources?
- Do UMR fish populations appear to be produced within the mainstem or in tributaries?
- Are there source locations or reaches that are important for production of multiple UMR fish species, or, conversely, are there locations or reaches of poor habitat quality that act as sinks for multiple UMR fish species?
- Are there indicators of adaptive differentiation across fish populations in the UMR that are related to patterns in habitat (quality or quantity)?
- Do fishes of differing life history strategy exhibit expected spatial patterns of adaptive differentiation?
- Can UMR Mimic and Channel Shiner be differentiated into distinct species? If so, where are each located in the UMR, are they intermixed, and do they hybridize?
- Does the high head dam separating Pools 19 and 20 (LD19) act as a barrier to upstream gene flow and contribute to genetic structure among certain fish species in the UMR?

We argue that due to the complexity in life history strategies, habitat requirements, and behaviors of UMR fishes, the addition of the selected species will facilitate an improved understanding of the nuances between similar species that have slightly different life histories and ecological preferences. In turn, this will inform the degree to which guild approaches may be applicable in assessing the fish community, relating fish community attributes to other environmental variables, and planning for habitat restoration projects.

Figure 1 depicts three life history attributes and the guild strategies (described below) on different axes, with the UMR fish community assemblage arrayed on them. The graphic shows how the UMR fish community exhibits a complex gradient of traits, and that the selected species will augment the guilds by both contrasting and complimenting those species already under evaluation.

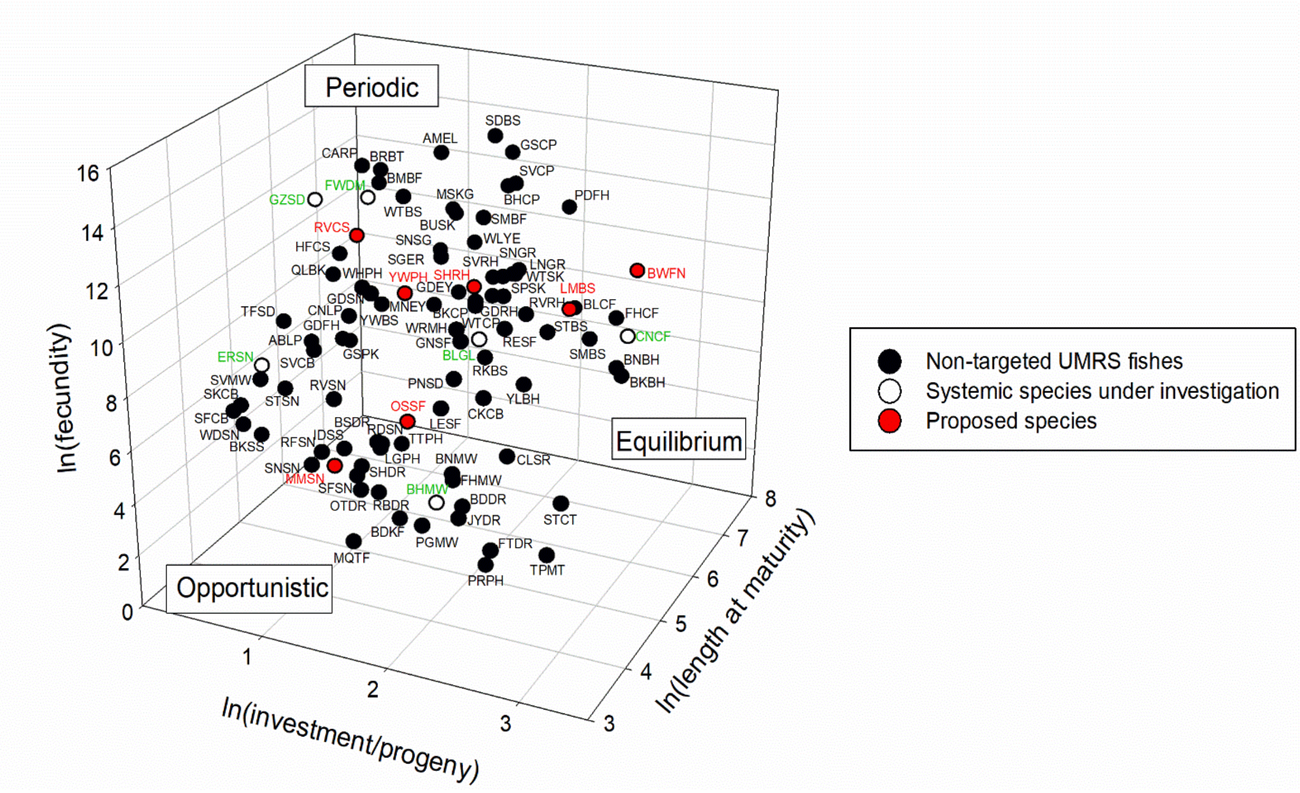

Figure 1. UMR fish assemblage arrayed on three life history attribute axes, highlighting current and proposed species for the UMRR vital rates project.

Known ecological characteristics for the funded and proposed fish species in the project are summarized in Table 1. Following, we provide a brief narrative for each species (funded and proposed), describing its characteristics and the associated expected analytical results from the proposed work.

Table 1. Funded* and proposed additional fish species for genetic and otolith microchemistry analysis in the 2020 UMRR fish vital rates project by life history strategy groups.

Species	Spawning Type	Spawning Substrate	Migrate	Habitat Pref.	Feeding Strategy	Cover Affinity?	Veg. Affinity?	Schooling	Turb. Tol.	Silt Tol.	Current Pref.	Large River Species
Opportunistic Spawners												
Bullhead Minnow	Nest	Crevice	No	Various	Grazing	Low	Low	Yes	High	High	Slow	No
Emerald Shiner	Scatter	Open Water	No	Channels	Filter	Low	Low	Yes	High	High	Mod.	Yes
Mimic/Channel Shiner	Scatter	Plants	No	Various	Grazing	Low	Mod.	Yes	Med.	Med.	Mod.	Yes
Equilibrium Spawners												
Bluegill	Nest	Silt/Sand	No	Backwaters	Grazing	High	Mod.	Yes	Med.	Med.	None	No
Bowfin	Nest	Plants	No	Backwaters	Ambush	Mod.	High	No	Med.	High	None	No
Channel Catfish	Nest	Crevice	yes	Channels	Benthic	Mod.	Low	No	High	High	Mod.	Yes
Largemouth Bass	Nest	Silt/Sand	Yes	Backwaters	Sight	High	Mod.	No	Med.	Med.	None	No
Orangespotted Sunfish	Nest	Silt/Sand	No	Backwaters	Grazing	Mod.	Low	No	High	High	None	No
Periodic Spawners												
Freshwater Drum	Scatter	Open Water	Yes	Various	Grazing	Low	Low	Yes	High	High	Slow	Yes
Gizzard Shad	Scatter	Open Water	No	Backwaters	Filter	Low	Low	Yes	Med.	High	Slow	Yes
River Carpsucker	Scatter	Gravel	No	Backwaters	Suction	Low	Low	No	High	High	Slow	Yes
Shorthead Redhorse	Scatter	Rock	Yes	Channels	Suction	Low	Low	No	High	Low	Mod.	No
Yellow Perch	Scatter	Plants/Wood	No	Backwaters	Sight	Low	Mod.	Yes	Med.	Med.	Slow	No

* Rows for currently funded fish species are highlighted in gray.

Opportunistic Species

Bullhead Minnow is one of the systemic VR species. They are a prototypical opportunistic species with small body size and short lifespan. They are generalists in many attributes, but are somewhat unique in that they nest in crevices and guard their young. Thus, they array slightly toward the equilibrium axis. They might be expected to have greater genetic structure and more simple otolith chemistry signatures than pelagic-spawning species, whose larvae may drift downstream more.

Emerald Shiner, another current VR species, exhibits classic opportunist traits, as well. They are pelagic spawners, remain in open water throughout their lives, and have an affinity for current. Thus, they are predicted to have very low genetic structure and quite a varied otolith microchemistry for a small-bodied fish.

Mimic Shiner/Channel Shiner are listed together because the program has not been able to determine a clear distinction between the two species. They are similar, not only in morphometry, but also in habitats and characteristics. They display very opportunistic life history traits, and are expected to have low genetic pool-level structure, if only one or the other is present. Genetic analyses are valuable in not only testing population structure predictions, but will help elucidate species boundaries and determine whether one, both, and/or hybrids are present in the UMR. At a riverscape level, we expect them to exhibit high population structuring and limited otolith chemistry complexity, as they are not presumed to move large distances throughout their short lives.

Equilibrium Species

Bluegill display intermediate life history characteristics (Figure 1), but are considered an equilibrium species because of their nesting and young-guarding traits. Their affinity for vegetation and aversion to current suggests that they will show strong genetic structure and limited otolith chemistry complexity.
Bowfin rank among the most extreme equilibrium strategists because of their strong young-guarding tendencies. Bowfin are expected to display strong genetic structure and simple otolith chemistry because of their lentic characteristics and affinity for vegetation.

Channel Catfish are nesting spawners, although they usually nest along current margins in cavities and crevices. Larval Channel Catfish are frequently captured in LTRM main channel trawl hauls. They are also considered migratory, and have an affinity for current. Thus, it is likely that Channel Catfish will exhibit low genetic structure, and high indices of geneflow in the UMR, and likely more complex otolith chemistry signatures.

Largemouth Bass are lentic, nesting spawners, but are also somewhat migratory. They have an affinity for vegetation and cover, similarly to Bluegill, but as a larger and more mobile fish, they are expected to show less genetic structure and more complex otolith chemistry than Bluegill.

Orangespotted Sunfish are a turbid water species and have low affinity for vegetation. They are a small, short-lived fish, tending toward opportunistic traits. Because of their tolerance to turbidity and lack of specific habitat requirements, they are expected to show low genetic structure. Due to their small body size, they are also likely to show simple otolith microchemistry.

Periodic Species

Freshwater Drum are a long-lived, large-bodied, large river species with classic periodic life history traits. They are also a highly mobile species, with low fidelity to specific habitats. They are expected to have low genetic structure and high indices of gene flow throughout the study region. They are also expected to have complex otolith chemistry, due to their long lives and mobility.

Gizzard Shad in upstream reaches of the UMR are a primarily short-lived species, due to severity of winter conditions. However, they can grow much larger and live longer in lower UMR reaches. Thus, despite their extreme opportunistic tendencies, they may exhibit a dichotomy of genetic adaptation (greater structure in northern reaches) and otolith chemistry (greater complexity in lower reaches).

Shorthead Redhorse are known to be migratory, and often spawn in tributary streams. They are somewhat intermediate in life history traits (Figure 1), but inhabit flowing channels and little affinity for vegetation or cover. Thus, it is expected that they will exhibit low genetic structure, but complex otolith chemistry.

