COPRODUCTION, DEVELOPMENT, AND APPLICATION OF NUMERICAL MODELING DECISION SUPPORT TOOLS FOR THE MISSISSIPPI RIVER AND GULF OF MEXICO

AN ABSTRACT

SUBMITTED ON 1ST OF MAY 2024

TO THE DEPARTMENT OF RIVER COASTAL SCIENCE AND ENGINEERING

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

OF THE SCHOOL OF SCIENCE AND ENGINEERING

OF TULANE UNIVERSITY

FOR THE DEGREE

OF

DOCTOR OF PHILOSOPHY

BY

Laura Manuel

(Laura A. Manuel)

Approved:

Ehab Meselhe Digitally signed by Ehab Meselhe Date: 2024.05.06 17:23:25 -05'00'

Ehab A. Meselhe, Ph.D., PE

Mead Allison Digitally signed by Mead Allison Date: 2024.05.07 11:22:42 -05'00'

Mead A. Allison, Ph.D.

Kelin Hu Digitally signed by Kelin Hu DN: cn=Kelin Hu, o=Tulane University, ou=Department of River-coastal Science and Engineering, email=khu1@tulane.edu, c=US Date: 2024.05.07 11:53:42 -05'00'

Kelin Hu, Ph.D.

Barbara A. Kleiss

Barbara A. Kleiss, Ph.D.

ABSTRACT

The interests of coastal industry, community, and environment are unique, yet commonly vested in the decisions made concerning the natural resources of coastal ecosystems which provide freshwater and habitat (Seitz et al., 2014), storm surge protection (Dasgupta et al., 2019), commerce and recreation (Littles et al., 2018), etc. Decision support systems to help natural resources managers understand system dynamics and evaluate strategies to maintain the health and integrity of these ecosystems. This dissertation presents a roadmap and detailed application of co-production strategies where managers and researchers are fully engaged in a collaborative manner in the design of a decision support tool for coastal ecosystems. It also emphasizes the importance of capturing end-users' (i.e., natural resource managers) priorities to refine the conceptual design of the decision support tool, while maintaining a sound scientific and modeling framework. The case study presented here centers on the Northern Gulf of Mexico, but the concept can be exported globally to other systems. This effort highlights foundational co-production strategies, including transdisciplinary team assembly, a knowledge sharing workshop, Toolbox Dialogue Initiative workshops to facilitate working across disciplines, core team and focus group meetings, and design charrettes. Further, this dissertation articulates the benefits and difficulties of executing a co-production process through virtual collaborations.

The management of freshwater allocation in coastal regions is one example of natural resources management in coastal regions. Systemic understanding of the Mississippi River sediment and water resources partitioning among various outlets or diversions is crucial to the sustained function of the Northern Gulf of Mexico's communities, habitats, and industries. This dissertation also discusses the development and application of a

Delft3D FM 3-dimensional hydrodynamic, salinity, and temperature model of the Northern Gulf of Mexico. We used this model to analyze and quantify the tradeoffs among various management scenarios for freshwater allocation in the lower Mississippi River through existing and proposed infrastructure and natural openings. We also explored the possibility of varying the operational strategies of existing structures to investigate the changes in service and protection to communities in the receiving basins. To maximize the benefits of the Mississippi River's water, sediment, and nutrients, this study emphasizes the continued analysis of management scenarios as an important step in the preservation and protection of the coast of the Gulf of Mexico while sustaining the support of relevant industries. We synthesized scoring metrics to facilitate communication of the efficacy of various management scenarios. The scoring metrics provide an evaluation framework covering physical, ecological, and indirect socioeconomic criteria. This approach can be used for other complex natural systems to explore viable strategies and tradeoffs balancing ecosystem services with socioeconomic interests.

Furthermore, advances in hydrologic forecasting are rapidly progressing due to progress in computing technology, modeling techniques, and data availability. However, the coastal zones remain a challenging frontier for coastal forecasting, particularly during extreme events, due to the complexity of coastal processes governing the behavior of dynamics in these regions. A promising solution to predicting coastal conditions is the development of process based modeling approaches, operating in a forecasting mode. Forecasting models are becoming more prevalent in coastal areas. This dissertation details the development of a coastal real time forecasting system for the Northern Gulf of

Mexico. The system provides a twice daily, ten-day forecast of two-dimensional hydrodynamics for the Northern Gulf of Mexico coastal zone. Additionally, this dissertation presents the application of the forecasting system to provide stream power forecasts for the Lower Mississippi River from Baton Rouge, LA to the Gulf of Mexico, which is not a product of any forecasting agencies at the time of this research.

COPRODUCTION, DEVELOPMENT, AND APPLICATION OF NUMERICAL MODELING DECISION SUPPORT TOOLS FOR THE MISSISSIPPI RIVER AND GULF OF MEXICO

A DISSERTATION
SUBMITTED ON THE 1ST OF MAY 2024
TO THE DEPARTMENT OF
RIVER COASTAL SCIENCE AND ENGINEERING
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
OF THE SCHOOL OF SCIENCE AND ENGINEERING
OF TULANE UNIVERSITY
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
BY

Laura Manuel

(Laura A. Manuel)

Approved:

Ehab Meselhe Digitally signed by Ehab Meselhe Date: 2024.05.07 07:56:59 -05'00'

Ehab A. Meselhe, Ph.D., PE

Mead Allison Digitally signed by Mead Allison Date: 2024.05.07 11:23:39 -05'00'

Mead A. Allison, Ph.D.

Kelin Hu Digitally signed by Kelin Hu DN: cn=Kelin Hu, o=Tulane University, ou=Department of River-coastal Science and Engineering, email=khu1@tulane.edu, c=US Date: 2024.05.07 11:56:16 -05'00'

Kelin Hu, Ph.D.

Barbara A. Kleiss

Barbara A. Kleiss, Ph.D.

ACKNOWLEDGEMENTS

This research was funded by National Oceanic and Atmospheric Administration's RESTORE Science Program, the Environmental Defense Fund, and Tulane internal funding sources. Additionally, this research was supported, in part, by the high-performance computing (HPC) resources and services provided by both the Louisiana Optical Network Infrastructure (LONI) and Technology Services at Tulane University.

I appreciate the work of Drs. Denise Reed, Kristy Lewis, Nazmul Bed, Ahmed Khalifa, and Thies Blokhuijsen who all provided significant scientific contributions.

I would like to thank my committee: Mead Allison, Barbara Kleiss, Arnejan van Loenen, Kelin Hu, and Ehab Meselhe. Their support and supervision formed and vetted this research over the last four years.

To my lab (and former lab), I thank you. Sherif and Ali, thank you for your kindness and never-failing tech skills. Emma and Claire, I am grateful for our fast friendship and constant support.

Katelyn and Ahmed, the “departmental guinea pigs” – I could not imagine two more wonderful people to journey through graduate school with than you both.

I am deeply grateful to my advisor, Dr. Ehab Meselhe, for trusting and mentoring me. I am profoundly aware of how his guidance has influenced the experience and education I have received these four years. He provided environments and experiences that fostered growth and maturity in me, and I am humbly thankful for the opportunity to learn from him technically, professionally, and personally. It has been a true honor to study with you, Dr. Meselhe.

I thank my family: my mother (Angela) and father (Michael) for supporting me in every step of my life-especially this one, my brothers (Clint and Grant) and their wives (Raquel and Heather) for unfailingly cheering me on and being the role models I most admire, and my nieces and nephews (Luke, Anne, James, Claire, and Levi) for being indescribable sources of joy, purity, giggles, and love to me. To Scot, thank you for believing in me, for encouraging me in every valley and celebrating me on every mountain top.

Finally, and most humbly, I would like to thank God for the blessings in my life. Though too numerous to name, I am grateful for the blessings of family, opportunity, health, safety, community, friendship, guidance, protection, stability during hardship, perseverance during doubt, and direction for my life. May my life honor him.

TABLE OF CONTENTS

Contents

LIST OF TABLES

LIST OF FIGURES

Overview

Natural resource management in coastal regions is a challenging task often requiring actions which impact both the natural and built environments within the coastal regions. Environmental management decisions made in coastal regions are inherently accompanied by tradeoffs associated with the natural environment's reaction to interventions. This dissertation aims to bridge the gap between scientific modeling tools and the natural resource management community by integrating numerical modeling strategies with stakeholder designed tools and output. The first chapter focuses on the coproduction strategies employed to facilitate the collaborative design of scientific modeling tools within a practical management context. The second chapter of this dissertation expands on the engineering and design of the numerical modeling tool using a three dimensional hydrodynamic, salinity, and temperature modeling system (Delft3D) (Lesser et al., 2004) and the model's application to a strategically designed set of management alternatives to explore what tradeoffs emerge. This second chapter studies the operation of the Lower Mississippi River existing and proposed diversions and the management of the natural outlets below the levee system. The final chapter of this dissertation focuses on the development of the numerical model into a real-time forecasting system for the Northern Gulf of Mexico. This forecasting system provides a twice daily ten days forecast of the Mississippi River and gulf conditions and is maintained by the Tulane River Coastal Science and Engineering Research Group. The flexibility and utility of the forecasting system was exercised through the exploration of stream power profile dynamics in the Lower Mississippi River.

Contribution of this Study

This dissertation contributes to the subject of natural resource management and decision making in coastal ecosystems, specifically the Lower Mississippi River and Gulf of Mexico region. The first chapter of this dissertation contributes a workflow for designing a decision support tool using coproduction strategies to incorporate stakeholder knowledge into the design process. The second chapter details the development of the decision support tool designed in chapter one, via process based numerical modeling development. The second chapter also applies the modeling tool to explore the natural resource management of freshwater allocation in the coastal region of the Lower Mississippi River and Gulf of Mexico. The third chapter further develops the numerical modeling tool into a real time forecasting framework to support the investigation the Northern Gulf of Mexico forecasted conditions and applies the system to examine stream power dynamics in the Lower Mississippi River.

1. Chapter (1): A Roadmap to the Co-Production of a Decision Support Tool for Coastal Ecosystems

1.1 Introduction

Coastal regions are complex social-ecological systems that require conservation and management by multiple stakeholder groups representing industries, government, tourists, and local communities. These groups are likely to have varying degrees of knowledge, and often conflicting desires, about how to best manage the system they are involved with or in which they live. Given the synergistic stressors occurring on ocean margins, the management of these ecosystems and their natural resources is an especially important yet challenging task (Masson-Delmotte et al., 2021; National Academies of Sciences, 2022; Nittrouer et al., 2017). Coastal ecosystems experience environmental stressors such as storm surge, severe rainfall events, sea level rise, and in certain regions, subsidence (Masson-Delmotte et al., 2021). These environmental processes make coastal ecosystems characteristically vulnerable, and gradually degrade their health as productive habitats. Coastal ecosystems also provide provisionary and cultural services of both commercial and non-commercial resources for coastal communities, while providing the supporting services of maintaining healthy natural system dynamics- including water filtration and carbon sequestration.

Coastal ecosystems and their natural resources provide services that support the environment, economy, and human society. The management objectives, and corresponding management strategies, across these three perspectives may not align, and often are antagonistic rather than synergistic to one another. It is quite rare, and practically impossible, to identify strategies that fully serve the objectives of all three components. There is a myriad of examples where these complex networks interact. For instance, in the Mekong river basin (China, Myanmar, Thailand, Lao PDR, Cambodia and Vietnam), farming, fishing, sand mining, and upper basin water management practices (through extensive series of dams), directly influence the hydrology and morphology of the system and its ability to sustain valuable natural resources (Nittrouer et al., 2017). Similarly, Chesapeake Bay and Florida's Everglades (USA) represent systems with major water quality challenges resulting from high density human development that ultimately altered the natural ecosystems and their living resources (National Academies of Sciences, 2020). Coastal ecosystems experience change through a range of natural and anthropogenic controls, and are likely impacted by the legacy of disturbances that perpetuate through the system in both time and space (McClenachan, 2016). Thus, management of these systems is increasingly complicated as we grapple with both the legacies of impacts and the future challenges of global change.

Considering the sensitivity of coastal ecosystems to natural and anthropogenic drivers, maintaining the health and vigor of coastal regions requires extensive, carefully coordinated management (Louisiana, 2017). This task necessitates the collaboration of experts, including both academically trained content experts and community context experts, meaning those who live, work, or have experience in the coastal ecosystem of interest. This partnership can provide complementary perspectives about living and working in the system under consideration (Mauser et al., 2013, Lang et al., 2012). Here we present a transdisciplinary (see Table 1 for a list of comment definitions used in this study) and collaborative approach to co-produce science tools directly used by natural resource managers to support coastal ecosystems. Generally, co-production is a combined effort that requires interdisciplinary or transdisciplinary participants with perhaps varying degrees of investment to work together (often simultaneously) to understand and define the problem and develop a solution (Lemos & Morehouse, 2005; Meadow et al., 2015). The coastal ecosystem system presented in this case study is the Northern Gulf of Mexico (NGOM; Figure 1). Like other coastal ecosystems, the NGOM supports a broad set of ecosystem services across multiple states and municipalities (Louisiana, 2017). The NGOM experiences a direct, and often immediate, response to climate change drivers (sea level rise, subsidence, frequency and intensity of coastal storms), and anthropogenic alterations (deepening and widening of channels to support navigation, levee systems, oil and gas activities, and upper basin water management practices). Management of natural resources in the NGOM is a shared responsibility among various local, state, and federal agencies, adding yet another level of complexity.

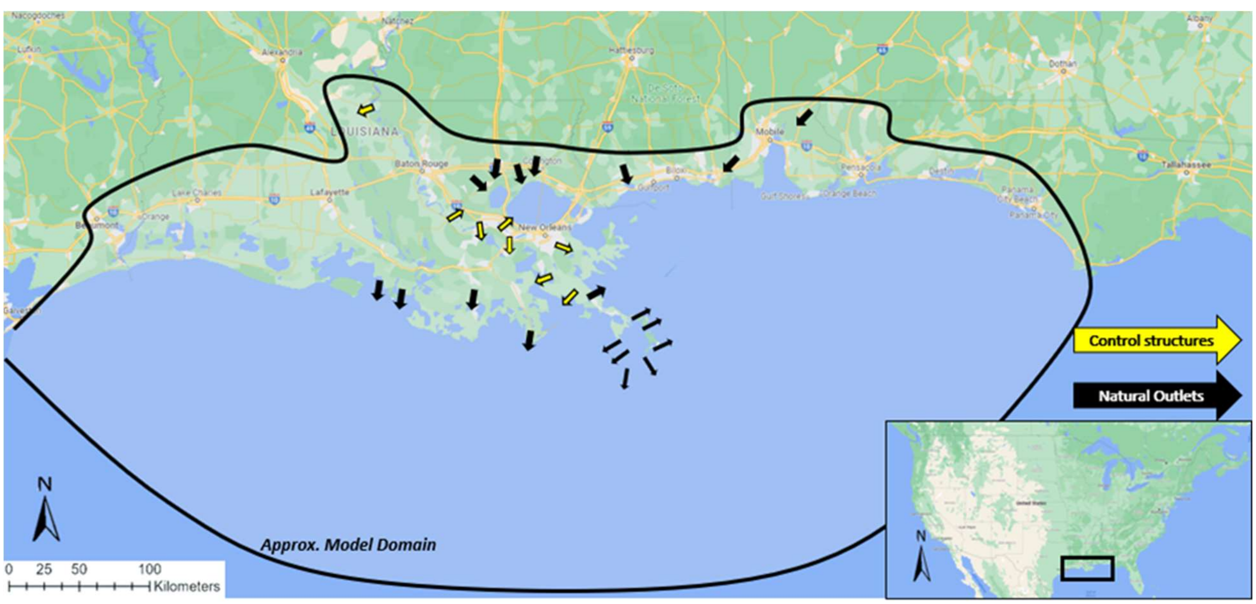


Figure 1 Northern Gulf of Mexico with approximate decision support tool domain- yellow arrows depict existing and proposed controlled structures; black depicts rivers and natural outlets

Table 1 We provide definitions to terms frequently used in this paper to offer more clarity of this work for an interdisciplinary audience. We recognize that multiple definitions may exist in the literature, but in this paper, we are using the provided definition as our theoretical framework

Term	Definition
Boundary Spanner	Entity (individual or organization) serving to prioritize the translation of information across disciplines (Meadow et al., 2015)
Community Context Expert	Those who live, work, and/or have experience in the coastal ecosystem of interest
Co-Production	A combined effort that requires interdisciplinary or transdisciplinary participants with perhaps varying degrees of investment to work together (often simultaneously) to understand and define the problem and develop a solution (Lemos & Morehouse, 2005; Meadow et al., 2015)
Decision Support Tool	Platforms designed to integrate, analyze, and display information to assist decision makers. They may provide information about the trade-offs of management decisions and supply scientific reinforcement to their management practice toolbox (Gibson et al. 2017).
Design Charrette	An intensive workshop that focuses on a specific problem addressed by the participation of members who employ a community-based and transdisciplinary problem solving strategy to achieve a design (Sutton & Kemp, 2006)
Natural Resource Manager	Individual responsible for making management decisions related to the natural resources in a particular domain. For this effort the decisions primarily include freshwater allocation and the planning, construction, and adaptive maintenance of restoration projects.
Non-academic actor	Member from any working sector outside of academia, namely Natural Resource Managers for this effort
Stakeholder	Individual with investment in the product. These are Natural Resource Managers for this project
Toolbox Dialogue Initiative	Workshop was organized to bridge gaps between disciplines and build avenues for team members to work together in a synergistic way. These workshops are coordinated to support cross-disciplinary research by facilitating conversations and team building communication for teams working in the realm of knowledge production (Crowley et al., 2010; Schnapp et al., 2012)
Trade-off	Acceptable negative outcome in return for achieving a desired positive outcome
Transdisciplinary	Research that combines interdisciplinary and multidisciplinary researchers and aims to co-produce knowledge with non-academic actors to unify knowledge to address complex socio-ecological challenges.(Lang et. al 2012)
Uncertainty in modeling	Uncertainty caused by bias or imprecision associated with compromises made or lack of sufficient knowledge in structure specificity, parameter estimation, or model calibration

The management practices of the NGOM basin range in scale (temporal and spatial) and strategy. Of particular interest are two primary management practices: the allocation of riverine freshwater through control structures and the construction and maintenance of restoration projects. Largely unique, but certainly related, these two management practices may require extensive analyses to fully understand, from a scientific perspective, the best approach for their on-the-ground implementation. The expertise required to support such studies resides within the research community (e.g., academia, federal laboratories, or specialized private firms) and is potentially disconnected from the natural resources management community and individuals who will be directly impacted by the management decisions.

Several drawbacks result from these disconnections. For example, the scientific tools used to perform the analyses are complex and require substantial knowledge about ecosystem modeling, rendering them generally unusable by managers. Therefore, managers are perpetually dependent on the model developers and researchers who rarely have the means and/or time to make them more accessible for managers by training or model adaptation. Thus, managers are unable to directly ask specific (often time-restricted) management questions needed for their decision-making. Even still, many models are currently used to guide management decisions in the region, and the complexity and "black box" nature of the models is a cause for deep concern among the coastal residents. Furthermore, managers are often limited in time and resources and are restricted by barriers between science and management. Such barriers may include divergent views of the problem, priority of actions to be taken, political communication and translation. (Dale et al 2019). Ultimately, due to the constraints of funding and time, incorporating community input is not usually feasible and managers are unable to prioritize studying the full range of scientific implications of their decisions. To account for the extensive complexities in the decision process, NRMs make management decisions that allow for adaptivity and iteratively with an emphasis on monitoring and learning how a problem evolves, changes, and responds to the external stimuli in response to the prescribed management actions (Walters, 1986, National Academies of Sciences, 2022).

In this study, we directly considered the disconnect between scientists and natural resource managers (NRM) in the development of a tool to support management practices This particular co-production effort used strategies, such as a virtual in-depth multi-day workshop (charrette), to prioritize the needs of NRMs. With resource managers as the primary stakeholders and end users (see Table 1 in Appendix), in collaboration with researchers, co-production strategies were used to design a science-based tool that captures the complexity natural resource management requires in the NGOM. The following research questions are addressed in this study: Can frequently applied co-production techniques be successfully used to scope a large, highly technical, transdisciplinary decision support system?" What are the advantages and challenges of executing a co-production effort through virtual communication and design methods? What role does decision making uncertainty have in the conceptual design of a decision support tool for coastal ecosystem management?

1.2 Background

1.2.1 Co-production theory

Effective solutions for large-scale environmental and water resources challenges require involvement from multidisciplinary managers and researchers with broad expertise (Cvitanovic et al., 2020, Cash et al., 2006). The method of integrating individual disciplines into a multidisciplinary effort can be executed in different ways. Cash et al.(Cash, 2006), describe the more traditional linear style, referred to as a loading dock approach to problem solving, where each discipline participates to a complete extent and then transfers the entirety of their work on to the next participant. This approach may sound familiar in its assembly line style of transferring science from scientists to developers to end users. However, the translation of scientific information as it moves into the decision-making context, specifically for policy or regulation, becomes dependent on the interpretation of interest groups that may conflict, compete, and reconstruct the scientific reasoning to suit their concern. (Jasanoff 2016). Therefore, the ability to retain scientific consistency in decision making presents a challenge if, at some point, the scientific community is disassociated.

Alternatively, for large-scale and complex environmental and water resources challenges, the co-production of strategies and solutions is a more effective approach (Arnott et al., 2020, Macher et al., 2021). Co-production is characterized by the democratic involvement of participants from multiple levels including scientists (physical, social, and ecological), managers, decision makers, and economists (Djenontin & Meadow, 2018). The co-production transdisciplinary research framework combines interdisciplinary and multidisciplinary researchers and aims to co-produce knowledge with non-academic actors to unify knowledge in an attempt to address complex socio-ecological challenges. Lang, et al. (2012) argues, "Transdisciplinary, community-based, interactive, or participatory research approaches are often suggested as appropriate means to meet both the requirements posed by real-world problems as well as the goals of sustainability science as a transformational scientific field." Transdisciplinary research can be viewed as a supplement to disciplinary, interdisciplinary, and multidisciplinary research; it should be clear that transdisciplinary research is NOT the same as interdisciplinary or multidisciplinary work. Multidisciplinary research is the "cooperation of researchers from several different disciplines, but each working in their own context with little cross-fertilization among disciplines, primarily sharing information and results at the end of their research to support the overall combined findings" (Lawrence et al. 2022). Interdisciplinary research in contrast, involves a much closer interaction, including transferring methods and knowledge between the academic disciplines (sometimes in turn leading to the development of new academic disciplines, with their own characteristic knowledge, approaches, and boundaries to other disciplines (Lawrence et al. 2022). Transdisciplinary research is not meant to replace these other approaches to research, but to supplement and complement them. Defining transdisciplinary research, however, has been an ongoing debate in the literature for over 50 years, but it generally centers around two schools of thought: unity of knowledge and social engagement.

Often, the process of co-production requires initial generalization in order to bridge communication barriers that inherently exist between disciplines (Guston, 1999). The advancement from general themes and overarching problem descriptions toward the detailed "nuts and bolts" of the solution is a well-documented, challenging aspect of co-production and is reflected in the iterative nature of efforts (Lemos & Morehouse, 2005), This integration and fusion of the technical expertise of each discipline can be eased by the facilitation of a boundary spanner or boundary organization (see Table 1), common to many co-production efforts.(Kirchhoff et al., 2013). The neutral zone or facilitation provided by a boundary organization creates an environment conducive to democratic participation and greater investment from participants (Gustafsson & Lidskog, 2018). Boundary organizations serve to prioritize the translation across disciplines (Meadow et al., 2015). For example, the timing and magnitude of flooding from an engineering discipline perspective (ex. max water depth/time to peak) can be translated into a timing of management actions and response discipline perspective (ex. road closures or deploy emergency services for evacuation). This translator allows participants to focus on contributing their expertise with confidence that the third-party facilitator will ensure its conveyance to the larger group. Their presence provides a non-biased facilitation "node" that minimizes the possibility of one discipline dominating the effort over another.

Key to the success of a co-production effort is the initial and sustained investment of stakeholders in the problem being addressed (Tompkins et al., 2008). Stakeholders, specifically, help to drive the effort by expressing their needs, involvement, and interaction with the problem of interest. Framing the efforts in the context of stakeholder needs ensures that the outcome of the co-production is appropriate, and consequently, more likely to be applied following the effort.

A large factor in the success of a co-production effort is the level of trust that is held by participants throughout its execution (Karcher et al. 2022, Cvitanovic et al. 2021). A level of trust must exist in (a) the expertise of other team members in their respective discipline, (b) the relevance of team member's contributions and investment to the problem of interest, and (c) the co-production process itself. Co-production relies on the expertise of its participants in their respective fields. This expertise implies that members of a co-production effort must be proficient in their discipline and broad enough to navigate the project components that lie in the gray areas between disciplines. Participants may need to field questions related to their discipline to educate the larger team or make connections between project details. These participants may provide knowledge from managerial, researcher, practical, local, indigenous, and experimental backgrounds (Raymond et al.

2010). The process of co-production may be a novel experience for participants, resulting in initial hesitancy by participants, requiring the need for strong encouragement and explanation up front to stimulate engagement. Further, the co-production process itself often changes the thinking of participants (Kirchhoff et al., 2013) by increasing their awareness and knowledge of the complex problem at hand, enlightening them to different frames of reference for viewing the problem, and requiring them to exercise the skills required to work with a non-traditional group.

1.3 Methods

1.3.1 Co-production Case-Study for the NGOM

When comprehensively considering the management of a basin on the geographic scale of the NGOM, transdisciplinarity is requisite. The NGOM is complex, providing natural resources supporting the region's economy, safety, culture, and environment. Specifically, a significant challenge for the NRM community is understanding the complexities of *managing freshwater allocation* through control structures for the purposes of flood risk management, navigation, and ecosystem benefits and the *planning, construction, and adaptive maintenance of restoration projects* within the context of naturally occurring distributaries and long-term environmental change. For this reason, our transdisciplinary team aimed to design a comprehensive decision support tool (using integrated ecosystem models), driven by the needs and active participation of NRMs, to support NRMs in their decision making. Decision support tools are platforms designed to integrate, analyze, and display information to assist decision makers. They may provide information about the trade-offs of management decisions and supply scientific reinforcement to their management practice toolbox (Gibson et al. 2017).

The co-production and transdisciplinary approaches themselves are not novel nor restricted to coastal ecosystem management. In fact, the U.S. Army Corps of Engineers (USACE) and other federal agencies have been organizing and planning projects this way for decades in a variety of applications and geographical locations (Barnes, 2010). These entities use transdisciplinary project development teams and often require stakeholder input prior to project execution to identify and resolve issues related to the project. We aimed to incorporate this line of thinking one step prior, by 1) using co-production in the preliminary design of a decision support tool and 2) formally involving stakeholders (the non-academic NRM community) as project members, rather than external/temporary participants. This co-production effort used virtual charrettes (Table 1) to prioritize the needs of NRMs in the NGOM and use those needs to drive the design process of the yet to be developed decision support tool. While this first effort did not include the community members or leaders as part of the process, we recognize the importance of expanding the co-production process to the coastal residents in the region. Here we outline the co-production process, which occurred over the course of 1 year, in temporal order before reflecting on the results and key topics that surfaced during the effort.

1.3.2 Team assembly

The complexities of coastal basin management require drawing together a team that represents the diversity of the problems. For the NGOM, some of these disciplines include NRMs, scientists, and engineers from entities in the public, private, and academic sectors. With an emphasis on the recruitment of NRMs, as their needs would drive the design process, a balanced team was formed. The balance reflects a blend in experience, geographical relevance, disciplines, level of expertise, agencies, and, subsequently, personalities. Team members were recruited through a series of individual or group virtual calls or emails, during which the project ideas were conveyed, and members expressed their level of commitment to join the effort. The members were solicited to capture: a) representation from both the federal and state sectors that participate in management of natural resources of this region; b) representation from broad set of academic backgrounds, e.g. ecology/biology, socio-economic, morphology, and hydrology; c) roles played by the team members, e.g., managers, decision makers, researchers, and planners. Diverse team composition is critical to ensure that a viable decision support system will be co-produced. The diversity of team assembly influenced the progression of work through the stimulation of ideas, development of strategies and ultimately the translation of the product following project completion. Boundary spanning (Table 1) team members played a critical role in providing guidance and facilitation of the project efforts. The team composition is illustrated in Figure 2. There is the exception where several team members are themselves multi-disciplinary (ex. John Doe is a natural resource manager (NRM) and numerical modeler), which provided unique perspectives to the group. Additionally, some disciplines, absent from the original team construct, were identified as valuable to solicit input from to continue this effort in future projects. Namely, economists and social scientists were vital to the continuation of this project, as the team worked to gather expertise that the tool development required for the next phases of tool development.

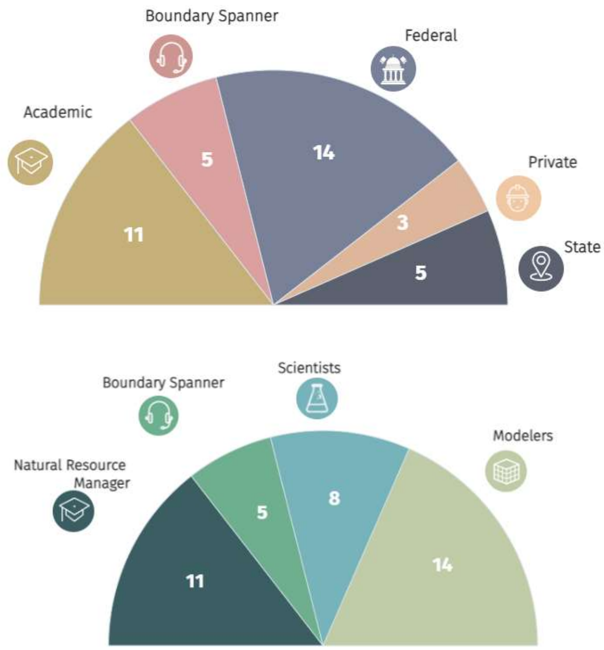


Figure 2 Team Diversity based on Agency Type (left) and Discipline (right). Note: modelers included backgrounds in ecology, engineering, and geosciences

1.3.3 Core Team and Focus Groups

The formation of a core team, consisting of 3-5 team members, was critical to the success of the co-production process for a large and complex ecosystem decision support system. For the application presented here, the core team was instrumental to maintain progress in the co-production effort while ensuring full engagement of all participants. The core team produced and synthesized material resulting from workshops and prepared material for the next steps. The group maintained the communication and coordination of the larger team and ensured that efforts and outputs aligned with the primary goals and objectives of the project.

While full-group meetings are essential to the co-production process, a series of focus group meetings were needed to address specific aspects of the conceptual design. Coordinating the timing of these various meetings supports team progress. Working in a space with members of the same discipline allowed for constructive and efficient communication, while keeping the larger project context in mind. These focused-group meetings also allow for a deep dive into individual disciplines with more freedom to use technical jargon. The two focus groups that met routinely included a NRMs group (the primary stakeholders) and a modelers group, since the decision support tool was designed as a suite of interconnected numerical ecosystem models. In sum, the focus-group meetings provided the opportunity for moments of clarity that could be concisely communicated back to the larger team and eliminate confusion.

1.3.4 Knowledge Sharing

The foundational step was a knowledge sharing workshop, which provided an opportunity for team members to gain familiarity with each other and share their experience and expertise relating to the project content. This event, led by our boundary organization, The National Charrette Institute (NCI; https://www.canr.msu.edu/nci/) allowed the team to build relations and discuss the current state of knowledge on multiple NGOM issues. The knowledge sharing workshop also set the precedent for subsequent communications and design efforts by demonstrating the role of the boundary spanner in facilitating team interactions.

The workshop involved a balance of educational tactics, including presentations, small group discussion, question and answer segments, large group discussions, and interactive polling. The interactive style of the workshop was critical for establishing a confidence between team members and the co-production process itself. After introductions and a reiteration of the overall project goals, small group discussions led to the identification of “what is known”, “where are the knowledge gaps”, and “what activities are needed to address the challenges" for four main topics: operational policies, primary riverine systems, existing forecasting systems, and critical natural resource issues.

The workshop provided material that shaped the next steps and revealed aspects of the effort that would be unique moving forward. For example, one unique aspect is that the evolutionary style of designing the system was different from the traditional style of science development to which team members were accustomed. This process of co-production introduced ambiguity initially, but the importance of the work and the needs of NRMs remained at the forefront to encourage forward progress. Differences in the use and understanding of scientific terminology were identified and highlighted the general communication barriers that existed between the transdisciplinary team. Additionally, team members discussed varying degrees of investment in the project effort and some inherent conflicting natures of the interest of basin management. For example, geographic "scale" emerged as an important topic because some experts may be concerned with the representation of the space an individual or select species occupies, whereas other experts are focused on the larger scale space necessary for adequate hydrodynamic representation.

1.3.5 Toolbox Dialogue Initiative Workshop

Following the Knowledge Sharing activity, the NCI then led a ©Toolbox Dialogue Initiative (TDI) workshop to bridge gaps between disciplines and build avenues for team members to work together in a synergistic way. These workshops are coordinated to support cross-disciplinary research by facilitating conversations and team building communication for teams working in the realm of knowledge production (Crowley et al., 2010; Schnapp et al., 2012). Prior to the TDI workshop, probing statements were developed (based on discussions in the knowledge sharing workshop) in prompts that would stimulate discussions. The prompts allowed topics to be explored from the perspectives of the whole team. The prompts in Figure 3 were designed intentionally to surface varying perceptions and opinions surrounding NGOM basin management.

Module One: Values & Trade-offs

1. Ecosystem health in the northern Gulf of Mexico should be a constraint on any commercially viable use of the ecosystem.
2. Scientific knowledge is inevitably disconnected from the places to which it is applied.
3. Our forecast model must anticipate ecosystem shifts due to climate change.
4. Social concerns should outweigh ecosystem needs when making decisions about what is included in our forecast model.
5. Natural resource managers should have as much decision-making power as the modelers in developing the model.
6. There are aspects of our project that we would not modify even in light of stakeholder input.
7. Navigation and flood risk management are non-negotiable constraints on the optimization of natural resources in the northern Gulf of Mexico.
8. Existing models are not sufficient to meet the needs of natural resource managers.

