ERDC SR-23-8

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Engineer Research and Development Center

Lowermost Mississippi River Management Program (LMRMP)

Real-Time Forecasting Model Development Work Plan

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September 2023

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Engineer Research and Development Center

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Final report

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Under CRADA C-2018-ERDC-2100-3, Amendment 3, “Research to Support Coastal and Lowermost Mississippi River Management”

Abstract

The objective of the Lowermost Mississippi River Management Program is to move the nation toward more holistic management of the lower reaches of the Mississippi River through the development and use of a science-based decision-making framework. There has been substantial investment in the last decade to develop multidimensional numerical models to evaluate the Lowermost Mississippi River (LMMR) hydrodynamics, sediment transport, and salinity dynamics. The focus of this work plan is to leverage the existing scientific knowledge and models to improve holistic management of the LMMR. Specifically, this work plan proposes the development of a real-time forecasting (RTF) system for water, sediment, and selected nutrients in the LMMR. The RTF system will help inform and guide the decision-making process for operating flood-control and sediment-diversion structures.

This work plan describes the primary components of the RTF system and their interactions. The work plan includes descriptions of the existing tools and numerical models that could be leveraged to develop this system together with a brief inventory of existing real-time data that could be used to validate the RTF system. A description of the tasks that would be required to develop and set up the RTF system is included together with an associated timeline.

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Preface

This work plan was conducted for the Louisiana Coastal Protection and Restoration Authority (CPRA) under Cooperative Research and Development Agreement C-2018-ERDC-2100-3, Amendment 3, “Research to Support Coastal and Lowermost Mississippi River Management.”

The work was performed by The Water Institute of the Gulf (the Institute) and the River and Estuarine Engineering Branch of the Flood and Storm Protection Division, US Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL). At the time of publication of this report, Mr. David P. May was chief, River and Estuarine Engineering Branch; Ms. Lauren Dunkin was acting chief, Flood and Storm Protection Division; and Dr. Julie Rosati was the technical director for Flood and Coastal Systems. The deputy director of ERDC-CHL was Mr. Keith Flowers, and the director was Dr. Ty V. Wamsley.

Additional input to this work plan was provided by Ms. Carol Parsons Richards and Dr. James Pahl (CPRA), Dr. James Lewis (Baird and Associates), Ms. Waleska Echevarria-Doyle (ERDC), Mr. Casey Mayne (ERDC), Ms. Alaina Grace (Royal Engineering), Ms. Mandy Green (Royal Engineering), Mr. Scott Mize (US Geological Survey [USGS]), Mr. Richard Rebich (USGS), Mr. Todd Baumann (USGS), Mr. Christopher Swarzenski (USGS), Dr. Shubhra Misra (previously at the Institute), and Ms. Sarah Charley Cameron (the Institute).

The report and all related items of information were prepared by the authors through a subcontract with the Louisiana CPRA, which was funded under Award No. GNTCP18LA0035 from the Gulf Coast Ecosystem Restoration Council (RESTORE Council). The data, statements, findings, conclusions, and recommendations are those of the author[s] and do not necessarily reflect any determinations, views, or policies of the RESTORE Council.

The commander of ERDC was COL Christian Patterson, and the director was Dr. David W. Pittman.

1 Introduction

1.1 Background

The Lowermost Mississippi River Management Program (LMRMP) is a large-scale program with the objective of moving the nation toward more holistic management of the lower reaches of the Mississippi River through the development and use of a science-based decision-making framework. Numerical and physical models are robust scientific tools that serve as a foundation for this framework along with focused observational data-collection efforts, as well as the synthesis and analysis of the large but underutilized abundance of historical river datasets. The United States Army Corps of Engineers (USACE) and the Louisiana Coastal Protection and Restoration Authority (CPRA) recently completed the Mississippi River Hydrodynamic and Delta Management Study (MRHDMS). The MRHDMS focused on developing a suite of multidimensional numerical models to evaluate the Lowermost Mississippi River (LMMR)[1] hydrodynamics, sediment transport, and salinity dynamics.

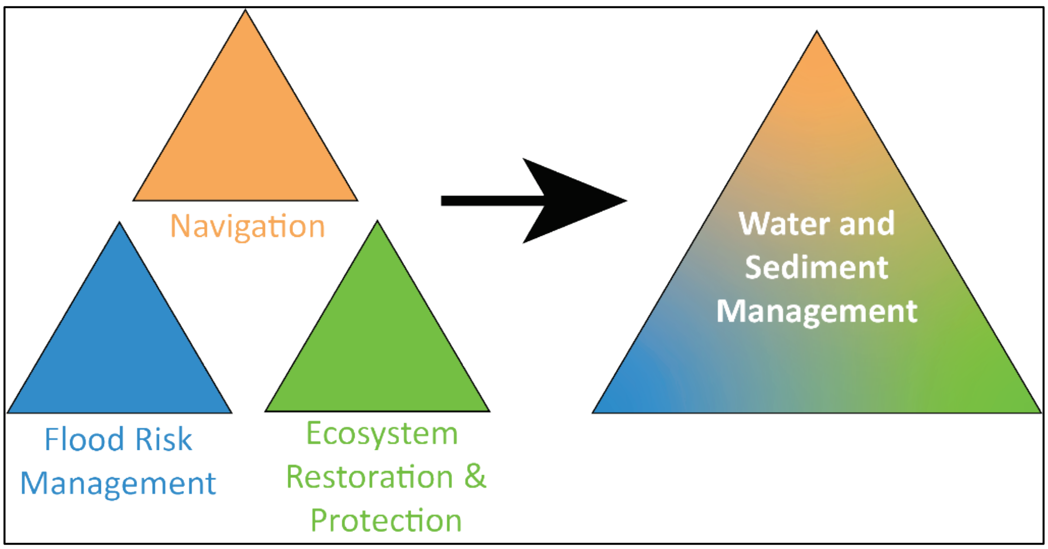
Currently, management of the LMMR is partitioned between federal and state entities with different missions and objectives. For instance, while the Operations Branch of USACE focuses on potential impacts on navigation and possible dredging to ensure the flow of commerce, missions within the same organization (e.g., Mississippi River flood control) focuses on flood-risk management and the protection of human life and infrastructure. Simultaneously, there is an increasing need for sediment resources for coastal wetland restoration to offset widespread land loss throughout the Mississippi River Delta Plain. These activities, and their resulting competing outcomes, demand coordination because they all aim to manage water and sediment. Thus, synergy around water and sediment management is essential to holistic management of the LMMR.

The aim of this work plan is to leverage improved scientific understanding acquired from MRHDMS along with numerical models developed in that study to improve holistic management of the LMMR. The proposed

1 This document uses the term Lowermost Mississippi River (LMMR) to refer to the portion of the river extending from just above Baton Rouge, Louisiana to the Gulf of Mexico. This is also the extent of the deep-draft navigation channel. The LMMR is the downstream portion of the Lower Mississippi River (LMR). The LMR extends from Cairo, Illinois to the Gulf of Mexico.

approach focuses on the standard elements of a large working river, such as dredging and navigation, flood control, and ecosystem health and considers additional elements such as delta restoration, storm-impact risk reduction, and sediment-diversion operations. The LMMR has multiple management elements, and those elements and their interdependence upon one another underscore the complexity of the system and highlight the importance of developing a range of scientific tools that can work in conjunction with one another to provide comprehensive management solutions and support informed decision-making (Figure 1).

Figure 1. Holistic management of the Lowermost Mississippi River (LMMR).



The LMRMP is composed of several subtasks, which correspond to different technical elements. While each subtask is focused, efforts are interrelated and designed to advance a science-based, holistic management philosophy. One of these technical elements is the development of a real-time forecasting (RTF) system for water, sediment, and selected nutrients in the LMMR. The RTF system would directly benefit sediment-diversion operations and maintenance-dredging operations in the LMMR. In addition, the RTF system could provide essential information to prepare for and respond to river flood events. The model output would inform and guide the decision-making process for operating flood-control structures and sediment-diversion structures. If needed and developed further, the RTF system may also report on various issues related to LMMR dynamics, such as estimating the timing and extent of the Gulf of Mexico hypoxic zone.

The scope of this report is to develop a work plan that describes the framework for the development and implementation of the RTF system.

1.2 What is a Real-Time Forecasting (RTF) System?

The primary goal of an RTF system is to anticipate, in real time, the magnitude and trend of a specific physical parameter (e.g., water level) or the likelihood of an event (e.g., flood) occurring within hours or days and the corresponding uncertainties related to these predictions. RTF systems can rely on maps, lookup tables, or more sophisticated tools such as numerical models that simulate specific parameters (e.g., water level, sediment load and concentration) or conditions (e.g., flooding and shoaling). These models, calibrated and validated using historical data outside of the RTF system framework, are used as the engine of an RTF system through connection to a digital platform able to run in real time using real-time data and external forecasts.

For this project, the goal is to forecast water levels, velocities, sediment transport, and selected nutrients within the LMMR. Therefore, this system would rely on hydrometeorological, oceanographic, sediment transport, and water-quality models and data.

In this report, the term *system* refers to the proposed RTF platform. The term *models* refers to the numerical tools used to simulate hydrodynamic, sediment transport, or nutrient dynamics. The model(s) is (are) part of the RTF system, but the system is an integrated robust platform that includes several additional components:

- Import of baseline, observation data, and external forecasts
  - A series of configuration scripts and codes (e.g., XML, bat, sh) would be configured to import data in real time from gages and monitoring stations, external weather forecasts (e.g., radar), and any additional data that may be important from a water-management perspective.
  - The imported data would be compiled and visualized within the RTF system's graphical interface, undergoing quality assurance and quality control using custom scripts to identify outliers or errors and preprocessed for use as input data for the numerical models (i.e., inputs, initial and boundary conditions). Displays and visualization products would be discussed and customized based on final users' requests and preferences.

- Numerical modeling
  - Numerical simulations would be performed using the selected models that are the engine of the RTF system, and the data downloaded at the previous step and used by the model.
  - Multiple models can be used in the RTF system, running in series if the output from one model is used as an input by another (e.g., output from a Hydrologic Engineering Center [HEC] Hydrologic Modeling System hydrologic model can be used as input for a HEC River Analysis [HEC-RAS] hydraulic model).
- Visualization of results
  - Model results generated in the previous step would be made available to the user via a graphical interface, dashboard, or a website.
  - Scripts and algorithms can be developed to offer optimal operational strategies under various scenarios and conditions.

This work plan provides details for these three core components of the RTF system.

1.3 Objectives

This report details a proposed RTF system for the LMMR. The work plan can serve as a template for CPRA and other organizations if funding becomes available to develop the RTF system.