Yellow Perch are a lentic fish with an affinity for vegetation, but are also tolerant of current. Their unique spawning strategy of dispersing long, helical egg strands sets them apart from all other UMR fishes in this regard. They are not known to be migratory, but do frequent open water. Yellow Perch are expected to display moderate genetic differentiation and perhaps complex patterns of gene flow, but intermediate otolith chemistry.

In summary, Equilibrium species in the UMR are expected to have the highest genetic structure and adaptation to specific locales because of their nesting strategy and general affinity for vegetation. Channel Catfish (mobility) and Orangespotted Sunfish (generalized habitat preferences) are exceptions to that prediction. Periodic fishes, because of their large size and broadcast spawning strategy, are expected to have greater intermixing, thus, lower genetic structure. We expect Periodic species to have the most complex otolith chemistry signatures, as they are generally the most migratory, but in many cases, more long-lived than other species. We expect the Opportunistic fishes to be of mostly mixed stocks because of their lotic, open water tendencies, but Bullhead Minnow to a lesser extent, because of its nesting strategy and preference for slower current velocities than the other two species.

This project serves as a test case for guild-based evaluations of fish habitat distribution and adequacy or hydrologic effects on UMR fishes. If species within guilds display similar VR, genetic, and/or otolith microchemistry patterns, then life history guilds may prove to be a powerful way to evaluate habitat restoration and disturbance effects on UMR fish communities, because of larger sample sizes, greater frequency of occurrence, and robust niche representation.

Methods:

Sample collection

Analysis of genetics and otolith microchemistry will be added to VR analyses on six regionally-abundant species that were included in the funded 2018 proposal "*Investigating vital rate drivers of UMRS fishes to support management and restoration."* (Table 2). These species were carefully chosen based on 1) life history strategy, 2) systemic and regional distribution, and 3) the ability of LTRM field stations to collect the majority of samples during regular LTRM field sampling. Most of the specimens to be used in this phase of the project were collected by LTRM field crews in 2019, and tissue and otolith samples have been retained at Missouri State University for analysis. Additionally, specimens of Mimic and Channel Shiner will be collected in 2020 by all six field stations, as well as samples for any species that were short of their quota in 2019. Pool 19 and 20 samples were previously collected in 2013 and 2014, except for river carpsucker, emerald shiner, and Bullhead Minnow, which will be collected in conjunction with LTEF sampling in 2020. Target sample sizes are 50 specimens per species per LTRM study reach, representing a total of 2,050 samples. The sampling locations are: Pool 4 (Lake City, Minnesota, RKM 1210-1283), Pool 8 (La Crosse, Wisconsin, RKM 1092-1131), Pool 13 (Bellevue, Iowa, RKM 841-896), Pool 19 (Burlington, IA, RKM 586.1-660.6), Pool 20 (Keokuk, IA RKM 552.3-586.1), Pool 26 (Alton, Illinois, RKM 325-389), La Grange Pool (Illinois River, RKM 80-158) and Open River (Cape Girardeau, Missouri, RKM 47-129).

Table 2. Species and target sample size of fishes selected for microchemistry and genetic analyses.

Species	Pool 4	Pool 8	Pool 13	Pool 19	Pool 20	Pool 26	Open River	La Grange
Bluegill				50	50			
Bowfin	50	50	50	50	50			
Largemouth Bass	50	50	50	50	50			
Orangespotted Sunfish				50	50	50	50	50
Bullhead Minnow				50	50			
Emerald Shiner				50	50			
Mimic/Channel Shiner *	50	50	50	50	50	50	50	50
Shorthead Redhorse	50	50	50					
Yellow Perch	50	50	50	50				
River Carpsucker				50	50	50	50	50

* Indicates fish that may be a single species, two species, or intergrades.

Genetic analysis

Genetic analysis will be led by Drs. Mark Davis and Milton Tan, and primarily conducted by a postdoctoral researcher in Mark Davis's Collaborative Conservation Genetics Laboratory, as well as a graduate student in Milton Tan's Biodiversity Genomics Laboratory at the Illinois Natural History Survey, Prairie Research Institute, University of Illinois Urbana-Champaign. To enable direct comparisons with population genomic data generated in Phase I by Wes Larson's team at the Larson Laboratory at UW-Stevens Point, the genetics team will be trained in the Larson Lab at Alaska Pacific University and use the same approach (detailed below). The first step in genetic analysis is to genotype genetic markers across the genome, as these genetic markers each provide information of population history, demography, and genetic diversity. Genotyping for the proposed project will be conducted using a genomic technique termed restriction-site associated DNA (RAD) sequencing that will facilitate genotyping of thousands of genetic markers per species. RAD sequencing employs a restriction enzyme (in this case *SbfI*) to fragment the genome into thousands of small pieces, which are then sequenced on a high-throughput platform, such as the HiSeq4000 (Illumina, San Diego, CA). Single-nucleotide polymorphisms (SNPs) are then discovered and genotyped from the sequence data. RAD sequencing is currently the most commonly employed technique to genotype thousands of SNPs in non-model organisms and was a significant catalyst for the genomics revolution in these organisms (Andrews et al. 2016). Dr. Wes Larson has over half a dozen funded projects that utilize RAD and is considered a regional expert on this method.

RAD sequencing will be conducted using the "Best RAD" method described in Ali et al. (2016). After RAD data are obtained, we will use the program STACKS (Catchen et al. 2013) to identify and genotype SNPs from RAD data, and SNP filtering will be conducted using the methods outlined in Larson et al. (2014) to produce a final dataset of high-quality SNPs. SNP genotype data will be used in population genetic analyses to investigate population structure, identify neutral and non-neutral (potentially adaptive) markers, test for association between genetic and environmental data, and estimate various genetic diversity metrics. Patterns of population structure will be assessed for each dataset using statistical analyses such as analysis of molecular variance (Excoffier et al. 1992), Bayesian clustering analysis (Pritchard et al. 2000), discriminant analysis of principal components (Jombart and Ahmed 2011), and individual-based principal component analysis (PCoA). Three of these analyses are individual-based, facilitating detection of population admixture and potential straying. We will also calculate various estimates of genetic diversity, including observed and expected heterozygosity, allelic richness, and the proportion of polymorphic SNPs in each population. Finally, we will estimate effective population size (N_e), which will allow us to determine roughly how many breeding individuals contribute offspring to the next generation in each population.

In addition, these data will be brought to bear to differentiate species boundaries and assess hybridization in the cryptic Mimic/Channel Shiner group. Using the generated SNP genotype data (as above), Bayesian clustering analysis (Pritchard et al. 2000) will be used to assign individuals to genetic clusters and provide prima facie evidence of hybridization. The program ADMIXTURE (Alexander et al., 2009) will be used to provide a more nuanced perspective on the tempo, mode, and (potentially) directionality of introgression in the Mimic/Channel Shiner group.

The suite of genetic metrics that we obtain will provide important information about connectivity and genetic health of the populations and species included in the study. For example, comparing patterns of genetic structure will allow us to identify common barriers to migration, such as dams, that influence connectivity across multiple species. Additionally, this information will allow us to determine whether certain species respond differently to the same habitat feature. For example, certain habitat features may potentially impede movement of some fish but not others. Finally, estimates of genetic diversity obtained in this study will provide information about the genetic health of populations that may not be obvious based on traditional metrics. This information will allow us to determine whether certain populations may have undergone recent bottlenecks and may therefore be genetically compromised. These potentially compromised populations may be more vulnerable to future environmental changes as well as stressors such as disease outbreaks and extreme conditions.

Otolith Microchemistry analysis

Dr. Greg Whitledge and a doctoral student will lead the microchemistry component. Water samples will be collected from each LTRM reach and from nearby tributaries of the UMRS during each LTRM fish sampling period to verify persistence of previously observed patterns in water chemistry among locations. Water samples will be filtered in the field by LTRM crews (Shiller 2003) and analyzed for strontium (Sr), barium (Ba) and calcium (Ca) concentrations using inductively coupled plasma mass spectrometry (ICPMS) by the doctoral student. Otolith microchemistry will be conducted on a subset of each species (n=50) from each LTRM reach. Sectioned otoliths (either those previously used for age estimation or a second otolith from each fish) will be analyzed for Sr:Ca and Ba:Ca using laser ablation-ICPMS. The laser will ablate a transect from the center of each otolith to the otolith edge to encompass each fish's environmental history. Natal environment will be inferred for each fish by comparing otolith core (the portion of the structure that reflects early life history) Sr:Ca and Ba:Ca to expected otolith chemical 'signatures' (Sr:Ca and Ba:Ca) of potential natal locations in the UMRS. Location-specific chemical 'signatures' will be calculated using water chemistry data (proposed collections and existing data) and relationships between otolith and water chemistry for the species listed above (Zeigler and Whitledge 2010); Laughlin et al. 2016; Whitledge, unpublished). Data on natal environments contributing to each of the selected fish species in each LTRM reach will be analyzed in relation to year class strength indices derived from the residual method. Movement patterns of fish among chemically-distinct locations in the UMRS will also be inferred from changes in Sr:Ca and Ba:Ca along laser ablation transects.

Constructing management units

We will use data from genetic analyses, vital rate estimates, and otolith microchemistry to define spatially appropriate management units for six fish species that span a range of life history strategies. First, we will compare data from these three sources for all species separately to determine whether consistent patterns exist. For example, do we see consistent differences in vital rates, genetic structure, and microchemical signatures across similar spatial scales? Next, we will integrate data across multiple species to determine conserved trends and trends that are not shared. In this phase, we may observe that certain locks and dams or other habitat features appear to be barriers to connectivity for all species whereas other may only be barriers for a few species. Finally, we will synthesize all of this information and propose management units that are specifically tailored to various species and life-history types. These management units can then be used to improve the impact and efficiency of conservation and restoration projects.

Timeline:
A timeline table is provided with project tasks and estimated dates of completion (Table 3). Data collection occurred during regular LTRM fish field sampling in 2018. Processing of samples will occur from late 2019 through 2020. Analysis and reporting will occur annually with the final report due in late 2021.

Table 2. A general timeline of all project components and tasks.

Task		2020			2021			2022		
		Spr	Sum	Fall	Spr	Sum	Fall	Spr	Sum	Fall
G	Laboratory analysis		▨	▨						

	Statistical analysis				▨	▨	▨			
	Genetics Final Report/Manuscripts							▨	▨	▨

Expected milestones and products:

Annual progress reports will be provided in the summer of each year. At the completion of this project, manuscripts will be prepared, published, and shared with the partnership. All manuscripts will be submitted no later than 31 December 2022. Research products will come in the form of written documents, in addition to power point presentations at regional UMRS-related meetings.

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Functional UMRS fish community responses and their environmental associations in the face of a changing river: hydrologic variability, biological invasions, and habitat rehabilitation.