Module Two: Communication & Collaboration

1. The success of our project depends on clear and regular communication between modelers and natural resource managers.
2. The biggest obstacle to successful management of natural resources in the northern Gulf of Mexico is divergence among the priorities of agencies and institutions that have a stake there.
3. We understand what co-development of a management and forecast system looks like for our project.
4. The most challenging part of our project will be reconciling the needs of the various resource managers while making a useful tool.
5. Scientific research is too abstract to be directly applicable to the problems natural resource managers face.
6. It is the researcher's responsibility to make their research accessible to natural resource managers.
7. Natural resource managers and researchers should jointly determine the criteria that guide particular management decisions.
8. New scientific tools should be designed to be easy to use by natural resource managers.

Figure 3 Toolbox Dialogue Initiative (TDI) prompts provided to participants during the TDI.

The discussions were facilitated by NCI and provided a democratic space for participants. The dialogue allowed the team to formulate strategies for working together moving forward and clarified discrepancies between terminology, assumptions, and project goals. Specifically, the group had discussions about the values and trade-offs related to coastal basin management in the NGOM and the collaboration and communication required to accomplish this task. NRMs emphasized that scientific tools are only one component of their decision-making process. They expressed that social, economic, and political factors influence decision-making and may conflict with the scientific suggestions for NR management. Another point highlighted in the TDI was the necessity of communication across disciplines in NR management beyond this particular project effort. Uncertainty was an important theme that emerged. The development of this decision support tool involves both the uncertainty related to model interpretation and inherent scientific uncertainties related to future projects.

1.3.6 Design Charrette

One of the key elements of the co-production process presented here, is a multi-day charrette. The design charrette served as the primary mechanism for achieving a preliminary or conceptual system design. A design charrette is an intensive workshop that focuses on a specific problem addressed by the participation of members who employ a community-based and transdisciplinary problem solving strategy to achieve a design (Sutton & Kemp, 2006). This style of co-production is characterized by an iterative process of information sharing, idea generation, prototyping, and prioritization to culminate in a designed product (Howard & Somerville, 2014). Charrettes have historically occurred in the Gulf States, organized by the USACE and other agencies, to address problems in the

NGOM (Engineers, 2003; "Louisiana Charrettes Move to Arabi," 2006). This mechanism of design requires active participation, encouraging the team to "design with" stakeholders instead of "design for" them in producing the outcome. For the NGOM application, boundary spanners (i.e., the NCI team) worked with the core team members to organize and prepare for the charrette. Breakout groups were strategically arranged to reflect transdisciplinarity, and topics were carefully constructed to serve as the guideposts for discussions. Activities were planned to gather feedback/input, along with a selection of virtual platforms and tools that would be employed to execute this meeting to create the framework for the decision support tool. The preparatory work was important because it structured activities and assignments that provided enough directive to members to guide them into interdisciplinary dialogue around project relevant content yet was flexible enough to allow the meetings/working sessions to evolve in response to the team's momentum.

The charrette was executed by the entire team working together in a concise time frame (~3 days, 5-6 hours/day, ~25 participants) to produce a preliminary design of the system framework. While charrettes are commonly held in person, due to COVID-19, this charrette was conducted through an extended video conference. It involved group-organized dialogue with the entire team and small breakout group discussions, ranging from 4-8 participants/group. It included an iterative process of brainstorming and review that was required for several design components to evolve concurrently. The process equated to efficiency and quality control of material produced. The primary platforms used to record and document the virtual workshop were ©Zoom and ©Miro. ©Miro frames and tiles were designed and refined throughout the charrette. Some tiles included material such as: decision support tool features, short term forecast questions the tool could help NRMs answer, applications of the tool, plans for advancing the design following the charrette, and more. Figure 4 illustrates two of the several ©Miro frames utilized during the charrette.

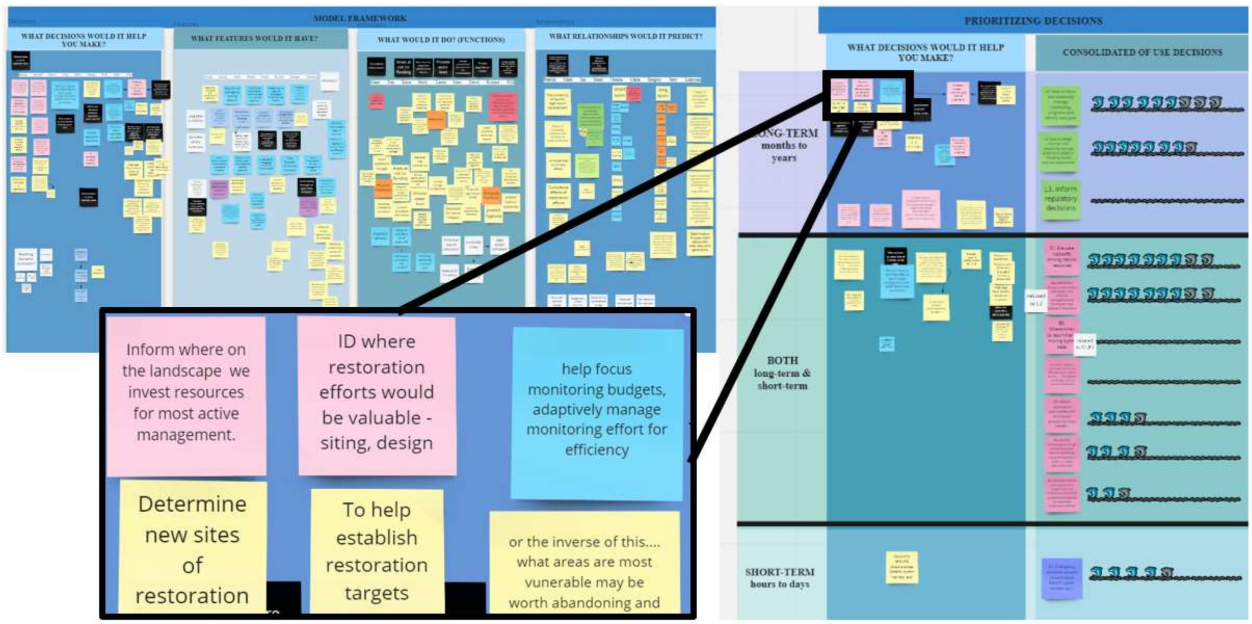


Figure 4 ©Miro frames created during the design charrette populated by sticky notes from participants. See inset image for subset of responses to the prompt "what decisions would it (the tool) help you make?".

Following the charrette, the core team synthesized the outputs and delivered it back to the team. As the charrette was the main vehicle for the conceptual co-produced system, the outcomes of the charrette are worth mentioning, listed next in sequential order. For the management system, NRM needs were defined. These needs were the driving focus of the design and were continually referred to by the team to maintain appropriate focus. From there, the team focused their efforts on the "nuts and bolts" of the system's conceptual design. The drivers, processes, parameters, and visuals of the system were organized and documented. The work reflected the aspects of existing scientific tools in combination with novel components, reflecting the needs unique to this project.

1.3.7 Virtual Collaboration and Support Material

Considering the amount of dialogue required by this co-production effort, it is worth mentioning that nearly the entire case study presented here was conducted in a virtual format. The ability to maintain stakeholder engagement and project advancement through virtual means has been recently evaluated in wake of the Covid-19 pandemic (Köpsel et al. 2021). Although some suggest that virtual collaboration may produce some hinderances to equal participation (Beaunoyer et al. 2020), we propose unique advantages to virtually executing the co-production effort. The notably recent shift of work from in-person to virtual platforms was advantageous for this effort, partly due to the level of proficiency that team members have with virtual meetings and participation. Additionally, the logistics (and cost) of physical team assembly was eliminated, allowing for a larger and more frequent degree of participation from team members who otherwise would have required extensive travel arrangements. As mentioned previously, the team used the online design tool ©Miro, through boundary spanner facilitation, as a working environment or design studio for the project. Often, activities within the meetings involved participants contributing to the design process anonymously (for example through adding an idea on a sticky note). The anonymity was advantageous to less outspoken team members, who might typically shy away from expressing their views had the meetings been conducted in person. The virtual and anonymous space created an unbiased and inclusive platform for members to participate and evaluate responses objectively, which is desirable in any scientific endeavor. In addition to virtual meetings, the team employed several communication tools (Figure 5) to maintain transparency, inclusivity, participation, and quality of work.

Figure 5 Communication tools employed for the project

The team shared online databases, archived documents, video recordings of all main meetings and workshops, and an active website. The dissemination of this material, particularly recordings that allowed the team to be privy to any meeting dialogue, provided a level of transparency that may not be achievable in all co-production efforts.

Team participation cycled from large to small working groups throughout the project life. The involvement of various disciplines fluctuated throughout the design process (Figure 6). A strong level of initial engagement of the entire team is evident, with intermittent smaller working sessions. The emphasis on initial engagement is important because of the characteristic time needed to establish cohesiveness among diverse stakeholders. (Karcher et al. 2022). Once engaged, the collaboration fostered continued ownership and accountability for both the problem and developed solution. (Mauser et al. 2013). Maintaining stakeholder investment was a critical component of this effort and was sustained through individual and group “check ins.”

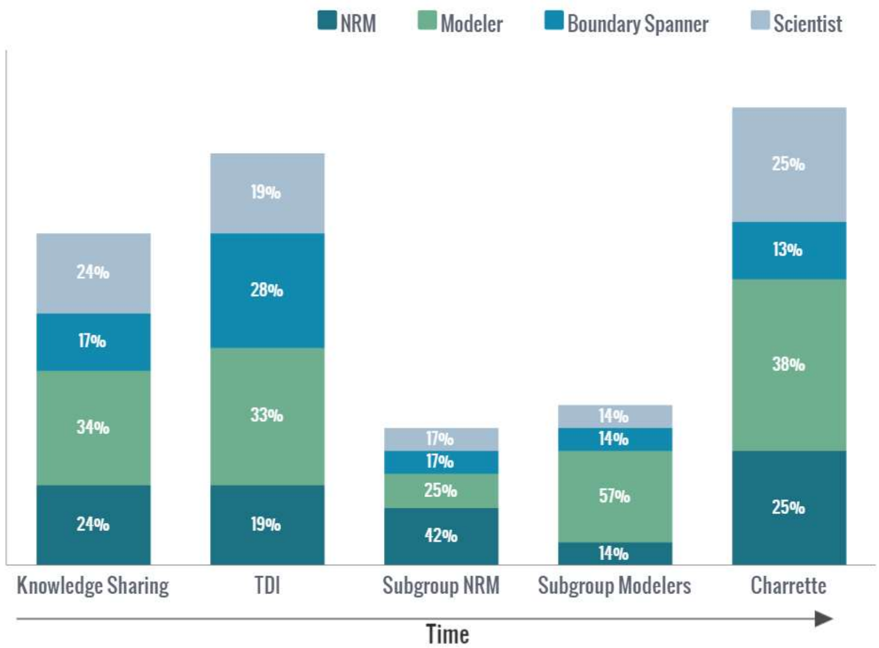


Figure 6. Participant involvement in the co-production process, separated by discipline

1.4 Results

Together, the authors represent members from the disciplines of science, engineering, management, modeling, and boundary spanning. The results discussed here express a collective reflection by the authors, who all participated in the co-production process for the duration of the effort.

1.4.1 Conceptual Design

It should be noted that formulating a system design does not necessarily equate to a successful co-production effort. Moving forward, an effectively developed system needs to be available and fully operational to a NRM to examine scenarios and issue a decision regarding freshwater allocations or siting/funding/prioritizing restoration projects. Starting with a clear and accessible conceptual design was the first step toward developing a tool that is accessible to NRMs, specifically those without modeling expertise. The design depicted in Figure 7 was developed to encompass the contributions from the co-production effort.

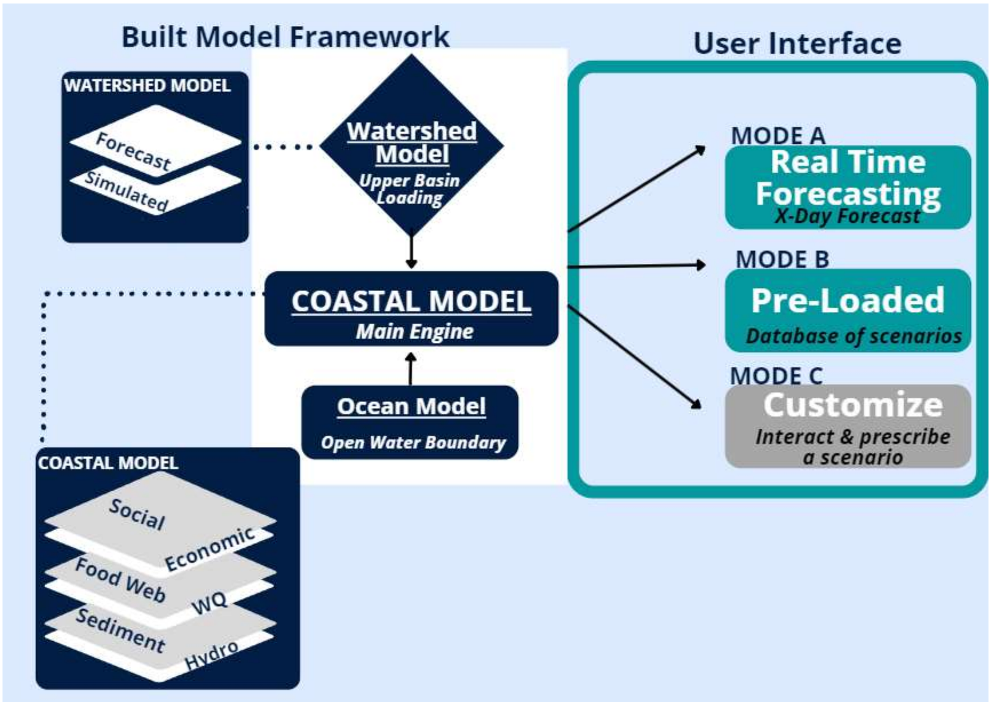


Figure 7. Preliminary decision support tool design developed during the co-production process.

The conceptual model framework (Figure 7) consists of a coastal model equipped with computational layers required to address the management decision in question. The coastal model is driven by freshwater, sediment, and nutrient loading from the upper basins and by the Gulf of Mexico conditions provided through an Ocean Circulation model. The team outlined a web-based portal that would operate in three modes: A) Operational Real Time Forecasting, b) Rapid Decision Support, and C) Customized Analysis. Mode A would provide real time forecasting of the basin in the time frame of days to weeks. Mode B consists of a preloaded database of model output that has been populated by a series of predefined permutations. These permutations (in the order of 100's or 1000's) would be formulated by NRMs based on envisioned upcoming needs and wish lists. Mode B would allow a NRM to browse scenarios that have already been computed to gain an understanding of tradeoffs and system response to basin management. Mode B may provide insight to the system's dynamics and response so that the NRMs can gain quantitative insights and help them formulate effective strategies beneficial to their NR of interest. Finally, Mode C would provide NRMs the opportunity to customize the modeling system for their particular decision of interest and produce output to reflect the scenario they have developed.

1.4.2 Applications

To explain and justify the continuation of this project from design to development, real-world applications were defined during the charrette to communicate the utility of this type of system. These example applications (Figure 8) were developed to concretely illustrate instances of system employment.

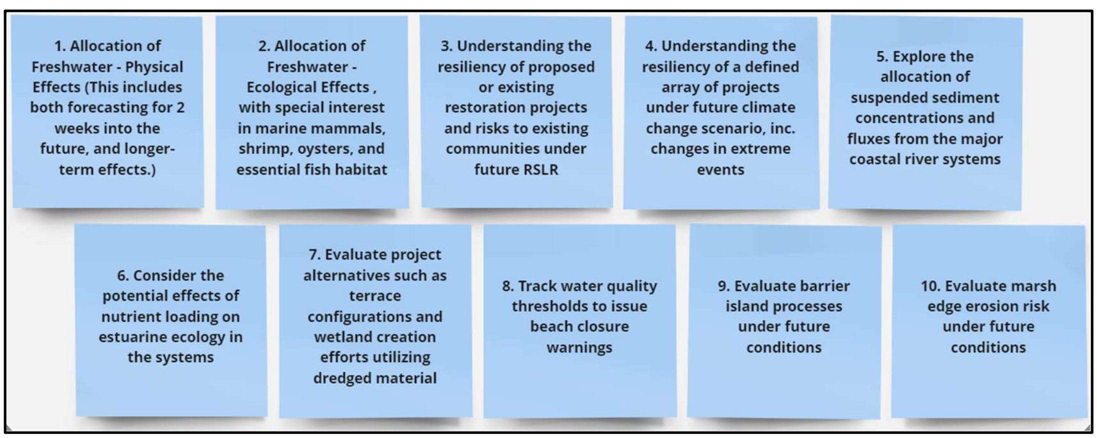


Figure 8 ©Miro frame of example applications of the decision support tool

Each application carries a description such as the context, scale, agencies involved, and desired model outputs. The specificity dually serves to verify the utility of the design that was formulated in the charrette and provides information that could supplement or enhance the proposed system design. It was a particularly useful exercise, requiring a thorough review of the charette material to capture the collective team sentiments. An example of an expanded application for the tool is provided (Figure 9).

Application #1 – Freshwater Allocation: Physical Conditions (example 1)

Objective: Explore options between the allocations of freshwater at the various man-made and natural diversions on the lowermost Mississippi River to simultaneously address flood risk management, navigation considerations, and natural resource management.

Description: There are numerous man-made and natural locations which divert freshwater out of the Mississippi River. Currently, there is no comprehensive tool which explores the relative merits and costs of utilizing one system over another (synergies and unforeseen outcomes to tone it down a bit – use effects instead of impacts). This tool will allow for various flows at all locations and report the resultant salinity at numerous nodes across the northern Gulf.

Participants: USACE, USGS, NOAA, States of AL, MS, LA

Regulatory Context: Water Control Manual for existing diversions including: ORCC, Morganza, Bonnet Carre' Spillway, Davis Pond, Caernarvon

Workflow:

Drivers	Parameters	Processes	Visuals
• Riverine FW inflows • Tides • Winds • Rainfall	• Discharge • Water level • Salinity • Temperature • Velocities	• Hydrodynamics • Estuaries, shelf, gulf circulation • Economic Impacts • Social Impacts	• Timeseries- at key locations in Maurepas, Pontchartrain, Bay St. Louis, Mobile Bay, Barataria, and Breton Sound Basins • Spatial static maps • Animations

Time Scale: Short term- days to months

Spatial Scale: ORCC to the AL/FL line to Atchafalaya

Data Sources: USGS, USACE, CRMS, NOAA,

Data Characteristics (format and metadata): projections, coordinate systems, units

Model Sources: Tulane Delft + Economic + Social +?

Mode of Operation: Explain how it will be used in various modes of operation

(Prototype developed)

Figure 9 Expanded example application illustrating the context for utilizing the decision support tool

1.4.3 Uncertainties of the Decision-Making Process

One of the biggest concerns of NRMs regarding the use of decision support systems and computer models in general, are the uncertainties associated with numerical-modeling-based decisions (Lempert, 2019). Thus, the team carefully considered effective approaches to address uncertainties in the decision-making process. Due to the presence of varying types and degrees of uncertainty, it is necessary to outline the specific uncertainties that relate to and emerged within this case study.

Commonly, two kinds of uncertainties are defined, epistemic uncertainty and aleatory uncertainty (Yoe et al., 2010). Epistemic uncertainty is due to a lack of knowledge on the part of the observer, and, in theory, is reducible, though it may be expensive or difficult to do so. A collateral advantage of setting up a numerical model or decision-support system is often that the structure of the system will expose obvious data gaps and the lack of critical knowledge about relationships between environmental factors, which can then be prioritized by the research community. An excellent example of epistemic uncertainty in the case study that describes a lack of precise understanding between the relationship of coastal salinity and the health of specific animal species. This topic was explicitly mentioned during the co-production process by NRMs from state and federal agencies. Aleatory uncertainty is due to a random process and is attributed to the natural variability of a quantity over time or space. It is considered irreducible and cannot be known simply by collecting more data, though the understanding of the variability of the parameter might change with more information. In this case study, the annual variation in the flow of the Mississippi River is an example of aleatory uncertainty.

Yoe et al. (Yoe et al., 2010) also state that it is common to see uncertainty categorized by its source. Uncertainty caused by bias or imprecision associated with compromises made or lack of sufficient knowledge in structure specificity, parameter estimation, or model calibration is called model uncertainty. Quantifying uncertainty arises when there is uncertainty associated with the value to use for an input parameter in a model to estimate outcomes. This source of uncertainty generally results from aleatory uncertainty. The uncertainty that results when the elements of a scenario or application to be tested are unknown or incomplete is called scenario uncertainty. Not fully understanding the response of an ecosystem to a specific aspect of climate change is an example of this type of uncertainty.

Many of the above types of uncertainties will be addressed within the development of the numerical model that will be used as the basis of the decision support system using a series of techniques common to model development, including the identification and focus on key uncertainties and sensitivity analysis. Using best available observations for extensive sensitivity analyses, along with careful model calibration and validation, will reduce (but obviously not fully eliminate) these uncertainties.

More important is the role that this decision support tool can contribute to guiding decision making when there is "deep uncertainty." Lempert et al. (Lempert, 2019) (2003) consider the resulting situation to be "deeply uncertain"—a situation in which the experts do not know or the parties to a decision cannot agree upon "(1) the appropriate models to describe the interactions among a system's variables, (2) the probability distributions to represent uncertainty about key variables and parameters in the models, and/or (3) how to value the desirability of alternative outcomes". Haasnoot (Haasnoot et al., 2013) adds that "deep uncertainty also arises from actions taken over time in response to unpredictable evolving situations." These descriptions define the situation in the NGOM where magnitude and intensity of long-term changes in many features such as climate change impacts on relative sea level rise, river flows and plant growth as well as effects from subsidence, ocean acidification, tropical storm frequency and intensity are unknown (National Academies of Sciences, 2022). Additionally, there are many non-scientific uncertainties, including future social and political positions, funding constraints and the timeframe in which decisions will be made.

To apply methods for decision making under deep uncertainty it is necessary to use analytical methods for decision support. Lempert et al.(Lempert, 2019) suggest using a definition from the US National Research Council (Council, 2009), which states that decision support represents a "set of processes intended to create the conditions for the production and appropriate use of "decision relevant information." Three key tenets for decision support are emphasized: 1) the way in which information is integrated into decision making processes is important; 2) the knowledge used must be co-produced by information users and producers; and 3) the decision process must be designed to facilitate learning. In this way, the development of this decision support tool, which is co-produced and designed to facilitate learning by NRMs, will address deep uncertainty by providing a reproducible analytical method to test scenarios and illustrate tradeoffs. Additionally, the collaborative process of designing the decision support tool incorporates the multiple types of knowledge relevant to solving problems with inherent uncertainty (Armitage et. al 2008).

Furthermore, the team reviewed three approaches for decision support under deep uncertainty that will be integrated into the design of the decision support system. The first, Robust Decision Making (RDM) is a set of concepts and processes that use computation not only to make better predictions but to make better decisions under conditions of deep uncertainty by systematically exploring the consequences of assumptions with myriad model runs (Lempert, 2019). Secondly, Walker et al. (Walker, 2000) describe Dynamic Adaptive Planning (DAP) as an approach which focuses on implementation of an initial plan and subsequent adaptation of the plan over time as new knowledge is attained. This method specifies the development of monitoring programs and outlines specific responses when explicit targets or trigger values are reached. Thirdly, Haasnoot et al. (Haasnoot et al., 2013) describe Dynamic Adaptive Policy Pathways (DAPP) as an approach which explicitly considers the timing of actions and is based on Adaptation Tipping Points. Although none of these approaches eliminate uncertainty, the implementation of these approaches can provide a more global perspective of the potential impacts of NRMs decisions. Furthermore, designing the decision support tool with both real-time forecasting and a long-term planning mode will provide a degree of scenario adaptation functionality (customizable by the end-user) that both DAP and DAPP suggest is key to addressing deep uncertainty inherent in management decision making.

1.5 Challenges and Reflections

This team was able to make unique contributions as a large group collaboration despite significant geographical and time zone disparities, along with prominent disciplinary differences. Using NRM's needs as the driving focus, the team accomplished its intended goal of a preliminary system design. Non-tangible outcomes were achieved, as well, which is fairly common in co-production efforts (Djenontin & Meadow, 2018). Generally, an overall enhanced understanding of the management of the NGOM and strategies for improvement. Team members were educated on the current state of basin management and gained a transdisciplinary understanding of the system.

Some of the challenges of our co-production efforts highlight opportunities for improvement in future efforts. One difficulty, as previously mentioned, is the variety in terminology across fields. With neighboring disciplines, several of the same words are used with a slightly different context. For example, the terms “urgency” and “stability” imply different meanings for the range of disciplines involved: ecologist, geomorphologist, engineers, etc. The term “uncertainty” begs elaboration and input from multiple disciplines because of its several interpretations and as discussed previously. This disciplinary jargon can be grounds for confusion, uncertainty, or lack of confidence in proceeding. Another challenge is that the initial vagueness of co-production efforts leads to a hesitancy of trust in the process. A lack of trust cascades to a more passive energy of members in their contribution to the conceptual design effort. Approximately halfway through the design charrette, core team members saw a decline in participation, likely attributed to frustration and fatigue that emerged during the system design and workshop proceedings. The presence of a third-party facilitator helped to counter this issue by providing structure for the communication and evolution of the system design. Another challenge in many co-production activities, is when dominant personalities cause an unbalanced level of participation by team members. By providing options, such as polling, voting, or group editable documents, we were able to minimize this difficulty and encourage healthy equal participation.

A notable challenge remains that the majority of this effort was conducted in a virtual format, equating to a lack of in-person, informal interactions. Although we pointed out the usefulness of virtual meetings, we contend that unstructured conversations between team members can often provide stimulation for new ideas or enhancements to the project. One counter to this challenge was the team’s ability to take advantage of an event external to the project: the 2022 Gulf of Mexico Conference. This professional conference took place during the co-production period. The team communicated the degree to which they would be in attendance and were able to arrange small meetings around the conference schedule. The conference interactions proved to be a great stimulus for design advancement, networking, and even a morale boost.

One key success metric is the interdisciplinary team retention beyond the planning effort described in this case study. Given that around 30 team members participated in the planning effort over the 1-year period, 30 members committed to a developmental phase of the decision support tool. Of the members who participated in the planning phase, 9 members were either replaced or added to the team. These team member changes occurred for various reasons, such as the need to incorporate economists and social scientists in the next phase of development, or other participants changing careers and leaving their discipline. In addition to team preservation, the 1-yearlong co-production planning effort documented ~70 meetings and ~8 presentations/conference outreaches involving the participation of anywhere from 3-30 team members per meeting. The buy in from the NRM community to employ such a sophisticated scientific tool is a crucial achievement of this process. The sustained engagement of NRM stakeholders provided expertise, trust, and commitment to the effort that could not be substituted by other means.

1.6 Conclusions

The management of a system as geographically large and complex as the NGOM requires the participation of several entities with various technical disciplines, jurisdictions, and regulatory authority. The representation and participation of this unique pool of managers and researchers who interact with and influence the ecosystem management, is key to the successful co-production of decision support tools. The transdisciplinary co-production described in this paper is not a rigid nor a linear process, but rather a flexible and collaborative approach to address complex ecosystem challenges where "traditional" and discipline-specific approaches have fallen short.

The team's co-production effort led to the design of a decision support framework to support NRMs that was driven by the specific needs of managers and reflected the desired attributes of those decision makers. In addition to designing tool components, NRMs explored specific applications of how they would be able to use the tool for their individual management decisions, paving the way for direct utility once the tool is developed. A summary of the steps and stages that ultimately resulted in the conceptual design are provided (Figure 10).

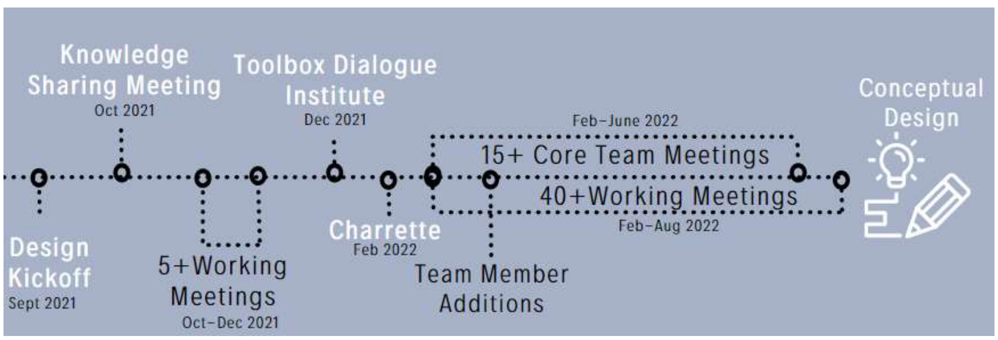


Figure 10 Summary of the timeline for the co-production of conceptual design of a decision support system

Though the preliminary conceptual framework will require refinement to move the product into development, the framework has the potential to provide support to NRMs in a manner currently unavailable to them. More importantly, the process that led to its development educated and invested a team of NRMs and set the infrastructure for their continued collaboration to see this product through development. The plan for continued collaboration and co-production is shown in Figure 11.

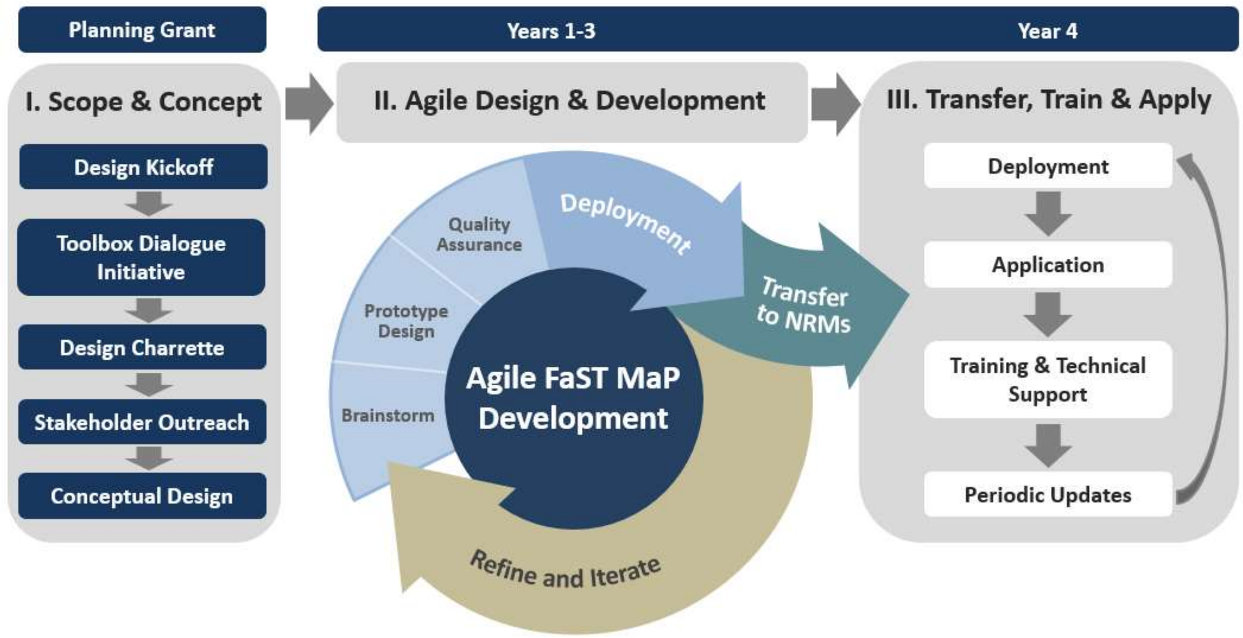


Figure 11 Co-production plan for design and development of NRM decision support tool

The plan for continued collaboration contains features reflecting the direct enhancement of using a co-production pursuit. Namely, the iterative design and deployment of the tool requires that the NRM community remains active in the transdisciplinary effort. In this way, a co-productive feedback loop can refine the tool design as it translates from concept to form. This type of user feedback would be completely void from a design effort that was restricted to a technical, academic, or single-disciplinary design group.

Through this effort, the priorities of NRMs focused on decision support systems that (a) provides information in a timely manner (short response time), (b) synthesizes and expresses the output in a manner directly relevant to management decisions, and (c) and integrates physical and biological sciences with socioeconomic outcomes. This collaborative effort also highlighted the need to focus on the ability of predictive tools to support making better natural resources management decisions, rather than dedicating effort to simply improve the numerical models to make better predictions. Further, the case study presented here clearly highlights the strong interest from the natural resource management community in actionable and translational science. We encourage others in the research community to dedicate efforts and attention to producing scientific tools that can be readily used to support management decisions.

2. Chapter (2): Systemic analysis of the tradeoffs associated with management strategies for natural and built Mississippi River outlets

2.1 Introduction

Natural resource management in coastal regions is a challenging task often requiring actions which impact both the natural and built environments within the coastal regions. The interests of coastal industry, community, and environment are unique, yet commonly invested in the decisions made concerning the natural resources of coastal ecosystems which provide freshwater and habitat (Seitz et al., 2014), storm surge protection (Dasgupta et al., 2019), commerce and recreation (Littles et al., 2018), etc. Environmental management decisions made in coastal regions are inherently accompanied by tradeoffs associated with the natural environment's reaction to interventions. For example, dam construction in large river systems around the world result in tradeoffs where flood risk is reduced, agriculture needs are better met while sediment starvation in the downstream reaches is induced (e.g. the Mekong Delta (Li et al., 2017), Yangtze River (Yang et al., 2007), and Mississippi Delta (Meade & Moody, 2010). The tradeoffs of constructing levee systems, such as in the Lower Yellow River (Walling, 2011) and Mississippi Rivers (Coleman et al., 1998), are that levees protect communities from flooding, but funnel sediments offshore and prevent natural crevassing and nourishment to adjacent wetland areas. Levees may induce channel alteration through aggregation that reduces channel capacity and stresses levee infrastructure, as seen in the Indus River (Mahmood et al., 2022). This study investigates tradeoffs associated with the environmental management of the Lower Mississippi River to support ecosystems restoration and mitigate flooding, through the diversion of river waters into adjacent estuaries, and other uses of the river and coastal system.

