FY2022 UMRR Science Proposals
Recommended for Funding

Listed below are four proposals recommended by the UMRR LTRM management team for FY2022 Science in Support of Restoration and Management funding. These recommendations are based on assessments of the proposals by the A-Team (representatives of MN, WI, IA, IL, MO, and USFWS), USGS UMESC, and USACE. There were a total of 13 proposals developed following the FY22 UMRR Science Meeting. The criteria used to assess the proposals are provided at the end of this document.

Proposals not funded in FY2022 may be reconsidered in FY2023 pending an assessment of current information needs, available funding, and adequate revisions to address questions and concerns raised during the 2022 review process. These proposals address important topics but were not judged to be of higher priority than any of the recommended proposals and may need revision to be re-considered for funding.

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

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

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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). There is evidence that climatic changes in precipitation regimes interact with land use changes to contribute to shifts in the hydrologic regime (Zhang and Schilling 2006). Increases in the frequency and intensity of precipitation events (Zhang and Villarini 2021), flooding (Mallakpour and Villarini 2015), and baseflow (Ayers et al. 2019) have been observed across the Midwest in recent decades. Similar observations have been made specifically for the UMRS where recent episodes of longer duration spring events and late season flood events and increases in average annual discharges (Van Appledorn, *in review*) raise questions about the potential for such conditions to be the "new normal," how such conditions may influence biota and habitats of the UMRS, and how best to design and implement resilient management actions.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