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Introduction/Background: Please address all these questions:
What's the issue or question?
Hydrologic modification, invasive species, and global climate change have resulted in rapid and dramatic changes in community structure across a wide range of ecosystems (Sheldon et al. 2011, Gaertner et al. 2014, Kong et al. 2017). Most studies designed to detect regime shifts and describe their proximate causes have focused on shifts of the dominant species (Capon et al. 2015). Dominant species regime shifts can greatly alter the functional ecology of an ecosystem; however studies often fail to identify or address functional changes within the wider biological community. Importantly, freshwater ecosystems and modified rivers are known to exhibit regime shifting behaviors and alternative stable states (Scheffer et al. 1993, Carpenter et al. 2011). These systems have high socio-economic value, are among the most altered and damaged ecosystems, and are most susceptible to both anthropogenic and environmental changes (Vörösmarty et al. 2010, Capon and Bunn 2015). The susceptibility of large rivers to these anthropogenic and environmental drivers can result in drastic and unexpected changes to their functional ecology. A better understanding of functional changes in the Upper Mississippi River System (UMRS) fish community in response to biological invasion, environmental change, and purposeful ecosystem management actions is paramount to conserving UMRS fish communities. The ability of such functional patterns to either respond to or resist change, under invasion or active ecosystem restoration management actions, is one definition of resilience, governed by notions of functional interactions that resist or give rise to change under threshold and alternate stable state theoretic concepts (Holling and Gunderson 2002).

What do we already know about it?
Preliminary analysis of fish community structure based on species abundances revealed changes in the UMRS fish community structure as high as 46% over a 25-year time period (Table 1). However, very little work has been done previously to characterize functional expressions of UMRS fishes. The UMRR LTRM program element has been observing the UMRS fish community in consistent, rigorous, and standardized ways using a well-established scientific sampling protocol for greater than 20 years (Ickes et al. 2014b). Recently, the UMRR-EMP LTRM fish component has assembled a life history database that can be linked to long-term observations on individual fish species (O'Hara et al. 2007). The life history database allows investigators to recast standardized observations into functional guild expressions while applying the same design-based estimation procedures that it does for single species abundance (Ickes et al. 2014b). This approach provides indexed functional expressions of fish guilds in units of abundance, mass, or even monetary replacement value. One example of exploring functional patterns in UMRS fish communities is provided by Figures 1a and 1b, presented as an example in O'Hara et al. (2007). Furthermore, the proposed research builds upon previous work that has described non-random trajectories of the functional fish community. These analyses determined that the northern three reaches have become functionally more similar; whereas, the southern three reaches have become functionally divergent. The proposed work aims to elaborate on recent work which described possible regime shifts in the UMRS using functional mass expressions (Bouska *in review*).

Table 1. Preliminary analysis of changes in UMRS fish community structure from 1994-2018 using SIMPER analysis. Log_{10}-transformed pool wide means from day electrofishing of each species were used to create abundance matrices for annual comparisons. Affected species contributed to a cumulative 50% of the observed differences and are listed in order from largest contribution to change to lowest. Systemic loss of common carp and the introduction of bigheaded carps have contributed a significant amount of changes to the UMR fish community over this time period.

Pool	Difference from 1994 (%)	Affected Species
04	32.00	CARP, WTBS, YWPH, WDSN, ERSN, LMBS, SFSN, RVSN

08	35.13	WDSN, GZSD, CARP, LMBS, FWDM, BLGL, MMSN, WTBS, SMBF
13	30.21	CARP, LMBS, WTCP, SMBS, WTBS, GDSN, SFSN
26	39.95	ERSN, CARP, GZSD, SVCP, BLGL, CNSN, LMBS
Open River Reach	46.37	GZSD, ERSN, CNSN, CARP, CNCF, BLGL, FWDM, SVCP
La Grange Reach	45.30	ERSN, SVCP, MQTF, GZSD, CARP, BMBF, TFDS, BHMW

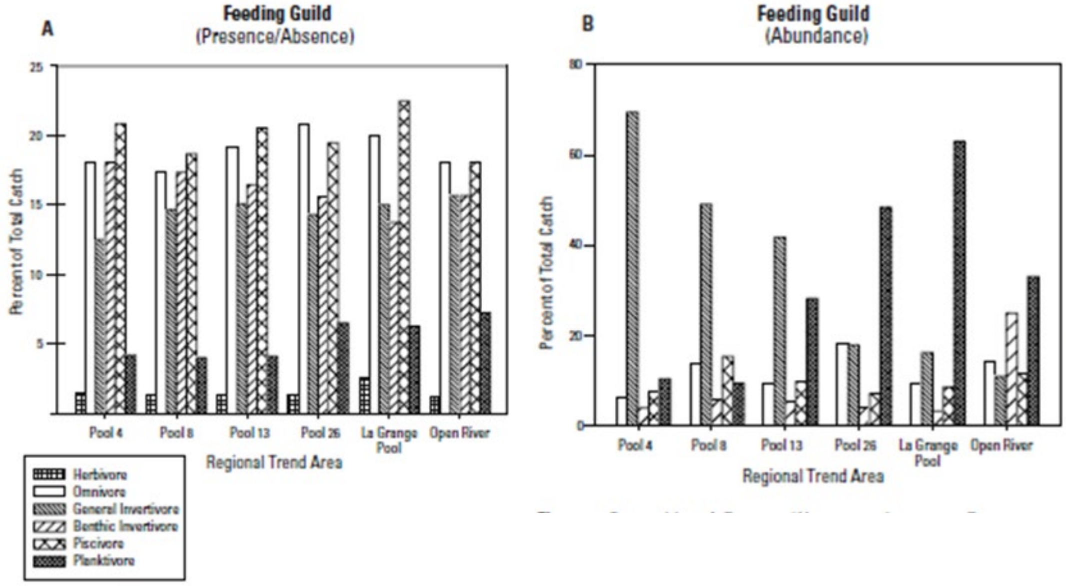

Figure 1a. Spatial patterns in the proportion of the fish community (species) represented in each of six functional feeding guilds based upon presence/absence data. This figure demonstrates that the proportion of species in each feeding guild is highly similar across a 1960 km gradient of river on the UMRS. From O'Hara et al. (2007). **Figure 1b**. Spatial patterns in the proportion of the fish community represented in each of six functional feeding guilds based upon abundance data. This figure demonstrates that the proportion of species abundances in each feeding guild are rather dissimilar across a 1960 km gradient of river on the UMRS and is suggestive that while the basic functional templates are highly similar among study reaches, strong functional counter-gradients are evident in numeric/abundance expressions. From O'Hara et al. (2007). Note: legend is the same as for Figure 1a.

How will the proposed work improve our understanding of the UMRS?
The UMRS represents a novel ecosystem within which to gain new insights into such functional patterns, including the roles of biological invasions and restoration management actions upon them. Its north-south axis of flow, traversing several degrees of latitude and profound contemporary gradients in habitat quality and ecosystem impairment, provides a perfect field laboratory to test several tenets of resilience, restoration ecology, and invasive species theory and application. This will help generate a greater understanding of feeding, reproductive, trophic, and habitat ecology across the full UMRS. It is crucial to identify long-term changes in the functional diversity of the UMRS and the environmental factors driving these changes over time. This information will provide insights into the comparative resilience of different UMRS river reaches in response to biological invasion and hydrologic modification.

Objective(s) or hypothesis
Our objective is to identify, test, and infer functional patterns in the UMRS fish community across a 1960 km gradient of river and over a 20+ year time period. Our primary goal will be elucidating demonstrably non-random patterns in UMRS fish community functional expressions and determining their environmental covariates.

Our primary hypotheses are (1) there is no difference in the basic functional template of the UMRS fish community over 1960 km of river (percent of species present in each functional guild class); (2) divergent patterns in either reproductive, feeding, or habitat guild mass expressions will be apparent and demonstrable from north to south within the UMRS; (3) habitat rehabilitation has not altered the functional attributes of the UMRS fish community; (4) the presence of invasive carp has altered the functional attributes of the UMRS fish community in the southern reaches; and (5) the northern reaches are functionally distinct from the southern reaches providing a buffer against invasion.

Relevance of research to UMRR: Please address all the following:

How will the results inform river restoration and management?
Understanding functional patterns in UMRS fish communities is critical to applied management interests within the UMRS. This approach ties ecological responses much more closely to habitat rehabilitation than past faunistic

approaches (Chick et al. 2005; Barko et al. 2005; Ickes et al. 2005). Knowledge of how functional mass patterns are presently expressed provides insights into the basic production pathways within the UMRS, and how they may vary spatially and over time. This will provide information on how changes in the river (i.e., impairment and rehabilitation) may influence functional attributes of the UMRS fish community. Furthermore, it will identify how habitat rehabilitation may be able to modify spatial attributes to affect fish community function. Identifying the drivers of functional responses in UMRS fish communities will better inform project planning, construction, and evaluation by suggesting and identifying alternative management actions designed to affect the functional ecology of the system in more socially desirable ways. These management actions can also be tailored for different regions based on their functional ecology and prevalence of species of high economic value. Results may also reveal biological or hydrologic constraints to the success of invading bigheaded carps.

How will the proposed work contribute to, or improve, the selection or design of Habitat Rehabilitation and Enhancement Projects (HREPs)?
As a habitat restoration and environmental monitoring program, the UMRR frequently seeks to incorporate multiple design criteria into its habitat projects and to bring unprecedented empirical observations into design considerations. This work will provide new results that relate to functional patterns and their environmental determinants, results that will be relevant for designing better projects to achieve socially-desirable functional responses (i.e., fewer carp, more native species).

Describe how the research addresses one or more of the 2020 Focal Areas.
The proposed work will focus on key questions associated with Focal Area 2.4 and understanding changes in the UMRS fish community. Specifically, the work will identify whether certain study reaches are more susceptible to invasion based upon functional differences in their guild composition. A key consideration in invasive species ecology concerns the functional niche of the invading organism, as well as the niches provided by the invaded ecosystem and occupied by the indigenous assemblage of possible sympatric competitors (Power 1992, McGill et al. 2006). This work will identify differences in functional guilds across a 20+-year time series and how these differences may either enhance or inhibit invasion by bigheaded carps. We will also consider the extent to which our results are consistent with the idea that the native community state or the invasive-dominated community state in lotic and lentic areas are alternate regimes. Any observed changes in the functional fish community will also be investigated to understand spatial-temporal trends in fish recruitment dynamics (see Work Group 4, Proposal 2, A. Bartels) and how this may influence observed changes in community structure. Furthermore, our work plans to link hydrologic parameters (days over flood stage, flood magnitude and frequency) to changes in the fish community and productivity of these species.

If work involves an HREP, name it
While this work is not tied to any specific HREP, it arguably has great relevance to all future HREPs and their design criteria. HREP's, by their nature, modify space in functionally-relevant ways and can be viewed as a selective force for functional groups of fishes that may have higher or lower social value (manage for or against assorted functional groups). This work will describe prevailing patterns in functional expressions of UMRS fish communities and will seek to identify environmental covariates associated with these patterns. With this knowledge, the environmental covariates found to be relevant can be considered more explicitly in habitat restoration planning activities. This work will also lay down a critical foundation for gauging how different UMRS fish assemblages, across a 1960 km gradient of river, may respond in time to bigheaded carp invasion.