River diversions reroute a portion of a river's flow from the course of the main river channel into an adjoining basin. Diversions occur naturally or are manmade. River diversions for ecosystem restoration seek to reconnect the river to nearby wetlands by periodically rerouting floodwaters laden with sediment and nutrients from the river (Gagliano et al., 1981) (Amer et al., 2017). River diversions have the potential to support large scale coastal restoration through land building with temporary impacts to the environmental system (Day et al., 2018). The existing engineered diversions along the Lower Mississippi River are used to manage flood risk, build land, and/or mitigate salinity intrusion. Diversion contribution to changes in salinity on local fish, oyster, and marine mammal species (De Mutsert et al., 2017; Garrison et al., 2020), land building optimization strategies (Khalifa, 2023; Peyronnin et al., 2017a), and effects of future climate conditions on the performance of diversions (Wang et al., 2017; White et al., 2019) have been investigated extensively in the Lower Mississippi River region.

Achieving the balance between flood control and extreme environmental change (e.g. over-freshening) due to operation is a challenging task for diversion managers. Although some diversions have been in service for over 90 years, there has been no significant change to operation plans since their construction, namely the Morganza Spillway and Bonnet Carré Spillway (BCS). Yet, it is evident that the complexities and negative responses from operating and/or avoiding operating these flood control structures spur increasing investigation into the management plans for these diversions (USACE (2023)). Events such as the 2019 flood reaffirmed observations from previous flooding events that the operation strategy of the BCS for required flood management led to severe damage to commercial fishing and oyster industry production for neighboring states (Gledhill et al., 2020; McAnally & Nail, 1995; Mishra & Mishra, 2010; Mize & Demcheck, 2009; S. M. Parra et al., 2020; Turner, 2006).

What if the Mississippi river flood risk management features were operated differently? How will new diversions affect the already highly managed ecosystem? With consideration of these questions, the goal of this study is to analyze the collection of diversions and natural outlets on the Lower Mississippi River as a system and examine different operational tactics of diversions to quantify what tradeoffs emerge. The study aims to quantify the impact of annual changes in hydrological conditions on the extent of basin change experienced due to the diversions. The study simulates existing diversions and proposed diversions by the state of Louisiana's Master plan, with consideration that these diversions would be the most probable candidates to join the landscape in the future. Scenarios were designed to place diversions or lower pass closures fully on or fully off the landscape to bracket the possibilities of basin response. This study establishes a framework that can be used for similar deltaic systems globally where ecosystem services intersect with socioeconomic interests requiring the pursuit of compromise for all stakeholders.

This study pursues the development and application of a version of the modeling tool designed in the co-production effort and utilizes a series of coproduction strategies throughout the design, development, and translation of the model output. Inspired by the coproduction effort, this study prioritizes stakeholder needs in the application of evaluation metrics to the analysis.

2.2 Methods

To examine the questions presented about the influence of diversions in this large-scale estuarine system, we developed, calibrated, and validated a numerical model to simulate a suite of scenarios across various hydrologic conditions. The Delft3D Flexible Mesh (Deltares, 2011) modeling suite was used for this study. This processed based modeling suite allows for the inclusion of wind, rainfall, temperature, and salinity, which previous studies indicate is necessary to appropriately capture the response of the NGOM to diversion impacts in coastal regions (Kelin Hu et al., 2023; S. Parra et al., 2020) . Furthermore, model was progressed to a three-dimensional state as a direct result of previous modeling in the coastal zone of Louisiana by Hu et al. 2023, which verified the necessity of three dimensionality to capture salinity and temperature setup in the near shore region. The translation of modeling output into meaningful metrics for decision-making is a vital component of this science support to decision making. The metrics in this study aggregate metrics from previous diversion studies (refer to Table 1) to provide a holistic group of criteria to evaluate diversion tradeoffs. The metrics include both physical processes (water and sediment), ecological processes (marsh vegetation, oysters, and marine mammals), and highly relevant socioeconomic interests of navigation and oyster suitability.

2.2.1 Study area

The Northern Gulf of Mexico (NGOM) includes the region from Galveston, TX to Panama, FL and Tarbert Landing, MS to the Gulf of Mexico. Though located in the state of Louisiana along the Mississippi river, existing large diversions, such as the BCS, have a historical record of propagating effects across multiple state coastal zones (Armstrong et al., 2021). This spatial domain allows the extent of influence to be captured without interference from the model boundary conditions. The South Louisiana estuarine basins within this study's analysis exhibit a natural salinity gradient from the most inland areas to the open gulf ranging from fresh to intermediate to brackish to salt water. These basins are relatively shallow, providing a generally well-mixed regime. Mississippi River diversions considered in this study were considered from the Old River Control Structure and including all diversions downstream to the Gulf of Mexico (See Figure 1).

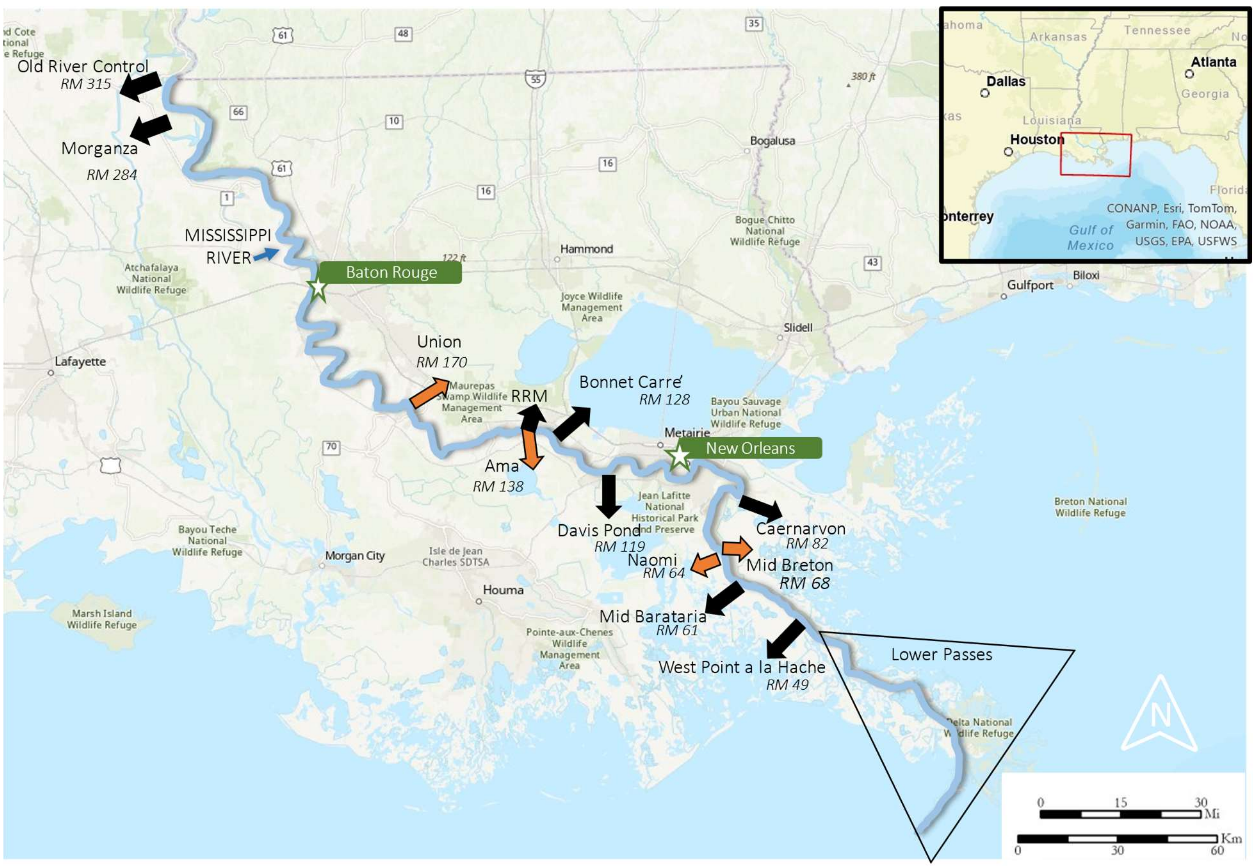


Figure 12 Mississippi River existing (black arrows) and proposed (orange arrows) diversions located in South Louisiana from the Old River Control structure to the Gulf of Mexico. More details about the lower passes are shown in Figure S4 in supplemental material

2.2.2 Lower Passes

Downstream of the levee system, a less regulated series of lower passes exists on the Mississippi River. These passes refer to all natural outlets on the river from Mardi Gras

Pass to the end of the Birdfoot Delta (See Figure 30 in Supplemental Material). Some passes are maintained via dredging for navigation purposes and others from an emergency management perspective, using rock closures or partial closures to restrict flow through an outlet. The remaining passes naturally evolve with intermittent monitoring by researcher groups or government agencies, provided they do not pose a threat to navigation or industrial functions. These natural diversions are dynamic zones that redistribute and deliver freshwater, sediment and nutrients from the Mississippi River to the adjacent basins and the delta. Increasing dredging problems due to reduced flow in the lower delta have drawn more attention to the management of these lower passes (Allison et al., 2023). Impacts of lower pass flows on navigation raise other concerns. For example, the recent natural expansion of the Neptune pass (USACE et al., 2022) evolved rapidly and began to divert upward of 16% of the flow from the Mississippi River, potentially threatening shipping traffic in the Mississippi River. The extensive time and resources required to address this unregulated diversion emphasizes the need to evaluate natural pass management protocol prior to an emergency response.

2.2.3 Model Setup

The model developed for this analysis built upon previous modeling efforts by Meselhe et al, 2019 (Meselhe et al., 2019), which have investigated this domain using the Delft3D 4 Suite (Lesser et al., 2004). The modeling effort described in this study utilizes the Delft3D Flexible Mesh (Deltares, 2011) (Delft3D FM) modeling suite which provides the option to utilize a flexible triangular mesh. The mesh ranges from ~17km near the coastal boundary to ~90m in the inland areas and contains over 4.3 million elements. The hydrodynamics are modeled beginning at the Mississippi River near Tarbert Landing through the entire river channel and the natural outlets. This results in the model capturing the natural behavior of flow passing in and out of natural openings without predefined fluxes.

The model grid was combined with topo bathymetric data from the USGS National Land Cover Database, USACE river bathymetric surveys, and CPRA. River discharge daily time series, provided by the USGS or USACE, were applied for the following rivers: Mississippi, Atchafalaya, Neches, Sabine, Calcasieu Amite, Tickfaw, Tangipahoa, Teche, Pearl, Mobile, Wolf, Pascagoula, and Biloxi. Additionally, daily discharge timeseries from the USGS were prescribed for the following diversions: Bonnet Carre, Davis Pond, Naomi, and Caernarvon. A water level tidal boundary condition was applied along 50 points across the gulf boundary. These 50 water level time series were provided by a larger Gulf-Atlantic model (Meselhe et al., 2019) simulated for the same year. This model features a spatial resolution ranging from 6 km near the Louisiana coast to 40 km in the Atlantic Ocean. From a tidal constituent database (Mukai et al., 2002), seven dominant constituents (O1, K1, Q1, M2, N2, S2 and K2) are considered to determine tidal levels at the open-sea boundary across the Atlantic Ocean.

Atmospheric forcing in the form of gridded wind velocity at 10m, surface air pressure, precipitation, air temperature, humidity, and cloud coverage were applied at a 6-hour timestep, provided by the Global Forecasting System's National Center for Environmental Prediction forecast model (GFS-NCEP). A spatially variable roughness was built into the model with discharge variable calibration scaling factors applied to the Mississippi river and floodplains. These scaling factors provide a means of calibrating the model to represent the following physical behavior: 1) floodplains provide a larger degree of resistance to the flow than the river bed (Aberle & Järvelä, 2013; Rowiński et al., 2018), and they interact with the Mississippi River only in the reaches north of Baton Rouge where the floodplains are connected to the river inside of the levee system, and 2) that as discharge in the Mississippi River increases, the degree of influence of the bed roughness decreases (Kopecki et al., 2017). Roughness scaling factors were calibrated for the 6 zones along the Mississippi River's length. The 3D model simulations feature 7 sigma layers and were utilized for final hydrodynamic, temperature, and salinity analysis. The progression of the model to a 3D is a direct result of previous modeling in the coastal zone of Louisiana by Hu et al. 2023, which verified the necessity of 3 dimensionality to capture salinity and temperature in the near shore region (K Hu et al., 2023).

2.2.4 Model calibration and validation

This model was calibrated for hydrodynamics, salinity, and temperature with data from the year 2018 and validated for the year 2019. The Mississippi River and its adjacent basins, specifically Barataria, Breton, Mississippi Sound, Maurepas, Lake Borgne, and Lake Pontchartrain, were calibrated to refine the study to the basins nearest to the diversion outfalls. Water level and discharge measurements were compared for river channel calibration using daily measurements from the USACE across 17 locations (see Figure 33 in the Supplementary Material). Additionally, the Mississippi River is directly connected to the gulf river below the levee system via several outlets, and these lower passes were calibrated using discrete measurements from the USACE.

The model performance in the basins was compared with recorded observations of water level, salinity, and temperature at +180 locations in the model domain from stations maintained by the NOAA, USGS, or CRMS. The interested reader may visit the webpage referred to in the Supplementary Material to review the hydrodynamic calibration and validation results. In addition to visual comparison, statistical analysis confirmed the model agreement using standard metrics and thresholds for performance (Meselhe et al., 2015). Specifically, the root mean square error, bias, and Pearson product-moment correlation coefficient were compared for all stations to indicate the model had reasonable agreement with the observations. Tables S1-S3 in the Supplementary Material documents the overall statistical performance of the model.

One important behavior that the model identified was the difficulty to capture salinity representation (particularly over freshening by 5-10 ppt) in some areas of the model, particularly in the outer Breton basin. This trend was noted in both 2018 and 2019 results comparison and previous modeling efforts. Model diffusivity sensitivity analysis for over 30 model setups were run for two-to-four-week simulated periods to identify settings necessary to tune the model settings to appropriately capture salinity behavior on the west side of the Mississippi River. Variations of model diffusivity values (0.1, 1, 10, 20, 50, 100, 500, and 1000 m2/s) were tested in combination with Smagorinsky model application variations (Smagorinsky, 1963). This diffusivity analysis resulted in the development of a spatially varied diffusivity map applied in the model setup.

2.2.5 Operation Scenarios and River Hydrographs

A set of eight scenarios were designed to analyze the system of diversions on the Lower Mississippi River using the model. The scenarios Table 1 include present day structures, (as of 2023) future proposed structures, and considered the option of closing lower river outlets. The model scenarios provide a plausible envelope of management plans with a system wide perspective of river and basin interaction.

Table 2 Eight operation scenarios for evaluation that illustrate an envelope of options for diversion management with either present day infrastructure or including future infrastructure

Operation Scenarios	*Bonnet Carré*				*Base Case*
	Morganza	*2023*	*Existing Infrastructure*	*Closures*	*A*
				No Closures	*B*

		Future	*Mid Barataria + Mid Breton*	*Closures*	*C*
				No Closures	*D*
			Union + Ama	*Closures*	*E*
				No Closures	*F*
			Mid Barataria + Mid Breton + Union + Ama	*Closures*	*G*
				No Closures	*H*

The proposed rules for the operation of each structure were not necessarily the optimum way to collectively operate the group of engineered features and crevasses. Rather, it was a suggested strategy to illustrate the benefit of conducting a scenario-based approach to evaluating trade-offs.

1. Morganza: The capacity of this structure is 16,990 cms (600K cfs). The structure would operate when the Mississippi River exceeds 35,396 cms (1.25 million cfs) at Tarbert Landing, MS and the stage at the spillway exceeds 15.85 m (52 ft) NAVD 88. This represents the water level that would overtop the potato ridge and fill the forebay area, making operation feasible.

2. Bonnet Carre': The capacity of this structure is 7,079 cms (250K cfs). The structure would operate when the Mississippi River exceeds 35,396 cms (1.25 million cfs) and the stage at the Carrollton exceeds 4.93m (16.18 ft) NAVD 88. The flow through the structure would be capped at 2,832 cms (100K cfs).

3. Davis Pond: The capacity of this structure is 283 cms (10K cfs). It will operate based on its historical performance, except in the case of a flood event. When the

Mississippi River exceeds 35,396 cms (1.25 million cfs) the diversion would be closed.

4. Caernarvon: The capacity of this structure is 212 cms (7.5K cfs). It would operate based on its historical performance, except in the case of a flood event. When the Mississippi river exceeds 35,396 cms (1.25 million cfs), the diversion would be closed.

5. Naomi: The capacity of this structure is 56.6 cms (2K cfs). It would operate based on its historical performance, except in the case of a flood event. When the Mississippi River exceeds 35,396 cms (1.25 million cfs), the diversion would be closed.

6. West Point a la Hache: The capacity of this structure is 56.6 cms (2K cfs). It would operate based on its historical performance, except in the case of a flood event. When the Mississippi River exceeds 35,396 cms (1.25 million cfs), the diversion would be closed.

7. River Reintroduction to Maurepas: The capacity of this structure is 56.6 cms (2K cfs). This structure would operate as described in (CPRA, 2014).

8. Union: The capacity of this structure is 708 cms (25K cfs). The structure would operate from 0-708cms from the Mississippi River near Union from 5,663 – 28,317 cms (200K- 1million cfs).

9. Ama: The capacity of this structure is 708 cms (25K cfs). The structure would operate from 0-708cms from the Mississippi River near Ama from 5,663 – 28,317 cms (200K- 1million cfs).

10. Mid Breton: The capacity of this structure is 1,416 cms (50K cfs). The structure would operate from 0-1,416 cms from the Mississippi River near Mid Breton from 12,743- 28,317 cms (450K- 1million cfs).

11. Mid Barataria: The capacity of this structure is 2,124 cms (75K cfs). The structure would operate from 0-2,124 cms from the Mississippi River near Mid Barataria from 12,743- 28,317 cms (450K- 1million cfs).

12. Lower Passes: For scenarios where the passes were prescribed "open", the outlets were functioning per their historical capacities (verified by calibration model results compared to discrete measurements from the USACE). For the scenarios where the passes were prescribed "closed", the lower outlets were closed by a simulated barrier (See figure in Supplemental Material) to represent a structural closure that could be implemented for management purposes. Closure of the lower passes leads to a constriction of flow to the main channel with the potential to assist navigable discharge in the Mississippi River to offset diversion discharge release upstream in some scenarios. Mississippi River discharge < 11,327 cms (400K cfs) at Empire is considered low flow for navigation in the lower river, leading to management action (Peyronnin et al., 2017b). The lower passes in this group include Mardi Gras Pass down to Fort St. Phillip Pass.

The eight operational scenarios depicted in Table 1 were modeled under three Mississippi River hydrograph conditions: high/wet, average/typical, and low/drought. The most recent water years at the time of this study that represented these conditions were used for this analysis. Refer to the Supplemental Material to see the figure depicting the annual volume of water passing the Mississippi River at Tarbert Landing, MS, below Old River Control

Structure over the last 50 years. The 5, 25, 50, 75, and 95 percentile lines were plotted against the data. The year 2022 served as the most recent drought year, below the 25% annual volume line. Similarly, the years 2021 and 2019 served as the typical (average) and wet years, respectively.

The diversion operations were implemented in the model using a source-sink discharge time series at the intake/outfall of each structure using a simplified and conservative method. Each time series was determined by applying the operation criteria in conjunction with the Mississippi river discharge upstream of the diversion. Using the river hydrographs for the years 2019, 2021, and 2022 with the eight operational scenarios, 24 scenarios were simulated using the model. Boundary condition time series hydrographs of each operational scenario can be found in the Supplementary Material. This study utilizes the Morganza spillway structure as an alternative structure to the Bonnet Carre spillway. Therefore, for the 2019 flood analysis, the historical time series release through BCS was applied directly to the Morganza structure.

2.2.6 Scoring Approach

Following the model simulations, scoring of each scenario was completed via scorecard metrics. These scorecards provide a means of evaluating operational scenarios consistently and holistically using the following six metrics: flooding communities, marsh inundation, oyster suitability, marine mammal suitability, sediment delivery, and navigation. The metrics were chosen such that they 1) reflect unique aspects of diversion purpose (i.e. flood management, land building, and salinity control/ecosystem health) without extensive overlap and 2) the metrics were consistent with previous studies of diversion effects in the Northern Gulf of Mexico. References to precedented studies supporting the methodology of each metric are recorded in Table 2 and in the Supplementary Material. This study seeks to combine the metrics as a tool for basin response evaluation of diversion operation plans. Criteria considerations for each metric in the scorecards are as follows:

Table 3. Scorecard Metrics to evaluate the operational scenarios

Metric	*Define Criteria Considerations*	*Target Value*
Flooding communities (days) *See Supplementary Material for location coordinates and aerial view.*	*Considered flooded day if water depth exceeds zero at access points (ex. Road, levee, driveway, etc.) to select vulnerable location per basin:* *Venice Marina* *Lower Lafitte Playground* *University of New Orleans research facility* *Amite diversion canal neighborhood* *Delacroix*	*Zero days flood.*
Marsh inundation (acreage)(CPRA, 2017, 2023; Gough & Grace, 1998; Mossa, 1996; Peyronnin et al., 2017b; Snedden et al., 2015)	*Unstressed marsh is any cell that has an Annual Inundation Depth < the Inundation Threshold Depth (based on the mean annual salinity- refer to CPRA, 2017 for more information on the relationship between salinity and inundation)*	*Acreage of available unstressed marsh in base conditions.*
Sediment Delivery (tons/year)(Allison & Meselhe, 2010; Snedden et al., 2007) *See Supplementary Material for rating curve information.*	*Sediment delivery in tons per year is calculated as the daily discharge through the diversion multiplied by the Mississippi River sediment concentration at the diversion location to produce the sediment load delivery. Sediment concentrations were based on the sediment rating curves from the Baton Rouge and Belle Chasse gaging stations.*	*Maximum delivery assumes that the only diversions open are those entering the basin of interest.*
Eastern Oyster Suitability (acreage)(CPRA, 2012, 2017, 2023; Wang et al., 2017) *See Supplementary Material for HSI information.*	*Coastal Master Plan 2023 Habitat Suitability Index formula.*	*Acreage with >0.5 HSI in base conditions within the Louisiana Department of Health designated oyster harvest areas.*
Marine Mammal Suitability (acreage)(Garrison et al., 2020; McClain et al., 2020; Meselhe et al., 2019; White et al., 2018) *See Supplementary Material for HSI information.*	*Meselhe et al. (2019) 'longest streak' formula applied to Bottle Nose Dolphins (compatible with the Environmental Impact Study for the Mid Barataria Sediment Diversion)*	*Acreage with <45 days salinity streak in base conditions*
Navigation (metric ton/year) *(Allison et al., 2012c; Nittrouer et al., 2008; Ramirez & Allison, 2013)* *See Supplementary Material for background information.*	*Bedform Transport Rate analysis* $y = 146.3e^{1.77E-4*x}$	*Bedform transport rate equivalent to base condition*

The metrics in Table 2 were calculated for 5 separate basins, with each basin comprising of combined ecoregion sections from precedented CMP efforts (CPRA, 2023). Using the scoring metrics, the model output was evaluated for each metric as it approaches or deviates from the Target Value. See equation 1:

$$\frac{Actual\,Value}{Target\,Value} * 100\% = \%Target_{scenariox} \qquad (1)$$

OR

The metrics were investigated as they deviated from the base condition toward or away from the target value. See equation 2:

$$\%Target_{scenariox} - \%Target_{Base} = \%from\,Base \qquad (2)$$

Applying the scorecard approach to each of the 24 model scenarios synthesizes the model output into a form that could be used for decision support for freshwater allocation management and evaluating associated tradeoffs.

2.3 Results

The full set of scenario results can be found in the Supplementary Material. The most dynamic results are included here as a subset including the wet and dry year output for Barataria, Breton, and Mississippi Sound.

2.3.1 Barataria Basin

Scenarios A and B did not impact Barataria basin with any significant trends. The only exception was the decrease in MM suitability by 14% in scenario A for a wet year. For all years, scenarios C, D, E, F, G, and H increased sediment delivery compared to the base case. Ama and Mid Barataria delivered approximately 2 tons and 8 tons per wet year, respectively. For the typical year, Ama and Mid Barataria delivered approximately 1 and 4 tons per year, respectively. For the dry year, Ama and Mid Barataria delivered approximately 1 and 3 tons per year, respectively. All simulations with diversions opening into Barataria produced a decrease from the base case in oyster suitability acreage within the harvest zones with an average of 23% for the wet year, 17% for the typical year, and 15% for the dry year. MM suitability decreased whenever diversions were opened into Barataria by 17-56% for the wet year, 13-22% for the typical year, and 17-28% for the dry year. Flooding to the access point for the selected location (Lower Lafitte Playground) was increased most notably from the base case in the wet year by anywhere from 7% in scenario E to 24% in scenario G. Marsh acreage above the inundation threshold increased slightly for all scenarios with diversions within 0-9%. The results for the wet and dry scenarios are shown in Figure 13.

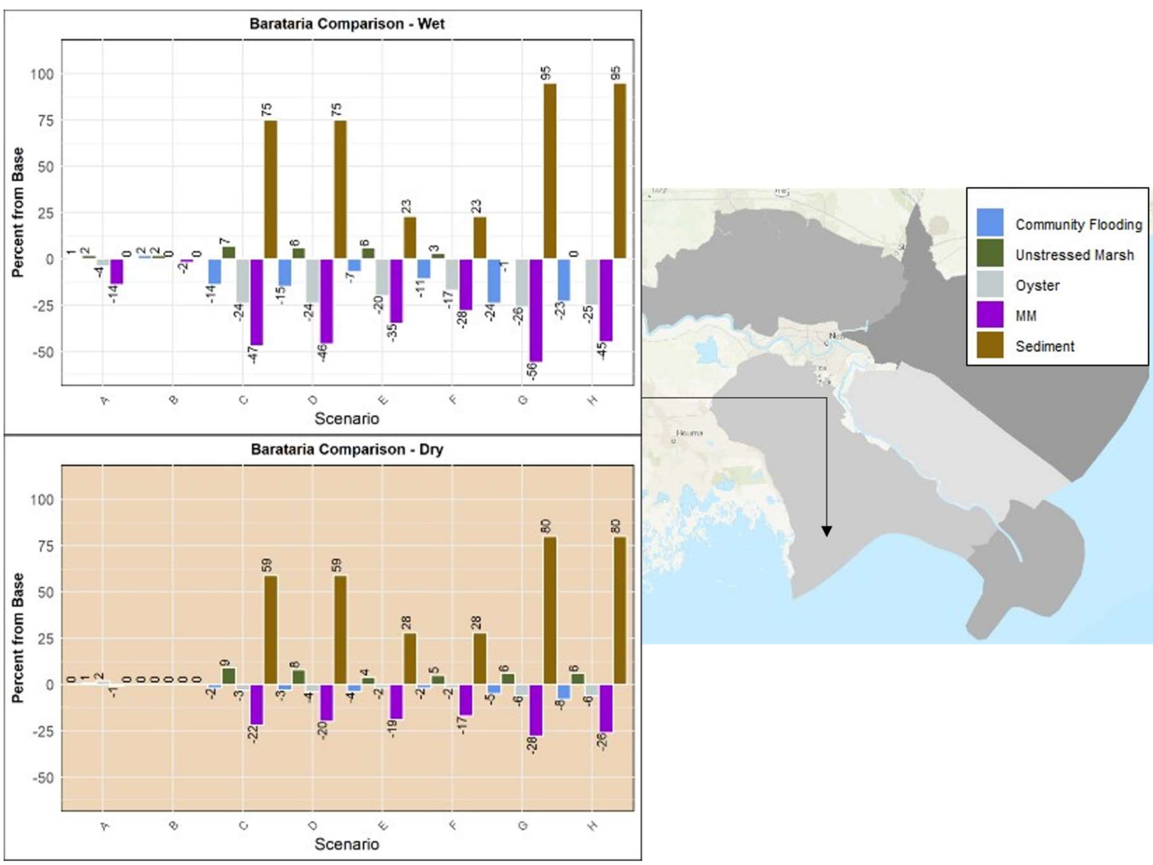


Figure 13 Barataria Basin Metrics Percent deviation from Base for the Wet and Dry year analysis

2.3.2 Breton Basin

Scenarios B and F did not impact Breton basin with any significant trends. The only exception was the increase in unstressed marsh acreage by 12% in scenario F for a dry year. For all years, scenarios C, D, G, and H increased sediment delivery compared to the base case. In terms of sediment delivery, Mid Breton yielded approximately 5 tons per wet year, 2 tons per typical and dry year. Scenarios A and E increase oyster acreage by an average of 86%, 74%, and 39% for wet, typical, and dry years, respectively. Scenarios C and G increase the oyster acreage by roughly 8% for wet and dry years and roughly 17% for a typical year. Scenarios D and H show decreasing oyster acreage by approximately 20% for a dry year. Scenarios A and E increase MM acreage by an average of 240%, 134%, and 83% for wet, typical, and dry years, respectively. Scenarios C and G increase the MM acreage by roughly 77% for wet, 50% for typical, and 27% for dry years. Scenarios D and H show decreasing MM acreage by approximately 10% for a dry year. Flooding the access point for the selected location (Delacroix) was increased marginally from the base case in scenarios with Mid Breton (C, D, G, and H). Marsh acreage above the inundation threshold decreased consistently for scenarios A, C, D, E, G, and H by an average of roughly 14% for a wet year and 9% for a typical year. Scenarios B and F did not show significant changes in marsh acreage for a wet or typical year. For a dry year, marsh acreage was increased by roughly 12% for scenario F and decreased by roughly 11% for scenario A. The results for the wet and dry year scenarios are shown in Figure 14.

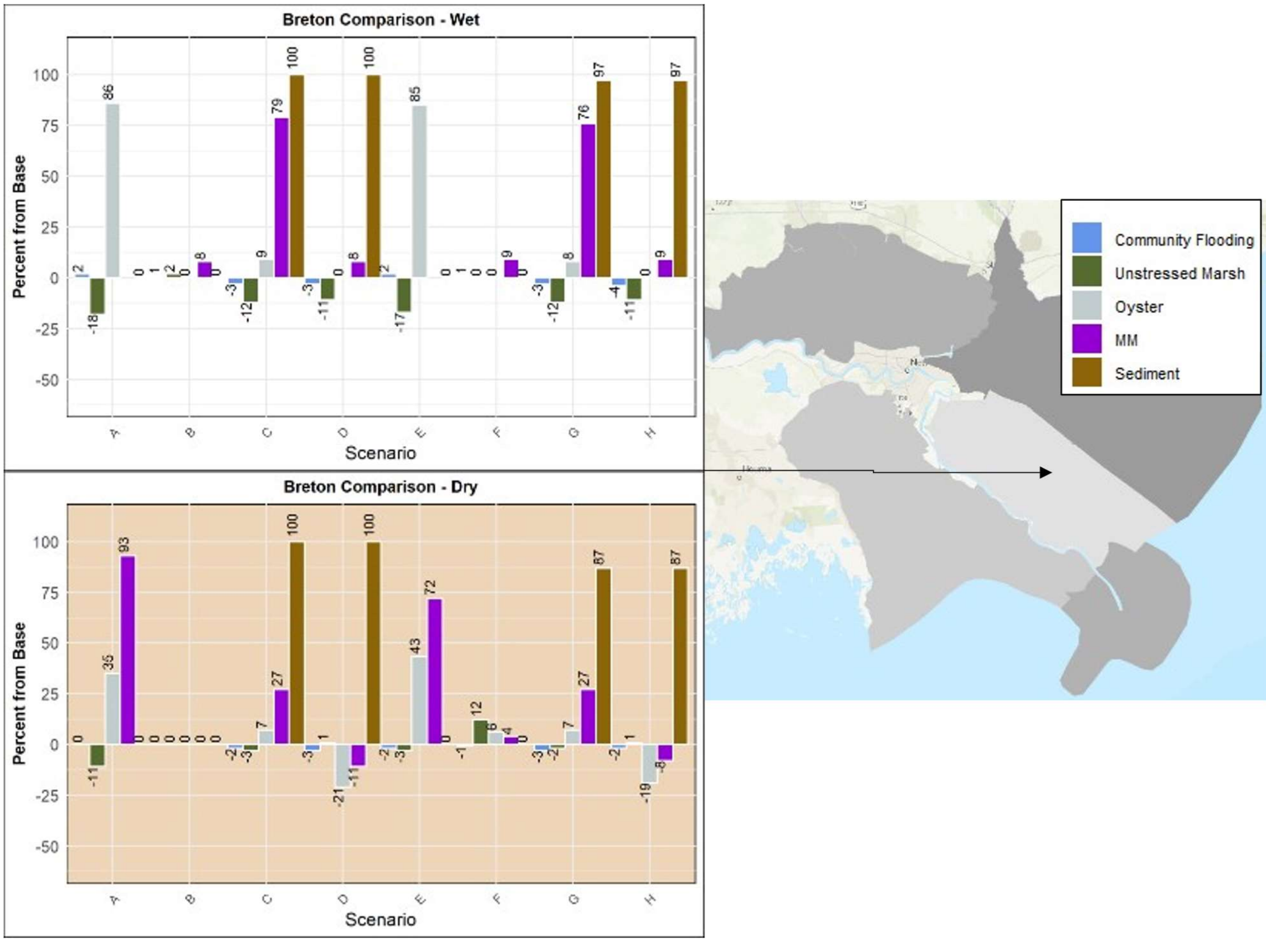


Figure 14 Breton Basin Metrics Percent deviation from Base condition for the Wet and Dry year analysis

2.3.3 Mississippi Sound

Impacts to Mississippi Sound were most notable in the wet year scenario results. The base case featured the historic opening pace for the Bonnet Carre spillway and the wet year scenarios apply the same historic opening pace to the Morganza spillway instead. Compared to the base case, suitable oyster acreage is increased for scenarios A, B, C, D, E, F and G for the wet year and scenarios with closures (A, C, E, and G) resulted in larger acreage increase in a wet year ranging from 40% for scenario A to 20% for scenario G. Scenarios B, D, F, and H increased acreage during the wet year from 1-5%. For the typical year, oyster acreage increased for scenarios A, C, and E on average of 11% and decreased for scenarios D and H by roughly 5%. Except for scenario E, all scenarios showed a decrease in oyster acreage from the base case by roughly 6%. Compared to the base case, suitable MM acreage is increased for all scenarios in a wet year with a range of 10-48%. For the typical and dry years, there is a much smaller degree of change with slight increases of approximately 1-4% for scenarios A and C and slight decreases of approximately 1-6% for scenarios D, F, G, and H. Flooding to the access point for the selected location (UNO Research Facility) was increased from the base an average of 5% for the wet year. Marsh acreage above the inundation threshold decreased for scenarios A, C, and E by an average of roughly 4% for a wet year. For a dry year, marsh acreage increased by an average of 4% for scenarios E, F, G, and H. The results for the wet and dry year scenarios are shown in Figure 15.