1.4 Approach

The Water Institute of the Gulf (the Institute), USACE, CPRA, and the United States Geological Survey (USGS) collaborated to support the work plan development for an RTF system to inform LMMR management decisions. This was done through a series of virtual meetings that discussed data needs, desired model outputs, and available data and models. Personnel from the Institute and the USACE then used the information from these meetings to create the proposed work plan, including a summary of existing resources and potential timeline.

1.5 Purpose and Scope of the Proposed Lowermost Mississippi River (LMMR) RTF System

The proposed RTF system described in this work plan aims to provide 7- to 10-day forecasts of daily water stage and discharge, sediment concentration, and selected nutrient concentrations. In addition, this work plan explores modeling capacity to evaluate existing models' potential application as a component of the RTF system. The primary user of this RTF system would be CPRA. The system is envisioned to be applied in house by CPRA staff, and initially, it would be focused on in-river conditions to inform Mississippi River diversion operations.

A scaled-up version of the RTF system is envisioned for the future in which the system would inform other efforts and support users beyond CPRA; however, that is not the focus of this work plan. Instead, this work plan describes the framework for a standard RTF system and explores options to upgrade to a more robust and complex RTF system that supports CPRA's mission to provide integrated risk reduction and coastal wetland restoration.

This work plan describes the following steps toward development of the RTF system:

- Review of existing real-time data sources along the Mississippi River (from Memphis, Tennessee, to the Gulf of Mexico) to determine model boundaries, identify existing data gaps, and discuss how results would inform recommendations for additional data collection.
- Compilation of an inventory of existing models and forecasting tools, including developing pros, cons, and recommendations for each candidate model and how they can be leveraged and considered for the RTF engine.
- Development of tools and a series of automated scripts to download, in real time, available data from public platforms and existing atmospheric and meteorological forecasts. These data and external forecasts would be preprocessed and formatted as inputs, boundary conditions, and drivers for the numerical model(s). A user-friendly interface to visualize the model results and forecasts in real time would be developed or adopted and customized for the project.
- Assessment of existing meteorological, hydrologic-hydraulic, and oceanographic models and forecasts that could be leveraged to drive

the model(s) and provide a 7- to 10-day forecast for water discharge, sediment load, and select nutrient concentration.

Engagement with the identified user community (e.g., state and federal agencies and potentially semipublic and private organizations) would be conducted during the implementation of the work plan to solicit feedback towards refinement of the framework and products.

This work plan also includes a description of the implementation of the RTF system and its related timeline.

2 Domain and Model Resolution

The definition of the study area and the spatial and temporal resolution needed for the outputs are key components for the RTF system, recognizing that different resolutions (spatial and temporal) may be beneficial in different areas of the study domain.

- A lower temporal and spatial resolution for the Mississippi River is suggested with more refined resolution around the distributaries and other outlets where the water and sediment routing needs to be updated frequently and sufficiently accurate to inform flow and sediment distribution through the outlets and distributaries.
- Depending on the desired lead time of the forecast, the upstream boundary of the model would likely need to be Vicksburg, Mississippi, or Memphis, Tennessee, which under average velocities would provide lead times of approximately 5 and 9 days, respectively. This decision would influence the simulation time, model performance and skills, and the required input data.
- Although not required, multiple models with overlapping domains or capabilities can be used. For example, one model can be used to simulate the sediment transport downstream, and the output used as input for another model. However, this would influence the robustness of the RTF system including computational time and resource allocation.
- The Barataria and Breton Sound basins can be added if CPRA desires.
- The Gulf of Mexico can be included as part of the domain, or the framework can be expanded to include oceanographic and storm-induced influences on the LMMR processes.
- An additional (or nested) 3D model for the Mississippi River Delta area should be considered to model salinity stratification and salt-wedge intrusion. This may be needed only for low-flow conditions and activated based on selected thresholds.

3 Parameters

The LMMR RTF system is intended to forecast the following:

- Hydrodynamics
  - Water level
  - Water depth
  - Water velocity
- Sediment transport
  - Bed load
  - Suspended load for multiple sediment fractions (e.g., sand, silt, clay) (Turbidity may be usable as a surrogate for suspended silts and clays.)
- Water chemistry
  - Nutrients (e.g., Nitrogen [N], Phosphorous [P])
  - Temperature
  - Salinity (often measured as conductivity)

The framework could use real-time data to assess the performance of the RTF system by importing the most recent observations into the RTF platform and continuously comparing them with the previous forecast (i.e., hindcast), if the data are accessible. By periodically comparing real-time data with the past forecast, a continuous model validation and performance assessment could be provided. Discrete observations could also be helpful to understand the dynamics of the river, including sediment and nutrient loads. The data could be used to finalize the calibration and validation of the numerical models used in the RTF system and to periodically update the models if a continuous deviation between data and model predictions is observed.

Consideration of morphological change, whether natural or by human intervention (e.g., dredging) for the selected river model is ideal. However, during the first phase of the RTF system, morphology can be omitted since broad morphological changes in the river happen at timescales that are longer than the 5- to 10-day forecast window. For instance, lateral bars vary on timescales that are longer than the forecast window, but bedforms moving over the bars do vary at smaller timescales (on the order of hours to days). Even if morphology is not directly simulated in the model, it would be necessary to periodically update the bathymetry and model roughness to reflect changes in the river and maintain a relevant and current model. Moreover, periodic bathymetry updates ensure model accuracy and reduce the risk for model predictions deviating from reality. This is a key component to ensure the performance of the model does not decrease over time.

Although nutrients are not currently planned as a trigger for sediment diversions, their forecast is important from an environmental perspective as these nutrients are the main drivers of the coastal eutrophication that promotes development of the dead zone in the northern Gulf of Mexico (Rabalais and Turner 2019; Robertson and Saad 2021). Management of N and P is important to reduce the nutrient impacts to the northern Gulf of Mexico. The Mississippi River–Gulf of Mexico Hypoxia Task Force has a goal to reduce 20% of total N and P load in the Mississippi–Atchafalaya River Basin by 2025 (US EPA 2014). The State of Louisiana is also planning on current and future nutrient reduction and management strategies to help reach that goal (Louisiana Nutrient Reduction and Management Strategy Interagency Team 2019). Therefore, nutrient forecasting could be a valuable addition to the RTF system during future development phases.

3.1 Available Data

Following an initial assessment of available data, the team identified that USGS,[2] USACE,[3] National Oceanic and Atmospheric Administration (NOAA), and Coastwide Reference Monitoring System (CRMS) stations represent the best available networks for real-time monitoring in the river and receiving basins. The following maps (Figure 2 to Figure 11) show where monitoring of critical parameters occurs at USGS, USACE, NOAA, and CRMS stations.

2 https://maps.waterdata.usgs.gov/mapper/index.html

3 https://rivergages.mvr.usace.army.mil/WaterControl/new/layout.cfm

Figure 2. Locations of United States Geological Survey (USGS) and United States Army Corps of Engineers (USACE) stations that measure water level for the Mississippi River below Memphis, as well as key tributaries and distributaries.

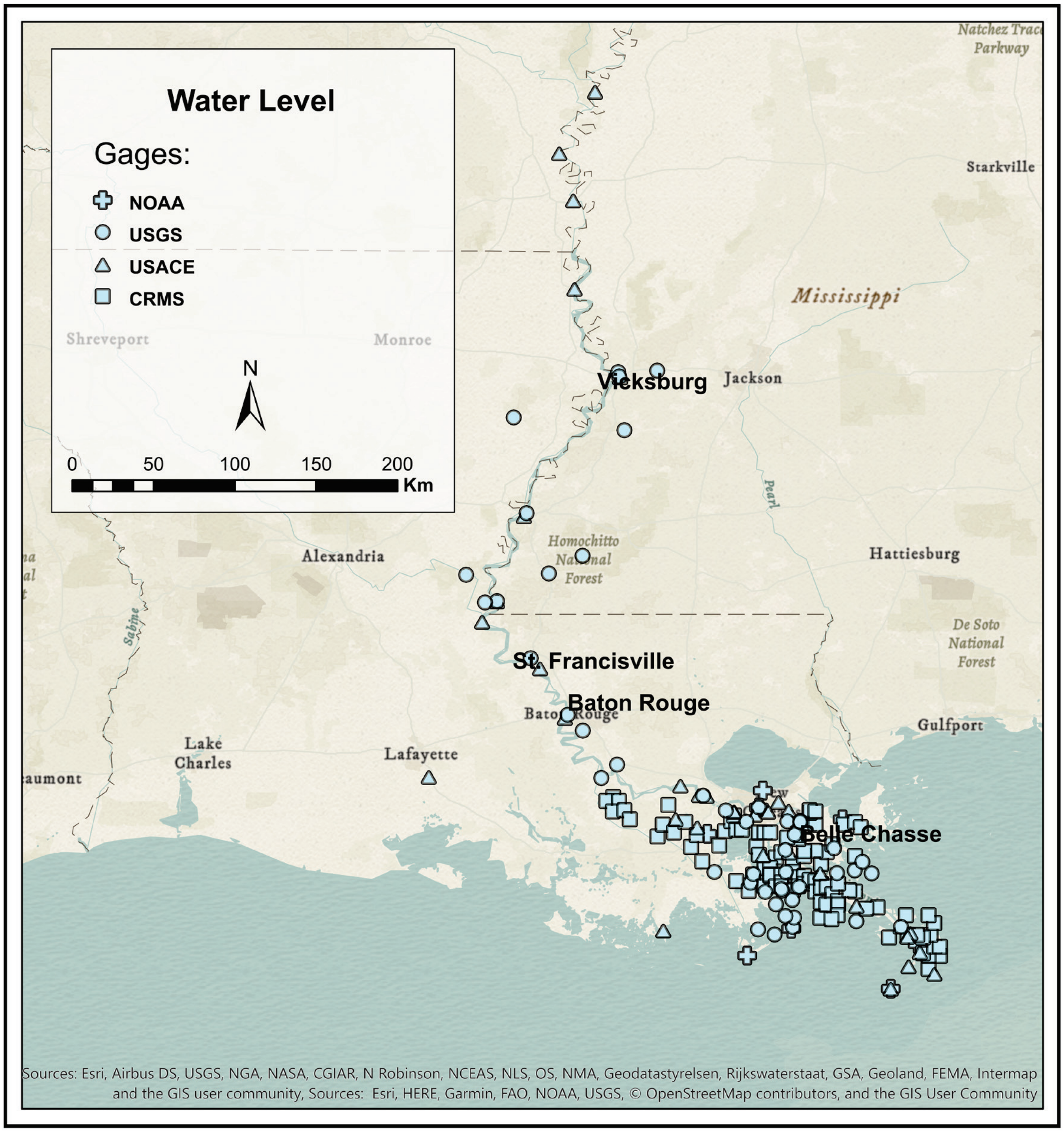


Figure 3. Locations of USACE and USGS stations that measure discharge for the Mississippi River below Memphis and related basins.