Methods:

Data assembly
UMRR-EMP LTRM fisheries data (1993-2019) will be gained from standard data portals available here: http://www.umesc.usgs.gov/data_library/fisheries/fish1_query.shtml, accessed 20 September 2019). These data assets will be relationally linked to the UMRR-EMP LTRM Fish Life History database (O'hara et al. 2007) using "fishcode", a unique species identifier, to relate species to their functional guild classes. Count and abundance observations from standardized LTRM monitoring efforts will be recast into mass units, per species, using 99 growth models, codified in the life history database and capable of estimating weight from standard length and abundance observations. Each species in the original LTRM monitoring database will be assigned a functional guild (feeding, reproductive, trophic, habitat type) membership class and mass per feeding guild class will be calculated for each sample. From this dataset, we will apply the standard LTRM design-based estimators to gain an indexed estimate of mass-per-unit-effort as our expression of functional mass. We will use the standard design-based estimators presented in Ickes et al. (2014) and Ratcliff et al. (2014) to gain these index statistics (Ickes et al. 2014a, Ratcliff et al. 2014). Environmental variables (days above flood stage, depth, total dissolved solids, temperature, etc.) will be extracted from water gauges located at each pool and from UMRR LTRM water quality data (1993-2019): https://www.umesc.usgs.gov/data_library/water_quality/water_quality_data_page.html, accessed 20 September 2019).

Analysis
Our initial work will be to identify gradients in the extant indigenous fish community (N species = 142) using functional (mass) expressions (feeding guilds), to determine whether there are spatial differences in these fundamental niches across the 1960 km UMRS.

Our first analysis will determine the basic functional template along the UMRS to address Hypothesis (1). We will test for spatial-temporal differences in functional community structure among all UMR-LTRM study areas, representing 1960 km of river. This will determine how certain feeding, reproductive, or habitat classes have shifted over a 25-year period causing a change in the overall ecosystem function of each study reach. Data matrices, based on both species' abundance and functional expressions, will be created for analyses of dissimilarity of the community. Changes within (temporal trends) and differences among (spatial comparisons) in the functional ecology of the system will be evaluated using SIMPER and ANOSIM tests for dissimilarity in the statistical package R.

Hypothesis (2) will be addressed by determining the proportional contribution (by species) of each feeding guild class. The percentage of all species in each study reach comprising each feeding guild class will be assembled into a contingency table. Formal test for differences among LTRM study reaches in the differences of the number of species in each guild class will be tested using a categorical data modeling routine in the statistical package SAS (v. 9.3) that uses Chi-square distributional assumptions. Differences among the six study reaches will also be evaluated using SIMPER. ANOSIM tests will reveal differences among study reaches with study reach as a categorical variable.

To address Hypothesis (3), we will test for difference in proportion mass expressions within feeding guild classes, per study reach. The idea is to first test whether the basic functional template differs among UMR-LTRM study reaches, and then to test whether observed functional community mass differs similarly, for this is an expression of energy and material transfer within the entire fish community. Again, a contingency table containing percent mass representation per study reach will be assembled and differences among study reaches will be inferred using a categorical data modeling routine in the statistical package SAS (v. 9.4) predicated upon Chi-square distributional assumptions. This will determine whether habitat rehabilitation has maintained the functional diversity of the UMRS. All the above analyses will be used to generate the first two proposed papers under expected milestones and products.

Our final analyses will address Hypotheses (4) and (5) by determining temporal shifts in functional guild classes. The abundance of invasive carp will be included as a covariate in the analysis to determine whether their presence has significantly altered or caused shifts in either feeding, reproductive, or habitat guild classes as described by Hypothesis (4). This will build upon the previously described methods which have identified the temporal trends in each guild class. We will identify the functional role that invasive carp play within the UMRS and determine whether invasion was a result of the niche being previously unoccupied in the southern three study reaches. Furthermore, we will identify whether the niche occupied by invasive carp is available in the southern three reaches but occupied in the northern three. Hypothesis (5) will be addressed by determining if a species(s) is occupying a niche necessary for invasion of Asian carp and directly inhibiting successful invasion within the northern three reaches. These analyses are directly linked to the third proposed paper under expected milestones and products.

Environmental covariates will be included in all analyses to determine if these variables are driving any observed shifts in the functional community for all hypotheses. A water quality matrix using the LTRM water quality data and a hydrology matrix using data from local water gages will be generated for a multivariate analysis of these covariates on changes in each described functional guild. A Mantel test will be applied to determine if changes in the functional guilds are correlated with changes in either water quality or hydrology independently. These covariates and the abundance of Asian carp will be included to address Hypotheses (4) and (5).

Timeline:
Assemble requisite raw data resources to address all primary research questions – June 30, 2020

Conduct literature review - August 31, 2020

Calculate design-based estimators of mass per unit effort by feeding guild membership – August 31, 2020

Complete analyses for all primary research questions – January 31, 2021

Draft manuscript(s) – September 30, 2021

Presentation(s) – As requested programmatically, as able at professional conferences

Expected milestones and products [with completion dates]:
Draft manuscript submitted for review "Evidence of alternative trophic pathways for fish consumers in a large river system" – September 30, 2021

Draft manuscript submitted for review "Has large scale ecosystem rehabilitation altered functional fish community expressions in the Upper Mississippi River System?" – September 30, 2021

Draft manuscript submitted for review "Why aren't bigheaded carps (Hypophthalmichthys sp.) everywhere in the Upper Mississippi River System?" – September 30, 2021

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Understanding landscape-scale patterns in winter conditions in the Upper Mississippi River System

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KathiJo Jankowski; USGS; kjankowski@usgs.gov; Oversee project, co-supervise postdoc, manage data collection, analysis and publication.
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Collaborators
Postdoc – UW Madison; Lead data analysis of long-term winter data and publication *(to be hired)*
Rob Burdis – MN DNR; robert.burdis@state.mn.us; Field design and data collection in Pool 4; assist with data analysis and publication.
Shawn Giblin – WI DNR; shawn.giblin@wisconsin.gov; Consult on field design; assist with data analysis and publication.
John Kalas – WI DNR; john.kalas@wisconsin.gov; Field design and data collection in Pool 8; assist with data analysis and publication.
Travis Kueter – IA DNR; travis.kueter@dnr.iowa.gov; Field design and data collection in Pool 13; assist with data analysis and publication.
Kyle Landolt & Stephanie Sattler – USGS; klandolt@usgs.gov, ssattler@usgs.gov; Field camera imagery processing; data publication.
Patrick Perner – USGS; pperner@usgs.gov; research technician and UW La Crosse MS Student; Oversee design, collection, data analysis, and publication of sediment survey.

Introduction/Background

Survival through the winter often is a key bottleneck for aquatic organisms in northern climates, yet we have limited understanding of patterns and controls of winter conditions that support aquatic food webs in the Upper Mississippi River (UMR) and rivers globally. Recent large-scale observations of changing ice and snow phenology (Sharma et al. 2016, 2019; Magnuson 2010), warmer winter temperatures (National Climate Assessment 2018), and increased recognition of connections between winter conditions and processes and patterns in other seasons (Katz et al. 2015; Hampton et al. 2017) have made understanding the fundamental controls on winter conditions and their effects on aquatic processes and communities increasingly important.

Overwintering habitat conditions are hypothesized to limit the production of several important fish populations in the Upper Mississippi River System (Knights, Johnson, and Sandheinrich 1995; Johnson et al. 1998; Gutreuter 2004, Ickes et al. 2006), and many Habitat Restoration and Enhancement Projects (HREPs) are aimed at restoring suitable conditions in backwater lakes. These efforts typically manipulate the quality of overwintering conditions through altering connectivity of backwaters to main channel flow or increasing the availability of deep areas that act as warm refugia during winter months. Suitable habitat in the UMR is generally defined by the ranges of four parameters: depth (≥ 1m), flow (≤ 0.01 m/s), temperature (≥ 1 °C) and oxygen (≥ 5 mg/L), which are based on a range of laboratory (Sheehan et al. 1990) and field studies (Knights, Johnson, and Sandheinrich 1995; Johnson et al. 1998) and primarily based on physiological requirements of the centrarchid species that use backwater lakes during the winter. However, to date, there has not been a systemic evaluation of where and how often during the winter this habitat typically occurs, how it varies from year to year or within winter, and the physical, hydrologic and climate-related drivers of its occurrence. The UMRR LTRM water quality component has 25+ years (1993-2019) of mid-winter water quality data from all 6 field stations, that include the parameters (velocity, temperature and dissolved oxygen concentration (DO)) that managers use to determine habitat suitability, and has occurred regularly starting the last full week of January each year. In addition, De Jager et al. (2018) developed new system-wide spatial data layers describing aspects of the hydrogeomorphology of the UMR known to influence winter conditions (e.g., depth distributions, physical metrics of hydraulic connectivity) that can be used to scale our understanding of habitat availability to areas where we don't have LTRM data. We intend to advance our large-scale understanding of the distribution, frequency and controls on over-wintering habitat for fish in the UMRS by combining these two datasets. Although these data are a snapshot of conditions at one point in time each year, the high spatial (5 reaches, 50+ sampling points per reach in backwater lakes) and temporal (25+ years) replication allows us to evaluate relationships of overwintering conditions with the morphometry of the riverine landscape as well as understand how variation in winter temperatures, hydrology, and ice/snow cover impact the availability of habitat.

Although LTRM data are spatially and temporally extensive, they do not address how conditions change throughout the winter. Winter conditions are not static through the season, and can change substantially in response to freeze up, snowfall and discharge fluctuations (Knights, Johnson, and Sandheinrich 1995; Katz et al. 2015; Akomeah and Lindenschmidt 2017; Grosbois et al. 2017). In addition, the extensive natural variation in the size, morphology, and connectivity of backwater lakes across the UMRS likely affects drivers of winter habitat conditions such as the timing of ice and snow cover, sediment characteristics and oxygen demand (Leppi, Arp, and Whitman 2016; Magee and Wu 2017) and vegetation abundance that affect how seasonal dynamics express themselves across backwater lakes. Therefore, we propose a two-part study that 1) uses long-term LTRM data to evaluate the spatial and temporal (inter-annual) variability in the occurrence and drivers of suitable overwintering conditions and 2) a short-term field study that evaluates the seasonal variation in conditions within winter in backwater lakes that range in their depth and connectivity. **Specifically, we will ask the following questions:**
1. What are the patterns and drivers of mid-winter habitat conditions in backwater lakes?
2. How variable is the occurrence, distribution, and extent of favorable habitat conditions among pools and backwater lakes among years and what are the drivers of that variation?
3. How do ice and habitat conditions change within winter across backwater lakes that span a range of connectivity and depth?