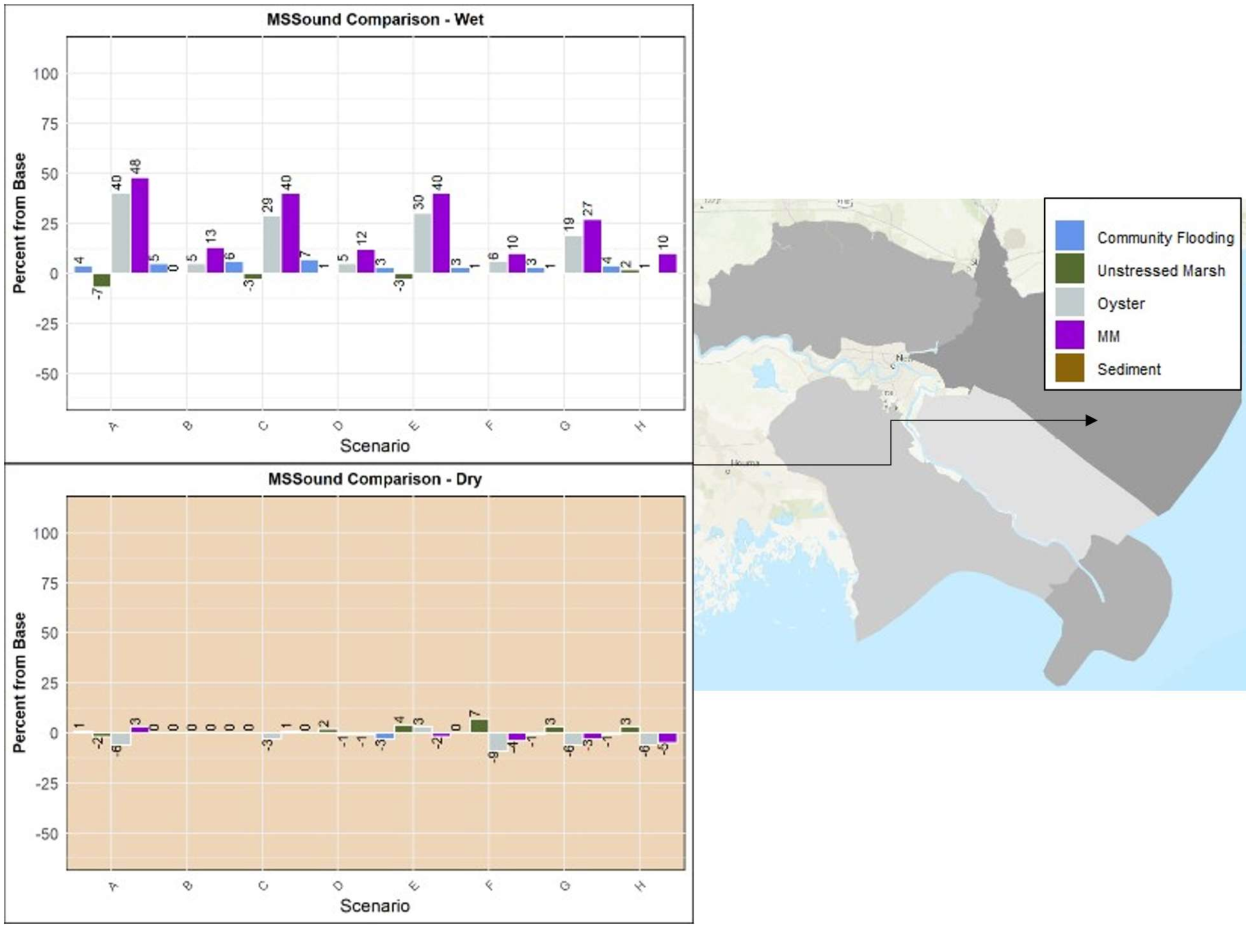


Figure 15 Mississippi Sound Basin Metrics Percent deviation from Base for the Wet and Dry year analysis

2.3.4 Maurepas Pontchartrain

For all years, scenarios E, F, G, and H increased sediment delivery compared to the base case. In terms of sediment delivery, Mid Breton yielded approximately 2 tons per wet and typical year, and 1 ton per dry year. Flooding to the access point for the selected location (Amite diversion canal neighborhood) was negligible. Marsh acreage above the inundation threshold decreased for scenarios E, F, G, and H by an average of 9%, 7%, and 6% for a wet, typical, and dry year, respectively. The Maurepas Pontchartrain result figures for the scenarios are included in the Supplementary Material

2.3.5 Mississippi River Delta

For all years, scenarios A, C, and E increased sediment delivery compared to the base case by roughly 10%, 3%, and 8%, respectively. Across all years, Scenarios D, F, G, and H resulted in an average sediment delivery decrease of 6%, 4%, 3%, and 11% respectively. Navigation criteria in terms of bedform transport rates were affected most notably during the wet year. In the wet year, transport rates increased by 12% and 3% for scenarios A and C, respectively and decreased by 3% and 4% for scenarios D and H, respectively. The marsh acreage and flooding to the access point for the selected location (Venice marina) was negligible. The Mississippi River Delta result figures for the scenarios are included in the Supplementary Material.

2.4 Discussion

2.4.1 Flooding Communities

The flooding metric is a simple representation of water depth based on a single point within the model domain. It does not represent the extent or magnitude of flooding, rather it is more reflective of how long water levels across the basin will be elevated from base condition due to each scenario. It is important to note that even if water levels do not exceed the elevation thresholds for communities, the sustained higher than base condition water levels in the basins may increase the vulnerability of communities, particularly in the event of hurricane events and storm surge. Additionally, diversions not designed for flood control have operation plans that require their closure during a storm event. More detailed studies of localized development could more accurately determine the impact of the diversions in terms of flooding. In general, this study highlights that the location and sizing of the diversions provide beneficial delivery of river sediments and nutrients to ecosystems while increasing the vulnerability (albeit not significantly) of adjacent communities. Furthermore, the flood risk to human life and property is a top concern of the state and federal government, who then prioritize improving basin infrastructure to protect vulnerable communities like Lower Lafitte (see Supplemental Material location map). This prioritization is seen in projects like the Lafitte Ring Levee in the Coastal Master Plan (CPRA, 2023) and the Lower Lafitte Tidal Protection project (NOLA.com, 2023), which is under construction at the time of this study.

2.4.2 Marsh Inundation

Marsh inundation was evaluated to examine the potential stress to the marsh area in the receiving basins due to diversion operation. Excess inundation is a potential tradeoff to the benefits that diversions offer marshes in terms of sediment, nutrient delivery and salinity intrusion prevention. Maurepas and Breton showed a slight decrease (~-10% and -12%, respectively) from target acreage with the operation of Union and Mid Breton, particularly during the wet year scenarios. Conversely, Barataria showed an increase toward target acreage (~6%) with diversion operations due to the freshening of the basin allowing for increased inundation tolerance. Generally, the simulations show that the diversion operations tested do not inundate the marsh significantly beyond the inundation threshold developed for each marsh type based on base condition salinity regimes. Considering the relative coarse resolution of the model, this metric represents the ability of each basin to drain the diverted river flow gulfward. In this case, Barataria drains excess water easier than Breton and Maurepas.

2.4.3 Marine Mammals

The metric to evaluate marine mammal suitability zone is the area with less than a 45-day streak of salinities below 5ppt, with gaps of 2 or fewer days allowed. The Supplementary Material shows the marine mammal suitability zone results in a map format. Due to its binary nature, the charts in the results section of this paper show the response of the basins to each scenario quite clearly. Barataria basin shows a general trend of decreasing BND suitability with increasing diversion openings. Barataria has a slight increase in negative response to the east side closures (scenarios A, C, E, and G), likely due to circulation changes due to more discharge leaving the river through southwest pass instead of the natural outlets on the west side. Breton basin shows the strongest positive response (increase in suitable area) to lower pass closures, even with Mid Breton on the landscape. Both Breton and Barataria basins show similar behaviors across wet, typical, and dry year scenarios. The Mississippi Sound zone does not change significantly (+/- 6%) during the typical and dry year scenarios. For the wet year, however, conditions are improved across all scenarios from 10-48%, primarily due to the use of Morganza instead of BCS, as well as the natural pass closures.

2.4.4 Eastern Oysters

Included in Figure 16 is the spatial distribution of the Eastern Oyster habitat suitability for the wet and dry year scenarios. Values reported in the results section of this study indicate the acreage of suitability >0.5 and within Louisiana Department of Health (LDH) delineated zones. Additionally, we can explore the dynamics of the HSI zones beyond the LDH zones, to examine the larger extent of the suitability ranges and how they behave across operation plans and hydrographic conditions.

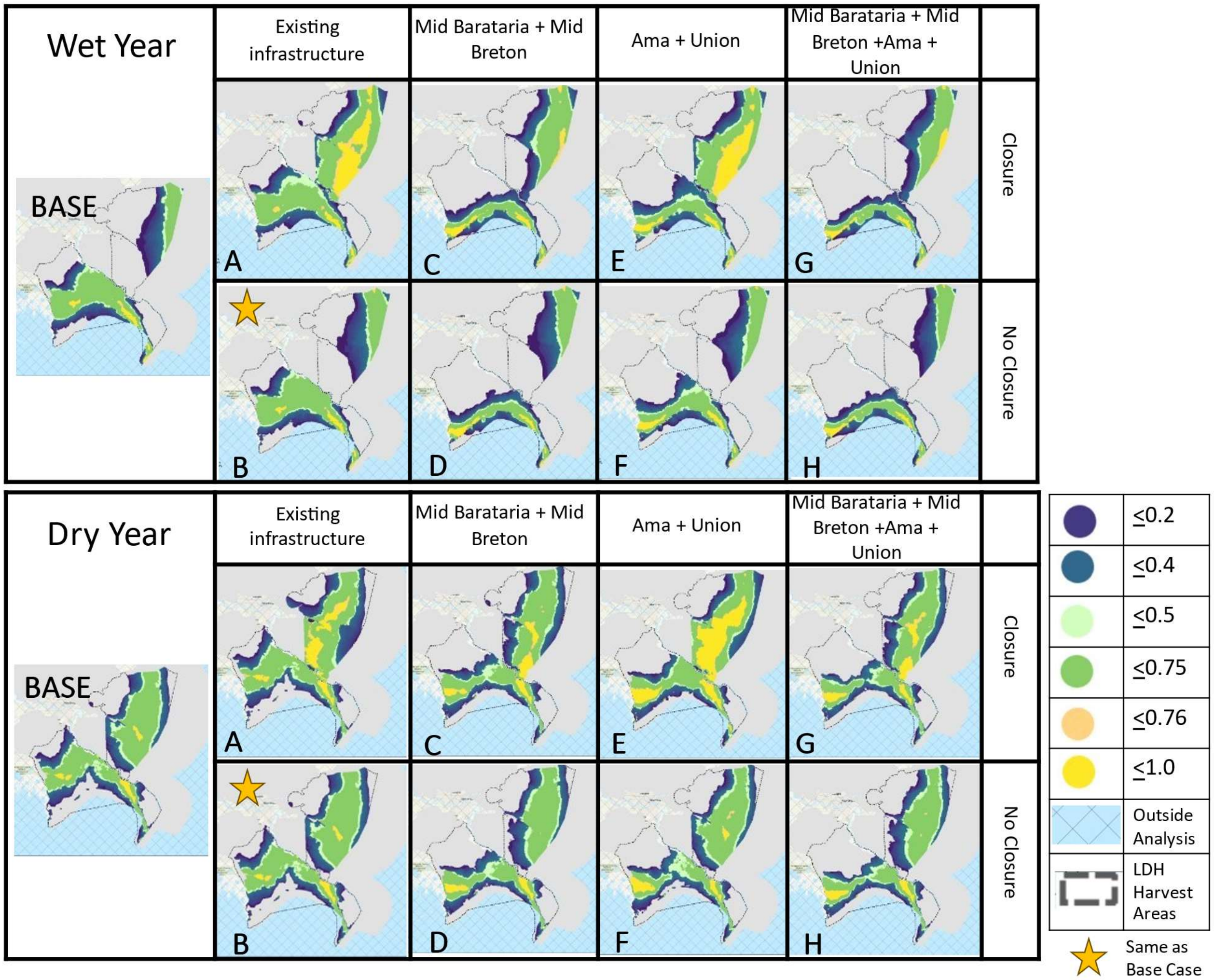


Figure 16 Eastern Oyster Habitat Suitability Indices (0-1) Results: Wet Year (Upper Panel) and Dry Year (Lower Panel). Lettering (ex. A, B, C, …) indicates operation scenario applied. Disclaimer: The maps illustrate only HSIs within LDH zones.

Generally, the size and location of the favorable footprint is determined by the hydrologic conditions (wet, typical, dry). Barataria basin has a strong response to diversions opening. The favorable oyster zone shows a basin wide migration gulfward and decrease in size with the opening of Ama and/or Mid Barataria. Mid Barataria operates at triple the capacity of Ama and operates directly in the base zone of favorability. Results indicate Mid Barataria produces a decrease in suitability and a strong gulfward push. Ama is a smaller diversion located near the northernmost side of Barataria. Ama still produces a strong response in Oyster HSI, showing the same gulfward migration and a squeezing or reshaping of the zone. Breton basin shows a strong response to the lower pass closures and the operation of Mid Breton. In general, the lower passes closures produce the largest increase in the suitability zone in this basin, specifically in scenarios A and E where Mid Breton is not on the landscape. The wet year analysis shows a similar footprint of HSI regardless of Mid Breton being opened or not. The effects of Mid Breton are more pronounced during the dry year analysis. Additionally, the response of the suitability zone is a gulfward migration in response to Mid Breton, where the favorable conditions are pushed further offshore. The freshening behavior and oyster suitability response compares to similar studies in this region (K. Hu et al., 2023; Wang et al., 2017). The closure of lower passes produces a larger suitable footprint for Breton. Mississippi Sound oyster suitability responds to several management features: Bonnet Carre, Morganza, Union, lower pass closures, and potentially Mid Breton. In terms of the size of the suitability footprint and proximity to the harvest areas, Mississippi Sound favorability is improved by the lower pass closures and decreased by diversion operations.

The changes in oyster suitability within the LDH zones illustrates one tradeoff to large scale diversion operation for restoring wetlands. Essentially, the diversion operations change the size and shape of the favorable footprint and move the zone of suitability further offshore. This implies that the oyster industry and potentially other aquatic industries will need to adapt immediately in response to changes in river management. Alternative oyster farming techniques are being explored in South Louisiana, such as off-bottom oyster farming(Chapman, 2019; Leonhardt et al., 2017; Wang et al., 2017). Cage oyster farming can provide protection from blanketing of sediment from river diversions and changes in salinity, both of which induce oyster mortality in the Gulf of Mexico region(Chapman, 2019; Leonhardt et al., 2017). These adaptive strategies and the plan to subsidize their implementation are formally investigated in the design of proposed diversions, as seen in the Mid Barataria Sediment Diversion Environmental Impact Study (USACE, 2022) . As alternative farming techniques continue to evolve, they may become a viable means of evolution for seafood industry in the gulf.

2.4.5 Sediment Delivery

The sediment delivery component of this study was conducted via rating curves and volumetric analysis (Allison et al., 2012b). The study shows the positive correlation across all scenarios between diversion openings and sediment delivery to basins. Figure 17. displays a downstream budget of total suspended sediment load for scenarios B and H, demonstrating open lower passes. Additional sediment budgets of scenarios A and G, demonstrating lower pass closures, are included in the Supplementary Material.

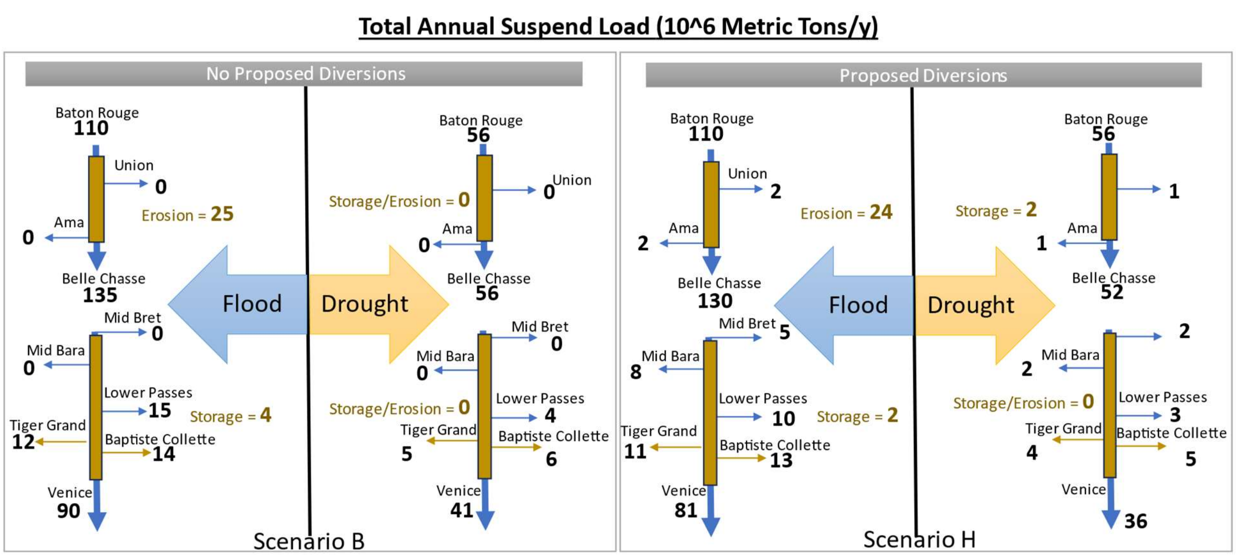


Figure 17 Average annual total suspended sediment discharge (in 10^6 tons/y) for the flood and drought years (2019 and 2022) scenarios A and G discussed in the present study for natural and man-made water exits from the Mississippi River below Baton Rouge, Louisiana. Also shown are annual channel storage rates (in 10^66 tons/y) for two sub-reaches of the channel between Baton Rouge to Belle Chasse and Belle Chasse to Venice. Rates were calculated via rating curve application to discharge at respective outlets.

The benefits of riverine sediment diversions include the introduction of riverine nutrients (Bentley et al., 2014; Peyronnin et al., 2017b; PontchartrainConservancy, 2022), provision of sediment and river material to sustain marsh elevations (Day et al., 2016; Meselhe et al., 2016; Snedden et al., 2007; USACE, 2022), distributing organic material and sediment in a receiving basin, as well as providing new detritus and riverine sediment to support ecosystem health (Mann, 1988). The quantity of sediment delivered is directly dependent upon the incoming source suspended sediment concentration (Allison et al., 2012a), as well as the structures design capabilities to capture that portion of suspended sediment (Gaweesh & Meselhe, 2016). The sediment concentration of the Mississippi River is known to be highly variable and can fluctuate due to factors such as hysteretic behavior (Mossa, 1996), upstream bank material contribution, hydrographic conditions, overbank sediment storage (Allison et al., 2012b), and time of the year (Galler & Allison, 2008; Peyronnin et al., 2017b). Regardless of the ability of the sediment diversions to build or sustain land, sediment delivery to adjacent basin marshes is considered a beneficial attribute of river diversions. One contrary to this would be the extensive blanketing of sediment over small seedlings immediately within the diversion's floodway(Gough & Grace, 1998; Levine & Stromberg, 2001) or over young oyster spat who might suffocate with sediment settling(Leonhardt et al., 2017).

2.4.6 Navigation

The bedform transport calculations are used here as a proxy indicator for maintaining uninterrupted navigation operations. Although there is uncertainty inherent in the bedform transport rate calculations, the results of this study do highlight some responses of the lower river to diversion operations and the impact of natural pass distribution on lower river hydrodynamics. The first key point is that the rules set to govern the lower discharge threshold of diversions prevent diversion operation from interfering with the navigation activities during low-flow (drought) events. The study showed no significant decrease in river stage or discharge during low flow, nor did the results show an extended duration of low flow conditions (below 400,000cfs at Venice, LA) beyond the base case. There is a relatively minor deviation in bedform transport (+/- <2,000 MT/d) during a dry year, which supports this first point. A second, and perhaps more interesting point, is that the study shows that the operation of diversions during medium or high discharge events has the potential to decrease bedform transport capabilities in the lower river significantly, most pronounced in the scenarios which utilized all the diversions without lower pass closures. Bedform transport graphics may be found in the Supplemental Material. The most extreme case (scenario H) decreases the transport rate peak from the base condition by approximately 35% and 26% for the typical and wet hydrographic conditions, respectively. From a management perspective, this is important to consider that an excessive operation of diversions during a typical or wet year may potentially prevent the river from "flushing" out the sediment in the lower river, leading to dredging concerns in the next low flow conditions. A third key finding of this study is the extensive impact of the natural passes in the lower river. In scenario G, with all proposed diversions operating and an entire closure of natural passes on the river's east side, the hydraulics conditions revert to the base-case conditions. This emphasizes the importance of monitoring, studying, and managing the river's natural outlets as more diversions come on to the landscape. They play a crucial role in maintaining the navigation activities in the lowermost reach of the Mississippi River.

Impacts to navigation of the Mississippi River may be thoroughly investigated via sediment transport modeling, as seen in the Mid Barataria Sediment Diversion Environmental Impact Study (USACE, 2022). In relation to this study, there are multiple scenarios and multiple diversions being added to the landscape with a lower pass system adding significant complexity to the situation. Therefore, the degree of uncertainty is too large to determine what the navigational implications would be for these scenarios without further modeling efforts. However, this effort serves as a viable screening tool to evaluate numerous scenarios to narrow down the plausible strategies for more detailed analysis.

2.4.7 Tradeoffs

While numerous permutations could be explored, this study's initial set of scenarios highlights important tradeoffs related to diversion operation. Diversion operation during high flow events has the potential to maximize sediment delivery for land building and mitigate stress to levee systems, but it reduces the lower river's capacity to transport bed material in the navigational corridor. Diversion operation during low flow events offers less land building potential yet yields significant basin side salinity gradient maintenance capabilities. Additionally, the impact on ecosystem health caused by the frequent use of the BCS could be mitigated by alternative measures, such as the use of the Morganza spillway. Morganza spillway provides a potential alternative to building new diversions that may cost multi-billions of dollars. The use of Morganza could provide ecological sustenance to an otherwise highly regulated freshwater basin that infrequently receives flood pulses that might reduce stagnation and sediment deposition in the basin (Hupp et al., 2008). Morganza spillway, as a surrogate structure to BCS, utilizes the river resources by flowing water, nutrients, and sediment through basins, rather than losing them to Lake

Pontchartrain and ultimately the Gulf of Mexico. Located upstream of the vulnerable city of New Orleans, the upper river diversions have the potential to operate as flood management structures in addition to functioning for land building and ecosystem restoration objectives. When comparing the Mid Barataria and Ama diversions for Barataria basin benefits, Ama may offer a greater return on investment by distributing nutrients higher in the basin and providing a potential for flood management, which Mid Barataria diversion logistically could not accomplish. Similarly, Union diversion may supplement RRM and facilitate a longer more desirable path of diversion through wetlands to the Gulf of Mexico than BCS. This study shows that the effects of Union do not propagate significantly to the Mississippi Sound region where excessive freshwater can inhibit fishing and aquaculture markets. Another tradeoff is the impact of the lower east side river outlets to basin salinity changes and lower river navigation. The natural passes are sighted in this study for the massive effect they have on these two criteria, particularly during high flow events. The use of natural outlets, even temporarily, may provide an additional management lever or an alternative strategy to building new diversions.

2.5 Conclusions

Coastal ecosystem management is a challenging task where management actions affect the interconnected natural and built environment that is inevitable in many coastal regions. Socioeconomic and ecological interests are often unique and potentially at odds with one another. Therefore, the challenging task of determining best management practices is often facilitated by extensive modeling efforts to reveal the most suitable choice of action to best support and balance stakeholder interests. Evaluating multiple management strategies through the scoring approach in this study provides a concise and quantitative means to compare management alternatives across multidisciplinary criteria (ecological, industrial, and community perspectives). This approach synthesizes a highly detailed numerical analysis into a succinct summary of performance metrics that is digestible to resource managers outside of the scientific modeling community. It is a transdisciplinary approach to evaluating management strategies to accelerate the transferal of science to the decision-making community by translating the model output into the final desired metric and directly comparing scenarios to one another. This research encourages the "full picture" or "holistic" implications of modeled management scenarios and processes the output more closely to the final product necessary to screen alternatives. Key findings identified through this analysis and highlighted through the scoring approach are as follows:

1. Natural hydrologic conditions have a greater influence on the conditions of the adjacent ecosystems than the quantity of diversions operating on the landscape.
2. There is a continued need for monitoring on the east side natural passes, as they largely influence the salinity of Breton and Mississippi Sound. Management of the natural passes can produce a basin side response that equals or exceeds the operation of diversions that drain into Breton and MS Sound.
3. The east side lower passes complex has a more pronounced effect on Breton than Mid Breton diversion.
4. Inundation due to proposed diversions depends on the ability of a given basin to drain into larger water bodies. For example, proposed diversions in Barataria do not pose significant stress to through marsh inundation, while Maurepas and Breton exhibit some added inundation stress. Further, the increased tolerance to fresh water works favorably to mitigate the impact of the diverted water volume. In the

proposed diversions, there is prescribed base flow of 5,000 cfs to modulate the salinity impacts during low flow conditions as prescribed in the EIS (USACE, 2022).

5. Navigation criteria of stage and discharge are preserved across all scenarios examined in this study, meaning that stage is not decreased in the lower river due to any scenarios, nor is the low water discharge period extended. This is due to the combination of multiple factors including a relatively small volume of water diverted compared to the main channel volume, the diversions closures during low flow, and the backwater condition prevailing in the tidally influenced lowermost reach of the river. As an alternative to an explicit (and computationally expensive) morphodynamic or sediment transport module, a simple indictor was used. This metric is based on a bedform transport formula. The analysis revealed a potential impact to navigation by demonstrating that increased diversion operation may attenuate flushing of bed material during a flood year. Consideration of the pulsed diversion idea could balance this impact. In scenario H, which represents the largest volume of water extracted from the Mississippi River through diversions or passes, the bedform transport rate is significantly decreased. The flood year analysis reveals that the bedform transport rates are reduced to nearly the equivalent rate of a typical or dry year (4,000 metric ton/day). The reduction may result in navigational impacts either through interruptions or increased cost of dredging. A detailed sediment transport analysis should be considered. However, the bedform transport rate analysis can be used as an efficient screening tool.

6. On the east side, a similar basin-wide response occurs via completely different management strategies. For example, swapping BCS for Morganza and opening Mid Breton and Union can create very similar MS Sound conditions for a wet year.
7. Dry year diversion operation leads to more dramatic responses in basin salinity spatial distribution. During a flood year, the basins are largely fresh, regardless of operation scenarios.
8. Upper river diversions "soak the sponge" by nourishing their immediate receiving basins with minimal gulf influence. They are proposed to operate with a relatively small capacity but can provide sustenance for the basins from an interior location. This is a beneficial strategy that demonstrates the "in between" approach from the large flood control and sediment diversion structures.
9. This paper supports the formalization of adaptive management of diversion control structures from a system wide perspective and the proactive management of both diversions and natural riverine outlets. Proactive management should be informed by observational data of basin conditions and result in diversion operations that prioritize the safety of human life and management infrastructure, as well as the health of the basin ecosystems.

Suggestions for future research considering this study include the modeling of partial natural pass closure scenarios, modeling pulsed diversion strategies, and modeling varying diversion capacities. This research highlights the need for increased monitoring of natural riverine outlets and Breton estuary. Beyond this modeling effort, investigation of the adjacent Atchafalaya basin response to varying Morganza Spillway operational scenarios should be pursed.

Additionally, the scoring approach developed in this study provides a synthesized method of evaluating several management strategies holistically. The approach provides an evaluation framework covering physical, ecological and indirect socioeconomic metrics. The scoring approach allows for 1) physical value comparison (ex. km^2/acres, m/ft, days, etc.), 2) comparison to target value (via percent of target value calculations), and 3) comparison to base conditions (via percent deviation from base condition). Amid potentially overwhelming quantities of data produced by simulating several operational scenarios, the scoring approach facilitates the succinct communication of the efficacy of multiple management scenarios across a range of hydrologic conditions. This scoring framework can be applied to other systems requiring natural resource management around the world. This approach can be used for other systems to explore viable strategies balancing ecosystem services with socioeconomic interests.

3. Chapter (3): Real Time Forecasting in the Coastal Zone: Stream Power in the Lower Mississippi River

3.1 Introduction

Hydrologic forecasting advances in recent decades take advantage of two aspects of the modern age: Big Data and Big Computing (Peters-Lidard et al., 2017). Data collection and data production have expanded due to the capability to collect (ex. radar or imagery) store, share, and disseminate (ex. cloud services) large data sets. Computing technology has advanced rapidly with even high-performance computing services available to the public. In response, hydrologic and hydrodynamic numerical modeling has soared in response.

Today the river forecast systems of the entire continental US are federally maintained and modeled. NOAA's National Weather Service River Forecast Center (RFC) and the Office of Water Prediction's National Water Model are two examples of inland river operational forecasting products (Adams, 2016). Publicly available and actively maintained, these tools have massive utility from an individual member of the public to a federal level. Namely, these agencies provide real time discharge and water level forecasts of up to 30 days for rivers and streams across the continental United States. Relative to this dissertation is the Lower Mississippi River Forecast Center (https://www.weather.gov/lmrfc/), which issues water level and/or discharge 3-day forecasts for approximately 276 locations and for up to 14-day forecasts for approximately 65 stations within their forecasting domain. Similarly, the National Water Model (https://water.noaa.gov/about/nwm)issues short (1 day), medium (10 day) or long (30 day) range forecasts for discharge for every reach in their modeled stream network.

Specifically, for the RFC forecast provision, a Delft-FEWS based infrastructure is utilized for forecasting services. The Hydrologic Engineering Center's (CEIWR-HEC) River Analysis System (HEC-RAS) hydrodynamic models developed by the USACE serve as the hydrodynamic engine, and the system is named the Community Hydrologic Prediction System (CHPS). CHPS services the river systems in the NGOM, however, a similar set of products to provide forecasts beyond the river channels in the coastal zones and the NGOM domain is not available with a comparable resolution or forecast window. The nearest available product providing a three-day forecast in the near coast regions of the NGOM is the Northern Gulf of Mexico Operational Forecast System (NGOFS2), which provides forecasted hydrodynamic, salinity, and temperature conditions. Inspired by the coproduction effort, this chapter explores the real time application of a decision support tool for forecasting basin conditions in the NGOM.

Similar efforts have been documented for other parts of the world with the goal of advancing flood forecasting (Titze et al., 2023) (Ming et al., 2020), the prediction of harmful algae blooms (Allen et al., 2015) and providing improved representation of physical responses to forecasted climatic and circulation conditions (Kordzadze et al., 2017). Providing hydrodynamic forecast in coastal zones is an obstacle for even the most reliable forecasting agencies. To bridge this gap, this study explores the development of a basin wide operational forecasting decision support system for the NGOM and the application of the system to provide stream power forecasts in the Lower Mississippi River.

3.2 Methods

3.2.1 Data and Models

The model developed for this study, referred to as the NGOM model, utilizes the Delft3D Flexible Mesh (Deltares, 2011) (Delft3D FM) modeling suite. The computational triangular mesh resolution ranges from ~17km near the coastal boundary to ~90m in the inland areas and contains over 4.3 million elements (see Figure 18). The model bathymetry was developed using the topo bathymetric data from the United States Geological Survey National Land Cover Database (USGS), United States Army Corps of Engineers (USACE) river bathymetric surveys, and Louisiana's Coastal Protection and Restoration Authority (CPRA). River discharge time series, provided by the USGS or USACE, are applied for river boundary conditions. A water level tidal boundary conditions are applied along 50 points across the gulf boundary. These 50 water level time series are provided by a larger Gulf-Atlantic model (Meselhe, 2019) simulated for the same year. The Gulf-Atlantic model features a spatial resolution ranging from 6km near the Louisiana coast to 40 km in the Atlantic Ocean. From a tidal constituent database (Mukai et al., 2002), seven dominant constituents (O1, K1, Q1, M2, N2, S2 and K2) are considered to determine tidal levels at the open-sea boundary across the Atlantic Ocean. Atmospheric forcing in the form of gridded wind velocity at 10m, surface air pressure, precipitation, air temperature, humidity, and cloud coverage are applied at a 6-hour timestep, provided by the Global Forecasting System's National Center for Environmental Prediction forecast model (GFS-NCEP). A spatially variable roughness was built into the model with discharge variable calibration scaling factors applied to the Mississippi River and floodplains. The Delft3D FM solver computes with an iterative timestep for the two-dimensional depth-averaged model simulations.