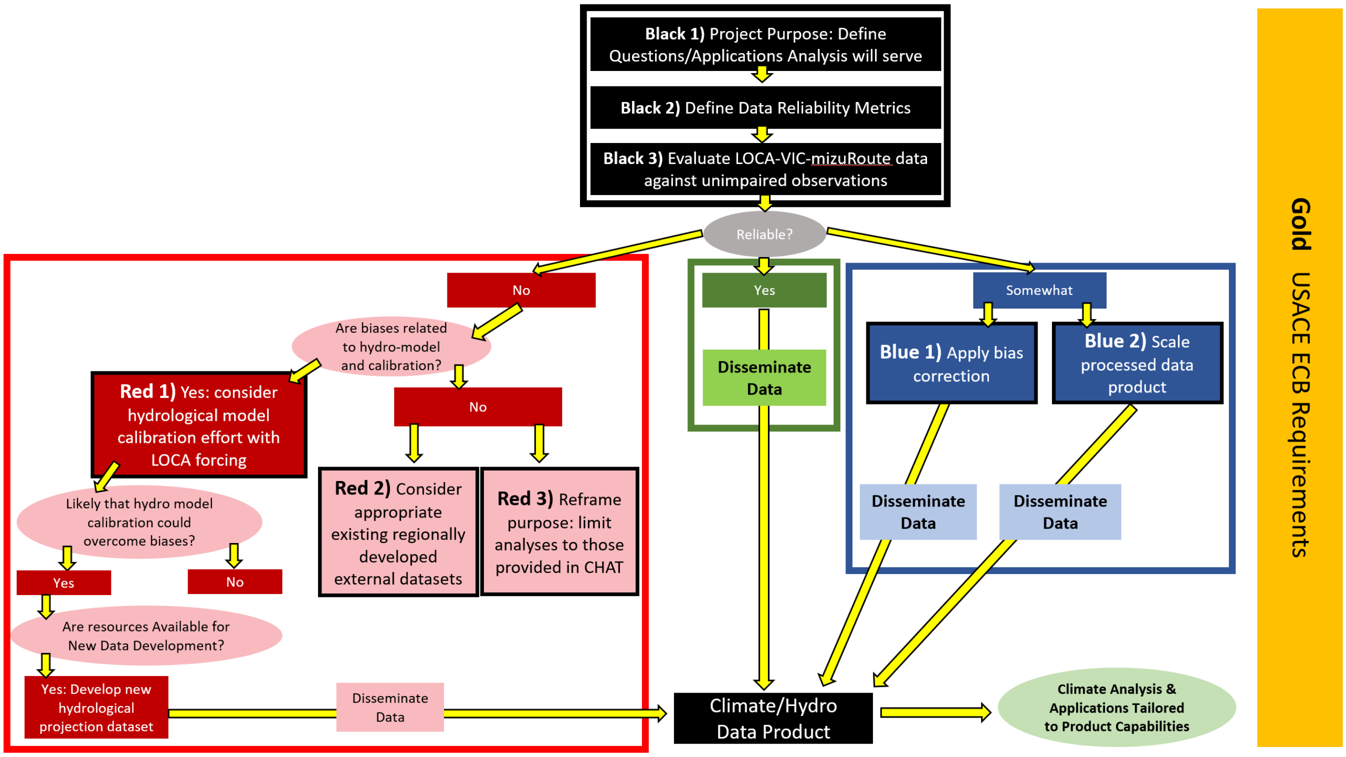

Figure 1: Workflow process for evaluating the LOCA-VIC-mizuRoute data products. Boxes are color coded to represent related sequences of activities described in the methods ("pathways").

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

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

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

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

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

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

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

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

Blue pathway
The blue pathway would be followed in the event the LOCA-VIC-mizuRoute data products were found to adequately represent the hydrological processes in the UMRS but still display some systematic underlying biases that would limit the intended interpretations and applications. In this pathway, the effects of these systematic

biases could be reduced by applying a bias-correction technique or scaling the intended applications of the processed data product.

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

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

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

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

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

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

Gold box
"Gold" (Fig. 1) represents fulfillment of ECB-2018-14, "Guidelines for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects," requirements and would begin in advance of or concurrent with the LOCA-VIC-mizuRoute evaluation ("Black 3," Fig. 1). This effort involves coordination with the Climate Preparedness and Resilience Community of Practice (CPR CoP), which has been ongoing and was initiated during the early scoping of the UMRR Future Hydrology Meeting Series. The qualitative assessment of climate change required by ECB-2018-14 will be conducted by a PI and includes a literature review of observed and projected trends in climate change, trend analysis and nonstationarity detection in observed hydrology and relevant climate variables. The CHAT will be used to evaluate trends in the projected annual maximum of average-monthly streamflow at the 8-digit HUC scale for the Upper Mississippi River (HUC 07) and Missouri River (HUC 10) watersheds and a watershed vulnerability assessment will be conducted at the 4-digit HUC scale using

the Vulnerability Assessment Tool (VAT). Recent qualitative assessments completed for both the Upper Mississippi River and Missouri River Flow Frequency updates will be leveraged to support the qualitative assessment proposed herein. As a result of this existing body of work, the primary focus of this effort will be to provide consistency, particularly in the use of the CHAT tool, between the Mississippi River and Missouri River analyses that were conducted independently. Updates to the vulnerability assessment will be required for the Ecosystem Restoration business line.

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

Special needs/considerations, if any: None.

Timeline: Project will initiate in Q4 of FY22 with the bulk of research activities occurring in FY23. Research activities will be completed in FY24. Any remaining duties related to manuscript publication is expected in FY25, pending journal peer review timelines. Please note that the initiation of evaluation steps ("Black 3," Fig. 1) is dependent on obtaining unaltered flow records from a separate USACE study currently underway. See Appendix A for a detailed project timeline.

Expected milestones and products [with completion dates]:

Milestones and products	Date*
LOCA-VIC-mizuRoute data product evaluation	31 March 2023
LTRM project management team update on evaluation results	31 March 2023
ECB 2018-14 compliance completion	30 June 2023
Annual update: Year 1	30 Sept 2023
UMRS projected hydrology data and documentation release	30 June 2024
UMRR webinar on UMRS projected hydrology data release	30 Sept 2024
Virtual workshop or LTRM project team update for red pathway outcomes	31 Dec 2023
Draft LTRM completion report	30 June 2024
Final LTRM completion report	30 Sept 2024
Draft manuscript	30 Sept 2024
Final manuscript publication	30 Sept 2025

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

References

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Appendix A.

Below is a detailed timeline for all proposed research activities. Note that not all activities will be undertaken as part of this project, as the outcome of the LOCA-VIC-mizuRoute evaluation (black boxes, Fig. 1) will determine whether the green, blue, or red pathways will be followed, and which options will be followed within the blue or red pathways. Pathways are exclusive of each other. Main pathway options are noted in the "Pathway" column; options within the blue and red pathways are labeled within the "TASK" description by the Figure 1 pathway box name (e.g., "Blue 1").