Relevance of research to UMRR

Restoration of winter habitat is a central component of many HREPs. This project will broaden our understanding of the spatial and temporal occurrence and drivers of favorable winter conditions across the UMRS and how they may respond to changes in ice cover and winter discharge. This proposal addresses **Focal Area 2.1** (Assessing the associations between aquatic areas and biota and biogeochemistry using existing data), Question 5 within **Focal Area 2.4** (How do habitat connectivity and heterogeneity contribute to resource availability, recruitment dynamics and accessibility of refugia for fish assemblages?), and several questions within **Focal area 2.5** (Consequences of river eutrophication for critical biogeochemical processing rates and habitat conditions).

Methods

Long-term spatial and temporal patterns in overwintering habitat *(Questions 1 and 2)*

To address Questions 1 and 2, we will use a combination of LTRM winter SRS data, GIS layers from the HNA Aquatic Areas dataset (example shown in Figure 1B), and other existing data from previous winter studies where available (e.g., J. Rogala, unpublished data; N. Manasco, Rock Island District overwintering data). Our aim is to create systemic GIS layers of winter conditions in backwater lakes that capture how aspects of the physical river landscape impact the availability of habitat and how that distribution responds to fluctuations in discharge and ice cover.

Spatial variation in winter conditions (Question 1):

Hypothesis: Lake morphometry and connectivity is related to the frequency of suitable habitat conditions in backwater lakes. These relationships can be applied to areas without long-term data.

First, we will compile all LTRM winter SRS DO, temperature, velocity and depth data from 1993-2019 for all LTRM pools. Second, we will combine these point data (Figure 1A) with spatial aquatic area data layers (Figure 1B) to quantify the frequency with which individual backwaters have met these overwintering criteria through time. We will aim to include only backwaters that have been sampled three or more times over the period of record. The LTRM water quality dataset includes greater sampling frequency in larger backwaters given their greater random probability of inclusion, thus this dataset will by nature skew towards larger backwaters. Third, we will quantify what aspects of backwater lake morphometry (e.g., surface area: volume, depth, fetch, shoreline development) and connectivity (e.g., percent channel, effective number of connections) influence greater frequency and extent of favorable overwintering conditions. We will assess the availability of “suitable” habitat using dynamic ranges of each component variable (e.g., 2-5 mg/L DO) and as a combined multivariate index.

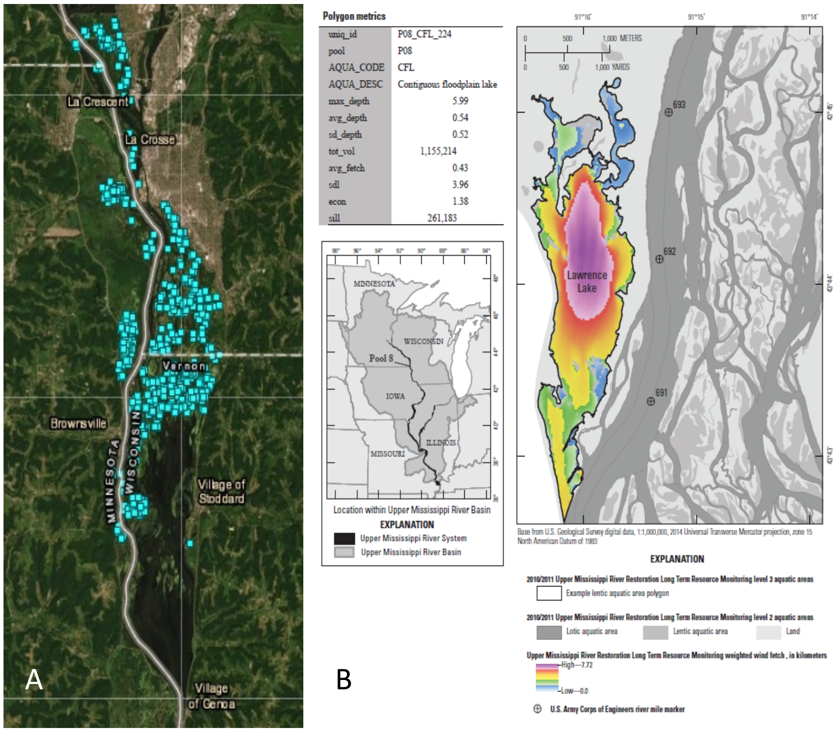

Figure 1. A) All winter SRS data points collected in backwater lakes in Pool 8 from 1993-2018 (figure generated using Spatial Data Query Tool; https://umesc.usgs.gov/ltrmp/spatial_data_query_tool.html. B) Example from Pool 8 of data layers available in HNA aquatic areas dataset for delineated aquatic area polygons (figure from De Jager et al. 2018)

Winter conditions through time (Question 2)

Hypothesis: Certain types of backwater lakes (e.g., deep vs shallow, low vs high connectivity) will have similar patterns in winter conditions through time. Inter-annual variation in winter discharge, ice, snow cover will affect the frequency of suitable winter conditions across years.

Winter conditions are affected driven by inter-annual variation in discharge and ice and snow cover, but the sensitivity of conditions to these drivers may vary across pools or backwater lake types. To assess the relationship of backwater winter conditions with inter-annual variation in these drivers, we will do an analysis at two spatial scales. First, we will evaluate the frequency of sites that have met suitability criteria across all backwaters for each LTRM pool and evaluate the relationship of that frequency with potential drivers such as discharge and ice cover. Second, we will do a similar analysis at a finer scale, by selecting individual backwaters from each pool that have at a relatively continuous data record through time (aim for n ≥ 1 per year; eliminate backwaters with greater than 5 missing years). Here, we will evaluate how specific backwaters have changed through time and whether there are shared trends among backwaters lakes that correspond with their physical features (Leppi, Arp, and Whitman 2016; Lottig et al. 2017; Collins et al. 2019). We will then look at the sensitivity of winter conditions in these backwaters to inter-annual variation in discharge, winter temperature, snow and ice cover. We will use multivariate time series models to assess shared trends and drivers among backwater lakes (MARSS models; Holmes, Ward, and Scheuerell 2018). These analyses will allow us to understand the sensitivity of these water quality variables across the river landscape to variation in hydrology and ice cover.

In summary, we will use these relationships developed with the physical template and temporal drivers to create system-wide datasets of the probability of favorable overwintering habitat.

Seasonal ice phenology and under ice conditions in backwater lakes *(Question 3)*

Hypotheses: Connectivity affects the timing and duration of ice cover in backwater lakes. Rates of oxygen decline in backwaters after freeze up or snow fall depend on backwater connectivity and sediment characteristics.

In addition to inter-annual variation, ecosystem processes and conditions in backwater lakes can vary substantially over the course of the winter (Knights et al. 1996, Powers et al. 2017), however, existing LTRM data do not include within winter variation. Therefore, we will initiate a new field study to address questions regarding intra-seasonal variation in winter conditions. Specifically, we will ask the following: 1) When do backwaters freeze, melt and breakup for the season? 2) What is the trajectory of dissolved oxygen and temperature through the season? 3) How quickly does oxygen decline after freeze up or snow fall and what drives this rate (e.g., sediment characteristics and oxygen demand, vegetation, ecosystem productivity)?

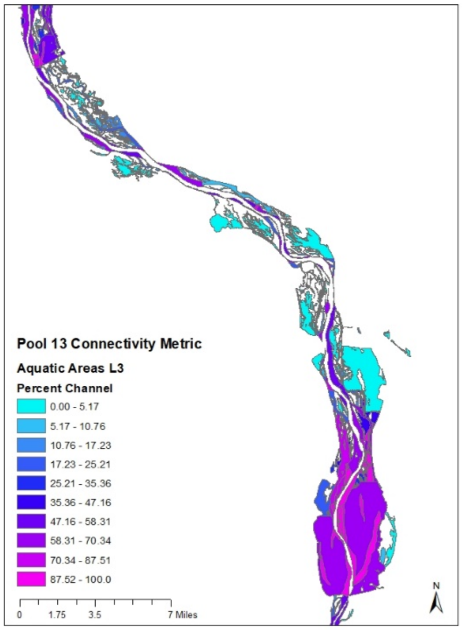

Figure 2. GIS-derived connectivity metric from HNA Aquatic Areas Level 3 dataset (De Jager et al. 2018) for Pool 13.

To answer these questions, we will do winter field surveys in six backwater lakes in Pools 4, 8 and 13 over the course of two years to address how connectivity and depth affect variation in ice cover and under ice conditions within the winter. To capture these important physical drivers, we will select backwaters across a gradient connectivity based on GIS-derived connectivity metrics (e.g. channel percentage from HNA aquatic areas dataset as shown in Figure 2) and on measured and modeled mean velocity (see Giblin et al. 2014; Houser et al. 2013; outputs from 2D hydraulic models where available). We will select shallow and deep backwaters to correspond with high, medium and low connectivity backwaters. Site selection will also be informed by initial analysis of the long-term dataset for Questions 1 and 2 that may highlight areas that are consistent vs. highly variable through time.

Ice and snow cover

To monitor ice and snow cover, we will deploy trail cameras (HP2X Hyperfire 2, Reconyx, Holmen, WI) at each site from November to the end of April in years 1 and 2 of the study (FY 2021 and 2022) set to take hourly photos. In addition, we will mount metered stakes within view at each location to document local snow depth information. This will allow us to document ice on, ice off, the presence of snow cover, and mid-winter melting events. Field staff will check camera memory cards and battery life monthly. Image analysis to quantify percent ice cover and snow depth will be done by UMESC GIS staff, who will generate daily values of ice and snow cover for all lakes in the field survey based on methods outlined in Ansari et al. (2017)

Under ice conditions

To assess dynamics of DO and temperature throughout the season, we will deploy 1-3 continuous DO and temperature loggers (Hobo U26 Dissolved Oxygen sensors, Onset Corp, Bourne, MA) during Year 2 at the same backwater lakes as the trail cameras. In all backwaters, we will deploy one logger over the deepest portion of the lake, as this is likely to capture the oxygen and temperature dynamics of the greatest volume of lake water. In backwaters that are larger or have complex morphology, we will deploy additional loggers to reflect gradients in shoreline complexity and flow. We will deploy loggers at mid-depth from November 2021-April 2022 during the second year of the study and will collect data at 10-minute intervals. We will also deploy underwater light sensors along with DO/temp loggers to provide more site-specific information on ice and snow cover induced changes to light availability that may not be visible from onshore cameras.

In addition to ice and snow cover, nutrient availability, vegetation cover and sediment characteristics can play important roles in the availability of oxygen in backwaters. Therefore, we will do mid-winter surveys of nutrients, vegetation cover and sediment characteristics at all sites. We will collect on sample for N, P and Si in each backwater and at three sites for fluorometric chlorophyll analysis. We will quantify vegetation cover and collect sediment at eight sites in each backwater lake. We will quantify the presence of vegetation in two ways. First, where available, will use existing LTRM vegetation occurrence and biomass data from the previous summer. Second, during the winter survey, we will quantify vegetation percent cover, density and type using the same methods as LTRM water quality field teams.