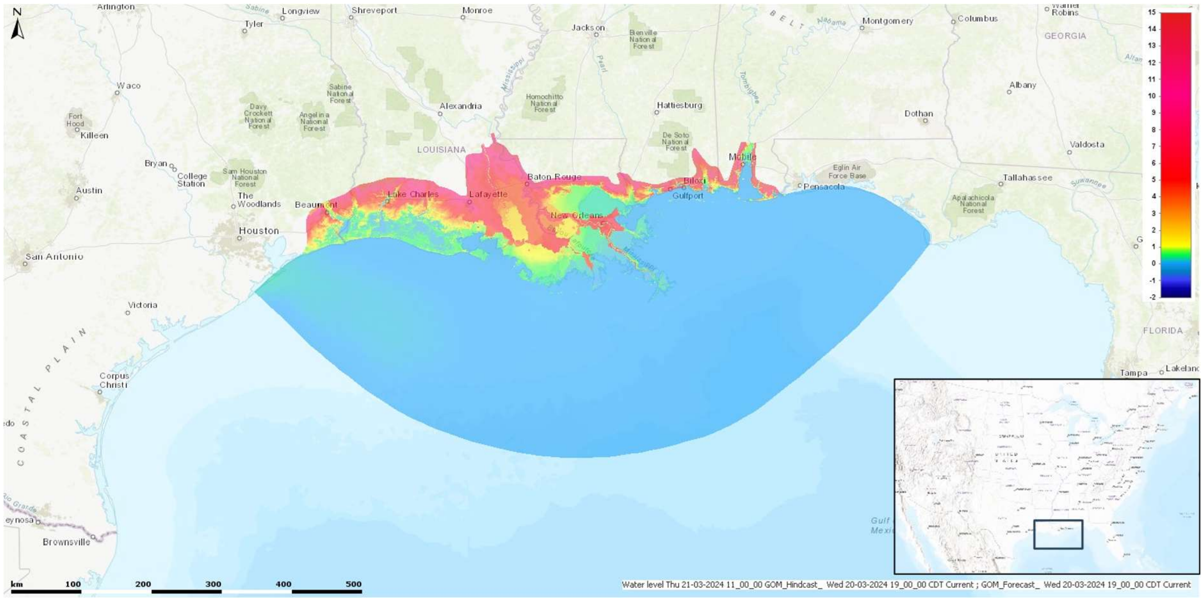


Figure 18 NGOM Delft3DFM model configured for the Tulane forecasting system. Right hand legend indicating water level and elevation from 16m (red) to -2m (blue).

Adjustments were made to the model components prior to configuration into the forecasting system due to the divergences between an external modeling format and the adapted format compatible for real-time operational models. The partitioning of both the Gulf Atlantic and NGOM models were adjusted to match the capacity of the hardware designated for the system home. The Gulf Atlantic model and the NGOM model were partitioned 3 and 48 times, respectively, and model input files were reduced to base formats, providing shell or template files to be continually rewritten as new forecasted conditions are provided to the system. Imported modules were configured to retrieve data relevant to both forecasted and historical conditions, as specified in Table 4.

Table 4 Tulane FEWs Import Schedule:

Tulane FEWs Data Import Capabilities	*Parameter*	*Schedule*	*Type*
Coastwide Reference Monitoring System (CRMS) *https://www.lacoast.gov/crms_viewer/Map/CRMSViewer*	*Water Level* *Salinity*	*1 Day*	*Historical*

	Temperature		
National Water Model (NWM)	*Discharge*	*6 Hour*	*Forecast*
https://water.noaa.gov/about/nwm	*Discharge*	*1 Day*	*Historical*
River Forecast Center	*Water Level*	*6 Hour*	*Forecast*
https://water.weather.gov/ahps/rfc/rfc.php	*Discharge*	*6 Hour*	*Forecast*
United States Geological Survey (USGS)	*Water Level*	*1 Hour*	*Historical*
https://maps.waterdata.usgs.gov/mapper/index.html	*Discharge*	*1 Hour*	*Historical*
National Oceanic and Atmospheric Administration Global Forecast System (NOAA-GFS)	*Pressure*	*6 Hour*	*Forecast Historical*
https://www.ncei.noaa.gov/products/weather-climate-models/global-forecast	*Wind*	*6 Hour*	*Forecast Historical*
	Precipitation	*6 Hour*	*Forecast Historical*
	Short wave radiation	*6 Hour*	*Forecast Historical*
	Cloud cover	*6 Hour*	*Forecast Historical*
	Relative humidity	*6 Hour*	*Forecast Historical*
	Temperature	*6 Hour*	*Forecast Historical*
	Temperature 2meter	*6 Hour*	*Forecast Historical*
National Oceanic and Atmospheric Administration Tides and Currents *https://tidesandcurrents.noaa.gov/*	*Water Level*	*1 Hour*	*Historical*
Louisiana Multi-radar multi-sensor (MRMS) *https://mrms.nssl.noaa.gov/*	*Precipitation*	*Hour*	*Historical*
United States Army Corps of Engineers (USACE)	*Water Level*	*6 Hour*	*Historical*
https://rivergages.mvr.usace.army.mil/WaterControl/new/layout.cfm	*Discharge*	*6 Hour*	*Historical*

The data imported from these agencies serves the purpose of either providing forecast or hindcast boundary conditions to the Gulf Atlantic and NGOM models or providing observation data to compare with forecasted model output for analysis of system performance over time.

3.2.2 Flood Early Warning System (FEWS) Architecture

The Delft-FEWS software provides a platform to integrate data retrieval, filtering, and processing, with model pre and post processing. FEWS offers a means of visualizing, archiving, and coordinating the tasks associated with modeling hydrologic and hydrodynamic simulations. The application of FEWS is used around the world for day-to-day operational management, real-time control, flood forecasting and warning, water quality monitoring, reservoir management, hydropower, navigation, groundwater, droughts, and dike strength monitoring (Werner et al., 2013). The Tulane forecasting system was developed via configuration of the FEWS application and integration of the Delft3DFM model. Each file contains instructions guiding the software to run individual tasks. Excluding all model related files, a total of 250 files were configured to provide an appropriate FEWS framework for the forecasting system. Most of the developmental effort involved the customization of 60+ files into each of the 6 module types described in the following bullets.

- Imports: These modules import data into the FEWS platform from external sources (USGS or USACE) and data from model simulations (Delft3D FLOW or Delft3DFM).

- Exports: These modules export data from the FEWS platform to an external directory. For example, data must be exported from the platform and written into boundary condition files (ex. Waterlevel.bc) within the model working directories for standalone forecasts or into the forecasting shell servers for operational forecasts. Also, model simulation results are exported from the FEWS platform into the Archive for long term storage. The internal database of the FEWS system must be periodically purged for storage capacity purposes, as all datasets locally in the platform have expiry times allowing them only temporary status for visualization purposes in the FEWS dashboard.
- Models: These modules initiate model tasks outside of the FEWS platform and contain all activity directives that allow the model directories to be purged, repopulated, model simulations to initiate, and model output to be imported back into the FEWS database.
- Maintenance: Maintenance modules contain amalgamation daily or weekly workflows
- Processing: These modules perform data processing tasks that occur at any point during the forecasting workflows. These tasks include, but are not limited to, spatial interpolation or extrapolation, temporal interpolation or extrapolation, merging, averaging, scaling, converting, combining, transposing, applying datum corrections, etc.
- Archiving: This module is applicable to the operational forecasting system. It is responsible for moving data from the internal FEWS database into a library directory located on the computer for long term storage. The archive modules are

set up for all the imported forecast hydrological and hydrodynamic conditions, as well as the Gulf Atlantic and NGOM model simulation outputs.

Another element of the system is the Module Dataset Files, which include the compressed version of each of the models described previously. The models were packed in a structure that can be read by FEWS and decompressed into their appropriate working directories or forecasting shell servers. The Module Dataset Files also contains scripts for retrieving data from web services for forecasts or observational data.

Figure 19. illustrates the finalized workflow schematic of the Tulane FEWS system designed to operate in 2 primary modes: Hindcast and Forecast. The Hindcast workflow executes all the modules and activities necessary to run the Gulf Atlantic model and the NGOM model for a T0 minus 1-day warmup period. This simulation is initiated with a warm state from the previous day’s model run and provides an initial condition at T0 for the next workflow.

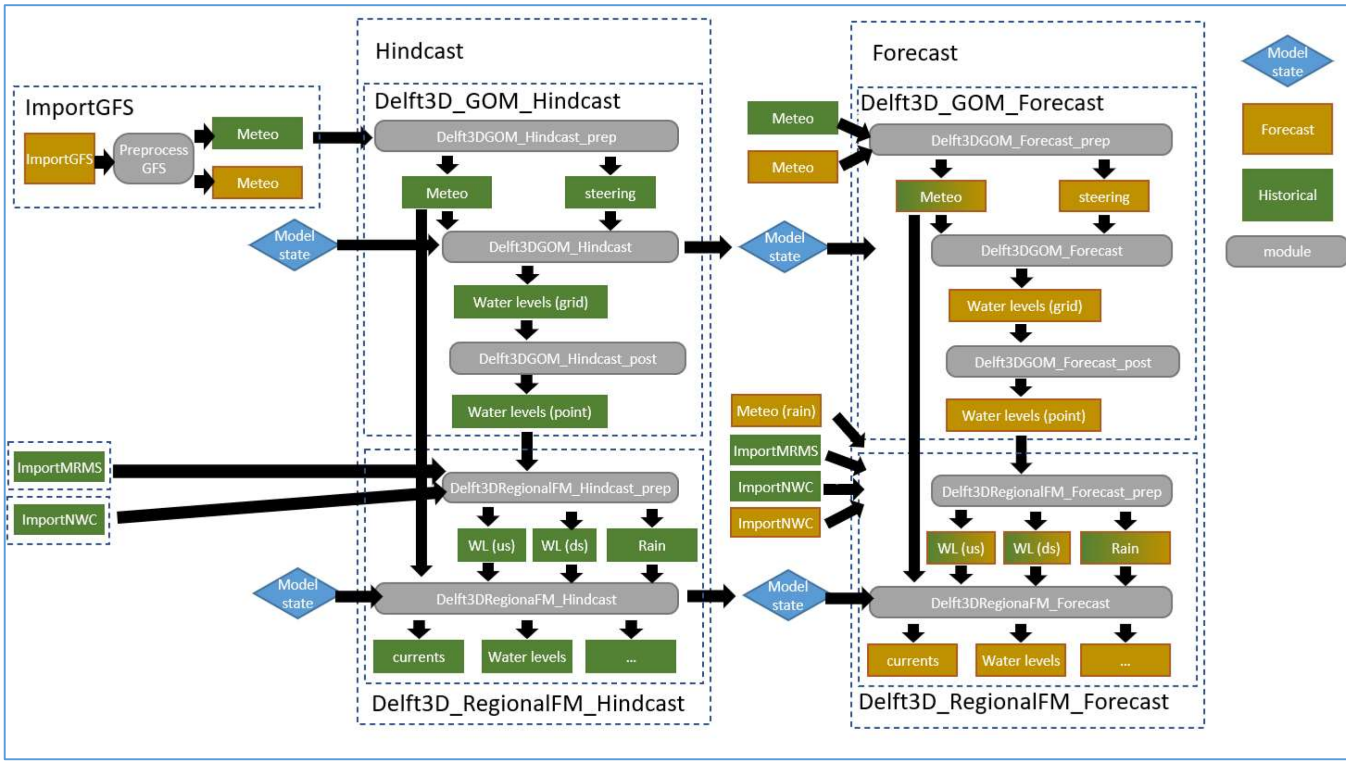


Figure 19 Tulane forecasting workflow configurations, featuring imports, pre/post processing, model runs, transformations, etc.

The Forecast workflow executes all the modules and activities necessary to run the Gulf Atlantic model and the NGOM model for a T0 minus 15 hours plus a 10-day forecast. The Forecast workflow picks up the T0 state provided by the Hindcast for a smooth transition (Figure 20) in model behavior as the boundary forcing data shift from being driven by external observational data to external forecasting data.

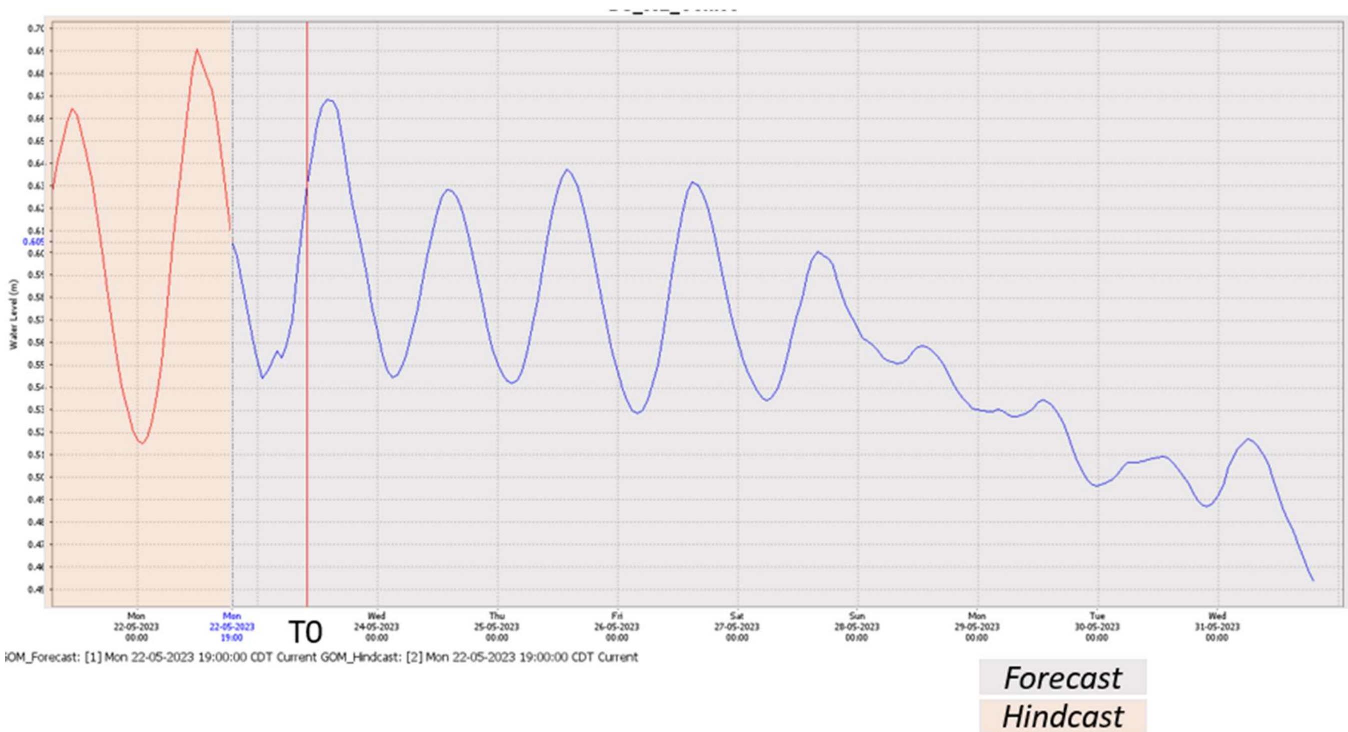


Figure 20 Example of FEWS system hindcast (red) and forecast (blue) simulation water level output for the Mississippi River at Venice.

3.2.3 Stand-alone Client, Real-time Operational Server, and Archive configuration

The stand-alone system setup can provide forecasts issued any time on any device with the following stipulations: the computational hardware has the parallelization capacity equal or exceeding 48 processors and contains both the FEWS software application installation and a copy of the Tulane forecasting system configuration files. This is a powerful and credible form of the forecasting system that is easily distributed and robustly packaged. The user must initiate all workflows in a stand-alone setup. Therefore, if a continuous simulated dataset is desired, the responsibility lies with the user to manually run all tasks required for Hindcast and Forecast simulations. Additionally, the agencies which issue forecasts and observations continue to update their web-based provisional datasets.

Therefore, a relatively small window of time exists in which to retrieve data and initiate model tasks for a continuous forecast dataset.

The second application is a live or client-server system setup. This live mode features a single configuration housed in the server that can be accessed by multiple users at the same time. The same architecture developed for the stand-alone application was migrated into the server. The workflows in the server run using Forecasting Shell Servers (FSS's) that are the computational nodes of the system. FSS's allow for multiple workflows to run simultaneously, rather than sequentially as the stand-alone functions. The operator client (OC) allows users to access the server system and can be activated on any device. The admin interface provides controlled access to the server and organizes administrative privileges for scheduling, maintenance, monitoring, web connection, and other operational tasks.

Workflow tasks schedules were carefully designed and calibrated to provide appropriate and continuous data to the server. Presently, the server is producing a twice daily 10-day forecast of hydrodynamic conditions in the NGOM model.

The Tulane forecasting archive configuration is responsible for collecting and maintaining a copy of all imported raw forecast data and all simulated forecasting model outputs. This archive is key to retaining system output because the local database of the server cannot retain the accumulating datasets, as they are significantly sized: a single NGOM model simulation produces over 2GB of output data. Therefore, the archiving sequence was arranged to file externally all imported data once a day and all model simulation results immediately upon workflow completion. The archive is organized by year/month/day and housed in the River-Coastal Science and Engineering Department. This archived data will serve to support future research in the group.

3.2.4 Stream power

Upon completion of the forecasting system development, the extraction of reliable new forecast information from the model simulations was of interest. Specifically, stream power in the lower most Mississippi River provides information about the potential ability of the river to transport sediment downstream. Stream power is described using the following equations (Bagnold, 1960):

$$\Omega = \rho g Q S \qquad (1)$$

Where:

Ω = stream power (Watts/m)

ρ= specific weight of water (kg/m3)

g= acceleration due to gravity (m/s2)

Q= discharge (m3/s)

S= local energy slope (m/m)

Considering the density of water to be constant, the stream power can be expressed in terms of discharge (i.e. cfs or cms) and energy slope as:

$$\Omega = QS \qquad (2)$$

The cross-sectional river discharge may be retrieved directly from model output. The energy slope may be approximated by the average or reach scale water surface slope between stations. Longitudinal reach scale slope extraction is a reliable method to evaluate variations in stream power. Jain et. al (Jain et al., 2006) explored several methods to calculate stream power profiles and found that a smoothed long profile approach to obtaining slopes was appropriate for describing the stream power, while local-scale stream power calculations reflect high variability resulting from local slope extremes. Local variability is further supported by the influence of coastal backwater conditions in the downstream reaches of the Lower Mississippi River. There exists a nonsystematic variation in stream power due to the low gradient changes in local slope and the high degree of natural pass connectivity in this region. Another example of coastal riverine interaction is the Trinity River (Phillips & Slattery, 2007), which also demonstrates the complexity associated with balance of river and coastal processes producing nonsystematic variations in stream power, water surface slope, and discharge. Local water surface slope variations are found in many downstream river reaches, particularly as they approach the coastal region (Knighton, 1999). Prior to configuring the stream power computation into the forecasting system, a sensitivity analysis was done to determine the level of agreement between water surface slope and energy slope in the Lower Mississippi River. Using a 1D HECRAS model of the same river region, the high flow conditions were extracted from the model. The comparison, seen in Figure 21, showed that the smoothed reach level water surface slope converged to the energy slope. Therefore, the reach scale water surface slope was the optimal variable to configure into the forecasting system.

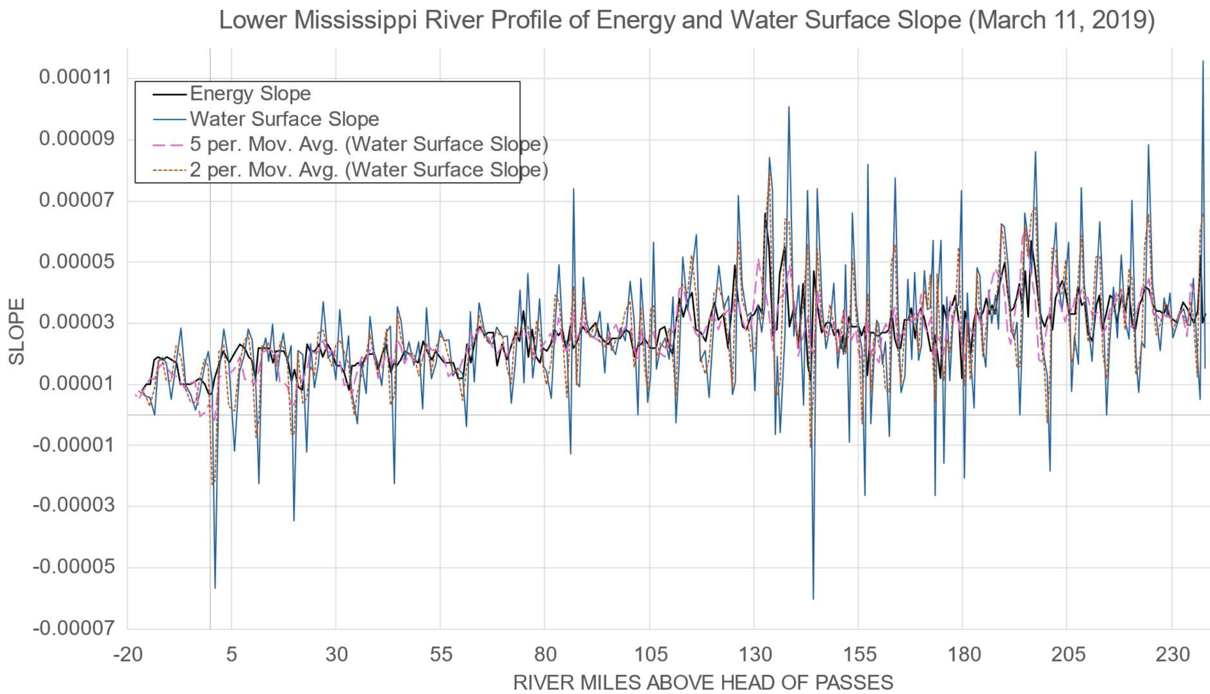


Figure 21 Lower Mississippi River modeled energy slope (black) and water surface slope (blue) profiles combined with the two period (orange) and 5 period (pink) moving average smoothed water surface slope profiles .

The reach scale water surface slope was chosen for stream power computation. The forecasting system was configured to include a cross section monitoring system within the model for the following locations along the Mississippi River main channel: Baton Rouge, Belle Chasse, West Point a la Hache, Venice, and Southwest Pass at East Jetty. Model output of discharge and water level are calculated in transformation modules within the forecasting system to provide forecasted stream power.

3.3 Results

Primary products of the forecasting system include 10-day water level, discharge, and current forecasts for the NGOM (Figure 22).

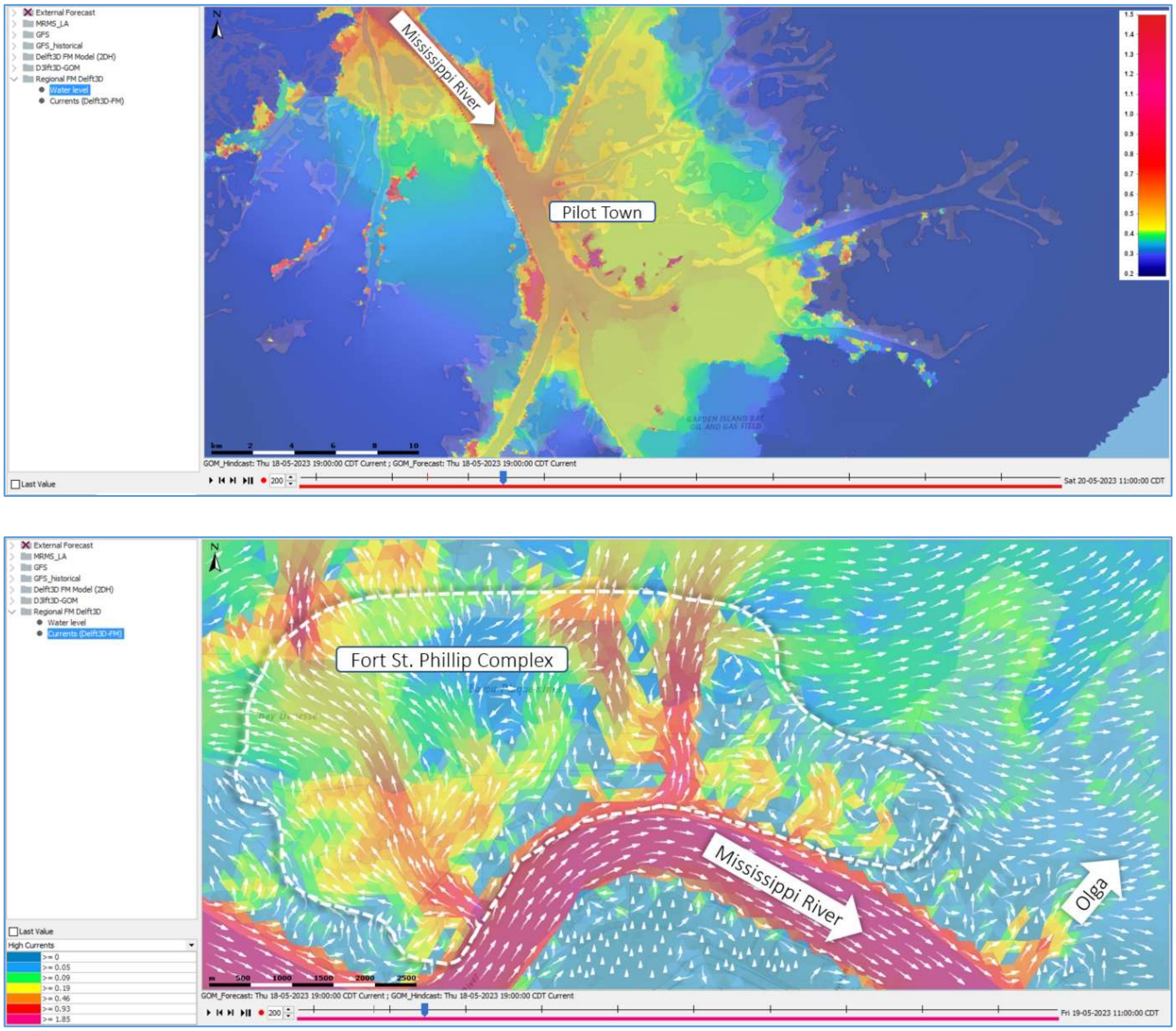


Figure 22 . Tulane FEWS system forecasted water levels (m) near the Birdfoot delta of the Mississippi River (UPPER) and 10-day forecasted currents (m/s) near the Fort St. Phillips complex on the Mississippi River (LOWER).

Additionally, the forecasting system provides forecasted distribution of flows through the lower passes of the Mississippi River. The forecasted discharge locations were configured into easily digestible schematic displays that provide dynamic shape and color indicators that adjust to reversible flows (see Figure 23).

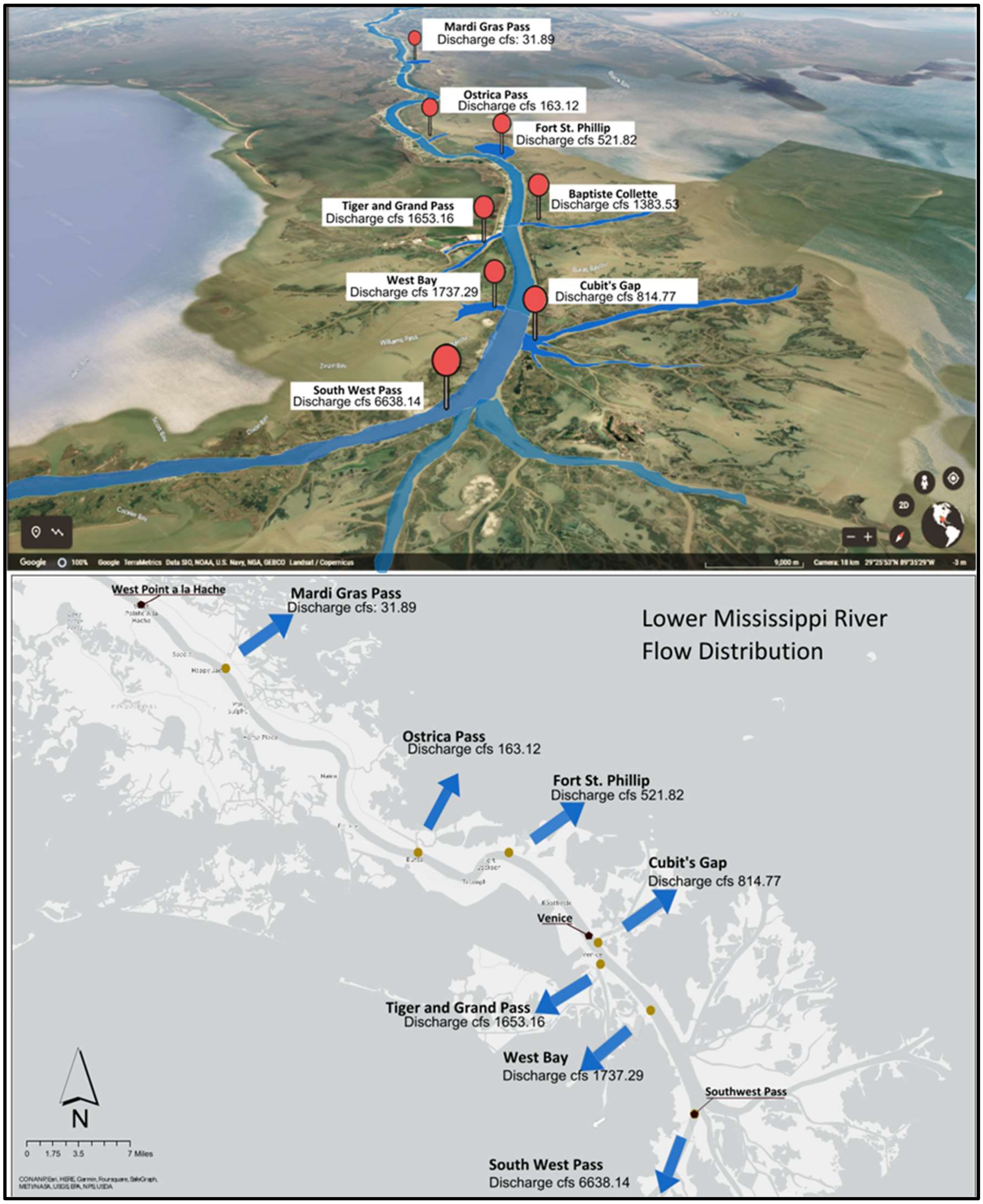


Figure 23 Tulane FEWS system forecasted discharge near the Birdfoot delta of the Mississippi River via two schematic displays.

The integration of stream power computational functionality into the FEWS system provides reach scale forecasting capabilities for the Lower Mississippi River from Baton Rouge, LA to Southwest Pass, LA (see Figure 24).

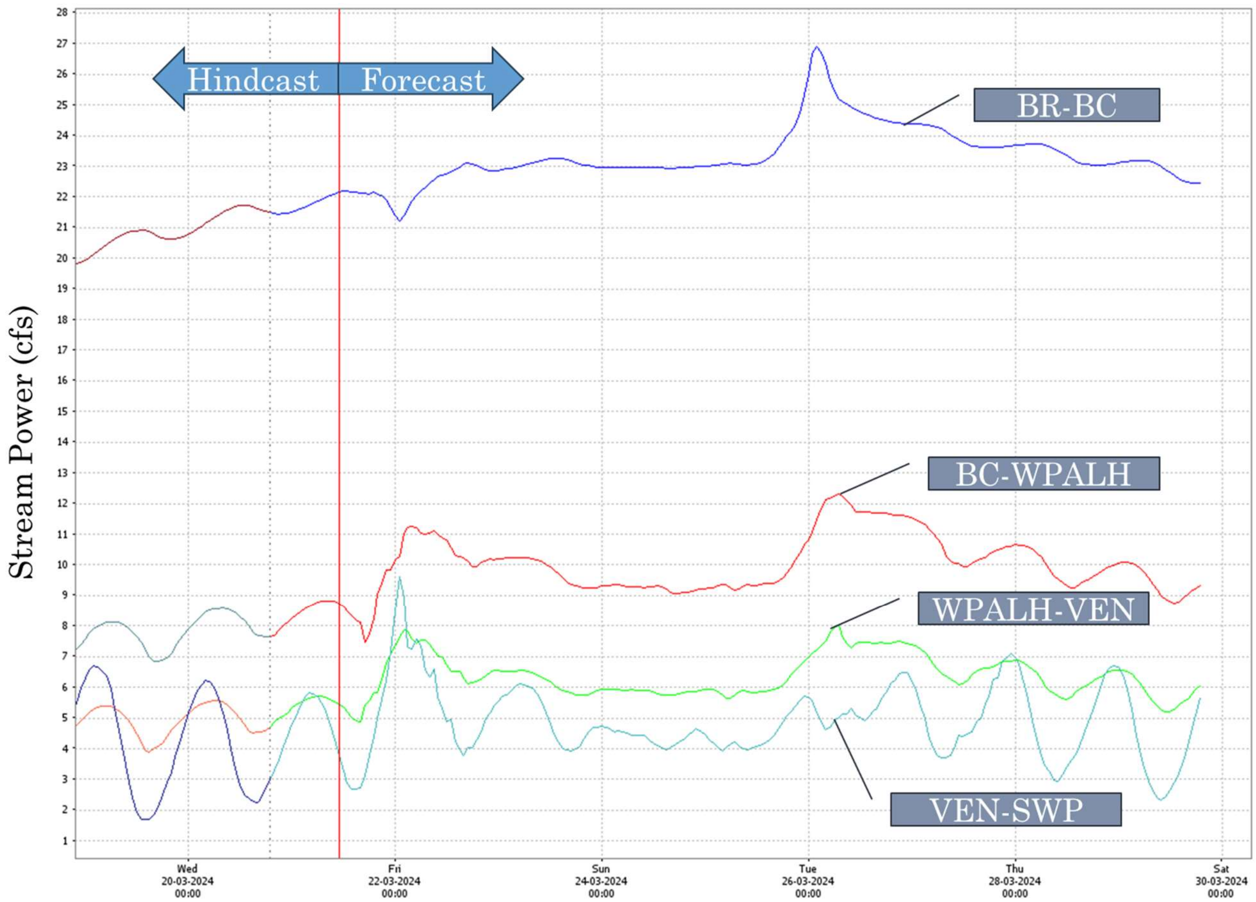


Figure 24 Tulane FEWS system hindcasted and forecasted stream power in the Lower Mississippi River from Baton Rouge, LA to Southwest Pass. Baton Rouge (BR) to Belle Chasse (BC) to West Point a la Hache (WPALH) to Venice (VEN) to Southwest Pass (SWP).