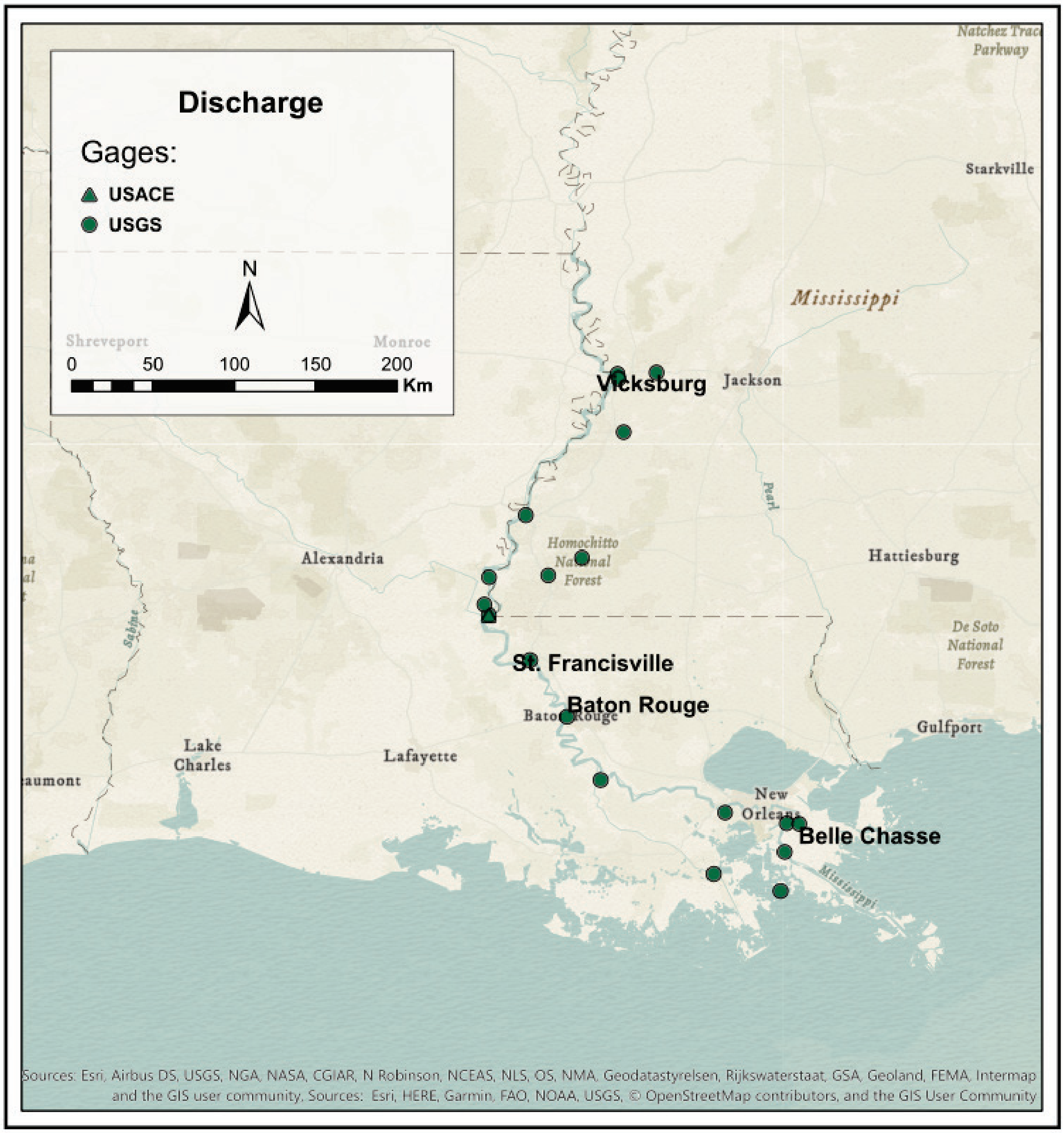


Figure 4. Locations of USGS stations that measure total suspended solids for the Mississippi River below Memphis.

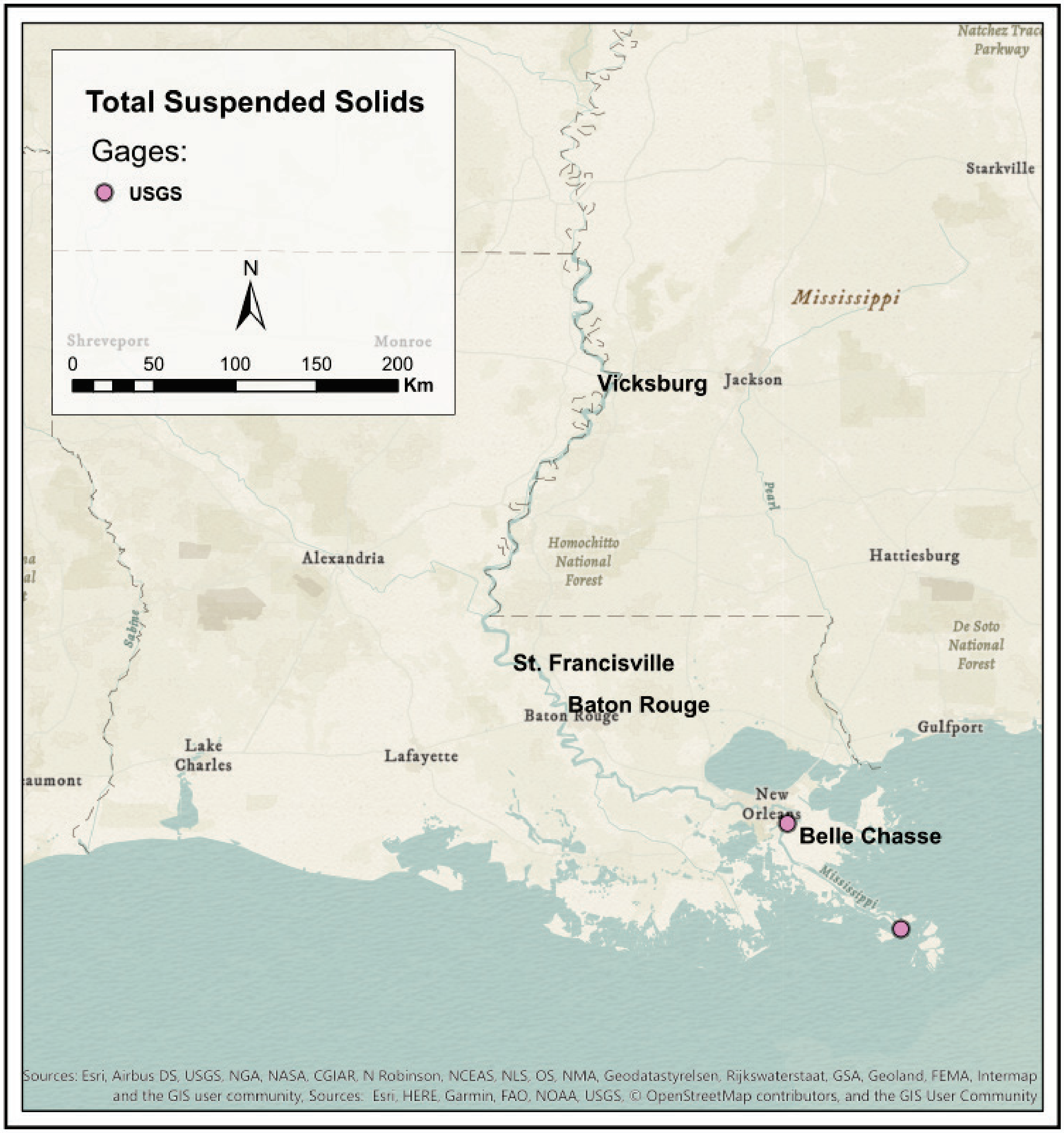


Figure 5. Locations of USGS stations that measure turbidity for the Mississippi River below Memphis.

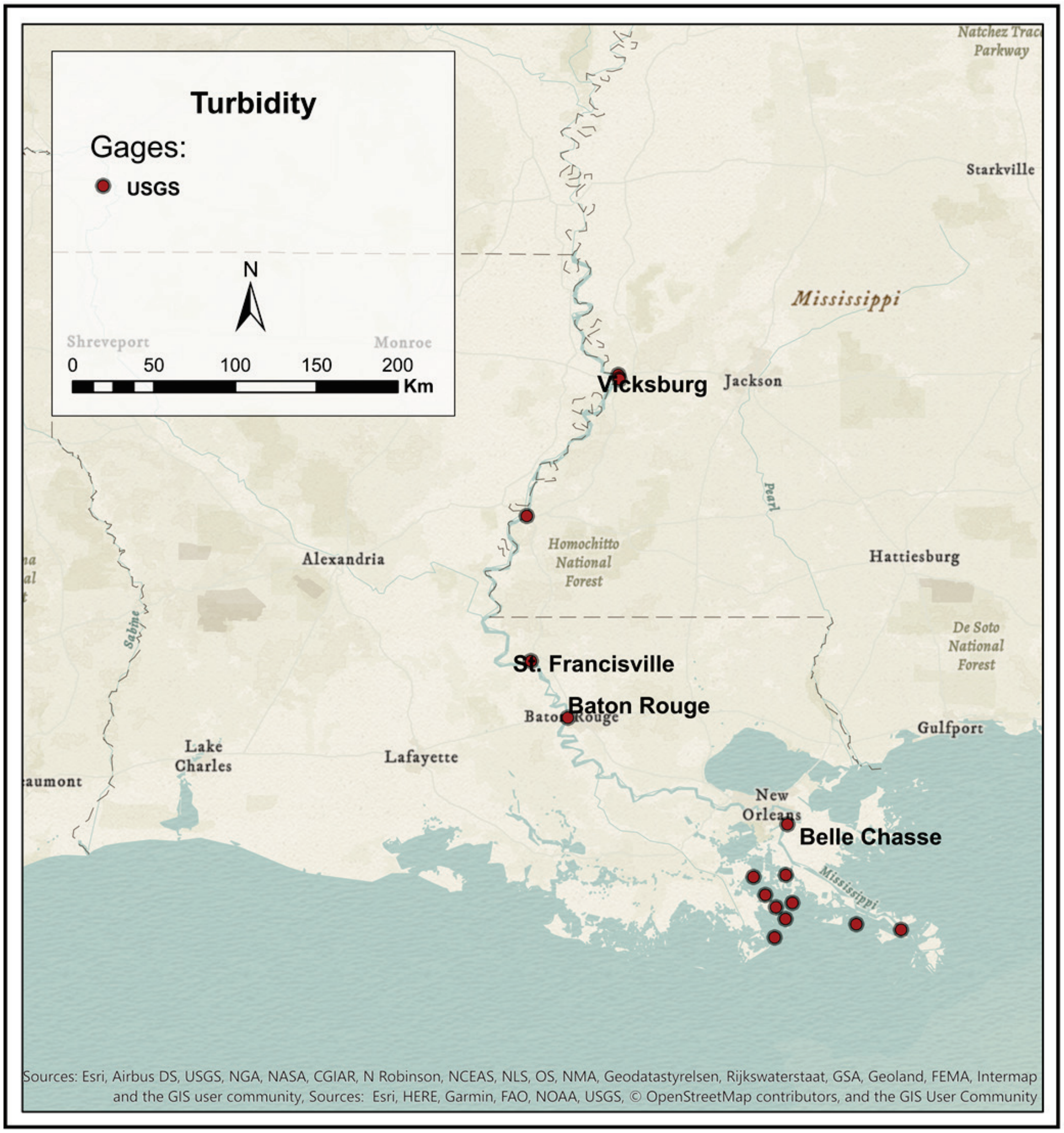


Figure 6. Locations of USGS stations that measure conductivity for the Mississippi River below Memphis.