For sediment analysis, we will perform a pilot study in year one to validate methods for a full survey in year two. During year one, we will collect intact sediment cores from Pool 8 to validate sediment oxygen demand (SOD) methods that will be used for the full sediment survey. During the second winter of the study, we will collect intact up to eight sediment cores at all the backwater lake sites to determine SOD and some of the sediment physicochemical variables that may be influencing SOD. The pilot study and existing sediment data (Rogala, unpublished data) will be used to determine the number of replicates required for the full survey. SOD will be measured at UMESC within 24 hours of sample collection according to Rong et al. (2016). Intact cores, with overlying site water, will be placed in environmental chambers set at ambient river water temperature. DO will be measured every 15 minutes until the water column DO drops to less than 1 mg/L. Sediment also will be analyzed for total nitrogen, total carbon, total organic carbon, total phosphorus, particle size, bulk density, and ash-free dry mass (Robertson et al. 1999).

Timeline

	FY20	**FY21**				**FY22**				**FY23**			
Task	**Su**	**FA**	**W**	**Sp**	**Su**	**Fa**	**W**	**Sp**	**Su**	**Fa**	**W**	**Sp**	**Su**
Q 1 & 2 - Spatial & temporal analysis of overwintering habitat (UW postdoc, HD, KJ, MM)													
Advertise postdoc	X												
Hire postdoc		X											
Data gathering (2D models, USACE dataset)		X											
Analysis			X	X	X	X							
Layers of overwintering habitat							X	X					
Draft Manuscript									X				
Q3a – ice monitoring (RB, JK, TK, KJ, MM)													
Purchase supplies and design mounts		X											
Deploy cameras			X				X				X		
Download data				X				X				X	
Analyze data					X	X			X	X			X
Q3b – sondes (RB, JK, TK, KJ)													
Purchase		X											
Construct platforms					X								
Deploy						X	X	X					
Analyze data									X	X	X	X	
Draft Manuscript													X
Q3c – Nutrient, sediment and vegetation survey (RB, JK, TK, RK, Perner)													
Trial			X										
Field Survey							X						
Lab Analysis								X	X				
Data Analysis										X	X	X	
Thesis/Manuscript													X

Expected milestones and products

This project will provide detailed information about system-wide controls on spatial and temporal variation in the availability of suitable winter habitat conditions the UMRS. Our analysis of existing data will provide information on the physical controls of the occurrence and frequency of suitable as well as its response to potential changes in winter discharge and ice & snow cover. The field study in Pools 4, 8, and 13 will quantify seasonal variation in ice and snow cover and under ice conditions, and pair that with information about backwater sediment characteristics across gradients in hydraulic connectivity. We anticipate that this project will produce system wide spatial layers of winter habitat conditions and up to three draft manuscripts (listed below):

1) "Landscape scale controls on overwintering habitat in a large river" (Postdoc, Dugan, Jankowski, Magee)
2) "Response of oxygen dynamics to ice and snow phenology in backwater lakes" (Jankowski, Dugan, Burdis, Kalas, Kueter)
3) "Patterns in sediment characteristics and oxygen demand across a winter riverine landscape" (Perner, Kreiling, Jankowski, Giblin)

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Forest Response to Multiple Large-Scale Inundation Events

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Introduction/Background

Understanding and predicting patterns of forest succession in floodplains is difficult due to the fact that they are strongly influenced by patterns of disturbance, which are often stochastic in nature. Flooding is the most common disturbance event on floodplains and often determines the distribution of forest species and communities with only slight changes in elevation (Bedringer, 1978; Streng et al., 1989; Yin et al., 2009; De Jager et al., 2012). The degree to which flooding influences tree survival is a function of how different species and size classes can tolerate differences in flood frequency, duration, intensity, and timing (Figure 1). Most floodplain trees are adapted to survive moderate frequency, moderate intensity and short duration flooding when it occurs between late summer and early spring during plant dormancy (Johnson and Bell, 1976; Yin, 1998). Tree mortality increases with flood frequency, intensity, or duration and when flooding occurs during the growing season, particularly for smaller size classes (Kozlowski, 1984; Cosgriff et al., 2007; Yin et al., 2009). Infrequent, large-intensity flooding is generally considered natural and may actually be a driving force of organism distribution and development, community and successional patterns, and even the recruitment of new tree cohorts required for forest sustainability at the landscape level (Duncan, 1993; Turner and Dale 1998). A recent large scale flood disturbance event in 2019 has provided an opportunity to better understand how differences in major flood attributes may impact tree survivorship and resulting forest community dynamics.

The 2019 flood was one of record for many of the river reaches of the UMRS. It was very similar in intensity, duration and timing as the 1993 flood event on the UMRS, for which forest mortality and species recruitment has been well documented (Yin, 1994; Yin 1998; Cosgriff et al., 2007; Yin et al., 2009). The intensity and duration of the 1993 flood was higher in the lower reaches of the UMRS and consequently forest mortality also increased in the lower reaches. Mortality approached 50% in Pool 26 and was negligible in Pool 4 (Table 1). Examination of 2019 hydrographs of Pools 4, 8, 22, and 26 shows that there are some unique differences between the two large scale flood events (Figure 2). River stages during the 2019 event were relatively higher earlier in the growing season and extended longer in duration than the 1993 event in the upper two reaches. The 2019 event was similar in duration and intensity as the 1993 event in the lower two reaches, but timing varied somewhat with the 1993 event cresting later in the growing season. Personal observation from USACE foresters following the 2019 event indicates higher mortality in the middle and upper reaches of the UMRS and much lower mortality in the lower reaches. Thus, the 2019 flood event provides a unique opportunity to understand how multiple large flood events shape floodplain forests across the UMRS floodplain spatially and temporally. We plan on using the same forest inventory sites and sampling protocol used in the 1993 flood study. This will allow us to directly compare the effects of two similar, but uniquely different events that had significantly different outcomes in forest survivorship.

Project Objectives

We propose to conduct a forest study examining the effects of the 2019 flood event in 8 reaches of the UMRS to:

1) Examine forest responses to two different large scale flood disturbance events at eight reaches of the UMRS by using the same inventory sites and protocol used in a 1993 flood study
2) Identify forest successional patterns following large scale flood disturbance events by examining and comparing survivorship following the 1993 and 2019 flood events
3) Predict individual species and community susceptibility to varying degrees of inundation expressed in the 1993 and 2019 flood events
4) Identify and compare regeneration patterns, including species invasions, following the 1993 and 2019 large-scale flood disturbances
5) Allow managers to make better decisions regarding forest structure and composition with what appears to be a change in flood intensity, duration and frequency

Relevance of Research to UMRR

The uniqueness of the 2019 flood event provides the opportunity to enhance our understanding of variance in large scale flood disturbance events and impact on forest dynamics at the cohort, species, community, and landscape levels. These events can be considered a driving force of organism, community and landscape successional patterns and can impact floodplain habitat composition and distribution across extended time scales. There is growing concern among the natural resource management agencies of the UMRS regarding forest loss across large portions of the floodplain landscape (Guyon et al. 2012, McCain et al. 2018). Yet there are also significant gaps in our understanding of how forests respond to large disturbance events, especially in the face of other global change drivers, such as invasive species (De Jager et al. 2013). Results from this study will help us quantify the degree to which large magnitude flood events contribute to forest loss, changes in species composition, and or invasion by non-native species. This information can subsequently be used to identify whether and where forest restorations could be most beneficial as part of future Habitat Needs Assessments (Theiling et al. 2000, McCain et al. 2018) and project-level planning of geomorphic features and species plantings.

Finally, while the primary purpose of this study will be to assess forest responses to large magnitude flood events, the data will be collected in a way that will support future analyses to help us better quantify species and size specific flood tolerance. Such analyses should help to better quantify the degree to which different species and age classes can tolerate different aspects of inundation (frequency, magnitude, timing, duration), thereby improving existing forecasting models for use at system (e.g., De Jager et al. 2019) and HREP scales.

This project will address the following two Focal Areas:
Focal Area 2.6 Understand, quantify, and simulate patterns of floodplain inundation in the UMRS.
Focal Area 2.7 Simulate floodplain vegetation dynamics and understand relationships among flood inundation, vegetation patterns, and soil nutrient dynamics.

Methods

Study Area

The UMRS includes the stretch of the Mississippi River from the confluence with the Ohio River near Cairo, Illinois, northward to the headwaters at Lake Itasca, Minnesota. It also includes the Illinois River, which merges with the Mississippi River approximately 218 miles upriver from the Mississippi-Ohio Rivers confluence, near St. Louis, Missouri; and navigable portions of the Kaskaskia, Black, St. Croix, and Minnesota Rivers. Sampling protocol and site locations will follow the 1993 flood study conducted in 1995 so that we can make direct comparisons between the two events. The study area included floodplain forests along the Mississippi and Illinois Rivers in eight different reaches; Pools 4, 8, 13, 17, 22, 26, Open River on the Mississippi River and LaGrange Reach on the Illinois River.

Sampling Methods

Forty-five plots will be selected in each of the eight river reaches from the original 1993 study and will be sampled during the growing season of 2021. A global positioning system (GPS) will be utilized to get as close to the original sites as possible. It is recognized that the error in GPS units during establishment of the original sites is considerable compared to modern GPS units and that the posts used to permanently mark site locations may be missing. If necessary, original plot data and newer geospatial layers will be utilized to establish the new plot in a forest community similar to the original. At each plot a 314 m^2 (10 meter radius) circular plot will be established. Taxonomic name, diameter at breast height (dbh) and vigor of each tree greater than 2.5 cm within the plot will be recorded. Vigor is defined as dead prior to 2019, dead after 2019, stressed, and currently vigorous.

Species importance values (IV) will be used to identify changes in species composition pre- and post- flood. IV's will be calculated by summing species relative density (trees/hectare), dominance (basal area) and frequency of occurrence (measure of distribution across floodplain).

Canopy Cover

Vegetation cover will be stratified and visually estimated at each quadrat (see below) to determine gap creation. The strata includes canopy (trees), subcanopy (saplings), overstory (combination of trees and saplings), understory (seedling and herbaceous cover), and total (combination of all strata) cover estimates.

Seedling and Herbaceous Measures

Within each plot, ten .25 m^2 (.5 m x .5 m) quadrats will be randomly established. Each woody seedling (<2.5 cm dbh) within the quadrat will be identified, height measured and age approximated. Herbaceous species will be measured within each plot through percent cover estimates.