3.4 Discussion

Stream power analysis is one of several applications of the coastal forecasting system described in this study. Practical implications of stream power potential include but are not limited to bedload transport (Bagnold, 1997), flood influence on sediment distribution (Magilligan, 1992), and natural river channel evolution (Nanson & Hickin, 1986).

Previous research regarding stream power on the Lower Mississippi River has recently been recorded. Biedenharn et al. (Biedenharn et al., 2000) provided a stream power record of the pre cutoff and post cutoff reach scale stream power profiles from Cottonwood point to Natchez. This stream power profile was derived from the peak flow record computation of discharge times the water surface slope across 13 reaches. Although stream power is most formally defined in terms of the friction slope, the approximation via the water surface slope is appropriate, where the water surface slope and friction slope are assumed to be comparable. Allison et. al (Allison et al., 2023) provide a high-water event stream power profile projection using a one dimensional HECRAS model for the Mississippi River from Baton Rouge to the Gulf of Mexico and demonstrate the relationship between stream power and the availability of natural pass outlets below the levee system. This study shows the stream power profile for the reach included in the Tulane forecasting system (Baton Rouge to the Gulf of Mexico) for high flow conditions. Figure 25 displays Mississippi River reaches in consideration for the Biedenharn et al. study (reaches 1-13) and for the Allison et. al study (reaches 14-17).

Figure 25 Reach locations on the Lower Mississippi River

Figure 26 illustrates the combined literature of stream power recorded on the Lower Mississippi River compared to this study (NGOM model). The Mississippi River stream power at Baton Rouge, LA is 87% larger during high flow conditions (>1.2Million cfs) than low flow conditions (<400,000 cfs). During high flow conditions, the river stream power diminishes by nearly 90% of its capacity from Baton Rouge to Southwest Pass. Understanding the dynamics of the Lower Mississippi River stream power profiles can inform decision makers seeking information about the sediment transport abilities of the lower river. From navigation and dredging to the operation of sediment diversions, knowledge of the real time forecasted duration of high and low stream power profiles provides a functional tool for decision making.

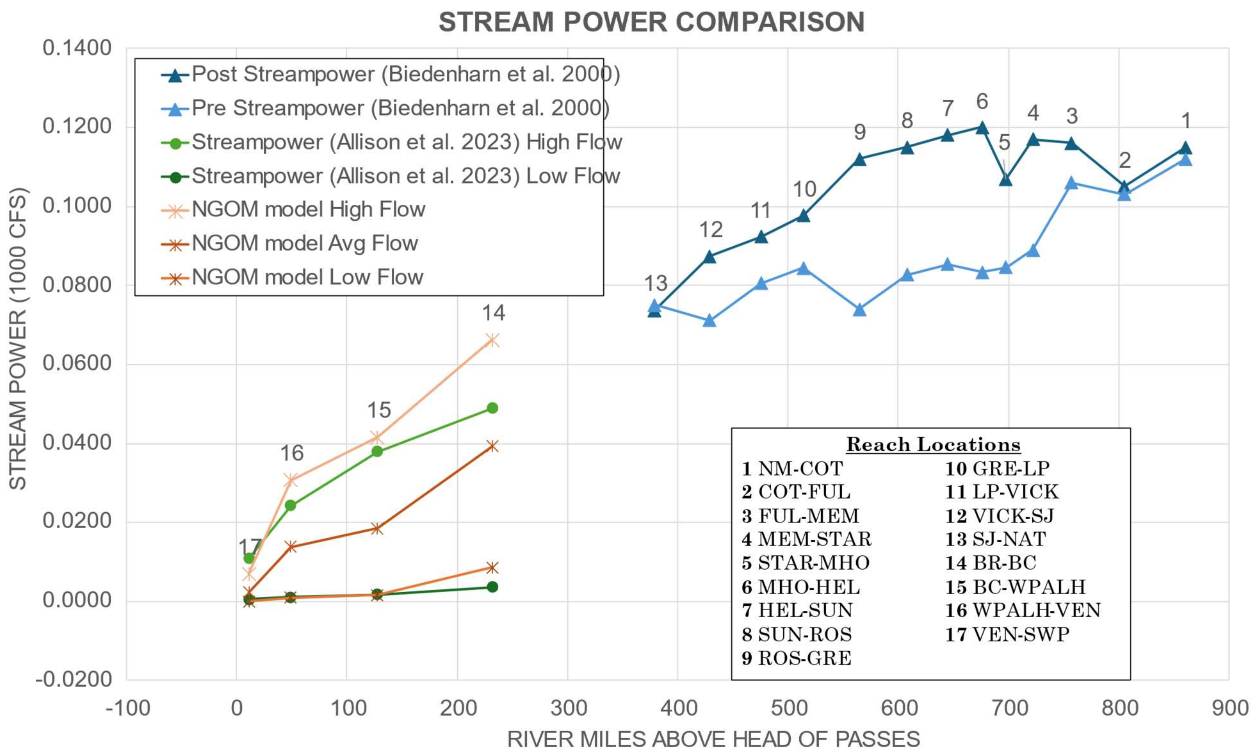


Figure 26 Stream power comparison for the Lower Mississippi River from New Madrid to the Gulf of Mexico. Biedenharn et al. datasets represent the Pre cutoff program and Post cutoff program (1972–1992) stream power profiles for the Mississippi River from roughly Cairo, IL to Natchez, MS. Allison et al. datasets are obtained from a one-dimensional HECRAS analysis, and the datasets represent the stream power profile variation between low flow and high flow in the Mississippi River from Baton Rouge, LA to Southwest Pass. The NGOM model datasets reflect output from the DelftFM modeling effort described in this study and show the variation between low, average, and high flow events.

3.5 Conclusions

In addition to the Lower Mississippi River hydrodynamics, the adjacent basin hydrodynamic output provides a plethora of data for the NGOM forecast conditions. Furthermore, the system demonstrates the potential for improvements to real time forecasting in the NGOM. The forecasting system supplies reliable, high-resolution data for a ten-day period that can supplement other coastal forecasting systems that provide information with either a shorter forecast window (ex. NGOFS system three-day forecasts) or on a less frequent spatial distribution (ex. National Weather Service River Forecast provided at discrete river gaging locations).

A key product of this system is the stream power forecasting capabilities in the Lower Mississippi River. This information can be used directly by river managers, such as the US Army Corps of Engineers, who are responsible for maintaining navigation in this reach of the river that requires substantial resources. For example, the 2024 maintenance dredging quantities were estimated to be 350,000 cubic yards for the Lower Mississippi River alone. Knowledge of the real time forecasted stream power potential in the river provides valuable data that can serve as a proxy for the river's ability to move bed material downstream or "self-dredge". Stream power data might inform the allocation of dredging resources, the scheduling of maintenance routines, and the further understanding of river dynamics in the lower Mississippi River to advise future dredging operations.

Developing the forecasting system to import observed and forecasted meteorological and hydrological data in the NGOM provides the infrastructure for additional modeling capabilities. This platform has the flexibility to accommodate other models such as machine learning algorithms or other process-based model engines (i.e. HECRAS, ADCIRC, etc.). Additionally, exploring different versions of the existing model could provide ensembled forecast data that may provide a more reasonable range of possibilities for the forecasted conditions. For example, the integration of a high flow calibrated set up and a low flow calibrated set up might provide greater quality control by folding in the scientific knowledge and variability related to hydrologic extremes with the unpredictability of forecasting conditions. The system flexibility provides opportunity to explore forecasting research in many directions.

4. Appendix

Table 5 NGOM co-production effort stakeholders

End User Stakeholders Organization
US Army Corps of Engineers
NOAA- Fisheries, Southeast Regional Office
National Park Service
Alabama Department of Conservation and Natural Resources
Louisiana Department of Wildlife and Fisheries
NOAA- Office of Water Prediction
Louisiana Coastal Protection and Restoration Authority
Mississippi Department of Environmental Quality
US Fish and Wildlife Services
Mississippi State University
Morgan State University
University of New Orleans
Louisiana Department of Environmental Quality
University of South Alabama
United States Geological Survey
Environmental Defense Fund
Pontchartrain Conservancy
Coalition to Restore Coastal Louisiana
The National Wildlife Federation

4.1 Diversion Background

4.1.1 Existing Diversions

Mississippi River diversions considered in this study were considered from the Old River Control Structure, located near Vidalia, LA, and including all diversions downstream until the Mississippi River meets the Gulf of Mexico (See Figure 27). With origins in the 1950s (Lewis et al., 2022), the Old River Control structures was initially designed to maintain the percent distribution of flow between two major rivers: 70% for the Mississippi River and 30% for the Atchafalaya River. Since the 1950s, the ORC has maintained the 70/30 split. Daily controlled by the United States Army Corps of Engineers (USACE), ORC operation is based upon a Water Control Manual that was Congressionally approved and has remained relatively unchanged since conception. Though it was a fixed point for this analysis, ORC operation strategies have been suggested for continued investigation. The recent Technical Assessment of the Old, Mississippi, Atchafalaya, and Red (OMAR) Rivers studies provide substantial resources regarding research in this regard (Lewis et al., 2022). These studies investigated current and future sediment diversion impacts from the perspective of basin health and hydroelectric operations, as well variations of the percentage split of flow for the Mississippi and Atchafalaya River's. The studies quantified the amounts of sediment distributed by ORC, water storage during flooding events, dredging impacts due to sedimentation, and outlined recommendations for future studies to support operations and management.

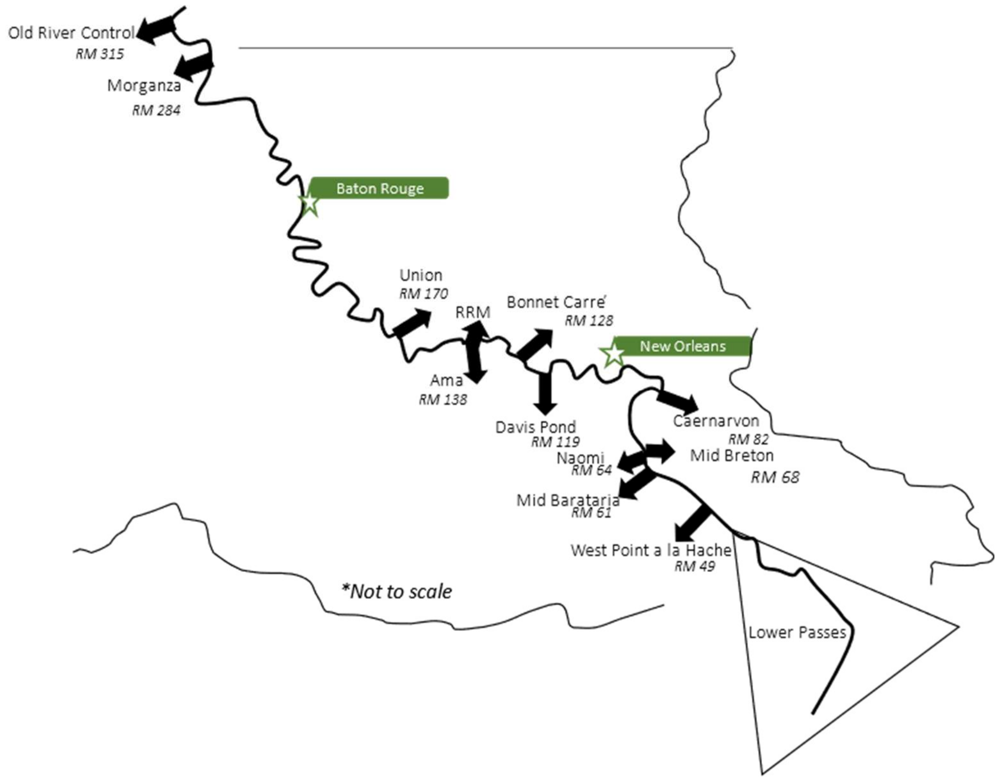


Figure 27 Schematic of Mississippi River existing and proposed diversions located in South Louisiana from the Old River Control structure moving downstream until the Gulf of Mexico

Downstream from the ORC are diversions considered for this analysis, beginning with the Morganza spillway. This flood risk management structure was completed in the mid-1950s providing a relief valve for the Mississippi River during high water events (See Figure 28). The Morganza spillway has been opened twice since construction: in 1973 and in 2011. The structure has a capacity of 16,990 cms (600,000 cfs) and operates strictly as an emergency flood management feature. Following the 2011 opening, modifications were done to repair scour damage (Shih et al., 2019) and require more gradual openings to allow relocation time for animals in the affected area, but the primary thresholds that govern the opening pace have remained the same since the structure was first designed.

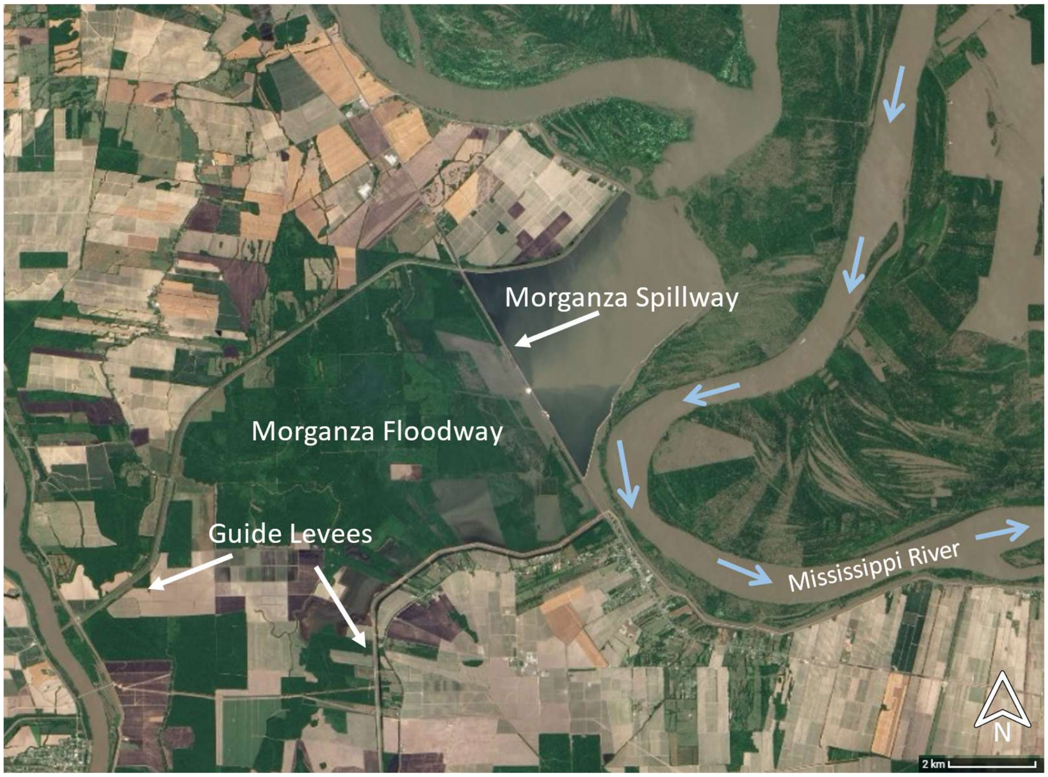


Figure 28 Aerial view of the Morganza control complex on May 15, 2011. Image credit: NASA Earth Observatory via Getty Images

Another flood risk management structure along the Mississippi River is the Bonnet Carré Spillway (BCS). With a design capacity of 7,080 cms (250,000 cfs), this diversion serves as primary protection for the city of New Orleans and the downstream levee system from the pressures of high-water events. The spillway ultimately connects the Mississippi river to the Gulf of Mexico by flowing water eastward into Lake Pontchartrain and through the Lake Borgne Estuary. Since its installment in the 1930s , the structure has been opened 15 times in 14 different years. The spillway openings stimulated exploration into diverted sediment loadings (Allison et al., 2014), nutrient loadings (Mishra & Mishra, 2010), operational tactics (Allison & Meselhe, 2010; Day et al., 2016), sampling methods and techniques (Iles et al., 2020), and salinity changes (Linhoss et al., 2023) that take place during an opening. However, little change has been enacted to the BCS Water Control Manual, and the affected gulf states (namely, Mississippi and Alabama) show increasing concern and investigation into the management of the BCS structure.

Besides flood management, the Davis Pond, Caernarvon, Naomi, and soon to be operating River Reintroduction to Maurepas Swamp (RRM) diversions operate to mitigate saltwater intrusion in the estuaries adjacent to the river and subsequently provide sediment and nutrients to the Barataria, Breton and Maurepas basins in South Louisiana. Caernarvon diversion is a 212 cms (7,500 cfs) operational capacity gated culvert structure, located near Braithwaite, LA. Operational since 1991, Caernarvon regulates salinity on the east side of the Mississippi River. The Naomi siphon is located near Naomi, LA with an operational capacity of 60 cms (2,144 cfs) and has been nourishing the western side of the Mississippi River since 1993. Davis Pond diversion is a gated culvert structure, located approximately 15 miles upstream from New Orleans, LA, with an operational capacity of 283 cms (10,000 cfs). Finally, RRM is the most recent of these diversions, as it is not yet operational at the time of this study. This diversion will supply riverine flow into the Maurepas freshwater swamp basin carrying a capacity of 56 cms (2,000 cfs). All four diversions supply freshwater, sediments, and nutrients to the adjacent estuarine marsh and wetlands. In addition to providing significant protection from storm surge via wave attenuation and buffering (Temmerman et al., 2023), these marsh and wetland areas supply valuable habitat for organisms and support the wildlife and fishery resources vital to the local communities.

4.1.2 Proposed diversions

Proposed diversions suggested by the state of Louisiana’s Coastal Master Plan are intended to support the existing diversion infrastructure in river and coastal management and protection (Bentley et al., 2014; CPRA, 2012). These diversions are large scale with capacities ranging from 708 cms (25,000 cfs)- 2,120 cms (75,000 cfs) and are estimated to cost in the order of billions of dollars apiece. The Mid Barataria diversion, for example, is estimated to cost three billion dollars at the time of this study (USACE, 2022). Seen in Figure 29, proposed diversions of this scale are evaluated through an intensive process of design, environmental impact analysis, and scrutiny from all levels of federal, state, and public inquiry before moving into final consideration for engineering and construction. Four proposed diversions considered in this study were the Union and Ama freshwater diversions and the Mid Breton and Mid Barataria sediment diversions. At the time of this study, Mid Barataria has moved into the construction phase, Mid Breton is in the engineering and design phase, and Union and Ama are still in the conceptual phase. Though there are potentially endless options of diversions to propose for coastal Louisiana management, the study will be limited to the forementioned structures.

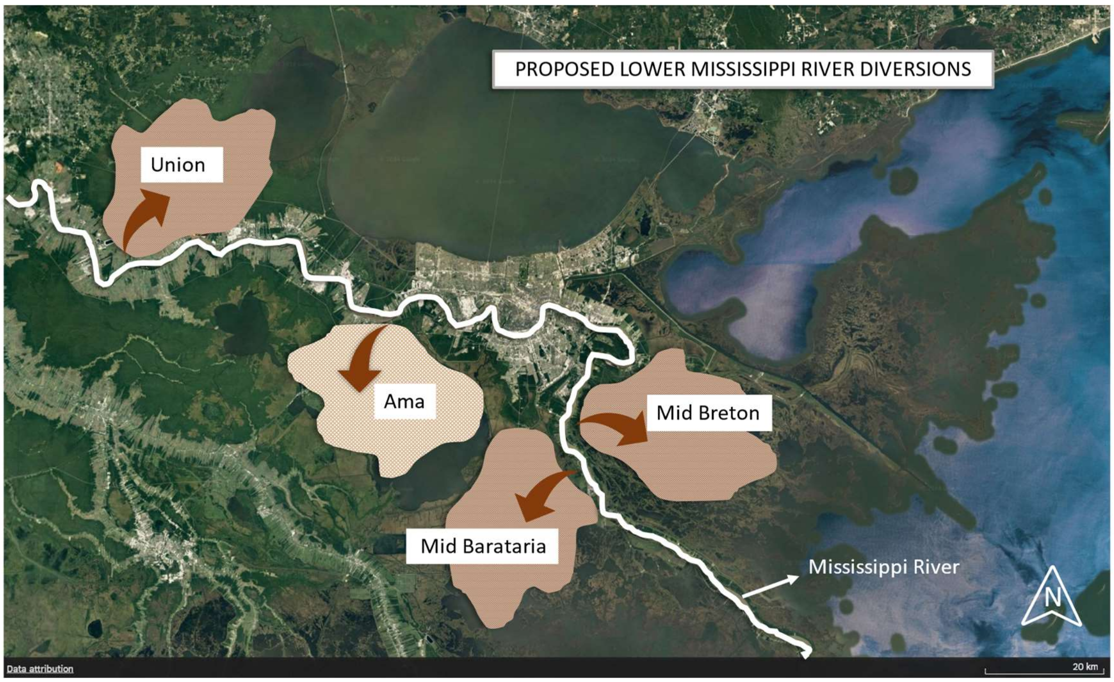


Figure 29 Proposed Lower Mississippi River diversions considered in this study: Union, Ama, Mid Breton, and Mid Barataria. Image credit: Google Earth

4.1.3 Lower Passes

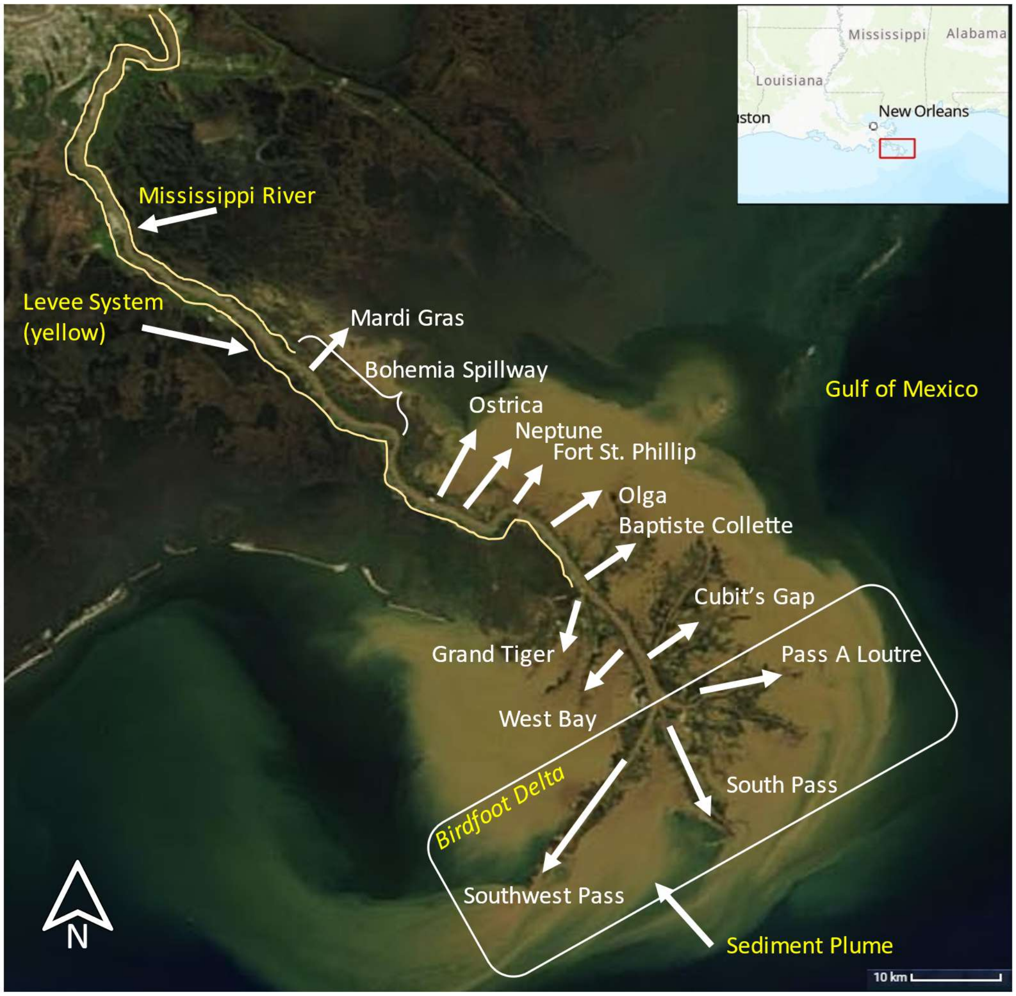


Figure 30 The Lower Mississippi River natural passes on March 4, 2018. Image credit: NASA Earth Observatory via Getty Images

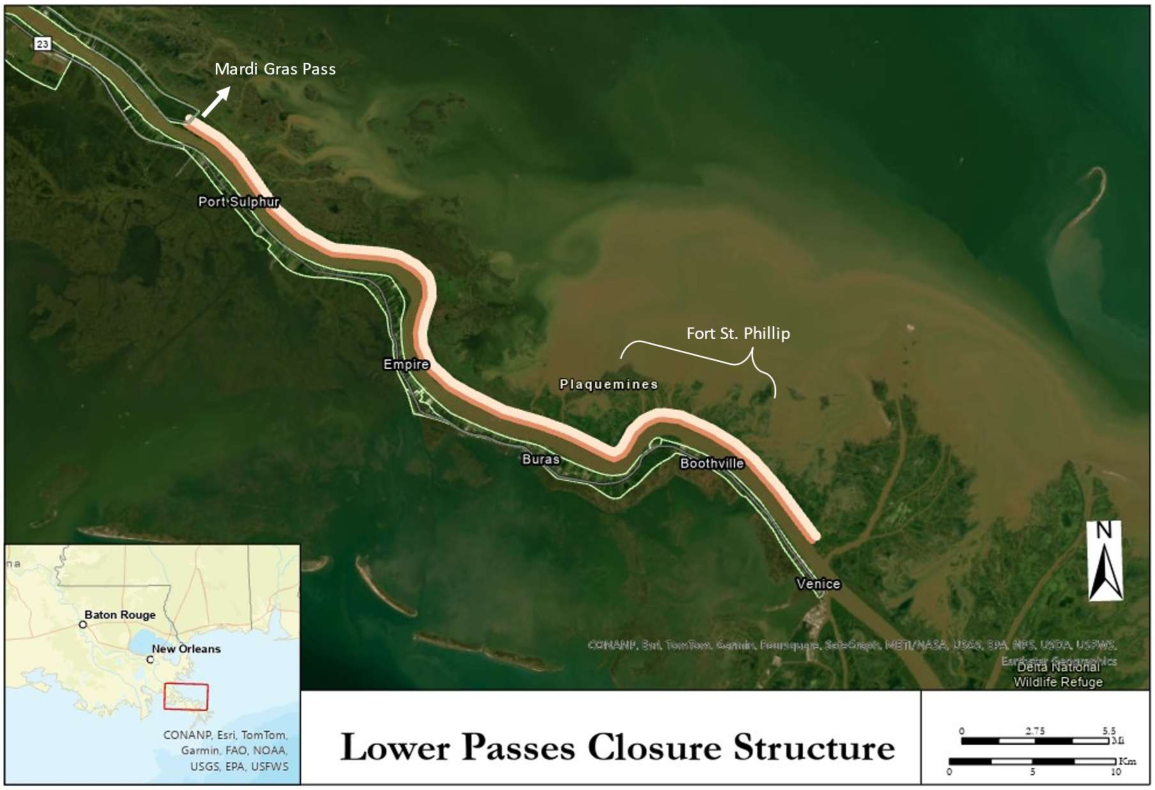


Figure 31 Location of lower passes closure (Pink line) in model domain, which extends from Mardi Gras Pass to the end of the Fort St. Phillips complex on the eastern side of the Mississippi River

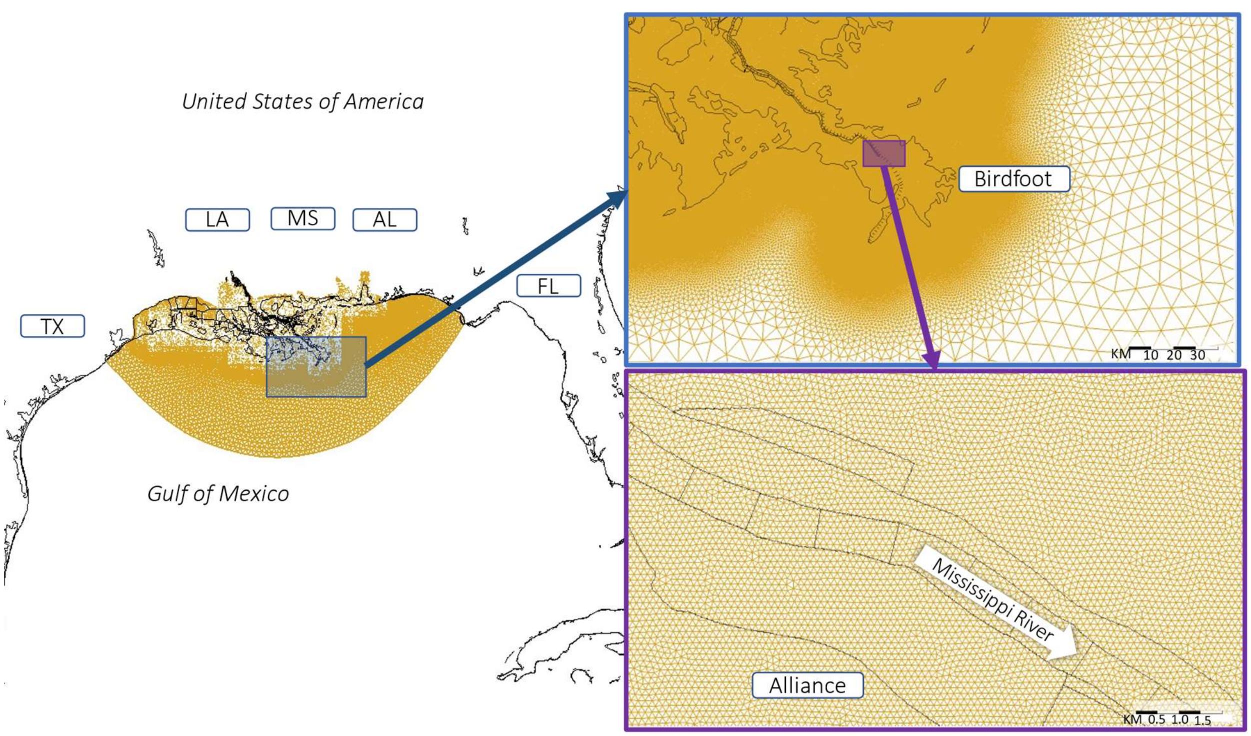


Figure 32 . Illustration of the Regional model flexible mesh design with variable spatial resolution and triangular grid. Model domain (left), Zoom in to Birdfoot delta near the mouth of the Mississippi River

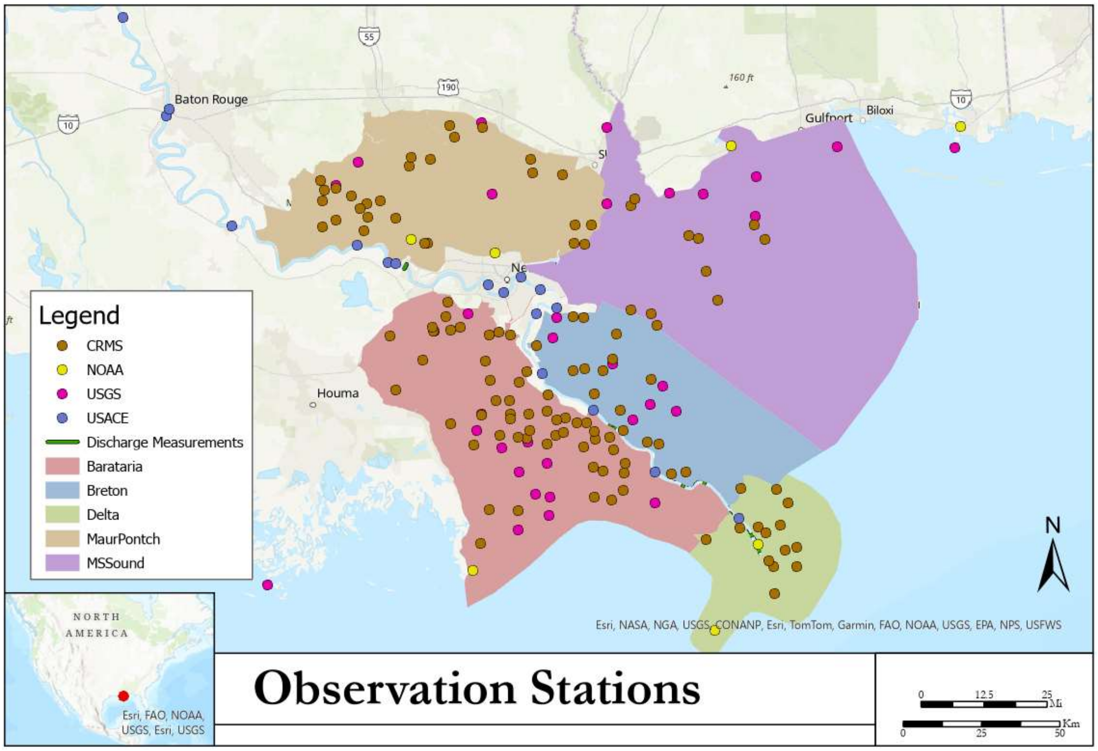


Figure 33 Calibration and validation basin observation stations used for water level, discharge, salinity, and/or temperature model comparison. Ecosystem region configuration for analysis: Barataria (pink), Delta (green), Breton (blue), Mississippi Sound (purple