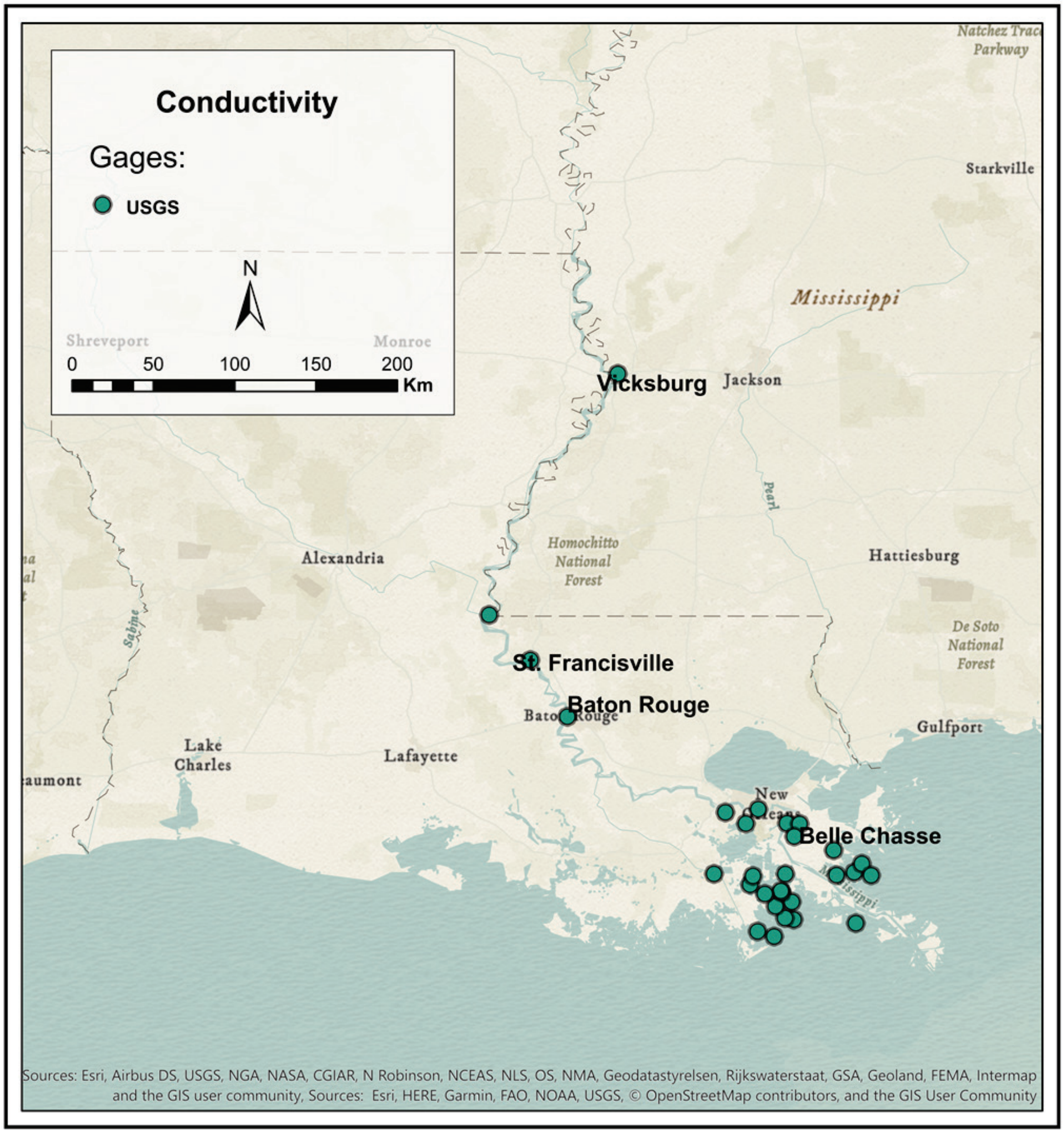


Figure 7. Locations of USGS and Coastwide Reference Monitoring System (CRMS) stations that measure salinity for the Mississippi River below Memphis.

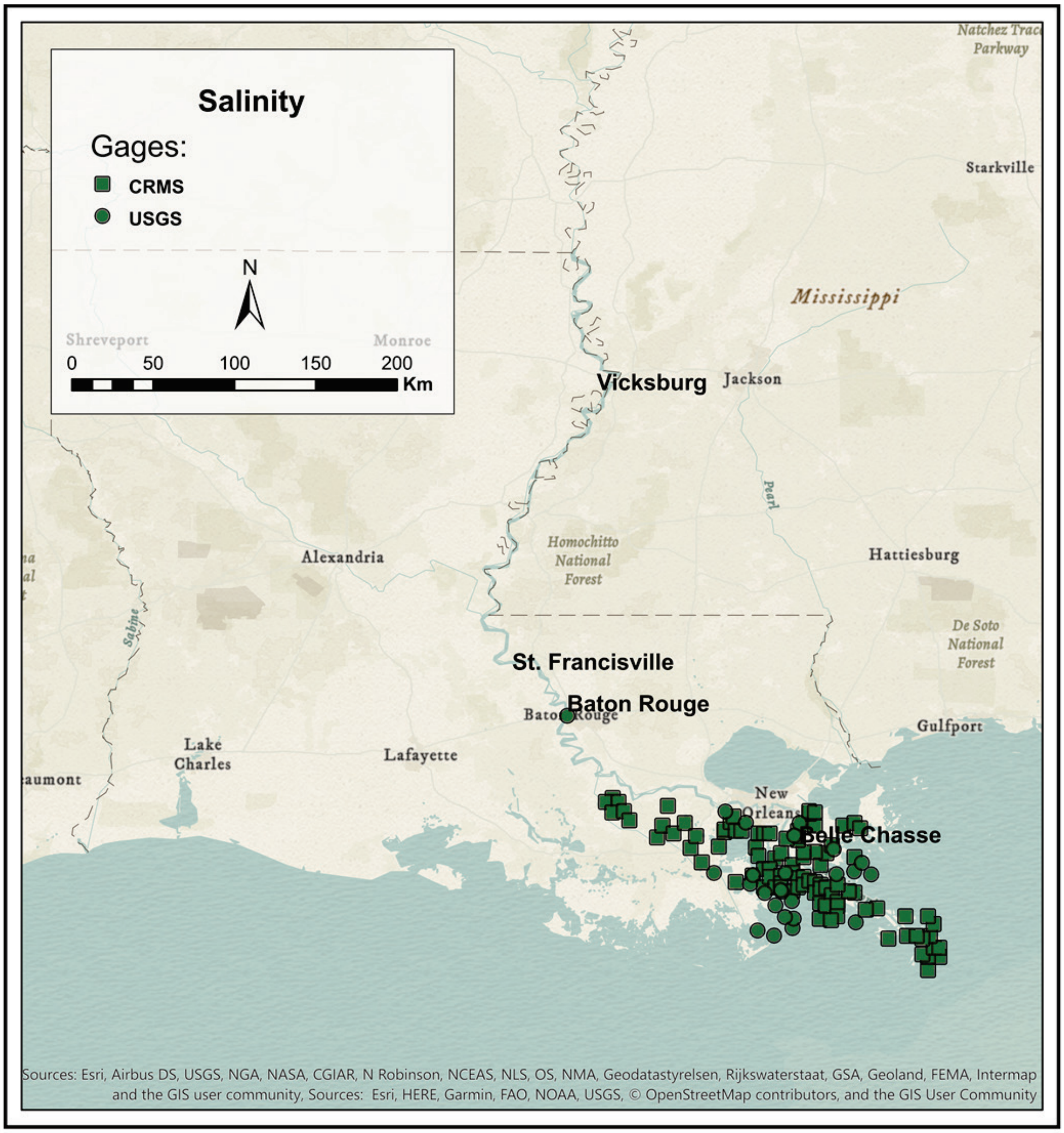


Figure 8. Location of USGS stations that measure organic nitrogen for the Mississippi River below Memphis.