Data Analysis

Our data analyses will aim to examine and compare forest responses to two different large-scale flood disturbance events at eight reaches of the UMRS. To identify forest successional patterns, we will compare forest community indices (e.g., diversity, multivariate species composition indices) among a) pre-1993 flood conditions, b) post-1993 flood conditions, c) pre-2019 flood conditions, and d) post-2019 flood conditions. These analyses will be conducted at plot, pool, and system (all pools) scales to identify patterns of forest succession in response to multiple disturbance events. To predict individual species and community susceptibility to varying degrees of inundation, we will conduct species-level analyses of survivorship at plot, pool, and system scales. Finally, we will identify regeneration patterns, including species invasions, by examining the seedling and herbaceous vegetation at plot, pool, and system scales.

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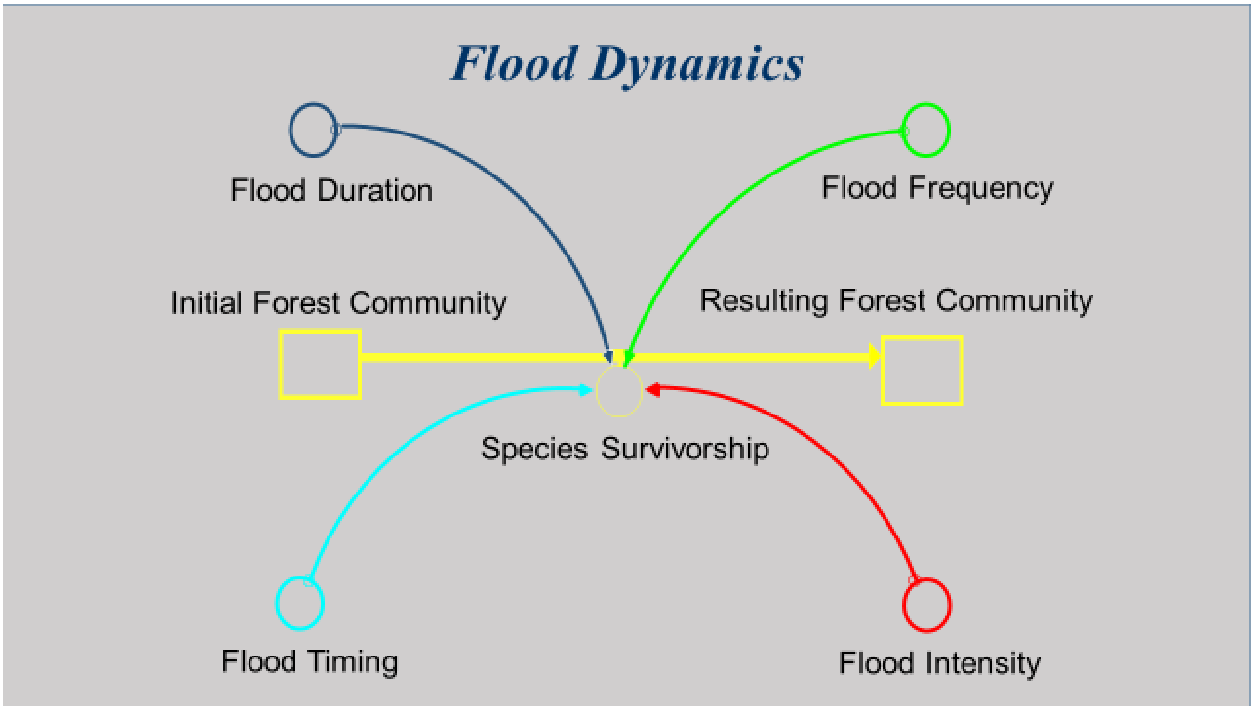


Figure 1. Conceptual model of dynamic flood variables and impact on forest distribution.

Table 1. Forest mortality following the 1993 flood on eight studies reaches of the UMRS.

River Pool 1995	**% Alive**	**% Dead**	**% Stressed**	**N**
4	85.51	7.56	6.93	2858
8	84.21	9.39	6.4	2470
13	80.53	9.84	9.55	2398
17	58.03	32.83	9.14	853
22	55.8	38.27	5.94	1061
26	47.9	47.86	4.24	2501
Open River	61.55	33.53	4.92	671
LaGrange IL	60.17	32.62	7.21	1082

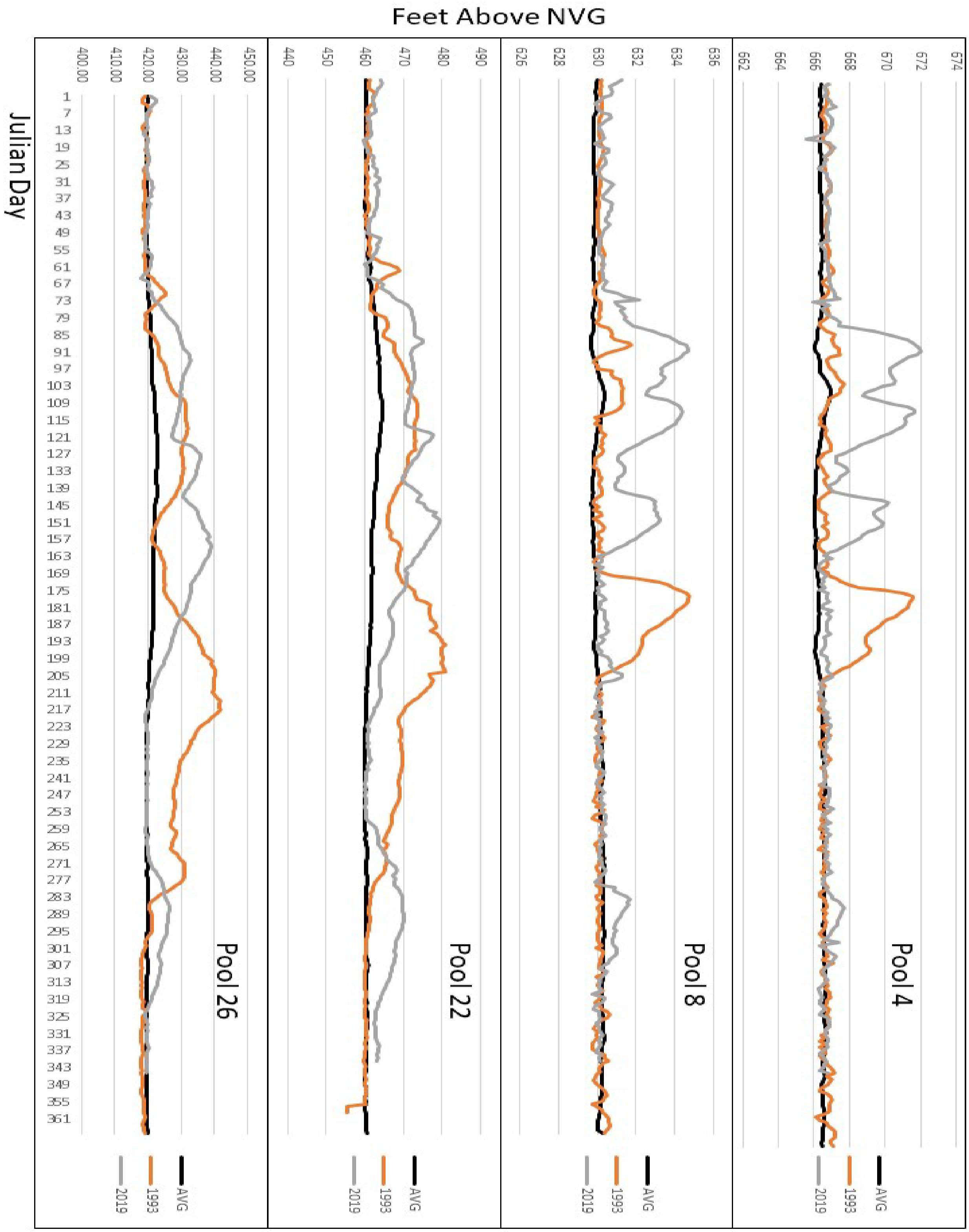
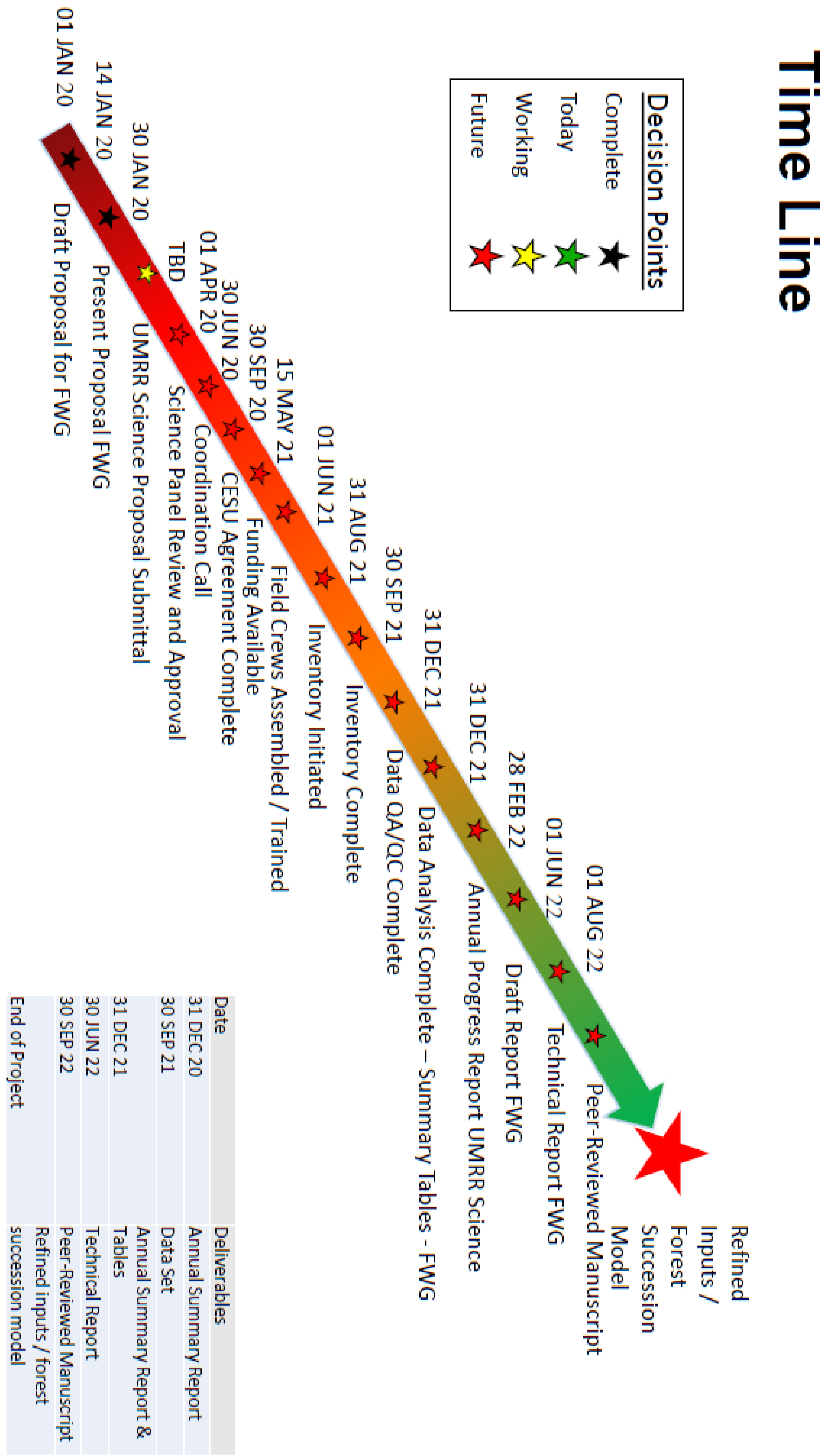


Figure 2. Hydrographs for four reaches of the UMRS comparing the 1993 and 2019 flood events.