4.2 Calibration statistics

Calibration and Validation Results:

https://storymaps.arcgis.com/stories/95c8f81e674440828acf3a7a76288b57

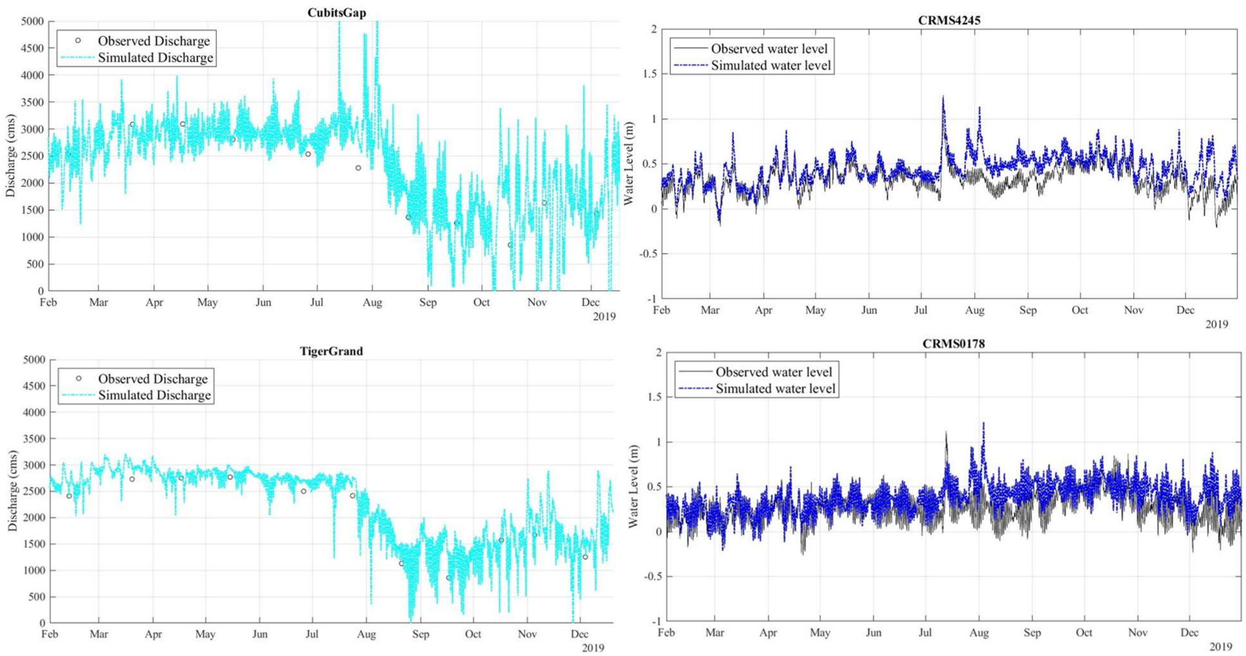


Figure 34 Barataria Basin sample 2019 water level and Mississippi River Lower Outlets sample 2019 discharge calibration plots: Blue (model) and Black (observations)

Table 6 CRMS station water level comparison statistics Hourly

Station	*R*	*RMSE (m)*	*Bias (m)*
CRMS0002	*0.859*	*0.141*	*0.105*
CRMS0003	*0.550*	*0.216*	*0.063*
CRMS0006	*0.816*	*0.095*	*0.008*
CRMS0008	*0.746*	*0.142*	*0.118*
CRMS0030	*0.875*	*0.125*	*0.078*
CRMS0033	*0.901*	*0.073*	*0.029*
CRMS0034	*0.899*	*0.115*	*0.078*
CRMS0038	*0.910*	*0.096*	*0.034*
CRMS0039	*0.376*	*0.083*	*0.024*
CRMS0056	*0.660*	*0.094*	*0.033*

CRMS0058	*0.558*	*0.156*	*-0.071*
CRMS0061	*0.903*	*0.136*	*0.103*
CRMS0063	*0.649*	*0.163*	*0.086*
CRMS0108	*0.600*	*0.213*	*0.091*
CRMS0114	*0.935*	*0.118*	*0.094*
CRMS0117	*0.876*	*0.146*	*0.121*
CRMS0118	*0.726*	*0.156*	*0.006*
CRMS0119	*0.581*	*0.228*	*0.135*
CRMS0120	*0.629*	*0.184*	*-0.023*
CRMS0121	*0.878*	*0.151*	*0.116*
CRMS0125	*0.707*	*0.140*	*0.012*
CRMS0129	*0.610*	*0.242*	*0.156*
CRMS0132	*0.899*	*0.137*	*0.106*
CRMS0135	*0.864*	*0.143*	*0.101*
CRMS0136	*0.757*	*0.190*	*0.127*
CRMS0139	*0.574*	*0.203*	*0.003*
CRMS0146	*0.883*	*0.162*	*0.132*
CRMS0147	*0.602*	*0.249*	*0.147*
CRMS0148	*0.809*	*0.148*	*0.071*
CRMS0153	*0.385*	*0.250*	*0.002*
CRMS0154	*0.659*	*0.139*	*0.037*
CRMS0156	*0.661*	*0.154*	*0.070*
CRMS0157	*0.794*	*0.112*	*0.036*
CRMS0159	*0.610*	*0.163*	*-0.012*
CRMS0161	*0.593*	*0.171*	*0.023*
CRMS0162	*0.667*	*0.146*	*0.056*
CRMS0163	*0.689*	*0.157*	*0.041*
CRMS0164	*0.698*	*0.158*	*0.087*
CRMS0171	*0.480*	*0.197*	*0.095*
CRMS0172	*0.581*	*0.189*	*0.090*

CRMS0173	*0.527*	*0.212*	*0.125*
CRMS0174	*0.587*	*0.211*	*0.117*
CRMS0175	*0.723*	*0.160*	*0.087*
CRMS0178	*0.603*	*0.164*	*0.045*
CRMS0179	*0.638*	*0.231*	*0.151*
CRMS0181	*0.548*	*0.193*	*0.058*
CRMS0188	*0.933*	*0.080*	*0.056*
CRMS0189	*0.283*	*0.149*	*0.031*
CRMS0190	*0.902*	*0.163*	*0.144*
CRMS0209	*0.675*	*0.207*	*0.138*
CRMS0211	*0.966*	*0.116*	*0.107*
CRMS0219	*0.590*	*0.123*	*0.016*
CRMS0220	*0.836*	*0.115*	*0.067*
CRMS0224	*0.596*	*0.151*	*0.053*
CRMS0225	*0.786*	*0.118*	*0.060*
CRMS0226	*0.760*	*0.152*	*0.083*
CRMS0232	*0.773*	*0.140*	*0.072*
CRMS0237	*0.621*	*0.179*	*0.091*
CRMS0248	*0.916*	*0.101*	*0.071*
CRMS0251	*0.752*	*0.128*	*0.054*
CRMS0253	*0.803*	*0.118*	*0.070*
CRMS0258	*0.773*	*0.134*	*0.076*
CRMS0260	*0.795*	*0.142*	*0.091*
CRMS0261	*0.894*	*0.113*	*0.082*
CRMS0263	*0.811*	*0.131*	*0.078*
CRMS0272	*0.560*	*0.215*	*0.122*
CRMS0273	*0.712*	*0.117*	*0.032*
CRMS0276	*0.805*	*0.097*	*0.038*
CRMS0278	*0.900*	*0.092*	*0.042*
CRMS0282	*0.671*	*0.233*	*0.176*

CRMS0287	*0.719*	*0.126*	*-0.041*
CRMS1024	*0.495*	*0.221*	*0.077*
CRMS1069	*0.555*	*0.209*	*0.053*
CRMS2608	*0.699*	*0.146*	*-0.069*
CRMS2614	*0.737*	*0.181*	*0.134*
CRMS2627	*0.710*	*0.122*	*-0.016*
CRMS2634	*0.660*	*0.157*	*-0.073*
CRMS2830	*0.911*	*0.131*	*0.102*
CRMS2854	*0.913*	*0.097*	*0.066*
CRMS2991	*0.562*	*0.119*	*0.098*
CRMS3054	*0.955*	*0.129*	*0.118*
CRMS3166	*0.897*	*0.111*	*0.091*
CRMS3565	*0.811*	*0.122*	*0.063*
CRMS3601	*0.810*	*0.124*	*0.066*
CRMS3617	*0.813*	*0.133*	*0.084*
CRMS3626	*0.867*	*0.156*	*0.124*
CRMS3650	*0.689*	*0.206*	*0.101*
CRMS3667	*0.774*	*0.099*	*0.017*
CRMS3680	*0.752*	*0.175*	*0.136*
CRMS3784	*0.751*	*0.149*	*0.054*
CRMS3913	*0.894*	*0.088*	*0.023*
CRMS3985	*0.942*	*0.094*	*0.074*
CRMS4094	*0.872*	*0.128*	*0.085*
CRMS4103	*0.944*	*0.074*	*0.036*
CRMS4110	*0.689*	*0.165*	*0.037*
CRMS4218	*0.868*	*0.122*	*0.088*
CRMS4245	*0.930*	*0.085*	*0.056*
CRMS4448	*0.827*	*0.102*	*0.033*
CRMS4529	*0.644*	*0.194*	*0.095*
CRMS4551	*0.778*	*0.165*	*0.075*

CRMS4557	*0.531*	*0.212*	*0.075*
CRMS4572	*0.665*	*0.187*	*0.064*
CRMS4626	*0.649*	*0.158*	*0.005*
CRMS4690	*0.824*	*0.138*	*0.076*
CRMS5255	*0.905*	*0.098*	*0.060*
CRMS5845	*0.904*	*0.095*	*0.019*
CRMS6209	*0.853*	*0.113*	*0.042*
CRMS6299	*0.897*	*0.089*	*0.053*

Table 7 CRMS station water level comparison statistics Daily

Station	*R*	*RMSE (m)*	*Bias (m)*
CRMS0002	***0.895***	***0.127***	***0.103***
CRMS0003	***0.921***	***0.092***	***0.062***
CRMS0006	***0.833***	***0.089***	***0.008***
CRMS0030	***0.909***	***0.112***	***0.077***
CRMS0033	***0.910***	***0.069***	***0.028***
CRMS0034	***0.916***	***0.107***	***0.077***
CRMS0038	***0.927***	***0.085***	***0.031***
CRMS0039	***0.389***	***0.080***	***0.022***
CRMS0056	***0.674***	***0.090***	***0.030***
CRMS0058	***0.567***	***0.154***	***-0.072***
CRMS0061	***0.931***	***0.123***	***0.095***
CRMS0063	***0.663***	***0.161***	***0.086***
CRMS0108	***0.906***	***0.116***	***0.092***
CRMS0114	***0.954***	***0.110***	***0.094***
CRMS0117	***0.898***	***0.140***	***0.121***
CRMS0118	***0.865***	***0.091***	***0.005***
CRMS0119	***0.927***	***0.160***	***0.147***
CRMS0120	***0.685***	***0.167***	***-0.020***

CRMS0121	***0.954***	***0.129***	***0.116***
CRMS0125	***0.723***	***0.133***	***0.013***
CRMS0129	***0.923***	***0.171***	***0.158***
CRMS0132	***0.942***	***0.123***	***0.105***
CRMS0135	***0.949***	***0.116***	***0.101***
CRMS0136	***0.944***	***0.141***	***0.127***
CRMS0139	***0.705***	***0.138***	***0.003***
CRMS0146	***0.955***	***0.143***	***0.131***
CRMS0147	***0.946***	***0.160***	***0.149***
CRMS0148	***0.933***	***0.099***	***0.071***
CRMS0153	***0.625***	***0.166***	***0.003***
CRMS0154	***0.896***	***0.072***	***0.038***
CRMS0156	***0.905***	***0.095***	***0.070***
CRMS0157	***0.955***	***0.057***	***0.036***
CRMS0159	***0.900***	***0.066***	***-0.012***
CRMS0161	***0.907***	***0.068***	***0.023***
CRMS0162	***0.894***	***0.084***	***0.056***
CRMS0163	***0.945***	***0.071***	***0.041***
CRMS0164	***0.958***	***0.096***	***0.087***
CRMS0171	***0.948***	***0.103***	***0.097***
CRMS0172	***0.958***	***0.100***	***0.093***
CRMS0173	***0.949***	***0.141***	***0.136***
CRMS0174	***0.972***	***0.125***	***0.121***
CRMS0175	***0.972***	***0.094***	***0.087***
CRMS0178	***0.935***	***0.069***	***0.045***
CRMS0179	***0.964***	***0.158***	***0.151***
CRMS0181	***0.940***	***0.079***	***0.060***
CRMS0188	***0.955***	***0.073***	***0.056***
CRMS0189	***0.289***	***0.147***	***0.032***
CRMS0190	***0.953***	***0.154***	***0.144***

CRMS0209	***0.952***	***0.147***	***0.137***
CRMS0211	***0.973***	***0.114***	***0.107***
CRMS0219	***0.597***	***0.121***	***0.016***
CRMS0220	***0.964***	***0.079***	***0.068***
CRMS0224	***0.951***	***0.077***	***0.070***
CRMS0225	***0.930***	***0.080***	***0.062***
CRMS0226	***0.966***	***0.092***	***0.083***
CRMS0232	***0.969***	***0.084***	***0.076***
CRMS0237	***0.937***	***0.110***	***0.098***
CRMS0248	***0.955***	***0.088***	***0.071***
CRMS0251	***0.954***	***0.070***	***0.057***
CRMS0253	***0.960***	***0.079***	***0.071***
CRMS0258	***0.939***	***0.091***	***0.077***
CRMS0260	***0.947***	***0.104***	***0.093***
CRMS0261	***0.955***	***0.095***	***0.083***
CRMS0263	***0.944***	***0.092***	***0.077***
CRMS0272	***0.953***	***0.133***	***0.127***
CRMS0273	***0.724***	***0.114***	***0.032***
CRMS0276	***0.921***	***0.063***	***0.041***
CRMS0278	***0.910***	***0.089***	***0.042***
CRMS0282	***0.931***	***0.185***	***0.175***
CRMS0287	***0.738***	***0.120***	***-0.041***
CRMS1024	***0.874***	***0.113***	***0.077***
CRMS1069	***0.917***	***0.085***	***0.055***
CRMS2608	***0.844***	***0.099***	***-0.069***
CRMS2614	***0.920***	***0.150***	***0.134***
CRMS2627	***0.957***	***0.045***	***-0.016***
CRMS2634	***0.836***	***0.108***	***-0.074***
CRMS2830	***0.927***	***0.127***	***0.102***
CRMS2854	***0.929***	***0.092***	***0.066***

CRMS2991	***0.572***	***0.118***	***0.098***
CRMS3054	***0.969***	***0.125***	***0.118***
CRMS3166	***0.913***	***0.107***	***0.091***
CRMS3565	***0.972***	***0.074***	***0.065***
CRMS3601	***0.944***	***0.083***	***0.066***
CRMS3617	***0.949***	***0.098***	***0.086***
CRMS3626	***0.905***	***0.146***	***0.124***
CRMS3650	***0.920***	***0.126***	***0.100***
CRMS3667	***0.797***	***0.092***	***0.014***
CRMS3680	***0.938***	***0.146***	***0.140***
CRMS3784	***0.926***	***0.084***	***0.055***
CRMS3913	***0.912***	***0.075***	***0.019***
CRMS3985	***0.962***	***0.087***	***0.074***
CRMS4094	***0.920***	***0.113***	***0.085***
CRMS4103	***0.961***	***0.065***	***0.036***
CRMS4110	***0.925***	***0.071***	***0.033***
CRMS4218	***0.955***	***0.101***	***0.091***
CRMS4245	***0.971***	***0.069***	***0.056***
CRMS4448	***0.947***	***0.058***	***0.033***
CRMS4529	***0.963***	***0.106***	***0.098***
CRMS4551	***0.907***	***0.105***	***0.074***
CRMS4557	***0.927***	***0.106***	***0.087***
CRMS4572	***0.915***	***0.095***	***0.064***
CRMS4626	***0.911***	***0.065***	***0.001***
CRMS4690	***0.975***	***0.087***	***0.078***
CRMS5255	***0.921***	***0.087***	***0.057***
CRMS5845	***0.920***	***0.086***	***0.019***
CRMS6209	***0.875***	***0.103***	***0.042***
CRMS6299	***0.919***	***0.077***	***0.047***

Table 8 USACE Mississippi River station water level comparison statistics Daily

Station	RWL	RMSEWL	Bias WL
Algiers Lock	**0.962**	**0.302**	**-0.103**
Alliance	**0.960**	**0.230**	**-0.084**
Baton Rouge Port Allen	**0.991**	**0.669**	**-0.543**
Belle Chasse USGS	**0.963**	**0.267**	**-0.108**
Bonnet Carre USGS	**0.977**	**0.349**	**-0.099**
Donaldsonville	**0.971**	**0.751**	**-0.453**
DS_WL_Venice	**0.873**	**0.148**	**-0.062**
Harvey Lock	**0.985**	**0.333**	**0.2202**
IHNC Lock	**0.970**	**0.269**	**-0.046**
New Orleans USGS	**0.977**	**0.326**	**0.181**
Reserve	**0.977**	**0.401**	**-0.134**
St Francisville South	**0.992**	**0.758**	**-0.649**
Red River Landing	**0.995**	**0.565**	**-0.470**
West point a la Hache	**0.938**	**0.302**	**-0.164**

4.3 Hydrograph scenarios

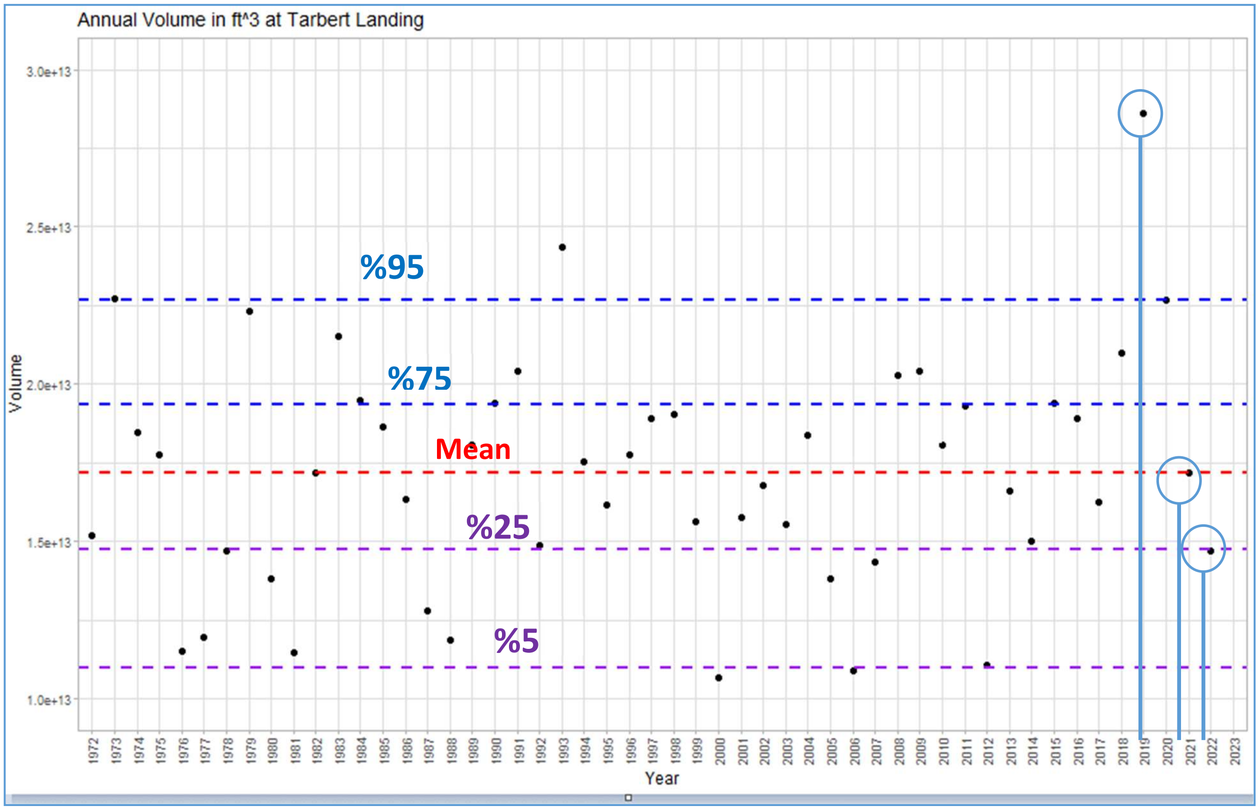


Figure 35 Fifty years of annual volume of Mississippi River passing Tarbert Landing, MS.