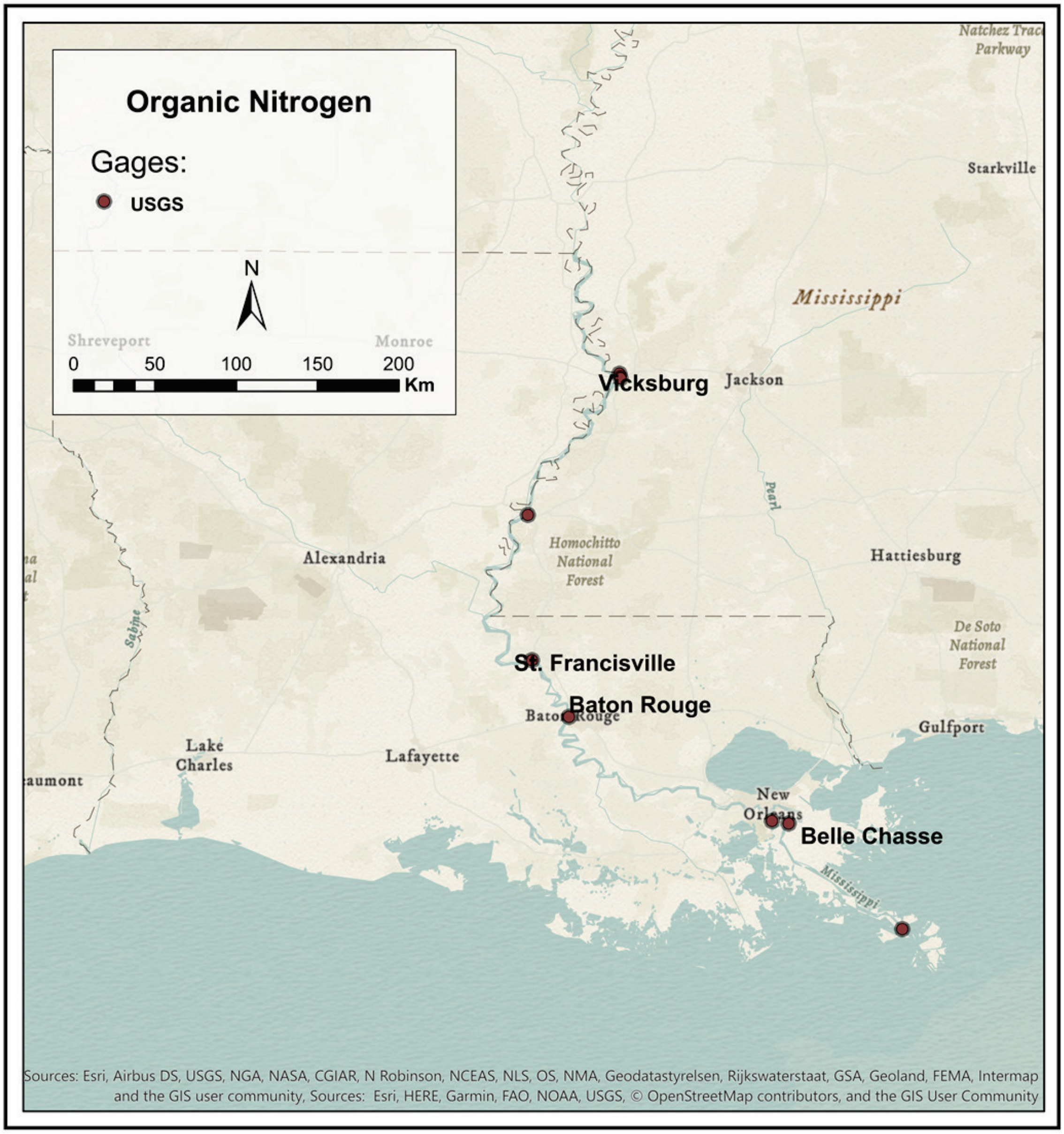


Figure 9. Location of USGS stations that measure total nitrogen for the Mississippi River below Memphis.

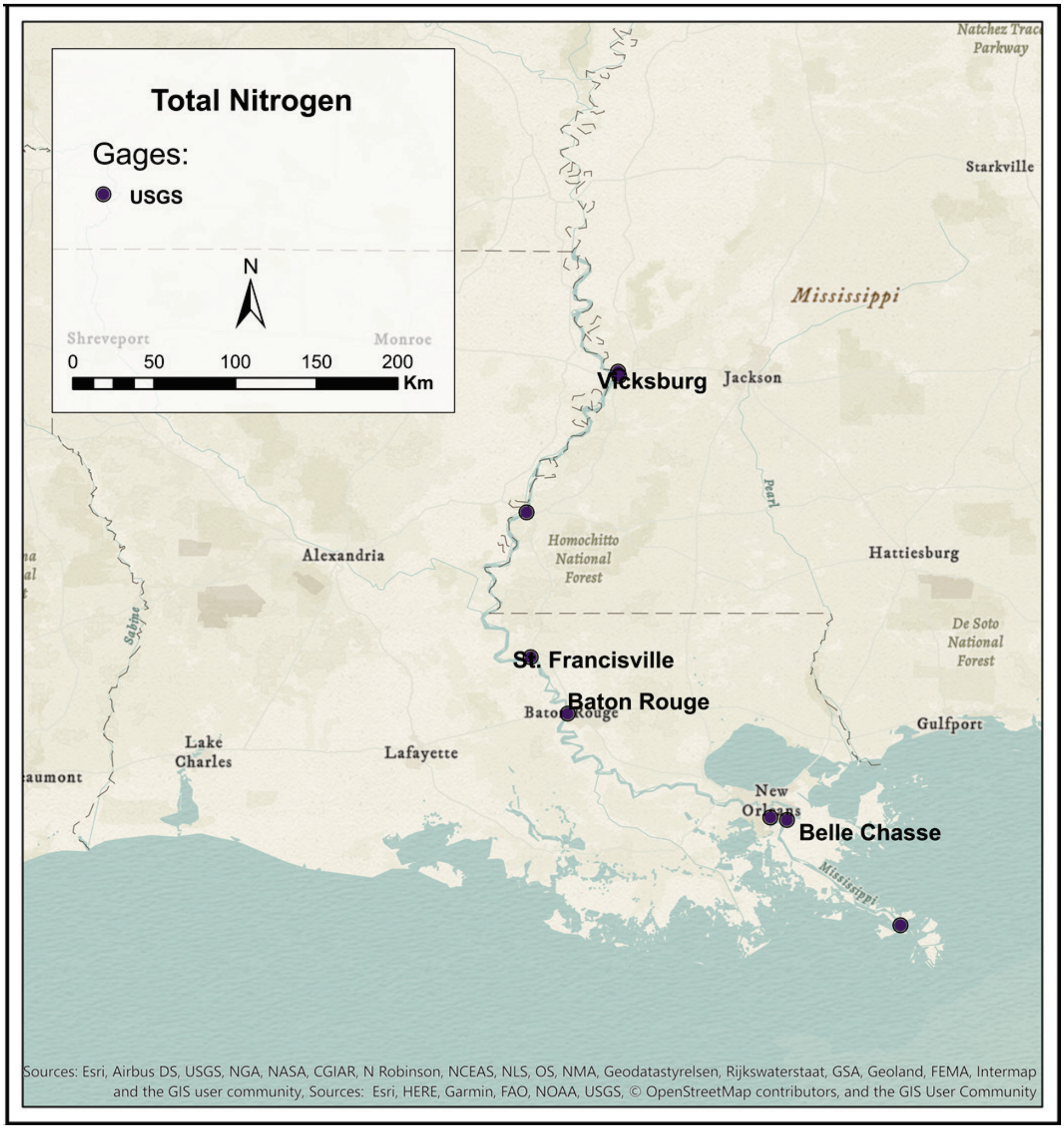


Figure 10. Location of USGS stations that measure phosphorus for the Mississippi River below Memphis.

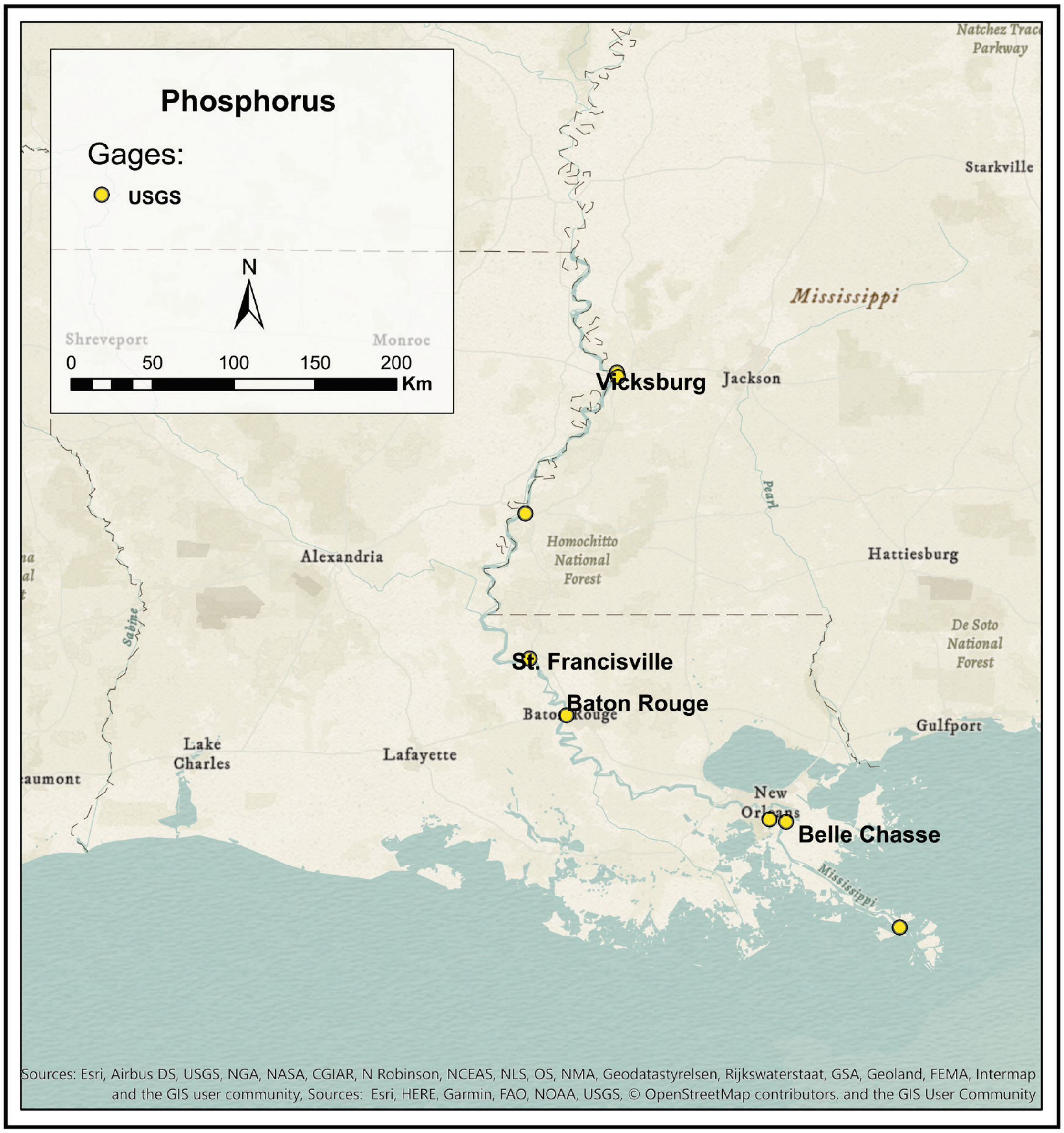


Figure 11. Locations of USGS, USACE, CRMS, and National Oceanic and Atmospheric Administration (NOAA) stations that measure temperature for Mississippi River below Memphis.