		FY22	FY23				FY24				FY25			
TASK	**Pathway**	**4 Q**	**1 Q**	**2 Q**	**3 Q**	**4 Q**	**1 Q**	**2 Q**	**3 Q**	**4 Q**	**1 Q**	**2 Q**	**3 Q**	**4 Q**
Define questions & applications (Black 1)	**Black**	■	■											
Define data reliability metrics (Black 2)	**Black**		■											
Evaluate LOCA-VIC-mizuRoute data (Black 3)	**Black**		■	■										
Share evaluation results with LTRM project management team	**Black**		■	■										
Initial scoping with CPR CoP coordination	**Gold**		■	■										
Literature review and data compilation	**Gold**		■	■										
ECB-2018-14 draft report	**Gold**		■	■										
ECB-2018-14 review and completion	**Gold**			■	■									
Draft data documentation materials	**Green**				■									
Website construction	**Green**				■	■								
Data & documentation release	**Green**					■	■							
UMRR webinar	**Green**							■						
Apply systemtic bias correction (Blue 1)	**Blue**				■	■	■							
Scale processed data product (Blue 2)	**Blue**				■	■	■							
Document bias correction / scale processed data	**Blue**				■	■	■							
Draft data documentation materials	**Blue**					■	■	■						
Website construction	**Blue**					■	■							
Data & documentation release	**Blue**								■					
UMRR webinar	**Blue**									■				
Evaluate whether improved VIC model calibration can overcome biases (Red 1)	**Red**				■	■								
Scoping workshop for hydrologic modeling (Red 1)	**Red**						■							
Identify and screen regional data products (Red 2)	**Red**				■									
Evaluation of regional data products (Red 2)	**Red**					■	■							
Share evaluation results with LTRM project management team (Red 2)	**Red**						■							
Workshop on reframed project purpose and CHAT tools (Red 3)	**Red**					■								
Annual Report						■								
Draft LTRM completion report									■					
Final LTRM completion report										■				
Draft manuscript									■	■				
Final manuscript										■	■	■	■	■

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

Previous LTRM project: None

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

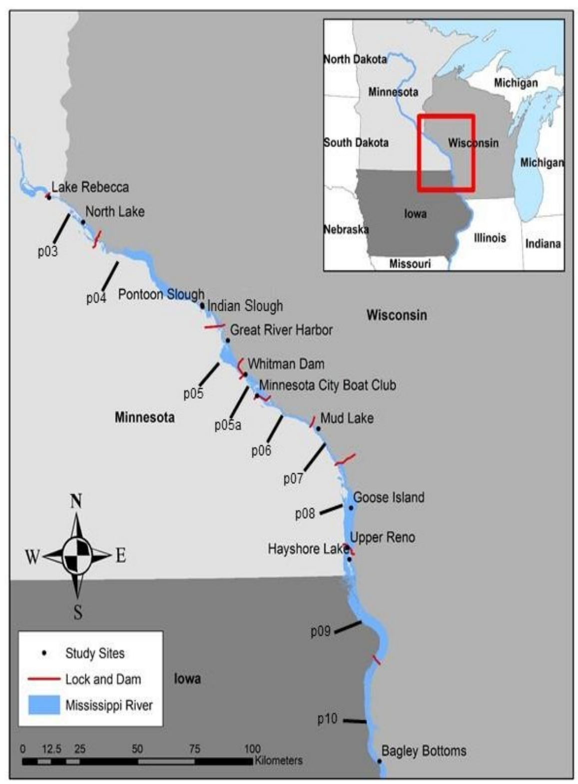

Figure 1: Location of study sites (black dots), locks and dams (red lines), and navigation pools (p03-p10) within the St. Paul District section of the UMR.