Timeline:



Date	Deliverables
31 DEC 20	Annual Summary Report
30 SEP 21	Data Set
31 DEC 21	Annual Summary Report & Tables
30 JUN 22	Technical Report
30 SEP 22	Peer-Reviewed Manuscript
End of Project	Refined inputs / forest succession model

Expected milestones and products:

Funding for this project will be used to collect forestry data and develop a large data set. In addition, this project will develop summary results tables and figures and a technical report. In the future, a peer-reviewed manuscript and refinement of inputs to a forest successional model are planned. While we consider those efforts to be a part of this project, funding is only being requested at this time for data collection, analysis, and technical report writing.

Date	Deliverables	Project
31 DEC 20	Annual Summary Report	Present
30 SEP 21	Data Set	Present
31 DEC 21	Annual Summary Reports & Tables	Present
01 JUN 22	Technical Report	Present
01 AUG 22	Peer-Reviewed Manuscript	Future
End of project	Refined inputs / forest succession model	Future

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

Tracking number	Milestone	Original Target Date	Modified Target Date	Comments	Lead
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, Henderson, Rogala, Erwin, Sawyer, Strange
2019CM5	Submit draft LTRM Completion report on hydrogeomorphic conceptual model and hierarchical classification system	31-Dec-2019	30-Mar-2020		Fitzpatrick, Henderson, Rogala, Erwin, Sawyer, Strange
2019CM6	Submit Final LTRM Completion report on hydrogeomorphic conceptual model and hierarchical classification system	30-Jun-2020			Fitzpatrick, Henderson, Rogala, Erwin, Sawyer, Strange
Develop a better understanding of geomorphic changes through repeated measurement of bed elevation and overlay of land cover data					
Determine geomorphic changes in selected side channels of selected reaches using hydroacoustics					
2019GC3	Submit draft LTRM Completion report	1-Mar-2020			Rogala, Stone
Establish a network of transects in backwaters to measure sedimentation					
2019GC6	Complete setting monuments and surveying remaining transects	30-Sep-2020			Kalas
2019GC7	Complete database for all transects.	30-Sep-2020			Kalas
Determine recent planform changes using UMRR LCU datasets					
Water Exchange Rates and Change in UMRS Channels and Backwaters, 1980 to Present					
2019WE1	Data Analysis	31-Mar-2019	30-Jun-2020	Delayed due to continuous flooding and high water along with other priorities	Hendrickson
2019WE2	Base Maps of Discharge Measurement Location	31-May-2019	30-Jun-2020		Le Claire
2019WE3	Submit draft LTRM Completion Report	30-Sep-2019			Hendrickson
2019WE4	Submit Final LTRM Completion Report	30-Mar-2020			Hendrickson
Intrinsic and extrinsic regulation of water clarity over a 950-km longitudinal gradient of the UMRS					
2019IE3	Submit Draft manuscript	30-Mar-2020			Drake, Carhart and others
2019IE4	Submit Final manuscript	30-Dec-2020			Drake, Carhart and others
Effectiveness of Long Term Resource Monitoring vegetation data to quantify waterfowl habitat quality					
2019WF7	Conduct final analyses, submit draft LTRM Completion report	30-May-2020			Schmidt, Straub, Schultz
2019WF8	Submit Final LTRM Completion Report	30-Sep-2020			Schmidt, Straub, Schultz
Understanding constraints on submersed vegetation distribution in the UMRS: the role of water level fluctuations and clarity					
2019FM2	Explore existing (and perhaps create additional?) geomorphic indices within the aquatic areas data set that may influence mussel assemblages and begin assessing patterns in mussel assemblages across a gradient of geomorphic conditions in existing data (Pools 3, 5, 6, and 18)	30-Sep-2019	9/30/2020 (will now include all pools)	Delayed since lead technician who was to perform most of the analyses took a new position; new hire in place (Jan.	Jim Rogala, Jason Rohweder, Teresa Newton
2019FM4	Annual progress summary	30-Dec-2019	15-Feb-2020		Teresa Newton
2019FM5	Calculate pool-wide population estimates of native mussels in Pools 8 and 13, finish assessing patterns in mussel assemblages across a gradient of geomorphic indices (all pools), begin conducting statistical analyses	30-Sep-2020	30-Sep-2021		Jason Rohweder, Teresa Newton, Catherine Murphy
2019FM6	Annual progress summary	30-Dec-2020	30-Dec-2021		Teresa Newton
2019FM7	Complete statistical analyses and prepare geospatial maps	30-Sep-2021	30-Sep-2022		Teresa Newton, Catherine Murphy, 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					
2019DD1	Annual progress summary	31-Dec-2018			Dr. Harley, Dr. Maxwell, MS students, Ben Vandermyde
2019DD2	Data collection	30-Nov-2018		Sample size low due to high water levels	Dr. Harley, Dr. Maxwell, MS students, Ben Vandermyde, Robert Cosgriff
2019DD3	Growth-ring chronologies and forest vegetation demographic and biophysical data	31-Jul-2019			Dr. Harley, MS students
2019DD4	Plot-level 3-dimensional subsurface floodplain sedimentation maps for each study site	31-Jul-2019			Dr. Maxwell, MS students
2019DD5	Annual progress summary	31-Dec-2019			Dr. Harley, Dr. Maxwell, MS students, Ben Vandermyde
2019DD6	Baseline dataset for promoting resilience of hard mast forest communities along the UMRS	30-Jun-2020	Delay in field work data collection has significantly altered the anticipated time		Dr. Harley, Dr. Maxwell, MS students
2019DD7	Submit draft manuscript	30-Sep-2020			Dr. Harley, Dr. Maxwell, MS students
Forest canopy gap dynamics: quantifying forest gaps and understanding gap – level forest regeneration					
2019FG5	Submit draft LTRM Completion Report	30-Sep-2020			Guyon, Thomsen, Meier, Strassman
2019FG6	Baseline dataset complete	30-Sep-2020			Guyon, Thomsen, Meier, Strassman, DeJager
2019FG7	Submit draft manuscript	30-Sep-2021			Guyon, Thomsen, Meier, Strassman, DeJager
Investigating vital rate drivers of UMRS fishes to support management and restoration					
2019VR6	Data collection will occur during regular LTRM fish field sampling	15-Oct-2020			LTRM Fish Component Leads
2019VR7	Annual progress summary	31-Dec-2020			Andy Bartels, Kristen Bouska, Quinton Phelps, Greg Whitledge
2019VR8	Data set complete (data delivered to Ben Schlifer, physical structures delivered to BRWFS)	30-Sep-2021			Quinton Phelps
2019VR9	Submit draft manuscript (Vital rates)	31-Dec-2021			Quinton Phelps, Kristen Bouska
2019VR10	Submit draft manuscript (Drivers of vital rates)	31-Dec-2021			Quinton Phelps, Kristen Bouska
2019VR11	Submit draft manuscript (Microchemistry)	31-Dec-2021			Greg Whitledge

FY19 Funded Science in Support of Restoration and Management Proposals

Tracking number	Milestone	Original Target Date	Modified Target Date	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					
2019epm1	Progress Report	30-Dec-2019	Postponed due to high water		Chick and McGuire
2019epm2	Progress Report	30-Dec-2020			Chick and McGuire
2019epm3	Draft LTRM Completion	30-Jun-2021			Chick and McGuire
2019epm4	Final LTRM Completion	30-Dec-2021			Chick and McGuire
Combining genetics, otolith microchemistry, and vital rate estimation to inform restoration and management of fish populations in the UMRS					
2019gen2	Progress Report	30-Dec-2020			Larson, Bartels, Bouska
2019gen3	Draft Manuscript	30-Dec-2021			Larson, Bartels, Bouska
Reforesting UMRS forest canopy openings occupied by invasive species					
2019ref2	Progress Report	30-Dec-2020			Guyon and Cosgriff
2019ref3	Draft LTRM Completion	30-Apr-2021			Guyon and Cosgriff
2019ref4	Final LTRM Completion	30-Sep-2021			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			Sobotka and Fulgoni
2019zoo3	Final LTRM Completion report on utility of zooplankton community monitoring for HREP assessment	30-Jun-2021			Sobotka and Fulgoni
2019zoo4	Draft 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-Dec-2020			Sobotka and Fulgoni
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			Sobotka and Fulgoni
The Role of Large Wood in The Restoration of Habitat in the Upper Mississippi River System					
2019LW2	Draft LTRM Completion Report	31-Dec-2020			Thomsen, Jankowski
2019LW3	Final LTRM Completion Report	30-Apr-2021			Thomsen, Jankowski

Illinois Water Way Navigation Closure Study Funded Science in Support of Restoration and Management Proposals

Tracking number	Milestone	Original Target Date	Modified Target Date	Date Completed	Comments	Lead
FY19 Funded Illinois Waterway 2020 Lock Closure						
Aquatic Vegetation: Navigation Closure Study						
2020SAV1	Field sampling - during lock closure	30-Aug-2020		Cancelled due to Covid-19 travel restrictions		Lund, Drake, Bales, others
2020SAV2	Progress Summary	30-Dec-2020				Lund, Drake, Bales
Pre- and Post-Maintenance Aerial Imagery for Illinois River's Alton through Brandon Lock and Dams, 2019-2021.						
XXXX	Acquire 4-band aerial imagery 2020	See 2020LCU1				Lubinski, Robinson, Finley, and Hop
Fish Community Response to the 2020 Illinois Waterway Lock Closure						
2020FSH1	Field sampling - during lock closure	30-Oct-2020				Lamer and Solomon
2020FSH2	Progress Summary	30-Dec-2020				Lamer and Solomon
Water Clarity and the IWW Lock Closures						
2020WC1	Background data collection on barge -driven wave action and sediment suspension	30-Dec-2020				Jankowski (collaborating with Fish and SAV studies)
2020WC2	Spatial survey of phytoplankton biomass	30-Dec-2020				Jankowski (collaborating with Fish and SAV studies)