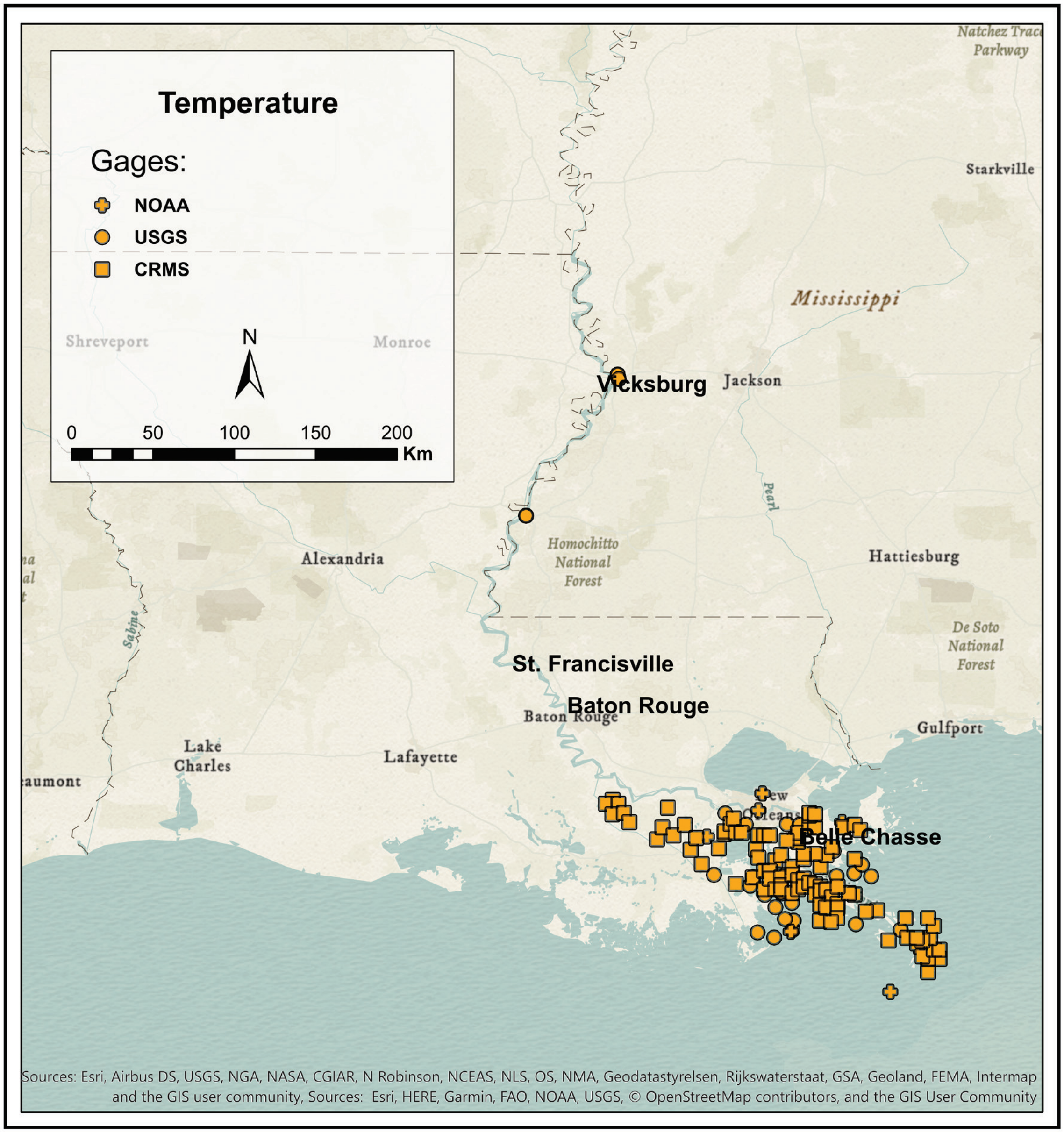


Figure 4 shows that the network of stations where suspended solids are measured is limited to two stations. At some stations, however (e.g., Belle Chasse, Louisiana, Baton Rouge, Louisiana, and Vicksburg, Mississippi; see Figure 5), turbidity is monitored in real time. Under another task within the LMRMP work plan, USGS is currently evaluating the potential use of turbidity to serve as a proxy for suspended sediment.

Currently, discrete surface-water samples are collected at USGS stations at Vicksburg, Saint Francisville, Baton Rouge, and Belle Chasse and analyzed for nitrates (NO_3^-), nitrites (NO_2^-), ammonium (NH_4^+), and orthophosphate (PO_4^{3-}). Table 1 summarizes the type and frequency (number per year) of discrete surface water samples taken in the LMMR at these four stations.

Table 1. Summary of the water-quality parameters, including nutrient concentrations, sampled at various locations in the Lower Mississippi River and their sample frequency. *ND* is no data.

Water-Quality Parameter	Vicksburg	St. Francisville	Baton Rouge	Belle Chasse
Dissolved Oxygen	12–14 times a year from 1973 to 1999	14–16 times a year since 1954	Daily since 2006	Approximately 8 times a year since 1977
Nitrate+Nitrite	12–14 times a year from 1973 to 1999 and then from 2008 and ongoing	14–16 times a year since 1954	Daily nitrate+nitrite since 2011	Approximately 6 times a year from 1985 to 1991 Approximately 8 times a year since 1991
Ammonium	12–14 times a year from 1973 to 1999	14–16 times a year since 1954	ND	Approximately 6 times a year from 1985 to 1991 Approximately 8 times a year since 1991
Orthophosphate	12–14 times a year from 1973 to 1999	14–16 times a year since 1954	ND	Approximately 6 times a year from 1985 to 1991 Approximately 8 times a year since 1991
pH	12–14 times a year from 1973 to 1999	14–16 times a year since 1954	Daily since 2004	Approximately 14 times a year since 2018

3.2 Data Needs for Future RTF Enhancements

Future development of the RTF system (see Section 6) could include other chemical parameters such as dissolved organic carbon, total organic carbon and total phosphorous (TP). TP is not easy to monitor with sensors but does correlate well to total suspended solids and turbidity that are often monitored with sensors (Baustian et al. 2018; Grayson et al. 1996). Therefore, recent datasets of these two parameters along with a brief *P* sampling campaign could be used to develop this relationship for use in the RTF system.

To understand the ecological status of the receiving basins, it is important to assess the nutrient loading as well as their chemical form (e.g., nitrate, ammonium, orthophosphate, and silicate). The chemical form of these elements is important because it controls the nutrient availability for phytoplankton and cyanobacteria growth within the river, wetlands, estuaries, and nearshore environment. The phytoplankton and cyanobacteria community of each of these environments in turn moderates the biogeochemical distribution of nutrients. Total nitrogen (TN) and TP contribute to vegetative growth in wetlands. Excessive TN and TP contribute to algae blooms across the inland, estuarine, and offshore environments (Bargu et al. 2019). The nutrient loading can also drive wetland above and belowground vegetation biomass responses (Elsey-Quirk et al. 2019; Morris et al. 2013).

Presently, there is a paucity of nutrient concentration observations and other water-quality observations in the LMMR (Table 1) to help establish robust rating curves for boundary conditions and predict accurate nutrient loads to the receiving basins and the northern Gulf of Mexico. Experimental short-term monitoring followed by an expansion of the current networks is highly recommended. This could include taking advantage of vessels of opportunity (e.g., adding sensors to USACE or commercial vessels that routinely traverse the length of the Lower Mississippi River; Stackpoole et al. 2021).

4 Available Tools

This section presents an inventory of the available models and tools that can be leveraged for the RTF system.

4.1 Watershed

Depending on the lead time needed by the end user of the RTF system (e.g., sediment diversion operation team), it may be necessary to model the upstream watersheds. However, incorporating a watershed model to inform the upstream boundary conditions for the river model within the RTF system increases complexity compared to having a framework developed to use a predefined inflow, either from the National River Forecast Center or other watershed models that are already operational.

Assuming the lead time provided by a forecast of approximately 5 days is sufficient for the RTF system users, gages at Vicksburg could provide upstream boundary conditions for the river model. Both observed and forecasted flow are required to run the system. The first is required to keep the operational model updated and provide an initial condition to the forecast simulation. The available USGS station at Vicksburg (number 07289000) reports real-time discharge observations with hourly resolution[4] and could be used for the hindcast simulation. The National Weather Service's Lower Mississippi River Forecast Center provides a 28-day discharge forecast at this location (VCKM6) with a corresponding uncertainty range.[5] This flow forecast is a good candidate for use as an upstream boundary condition of the model.

A regression-based Spatially Referenced Regression On Watershed attributes (SPARROW) model exists to estimate the TN and TP loading sources in the Mississippi–Atchafalaya River Basin (Robertson and Saad 2021). This model is based on long-term trends (e.g., 5 years). The RTF system that this work plan describes would have a forecast time horizon on the order of days, but the long-term trends from the SPARROW model may help validate the annual nutrient loading to the Gulf of Mexico. In addition, artificial neural networks could be used to improve boundary conditions of nutrient loading to the RTF system.

4 https://waterdata.usgs.gov/nwis/uv?site_no=07289000

5 https://www.weather.gov/lmrfc/experimental_28day_mississippi_plot#

This USGS station at Vicksburg also monitors in real time (hourly) gage height and nitrate+nitrite. The additional real-time data would be useful to periodically assess the RTF system performance. Historical turbidity data are available from December 2013 to October 2015. The gage is also sampled 14 times per year for the USGS National Water Quality Network. Monitoring data are collected using the equal-discharge increment, depth-integrated method, and the parameters collected include total suspended sediment concentration, proportion of sand and fine sediment, sand size analysis (Manning and Rebich 2021), and continuous nitrate sensor readings. This historic data could be used to develop rating curves for sediment and nutrient loads that can be fed into the RTF system.

If a forecast of approximately 5 days is not sufficient, modeling of the river farther upstream would be required and, potentially, modeling of the upstream watersheds. This would add a significant level of complexity. In this case, both precipitation and nutrient loads in the watershed would need to be considered for nutrient concentration forecasting. Uncertainties related to precipitation forecast would play an important role in the RTF system's overall uncertainties. Precipitation forecasting comes with a level of uncertainty in terms of quantity, time, and space (e.g., the predicted amount of rain might be different or in a different basin).

4.2 Mississippi River

The following models already exist for the Mississippi River and are available for direct use and implementation:

- US Army Engineer Research and Development Center (ERDC) developed a fully unsteady, 1D, hydraulic and sediment model using HEC-RAS (Dahl et al. 2018).
- USACE also developed a separate hydraulic HEC-RAS model for the river (Lewis et al. 2018). This does not include sediment transport.
- USACE developed a 1D HEC-6T sediment transport model of the Mississippi River from Cairo, Illinois, to the Gulf of Mexico over a number of years (Thomas 2012; Sharp et al. 2013; Copeland 2018; Copeland et al. 2020). HEC-6T is a proprietary software package and does not include the ability to simulate nutrient transport or processes.
- ERDC developed multiple 2D Adaptive Hydraulics (AdH) models that cover portions of the Lower Mississippi River. These model domains include Natchez to Baton Rouge (Leech et al. 2018) and Tarbert

Landing to Head of Passes (Brown et al. 2018). AdH is a computationally demanding model, and these model domains require a high-performance computing (HPC) system to run, with execution times of several hours to simulate a few days.