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

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

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

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

Dendrochronology – New Data Analysis for Proposed Study

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

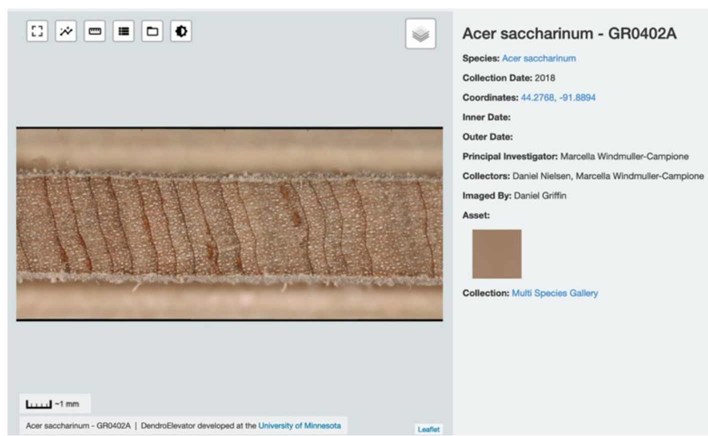

Figure 2. Example of processed tree cores that are scanned and measurements occur within an open source software platform allowing for more flexibility, quality control, and greater ability to share results across institutions, disciplines, and organizations

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

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

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

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

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

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

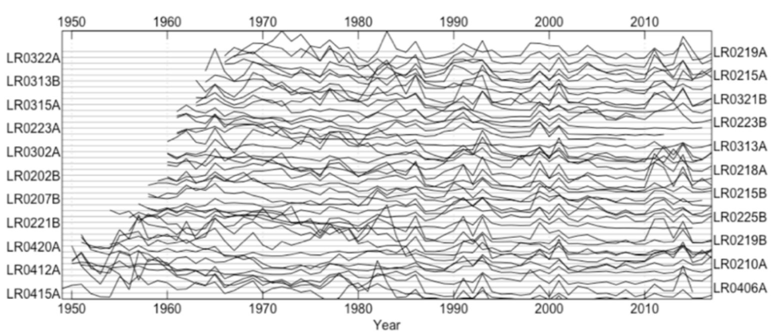

Figure 2. Ring-width chronologies for silver maple at Lake Rebecca in Pool 3. Each line represents an individual tree and the height of the line indicates the amount of annual growth (from Crawford et al. 2020).

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Special needs/considerations, if any: none

Timeline: Proposed period of performance dates are 1 Oct 2022 - 31 Sept 2024. There are no constraints in beginning this work since data are already collected.

Expected milestones and products [with completion dates]:
Project year 1 (1 October 2022 – 31 September 2023)

- Begin undergraduate training in scanning of cores – completed by 15 October 2022
    - Prioritization of cores for processing will be developed by the PIs and collaborators on the project to ensure that the post-doc can begin analysis while undergraduate students are scanning
- Hire post-doc through the U of MN – completed by 1 November 2022
    - Post-doc will begin expanding the work of the preliminary analysis completed for Lake Rebecca
    - They will focus developing histograms of age data across sites and species and developing the analytical tools for more complex analyses using the preliminary dataset

    - As noted above, the prioritization of processing will allow them to simultaneously work on analysis
- Finalize the scanning of 1,100 tree cores uploaded into DendroElavator by 31 September 2023

Project year 2 (1 October 2023 – 31 September 2024)

- Begin analysis linking tree growth with environmental variables (1 October 2023)
- Presentation of results at local, regional, and national conference (on going throughout Project year 2)
- Summerization of key data for management meetings (1 January 2024)
    - Coordination and scheduling for three to five virtual meetings (1 Febuary – 30 April 2024)
        - Meetings with address current objectives outlined in Activity 3 and future direction
- Submission of Paper 1 – Age data of floodplain forests of the Upper Mississippi River (15 January 2024)
    - Prior to submission data stored on the DRUM
- Submission of Paper 2 – Growth Dynamics of Silver Maple of the Upper Mississippi River (31 July 2024)
    - Prior to submission data stored on the DRUM
- Final report writing, edits on manuscript, and completed all storage of data (31 September 2024)

References

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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Introduction/Background:

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

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

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

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

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

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

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

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

Primary objectives include:

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

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

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

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

Relevance of research to UMRR:

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

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

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

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

Methods:

Benthic sampling:

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

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

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

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

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

Rock bag samplers:

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

Screening level mayfly tissue analysis:

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

Data management procedures

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

Special needs/considerations, if any:

Funding for annual salary and benefits of one postdoctoral researcher and two-technicians will be

required for field and laboratory processing of samples, analysis of data, project coordination, and writing. Funding would also be needed for laboratory supplies outlined by Theil and Sauer (1999), travel expenses, publication costs and consulting fees for species-level identification during the first year of the project. Contracted work through Rithron or UW-La Crosse can be established through purchase order or subaward through University of Illinois. (See attached budget for details)

Field station in-kind commitments:

MNDNR – 2 people at 200 hours each
WIDNR – 1 person at 200 hours
IADNR – 2 people at 200 hours each
INHS GRFS – 2 people at 200 hours each
INHS IRBS – 3 people at 200 hours each
MDC – 2 people at 200 hours each

Timeline:

April 1- June 14, 2023-2025: Field collection of macroinvertebrates following established protocols outlined by Theil and Sauer (1999) and McCain et al. (2015).

July 1- April 30, 2023-2025: Laboratory identification of any macroinvertebrates. This would include sending specimens for expert identification and verification.

July 2023-September 26, 2025: Data analysis and completion of, at minimum, draft LTRM completion report. Peer reviewed publication to be pursued at discretion of PI, collaborators, and UMRR personnel.

Expected milestones and products [with completion dates]:
A UMRR LTRM completion report is expected from data collected and analyzed by this project, and completion of a draft of this report is expected by September of 2026. In addition, results of this project will be presented at both state, local, and national conferences. Peer reviewed publications describing the differences in the macroinvertebrate community in response to environmental changes and those focusing on more targeted research objectives will be pursued from 2023-2025+. Data will also directly support the ongoing Resilience project by validating conceptual models developed and will be available to inform future resiliency efforts pursued by UMRR.

References

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

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

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

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

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

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

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

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

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

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

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

Thiel, P. A., and J. S. Sauer. 1999. Long Term Resource Monitoring Program procedures:

Macroinvertebrate monitoring. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, revised May 1999. LTRMP 95-P002-2 (Revised 1999). 9 pp. + Appendixes A–H.

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

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

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

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Introduction/Background:

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

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

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

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

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

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

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

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

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

Relevance of research to UMRR:

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

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

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

Methods:

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

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

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

*** Indicates samples funded by this proposal**

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

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

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

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

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

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

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

Data management procedures

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

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

Timeline:

	FY 22	FY23				FY24			
Task	Su	Fa	Wn	Sp	Su	Fa	Wn	Sp	Su
RQ1 – long-term trends in phytoplankton communities									
Samples to contractor	x	x							
Data analysis and writing			x	x	x				
Manuscript 1						x			
Data synthesis and metadata production		x	x	x					
Dataset publication					x				
RQ2 – FloCam methods development and comparison									
Sample collection and analysis			x	x					
Samples to contractor					x				
Data analysis and writing					x	x	x		

Expected milestones and products [with completion dates]:
This project will provide system-wide information about the composition, abundance, and trends in UMRS phytoplankton communities. We will place a particular focus on understanding the dynamics and drivers of potentially harmful species over time to inform future efforts aimed at managing HABs events. There currently is limited data at the system-scale to address and focus our HABs-related research and management efforts, a knowledge gap that this proposal and its expected products will help fill. In addition, this proposal will provide critical information on potential methods for more efficient sample and data processing for ongoing LTRM phytoplankton sampling. **The archive has outgrown its storage space and there is a critical need to decide on efficient, inexpensive processing techniques that inform current and future sampling efforts.** We will produce several products as a result of this effort.
Question 1: Long-term change in phytoplankton communities:

1) System-wide phytoplankton community dataset. We will generate and publish a dataset that merges existing data from previous projects with new community information generated by this project (Table 1). This dataset will be published on the LTRM website for public use.
2) Manuscripts. We will also generate a manuscript on one or both of the following topics: a) Phytoplankton community composition over the past 20 years in the Upper Mississippi River: distribution of harmful taxa and relationships with environmental trends, and b) Relating phytoplankton communities to distinct vegetation recovery trajectories in Pools 4 and 13

Question 2: Assessment of FloCam methods for characterizing phytoplankton communities in archived and newly collected LTRM phytoplankton samples

1) Report: Assessment of FloCam for use on archived and fresh phytoplankton samples for LTRM sampling
2) Manuscript: Comparison of trends captured by microscopy and FlowCam phytoplankton community analysis

References

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Estimated Budgets

Proposal title	PIs	USGS	USACE	States	CESU	Total Estimated Budget
Evaluating the LOCA-VIC-mizuRoute hydrology data products for scientific and management applications in the UMRS	Lucie Sawyer (USACE), Molly Van Appledorn (USGS UMESC), John Delaney (USGS UMESC)	$ 69,218	$ 321,310			$ 390,528
Putting LTRM's long-term phytoplankton archive to work to understand ecosystem transitions and improve methodological approaches	James Larson (USGS UMESC), KathiJo Jankowski (USGS UMESC), Madeline Magee (WDNR), Jessica Fulgoni (Kentucky Wesleyan College), Nicole Ward (MDNR), Ashley Johnson (IDNR)	$ 447,158				$ 447,158
Assessing long term changes and spatial patterns in macroinvertebrates through standardized long-term monitoring	Jim Lamer (INHS), Molly Sobotka (MDC), Levi Solomon (INHS), Kris Maxson (INHS), Shawn Giblin (WDNR), Scott Gritters (IDNR), Steve DeLain (MDNR), Ross Vander Vorste (UW-La Crosse)			$ 687,851		$ 687,851
Assessing Forest Development Processes and Pathways in Floodplain Forests along the Upper Mississippi River using Dendrochronology	Marcella Windmuller-Campione (University of Minnesota), Molly Van Appledorn (USGS UMESC), Andy Meier (USACE)	$ 4,518			$ 322,468	$ 326,986

UMRR SCIENCE PROPOSAL EVALUATION AND RANKING CRITERIA

Note that score for first criterion is double the weight of the subsequent three. Use only whole numbers for scoring (no decimals).

Total Score (sum of Scores 1 – 4):________ (enter this number (or the avg of this number across reviewers in your agency) on the Scoring Spreadsheet)

1. How important is the proposed activity to advancing knowledge and understanding needed for managing and restoring the UMRS**? Base your assessment of importance on how well the work address one or more 2020 Focal Areas.** Raw score (0 to 9): ________ X 2 =total score (0 to 18) _________[**Score 1**].

0	Not important – unlikely to contribute to our understanding of any focal areas.
1 - 3	Somewhat Important –will likely make a small contribution to our understanding of at least one focal area.
4 – 6	Important but could be addressed at any time. Expected to make a significant contribution to our understanding of one or more 2020 Focal Areas.
7 - 9	Very Important and should be addressed now. Expected to make a substantial contribution to our understanding of one or more 2020 Focal Areas and is addressing an urgent need or taking advantage of an unusual opportunity.

2. Are the study objectives clear and realistically achievable? That is, has the problem or question to be addressed been clearly identified and are the research questions or hypotheses clearly stated. Score (0 to 9): ___ [**Score 2**]

0	Objectives (including questions or hypotheses to be addressed) are poorly described or unlikely to be achieved.
1 – 3	Objectives (including questions or hypotheses) are clearly identified but it is unclear the extent to which the proposed work will achieve them; little significant new information is likely to be obtained
4 – 6	Objectives (including questions or hypotheses) are clearly identified and are likely to be at least partially achieved, such that some significant new information is likely to be obtained.
7 – 9	Objectives (including questions or hypotheses) are clearly identified and likely to be fully achieved such that substantial new information is expected to be obtained.

3. Are the methods clearly described? Do the PIs and collaborators have the necessary expertise to conduct the work? Will the methods produce the data or information required to get effectively address project objectives?
Score (0 to 9): ____ [**Score 3**]

0	Methods are not clearly stated
1 – 3	Methods are clearly stated, but are not likely to produce needed data/information
4 – 6	Methods are clearly stated, but unclear how well the results will address specified objectives
7 – 9	Methods are clearly stated and likely to effectively address specified objectives

4. What is the scale of the problem (even if tested or applied at a local scale)? Score (0 to 9): _______ [**Score 4**]

0	Local problem only
1 –3	Local problem with reach-wide generality or application
4 – 6	Reach-wide problem
7 – 9	Systemic problem, with great generality