- A Routing Application for Parallel computation of Discharge (referred to as RAPID) model that does hydrologic routing per segments has been used by ERDC researchers for multiple studies (Lytle et al. 2020; Tavakoly et al. 2017).
- Delft3D-4 is a 2D superregional model developed by University of New Orleans (UNO) that extends from River Mile 124 to River Mile 0 (Reins, n.d.). Some variations of this model were developed both by UNO and the Institute. An inventory of those models can be found in the AirTable developed as part of the TO69 project for CPRA.[6]
- Other models that cover a smaller portion of the Mississippi River exist. They would require major edits and domain expansion to become the main engine of this RTF tool but could be used for some ad hoc analyses. An inventory of these other models can be found in the AirTable developed as part of the TO69 project for CPRA.[7]

All these models could potentially be leveraged and used as the core engine of the RTF system. However, based on CPRA's computer requirements, simulation time, and completeness of the model, the ERDC HEC-RAS, hydraulic and sediment model is recommended in this work plan.

4.3 Receiving Basins

CPRA's primary use of the RTF system is currently anticipated to focus on in-river conditions to inform diversion operations. For this reason, the RTF system described in this work plan would include only a river model. However, the work plan also describes future developments and possible expansions of this RTF system to include receiving basins (the Barataria, Breton Sound, and Pontchartrain basins). Receiving basin models should be capable of simulating hydrodynamics as a minimum, with additional requirements to simulate suspended sediment transport and nutrient concentrations. The following existing models can be leveraged for this effort and included in the RTF system:

6 LMRMP Data/Model Inventory and Model Design: Models–Airtable

7 LMRMP Data/Model Inventory and Model Design: Models–Airtable

- AdH: 2D models for the Barataria and Breton Sound basins (Brown et al. 2019a; Brown et al. 2019b)
- Delft3D-FM: 2D model developed by the Institute for Partnership for Our Working Coast (The Water Institute of the Gulf 2022)
- Delft3D-FM: 2D model developed by the Institute for the Gulf Sturgeon suitability hindcast in the Pontchartrain Basin[8]
- Delft3D-4: 2D Basin Wide model developed by the Institute which includes the Barataria, Breton Sound, and Pontchartrain basins

  - Version 1: Developed and applied to MRHDMS[9]
  - Versions 2: Updated and used for sensitivity analyses[10] [11] [12] [13]
  - Version 3: Updated and improved to inform the Mid-Barataria Sediment Diversion Project Environmental Impact Statement (EIS)[14]

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8 Messina, F., M. Bregman, S. Zou, I. Y. Georgiou, S. Dalyander, and M. Miner. Unpublished. 2022. *Lake Borgne Gulf Sturgeon Monitoring and Habitat Characterization* (Draft). The Water Institute of the Gulf. Produced for and funded by Coastal Protection and Restoration Authority under Task Order 81.

9 Meselhe, E. A., M. M. Baustian, A. K. Khadka, H. Jung, K. Sadid, S. M. Duke-Sylvester, J. M. Visser, J. G. C. Smits, B. van Maren, V. Harezlak, and M. Jeuken. Unpublished. 2015. *Basinwide Model Development for the LCA Mississippi River Hydrodynamic and Delta Management Study* (No. Chapter 4). Baton Rouge, LA.: The Water Institute of the Gulf. Prepared and funded by the Coastal Protection and Restoration Authority.

10 Jung, H.-S., M. M. Baustian, and E. Meselhe. Unpublished. 2016. *TO15/16: Outfall Areas in Barataria and Breton Sound–Vegetation Model Improvement*. Baton Rouge, LA: The Water Institute of the Gulf. Funded by the Coastal Protection and Restoration Authority under Task Orders 15/16.

11 Liang, M., K. Sadid, F. Xing, F. Messina, and E. Meselhe. Unpublished. 2016. *TO15/16 Improvement of Model Grid and Bathymetry*. Baton Rouge, LA: The Water Institute of the Gulf. Funded by the Coastal Protection and Restoration Authority under Task Orders 15/16.

12 Messina, F., and E. Meselhe. Unpublished. 2016. *TO15/16: Improvements to the Hydrodynamics and Salinity in Barataria* (pp. 758–767). Baton Rouge, LA: The Water Institute of the Gulf. Funded by the Coastal Protection and Restoration Authority under Task Orders 15/16.

13 Sadid, K., E. Meselhe, M. Allison, and B. Van Maren. Unpublished. 2016. *TO15/16 Sediment properties Used in the Basin Wide Model* (pp. 1–8). Baton Rouge, LA: The Water Institute of the Gulf. Funded by the Coastal Protection and Restoration Authority under Task Orders 15/16.

14 Sadid, K., F. Messina, H. Jung, B. Yuill, and E. Meselhe. Unpublished. 2018. *TO51: Basinwide Model Version 3–Basinwide Model for Mid-Breton Sediment Diversion Modeling* (Funded by the Coastal Protection and Restoration Authority under Task Orders 51). Baton Rouge, LA: The Water Institute of the Gulf.

  - Version 4: Updated and improved to inform the Mid-Breton Sediment Diversion Project EIS[15]

- Finite-Volume, primitive equation Community Ocean Model (FVCOM): 3D models for the Barataria Basin developed by UNO; 3D Model for Barataria Basin developed by Dr. Haosheng Wang and Dr. Dubravko Justic; 3D model for Barataria Basin developed by Dr. Giulio Mariotti and Dr. Dubravko Justic
- Coupled-Ocean-Atmosphere-Wave-Sediment Transport: 3D model for Barataria Basin developed by Prof. George Xue, Louisiana State University (LSU)
- FVCOM: 3D model for the Pontchartrain Basin and the Mississippi River developed by Dr. Ioannis Georgiou, UNO
- FVCOM: 2D model for the Barataria estuary developed by Dr. Dubravko Justic (LSU)

These models would likely be run in series along with the Mississippi River model selected for the RTF system. There are various options for how river and receiving basin models can be coupled. One option is running these models in series, with one-way coupling between river model and receiving basin model. Alternatively, models can be run with two-way coupling, which requires more effort and coordination on the degree of connectivity and the frequency of information exchange between the two models. Finally, a single model that includes both river and receiving basins can be considered if all processes and parameters of interest are simulated by this model.

4.4 Meteorological Models

Meteorological forcing such as wind and precipitation are important to the circulation and water-level setup along the coast and should be considered and included in the modeling. Air temperature and evapotranspiration are key parameters to include for nutrient dynamics and nutrient cycling, especially if receiving-basin modeling is considered.

15 Bregman, M., F. Messina, H. Jung, B. T. Yuill, M. M. Baustian, and I. Y. Georgiou. Unpublished. 2020. *Basin Wide Model Version 4: Basin Wide Model for Mid-Breton Sediment Diversion Modeling.* Task Order 51.3. Final Report. Baton Rouge, LA: The Water Institute of the Gulf. Funded by the Coastal Protection and Restoration Authority.

Real-time wind and precipitation observations would be needed, as well as forecasts. Operational forecasts from federal agencies such as NOAA would be used for this purpose. The following resources would be considered:

- The Lower Mississippi Real-Time Forecasting Center: https://tgftp.nws.noaa.gov/data/
- The global forecast system from NOAA: https://www.ncei.noaa.gov/products/weather-climate-models/global-forecast

If, in future developments, the receiving basins were to be included in the RTF system, it would be important to implement the correct boundary conditions at the Gulf of Mexico. The following forecast tools are available:

- The Northern Gulf of Mexico Operational Forecast System (NGOFS) and NGOFS2 provide a 2-day water level in the Gulf: https://www.tidesandcurrents.noaa.gov/ofs/dev/ngofs2/ngofs_info.html.
- Extratropical Surge and Tide Operational Forecast System provides a 7-day forecast for water level in the Gulf: https://polar.ncep.noaa.gov/estofs/.
- Hybrid Coordinate Ocean Model provides a 7-day forecast for salinity and temperature in the Gulf: https://www.hycom.org/.
- Coastal Hazards System provides prestaged results for hypothetical but likely storms calculated using CHL's Coastal Storm Modeling System: https://chswebtool.erdc.dren.mil/.

5 System Platform and Dashboard

The RTF system would be built within a digital platform that could be used to download and compile all the real-time data and external forecasts required, initialize the numerical simulations, visualize the model results and, eventually, run scripts and algorithms to inform CPRA diversion project operational strategies under various scenarios and conditions and provide message alerts. Different software or codes could be used for this effort:

- The Corps Water Management System (CWMS): This software is developed by HEC for use by USACE Districts and has established workflows for linking together the HEC products (e.g., Hydrologic Engineering Center-Hydrologic Modeling System [HEC-HMS], Hydrologic Engineering Center-Reservoir System Simulation [referred to as HEC-ResSim], and HEC-RAS) to make water-management decisions. There is a version of CWMS called Hydrologic Engineering Center-Real Time Simulation (referred to as HEC-RTS) for use by non–USACE water management organizations.
- Delft-Flood Early Warning System (FEWS): This platform allows users to compile data from external sources (e.g., federal weather forecast, real-time data, other hydrologic forecasts), use them to drive a specific hydrological model, and visualize the final results. Delft-FEWS is a freely available software platform that is widely used in the United States and elsewhere by forecasting agencies. Delft-FEWS configuration files are based on .xml code. Delft-FEWS allows for customized dashboard and can be linked to a wide variety of numerical models (e.g., HEC-HMS, HEC-RES, Delft3D).
- Louisiana Flood Forecasting System (LFFS) developed by the Institute for other real-time forecasting efforts: This is a generic system controller that currently controls ADCIRC and 2D HEC-RAS models for storm-surge forecasting efforts in high-performance computing environments. Because the system is engineered to be generic, it can be easily updated to include 1D HEC-RAS models. However, most efforts within the LFFS focus on 2D and 3D models, so it is likely more complex than what is required for this effort.
- Customized code: A series of Python scripts could be developed to build the RTF platform. This method allows for a high level of customization but would be the most time consuming and expensive.

The term *dashboard* indicates the final graphical interface where the user would visualize data, model results, model performance, alerts, run specific scenarios, etc. The dashboard can be customized to address the needs of the end users. Multiple dashboards with different functionality can be developed to address the needs of different user groups.

During the development phase, the RTF system would be built in a manually operated mode, allowing for troubleshooting, testing, and editing. When the system is ready, it would be upgraded to an operational model. The system would then run automatically following a predefined schedule. The frequency for data downloads and to run the numerical models would be defined. Users, or a specific subgroup of users, could have the ability to run some additional what-if scenarios by tweaking some input parameters. The standalone version of the system can be kept for troubleshooting potential issues or for testing future expansion and updates of the system.

CPRA is intended to be the primary host for the system. Training would be conducted to prepare CPRA personnel to use the system and its dashboard and to run what-if scenarios. The system will require maintenance to make sure all data are imported correctly, all links to external data and forecast are updated, and that the model is up to date and performing well. CPRA personnel could be trained to perform this maintenance, especially if a Windows-based platform like Delft-FEWS, which is more user friendly compared to other platforms, is selected. Otherwise, continuous maintenance could be contracted out. This might be necessary if web development assistance will be required (e.g., if a system like LFFS or other customized code is selected as framework of the platform).

Based on the numerical model(s) selected as the engine of the RTF system, different information technology (IT) infrastructure would be needed. This might range from the following:

- High-end desktop machine
- Cloud-based virtual machines
- HPC system
- The LFF-based system might help save on costs related to Windows desktop licenses but would be more complex to maintain, and CPRA may need to rely on external expertise for system maintenance and updates.

- Cloud deployment (e.g., Amazon Web Services, Microsoft Azure): one or two cloud Windows desktop machines would be sufficient to host a Delft-FEWS based RTF system with a 1D HEC-RAS model. The cost of this IT requirement ranges from $1,400 to$4,500 per month for an 8-core and 32-core (respectively) cloud-based AMD Windows virtual machine deployment with 5 TB[16] of storage (as of late 2022). A significant cost saving can be achieved if the virtual machines are purchased for multiple years in advance.

The system would leverage national and federal forecasts (e.g., meteorological forecast) and use data from different agencies. Any limitations associated with this would be considered and addressed when developing the system.

16 For a full list of the spelled-out forms of the units of measure and unit conversions used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office 2016), 248–52 and 345–347, respectively. https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

6 Work Plan and Timeline

6.1 Initial Activities

The following activities are recommended for the development of a CPRA RTF system. The timeline for each activity is presented in Table 2. CPRA's primary use of the RTF system would focus on in-river conditions to optimize diversion operations, and this is shown by the *dark blue cells* in the timeline. Possible timelines associated with more complex activities such as modeling, model domain expansion, or the inclusion of watershed and receiving basins are presented in Table 2 with *light blue cells*. Note that while the table shows all tasks as occurring sequentially, some of the development may occur in parallel.

6.1.1 Activity 1: Preparation

Initially, all available real-time and historic data for river stage, discharge, sediment, and nutrients would be identified, archived, analyzed, and used to develop sediment and nutrient rating curves where sediment and nutrient data are sufficient and reliable. Following this analysis, data gaps and additional data needed to support the development and assessment of the RTF system performance would be identified.

In addition to in-river stations with observations, an inventory of available national or federal forecast systems would be identified to help constrain atmospheric, watershed, discharge, and sediment inputs at the upstream and Gulf of Mexico boundaries.

This activity would include selection of the river model to be used as the engine of the RTF system. The selected river model would undergo additional (as needed) adjustments to the model domain, additional calibration and validation, fine-tuning, and optimization.

This activity would last approximately 3 months. This phase may last up to a total of 5 months if extra activities are required. Such additional activities could include the need for model refinements and additional calibration and validation of the riverine model or if watershed models would need to be included in the system to increase lead time. Assuming watershed models are available and operational, this extra activity should be completed within the extra 2 months shown in Table 2. If there is a need to develop or refine new watershed models, then Activity 1 may extend beyond 5 months.

Table 2. Workflow activities and corresponding timeline shown with *dark blue cells*. Possible timelines associated with more complex activities shown with *light blue cells.*

Activity	Months (each cell represents 1 month)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1–Preparation															
2–Real-time data and external forecast collection and visualization															
3–Numerical model set up															
4–Dashboard															
5–Operational and archiving															
6–Training															

6.1.2 Activity 2: Real-Time Data and External Forecast Collection and Visualization

This activity involves scripting and coding development to automate real-time observational data and forecast model output and build a dashboard within the RTF system platform to assess and visualize real-time and forecast data.

This activity would last approximately 3 months.

6.1.3 Activity 3: Numerical Model Set Up

This activity links the river models(s) selected during Activity 1 to the RTF platform and fine tunes scripts and codes developed under Activities 1 and 2. During this activity, scripts and executables would be developed to connect the RTF system with the numerical model(s) to automate the following steps:

- Preprocess the observational data and forecast model outputs to conform to the required format for model boundary conditions.
- Initiate the numerical simulation from within the RTF system graphical interface.
- Import model results into the RTF platform.
- Set up selected modifiers to run specific model ensembles if CPRA indicates preference for an ensemble approach.

This activity would take approximately 3 months. Any additional models (e.g., watershed or receiving basins) added to the system would take an additional 1 or 2 months, depending on the model complexity and model connectivity.

6.1.4 Activity 4: Dashboard

During this activity, the RTF system graphical interface would be developed further and finalized. This activity would also expand products from Activities 2 and 3 to customize the model results visualization engine based on user input and priority needs. Various groups of users may be developed with tiered privileges, system permissions, and notifications (e.g., e-mails, visual icons) as CPRA requires. This activity would also develop automated model performance statistics for each model forecast.

This activity would take approximately 3 months.

6.1.5 Activity 5: Upgrade System to Operational Status and Set Up Archive

During this activity, RTF system developers would meet with CPRA and IT personnel to solicit input to help build an archiving system to accommodate CPRA's needs.

This activity would take approximately 2 months.

6.1.6 Activity 6: Training

Once the RTF system is finalized, CPRA personnel would be trained to use and maintain the system. This would be accomplished through a series of in-person meetings or webinars and the development of a user guide.

This activity would take approximately 2 months to allow for feedback and iteration among teams.

7 Future Development and Recommendations

The RTF system outlined in this work plan is intended to be a tool that helps inform CPRA decision-making. The RTF system is not envisioned to be static but as a tool that can be expanded and improved over time to provide additional information and to adapt to other potential needs.

Implementing a model (or more) that includes the Barataria, Breton Sound, and Pontchartrain basins is possible for future system developments. The environmental conditions of the receiving basins (e.g., water level, salinity, and other water quality indicators) could be included in the RTF system and leveraged further to support operational management and decision making. The RTF system could model the receiving basins using one or several models (2D or 3D) connected to the river model implemented in the first phase of the work plan. The river model predictions and forecasts could inform boundary conditions for the basin model(s), which can run at the same frequency as the river model (or less frequent), depending on their complexity, simulation time, and desired coupling intervals.

For example, if specific areas of the river or the receiving basins require higher resolution to inform localized operational decisions, supplemental high-resolution models can be developed and incorporated into the system.

If CPRA decides to increase the RTF system's lead time, models that include upstream watershed processes could be considered. Consistent with previous statements, this approach would add significant system complexity and lengthen runtimes. Moreover, uncertainties related to precipitation forecasting in time and space would influence the approach, methods, and workflow to resolve meteorological predictions driving the watershed models.

Following the discussion in the Parameters section (Section 3) of this work plan, the availability of water-quality data remains a challenge. Hence, additional data collection would be advised if the data gap analysis in Activity 1 highlights the lack of nutrient data. Also, CPRA could consider implementing a less-sophisticated water quality model at the initial deployment of the RTF system. Further, it is advised that CPRA consider dedicating a funding stream to continue the development of water quality models while simultaneously reimplementing or expanding water quality observations. This includes reinstatement or maintenance of the water quality station near Vicksburg, Mississippi, between the Yazoo River and Big Black River confluences, to serve as a boundary condition for the water quality module of the RTF system. Implementing a more complex nutrient-dynamic model able to simulate several parameters of interest, nutrient cycling, and ecosystem indicators would be essential for the holistic management of the LMMR.

Finally, a more sophisticated dashboard and public-facing platform or website could also be developed in future phases.

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Abbreviations

AdH	Adaptive Hydraulics
CPRA	Louisiana Coastal Protection and Restoration Authority
CRMS	Coastwide Reference Monitoring System
DOC	Dissolved Organic Carbon
EIS	Environmental Impact Statement
ERDC	US Army Engineer Research and Development Center
FEWS	Delft-Flood Early Warning System
FVCOM	Finite-Volume, primitive equation Community Ocean Model
HEC	Hydrologic Engineering Center
HEC-HMS	Hydrologic Engineering Center-Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center-River Analysis System
HPC	High-Performance Computing
IT	Information technology
LFFS	Louisiana Flood Forecasting System
LMMR	Lowermost Mississippi River
LMRMP	Lowermost Mississippi River Management Program
LSU	Louisiana State University
MRHDMS	Mississippi River Hydrodynamic and Delta Management Study
N	Nitrogen

NGOFS	Northern Gulf of Mexico Operational Forecast System
NOAA	National Oceanic and Atmospheric Administration
P	Phosphorus
RAS	River Analysis
RTF	Real-Time forecasting
SPARROW	Spatially Referenced Regression On Watershed
TN	Total nitrogen
TP	Total phosphorous
UNO	University of New Orleans
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey

REPORT DOCUMENTATION PAGE

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED START DATE	3. DATES COVERED END DATE
September 2023	Final report	FY20	FY22

4. TITLE AND SUBTITLE
Real-Time Forecasting Model Development Work Plan

5a. CONTRACT NUMBER	5b. GRANT NUMBER	5c. PROGRAM ELEMENT
5d. PROJECT NUMBER	**5e. TASK NUMBER**	**5f. WORK UNIT NUMBER**

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
See reverse.	ERDC SR-23-8

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)	11. SPONSOR/MONITOR'S REPORT NUMBER(S)
Coastal Protection and Restoration Authority 150 Terrace Ave Baton Rouge, LA 70802	CPRA	

12. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution Statement A. Approved for public release: distribution is unlimited.

13. SUPPLEMENTARY NOTES
CRADA C-2018-ERDC-2100-3, Amendment 3, "Research to Support Coastal and Lowermost Mississippi River Management"

14. ABSTRACT
The objective of the Lowermost Mississippi River Management Program is to move the nation toward more holistic management of the lower reaches of the Mississippi River through the development and use of a science-based decision-making framework. There has been substantial investment in the last decade to develop multidimensional numerical models to evaluate the Lowermost Mississippi River (LMMR) hydrodynamics, sediment transport, and salinity dynamics. The focus of this work plan is to leverage the existing scientific knowledge and models to improve holistic management of the LMMR. Specifically, this work plan proposes the development of a real-time forecasting (RTF) system for water, sediment, and selected nutrients in the LMMR. The RTF system will help inform and guide the decision-making process for operating flood-control and sediment-diversion structures.

This work plan describes the primary components of the RTF system and their interactions. The work plan includes descriptions of the existing tools and numerical models that could be leveraged to develop this system together with a brief inventory of existing real-time data that could be used to validate the RTF system. A description of the tasks that would be required to develop and set up the RTF system is included together with an associated timeline.

15. SUBJECT TERMS
Environmental management; Flood control; Forecasting; Hydrodynamics; Mississippi River; Salinity; Sediment transport

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	C. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES
Unclassified	Unclassified	Unclassified	SAR	51

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