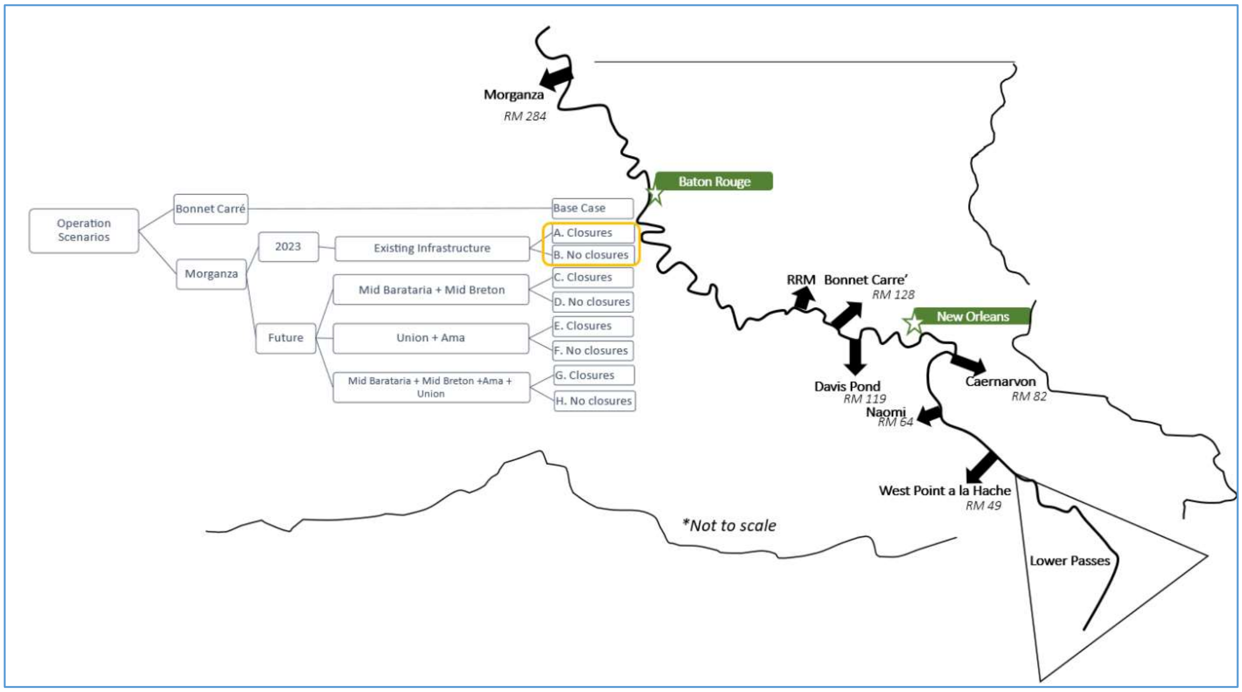


Figure 36 Operational Scenarios A and B schematic

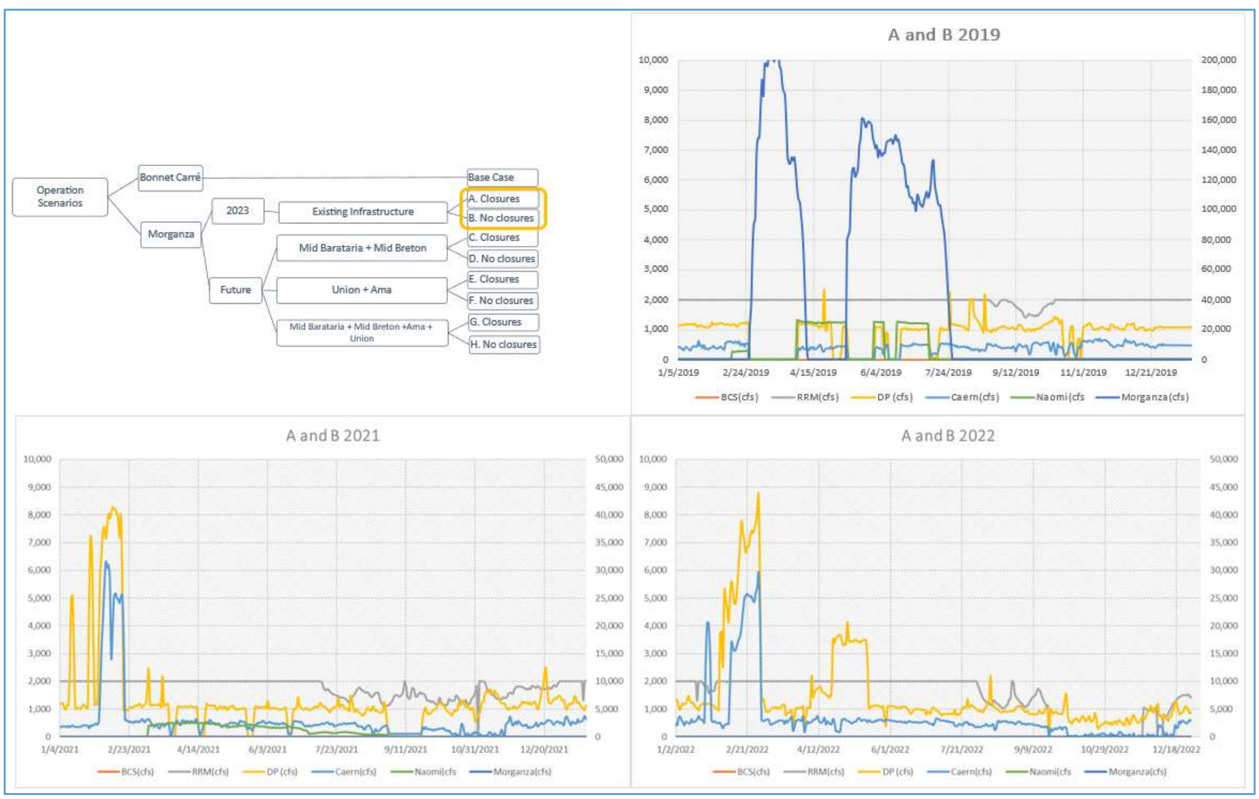


Figure 37 Operational Scenarios A and B Hydrographs

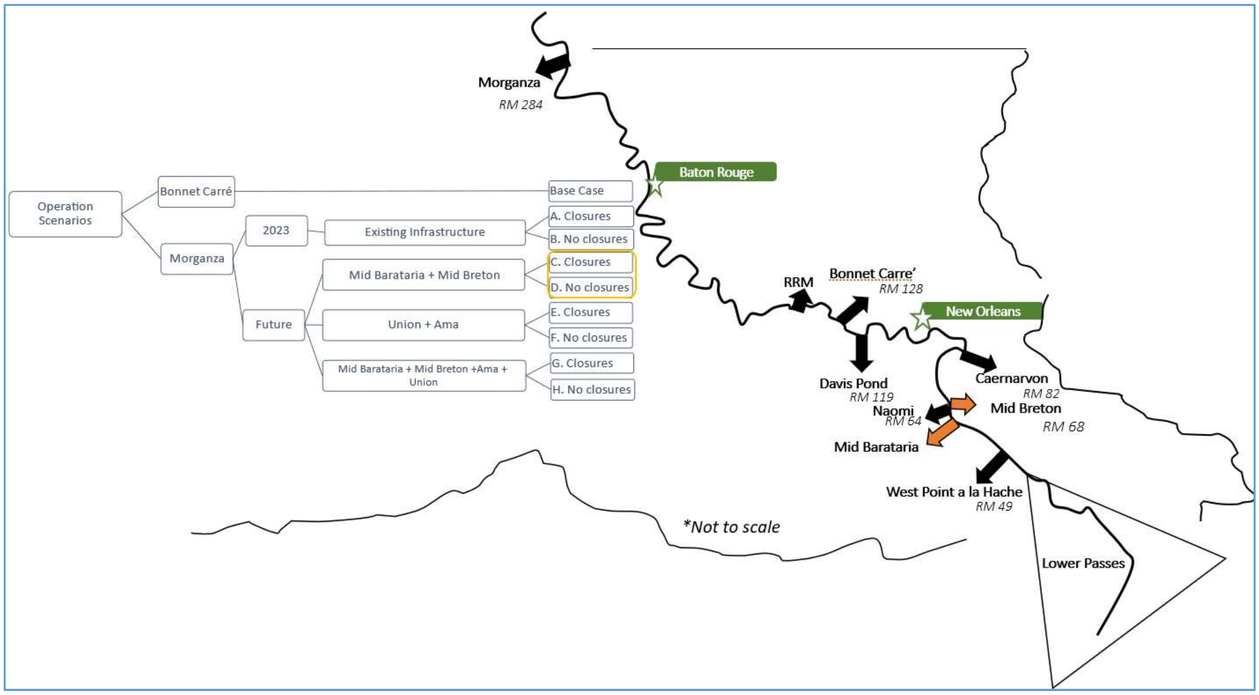


Figure 38 Operational Scenarios C and D schematic

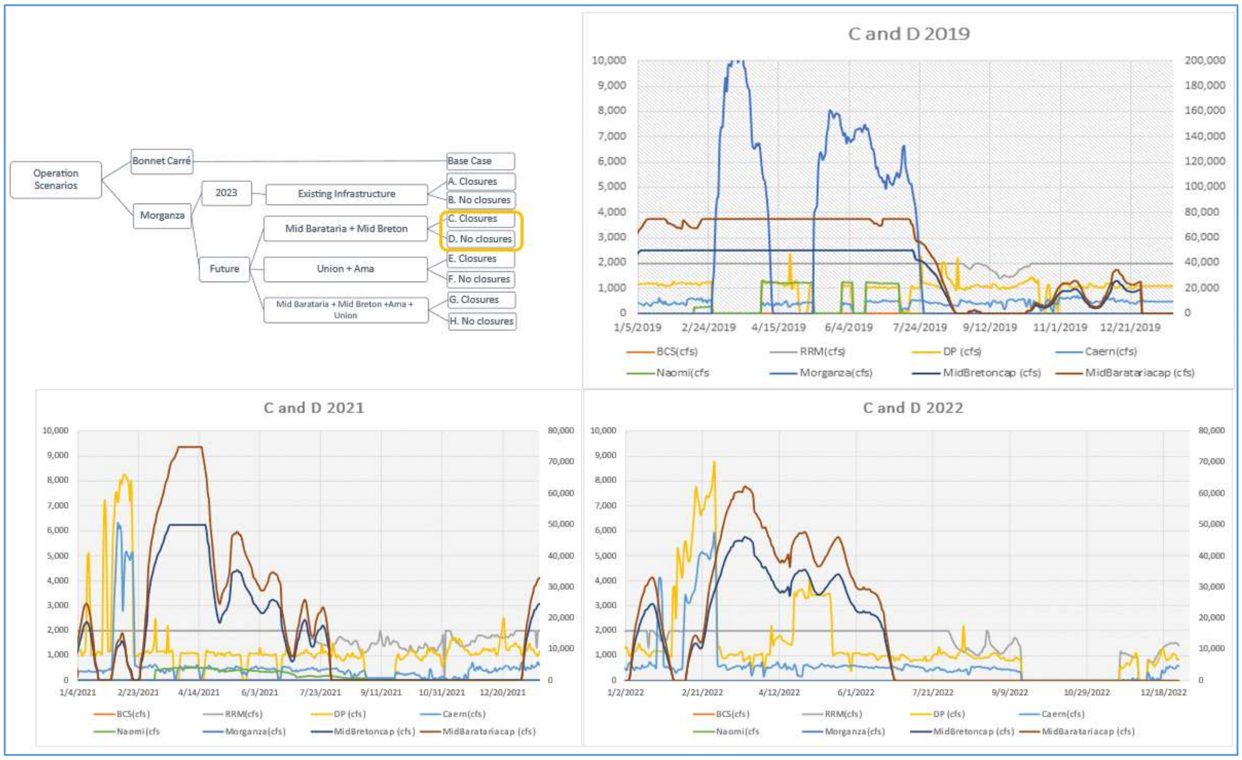


Figure 39Operational Scenarios C and D Hydrographs

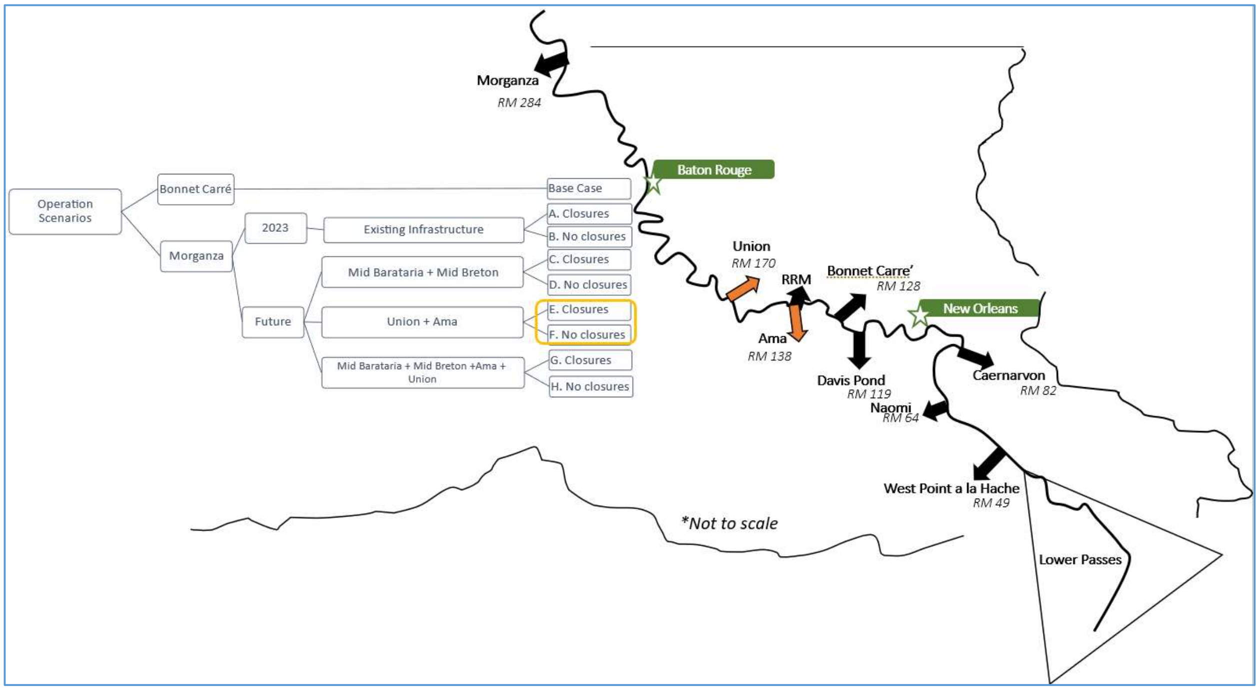


Figure 40 Operational Scenarios E and F schematic

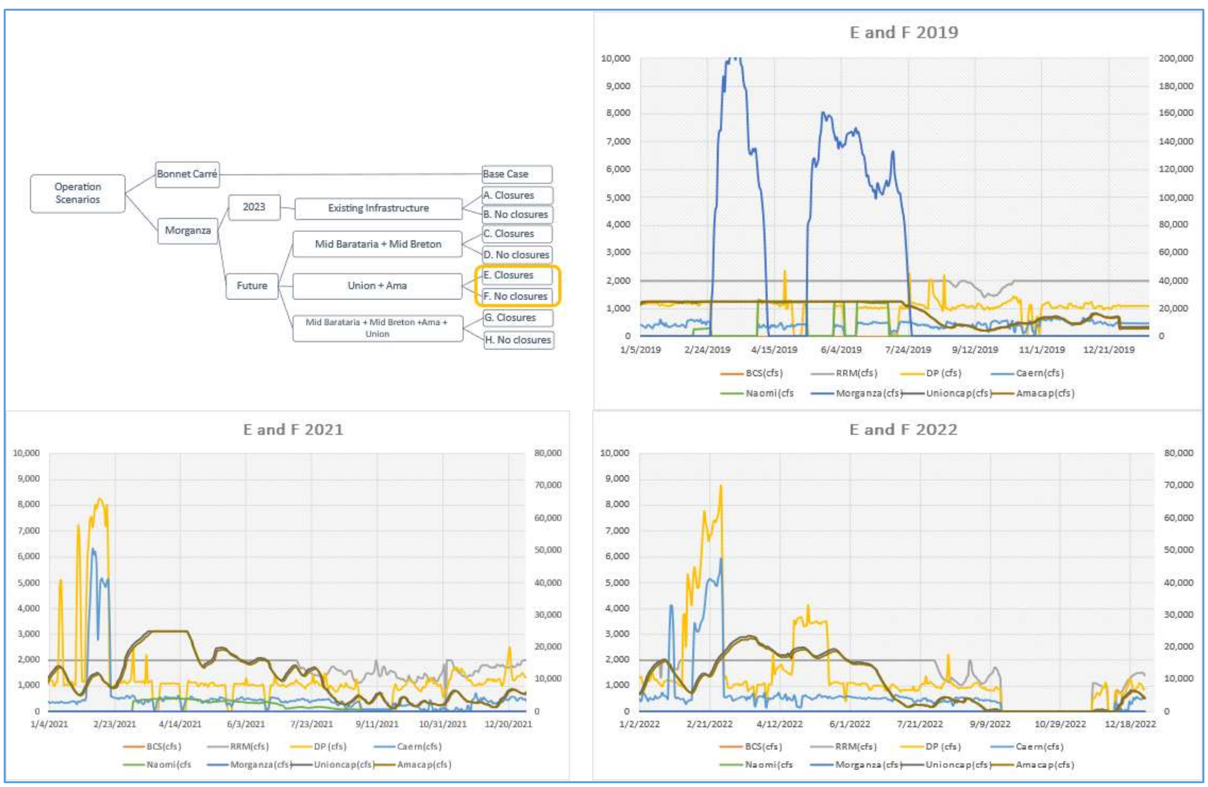


Figure 41 Operational Scenarios E and F Hydrographs

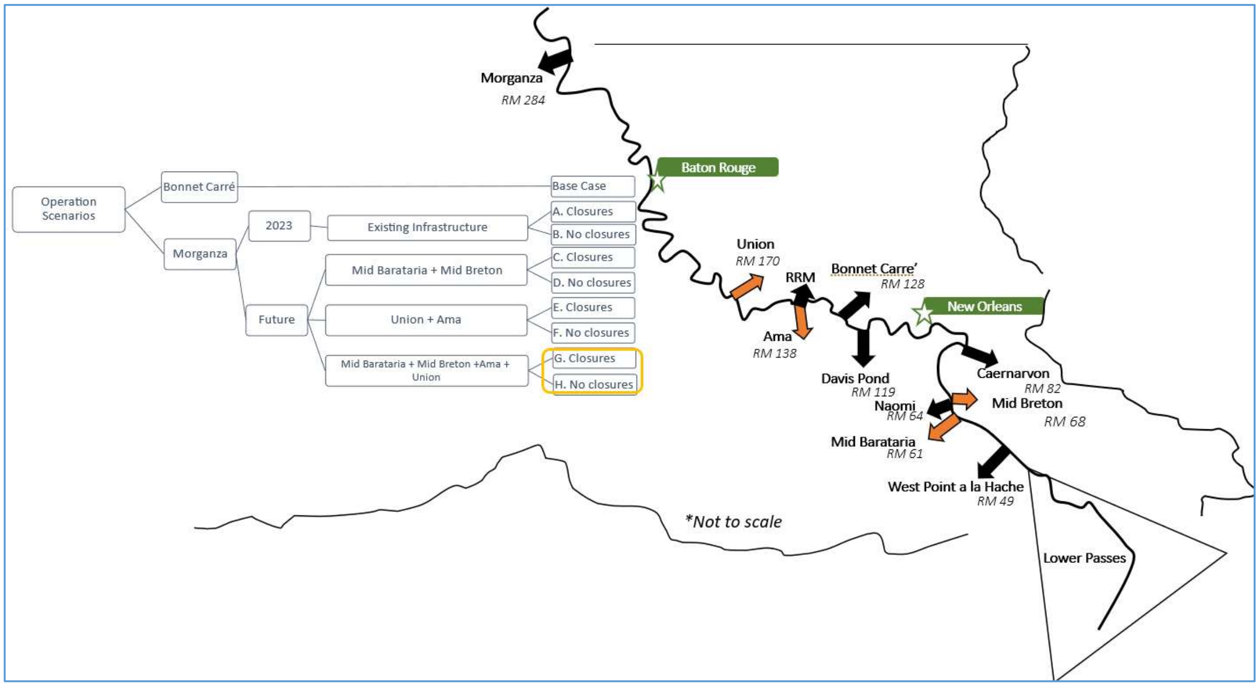


Figure 42 Operational Scenarios G and H schematic

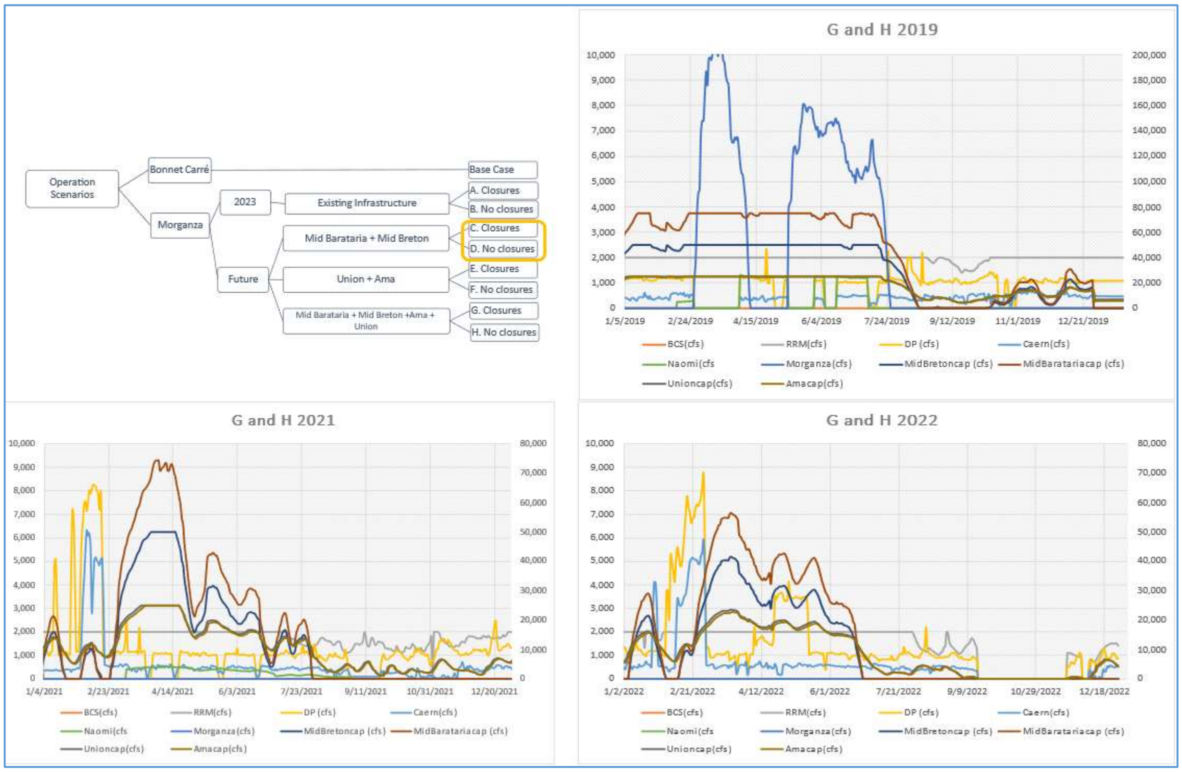


Figure 43 Operational Scenarios G and H Hydrographs

4.4 Scoring Metrics Background

4.4.1 Flooding Metric Locations

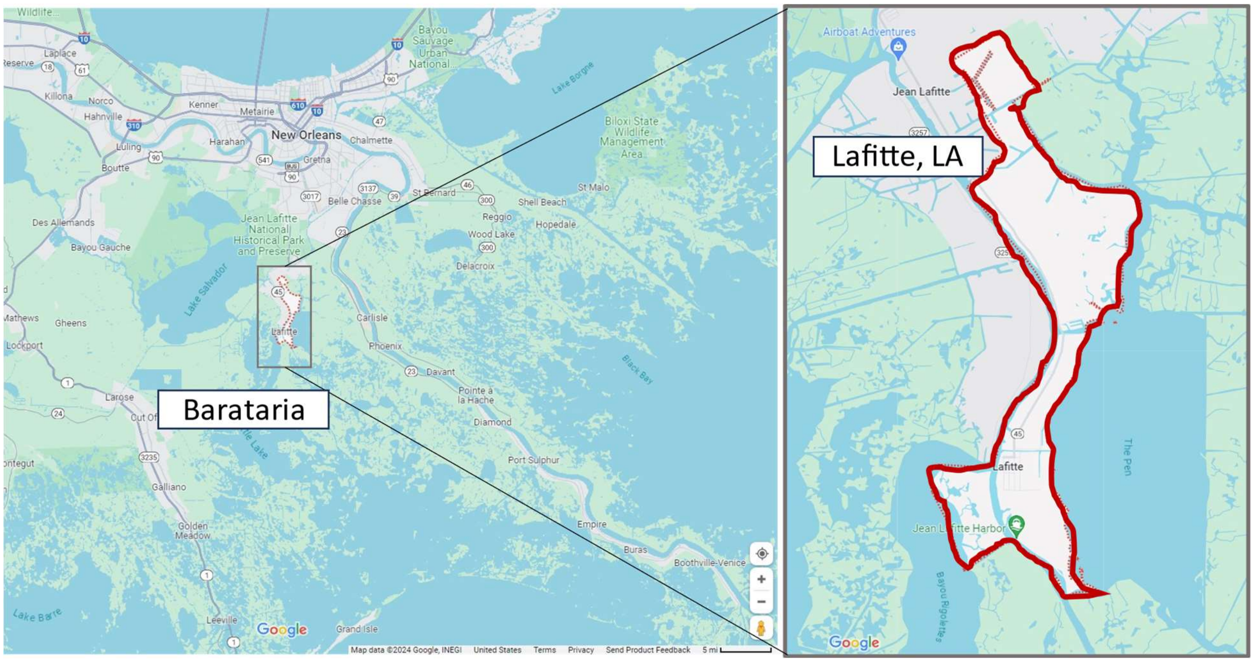


Figure 44 The community of Lafitte located in Barataria, LA

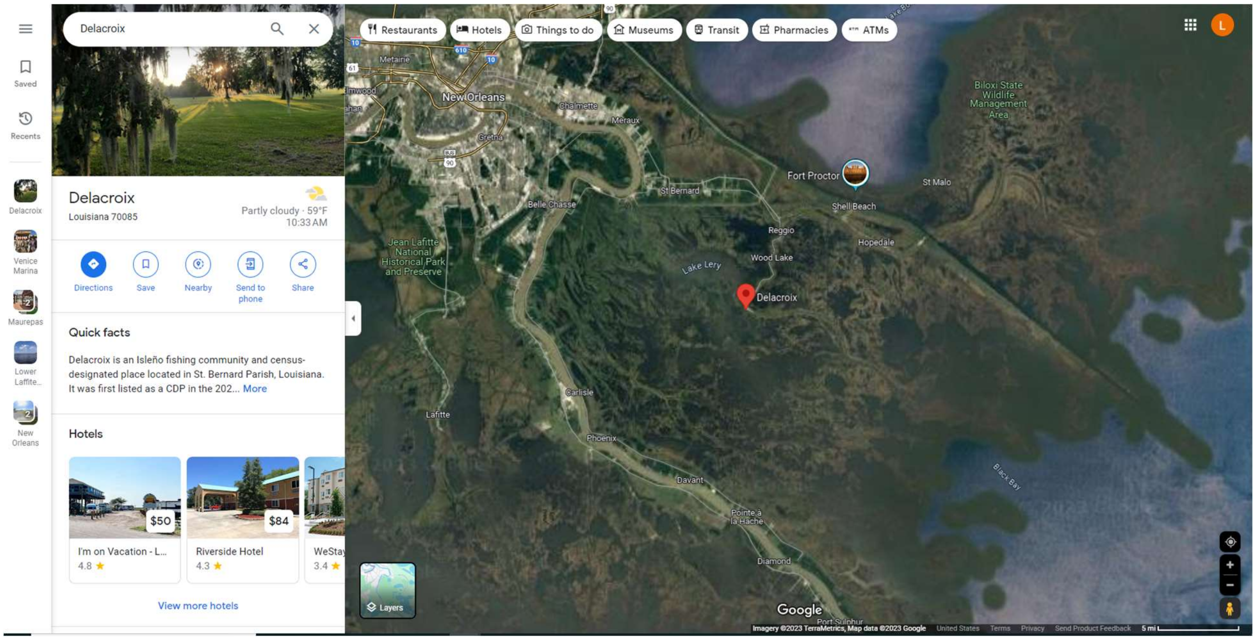


Figure 45 Basin: Breton; Location: Delacroix; Coordinates: 810215 3296690

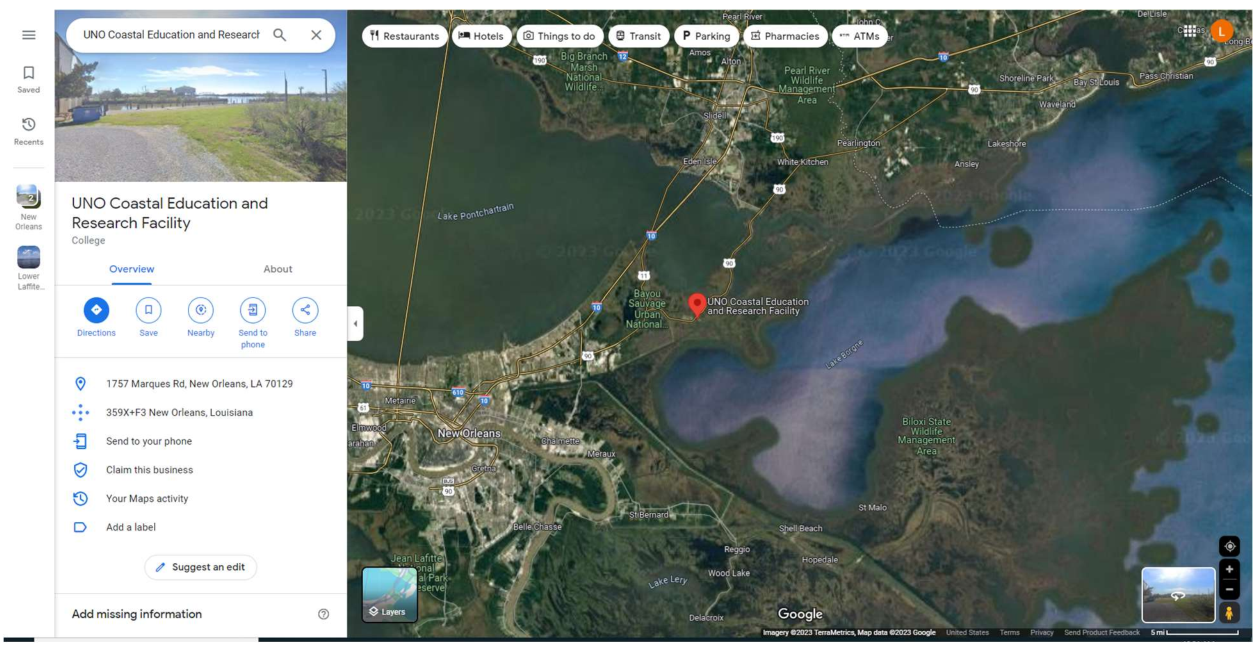


Figure 46 Basin: Mississippi Sound; Location: University of New Orleans Coastal Education and Research Facility; Coordinates: 810595 3329469

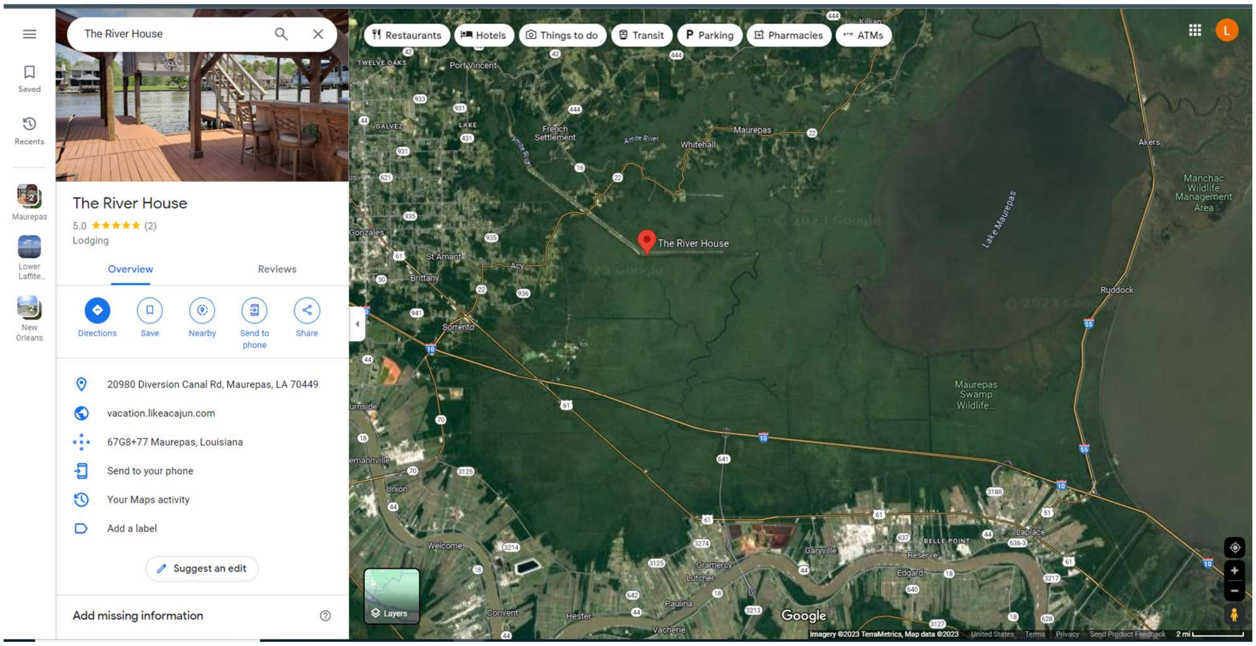


Figure 47 Basin: Maurepas/Pontchartrain; Location: Amite Diversion Canal Neighborhood; Coordinates: 725200 3346143

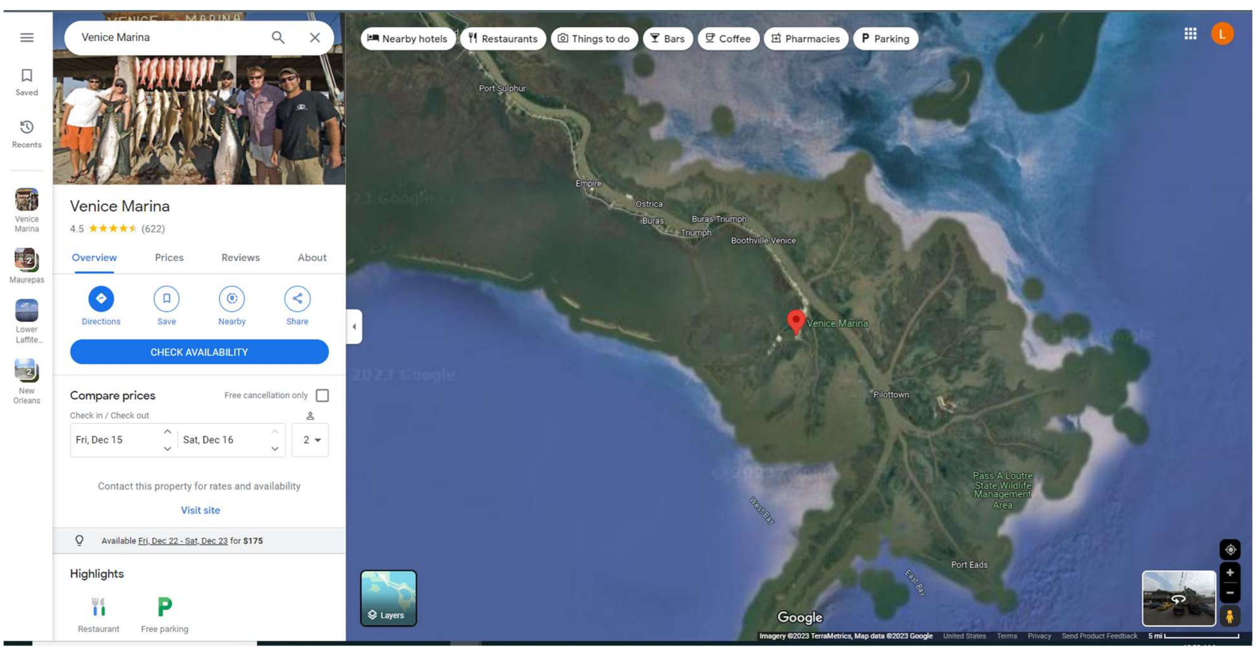


Figure 48 Basin: Mississippi River Delta; Location: Venice Marina; Coordinates: 853968 3239835

4.4.2 Habitat Suitability Indices

Habitat Suitability Indices (HSIs) provide information about the ability of a habitat to support a particular species based on its environmental conditions. They provide a simple expression to determine which areas are suitable for a species to live based solely on environmental variable information. Suitability is standardized on a scale of 0-1, with 0 indicating no suitability and 1 indicating most suitability. HSIs were applied to two species of animals living in the NGOM: Eastern Oysters and Bottle Nose Dolphins (BND).

Oyster HSIs were applied following the approach of the 2023 Coastal Master Plan (CMP)(CPRA, 2023) (Lindquist et al., 2020). The criteria for determining suitability in the CMP is based on 6 evenly weighted parameters including: % bottom cultch cover (SI_1), mean salinity during spawning season (April-November) (SI_2), minimum monthly salinity separately for warm and cool months(SI_3), mean annual salinity(SI_4), percent land cover(SI_5), and sediment deposition(SI_6). As the model does not include sediment dynamics, the sediment deposition parameter was not included. The land and cultch cover parameters were excluded from the analysis, as well as the spatial extent of these parameters were assumed static for these simulations that are evaluated over the course of one year. Therefore, the dynamic parameter for analysis is salinity, which was utilized for this study. The resulting oyster HSI formula for this analysis is computed as:

$$Oyster\ HSI = (SI_2 * SI_3 * SI_4)^{1/3}$$

Where:

SI_2 = Mean salinity during spawning season (April-Nov)

SI_3 = Minimum monthly salinity separated into warm and cool months

SI_4 = Annual mean salinity

Please see the Supplementary Material for the SI criteria details. Suitability values greater than 0.5 are calculated to represent potential habitat for oysters.

BND HSIs were applied following the approach of Meselhe et al. (Meselhe et al., 2019) utilizing the 'longest streak' by Garrison et al. (Garrison et al., 2020; K. Hu et al., 2023). The longest streak of consecutive days below 5ppt with breaks of 2 or less days in between is considered the longest streak. The suitability of BND habitat is contingent upon the amount of exposure time they have to these low salinity conditions within their inhabited zone. 45 days represents the %50 survival rate for BND. Therefore, the area of the basin with a longest streak of 45 days or less was reported for BNDs.

4.4.3 Sediment Delivery Rating Curves

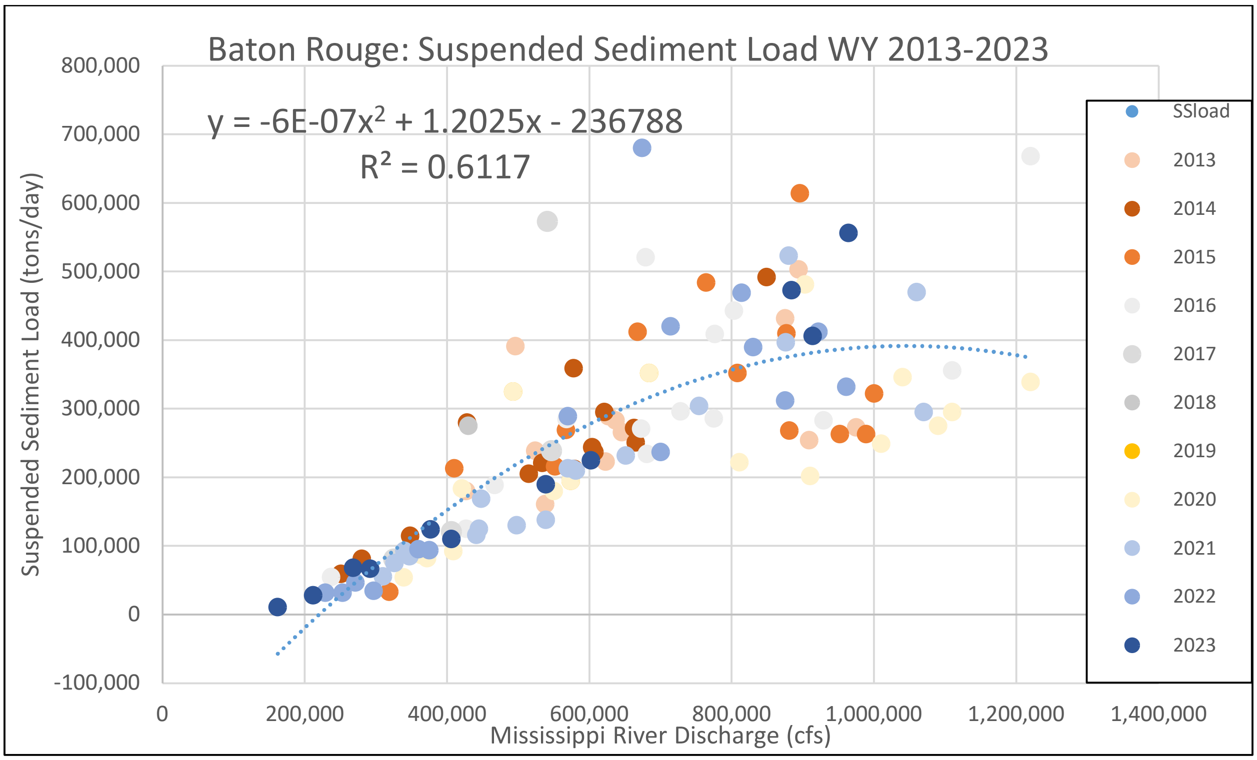


Figure 49 Baton Rouge Suspended Sediment Load Rating Curve

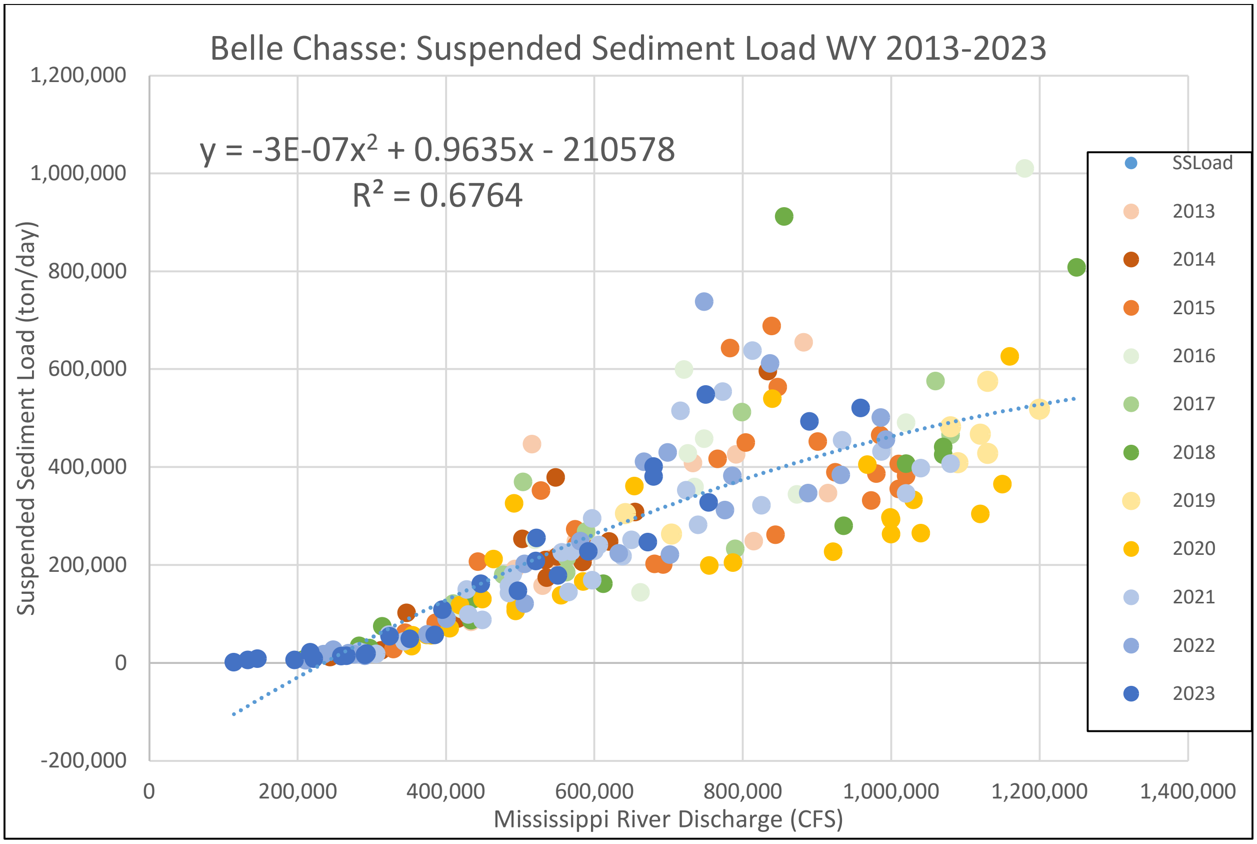


Figure 50 Belle Chasse Suspended Sediment Load Rating Curve

Suspended Sediment Load rating curves were developed for the Baton Rouge and Belle Chasse stations on the Mississippi River using data from the USGS 2013-2023 dataset. These curves were built using second degree polynomial fit curves. The rating curves were applied to the model output for all scenarios to obtain sediment delivery tonnage, fulfilling the sediment delivery metric.

4.4.4 Navigation Metric

The scorecard criterion values for "Navigation" were calculated using bedform transport rates. This transport rate is considered here as the river's ability to "self-dredge" or move the material along to avoid impediment to navigation activities. Navigation on the lowermost Mississippi River is a key metric that reflects the river's response to diversion operation. As the nation's primary waterway facilitating industrial and military navigation as well as the exportation of agricultural and other market goods, it is a priority of the federal government to maintain key navigable depths along the entire river channel. Dredging costs associated with channel maintenance are a reoccurring expenditure for the USACE, as sedimentation in the lower river continuously reduces the water depth in this region. The model used for this study does not include sediment transport or morphology. However, changes in hydrodynamics can be investigated to relate to the river's potential to transport sediment in the lower region and how that might be affected by the operation plans. Nittrouer, Allison, and Rameriz have investigated the relationship between river hydraulics (discharge) and the transport rate of bed material load through data collection of sediment concentrations and survey dune migrations. See Figure S18.(Allison et al., 2012b; Nittrouer et al., 2008; Ramirez & Allison, 2013)

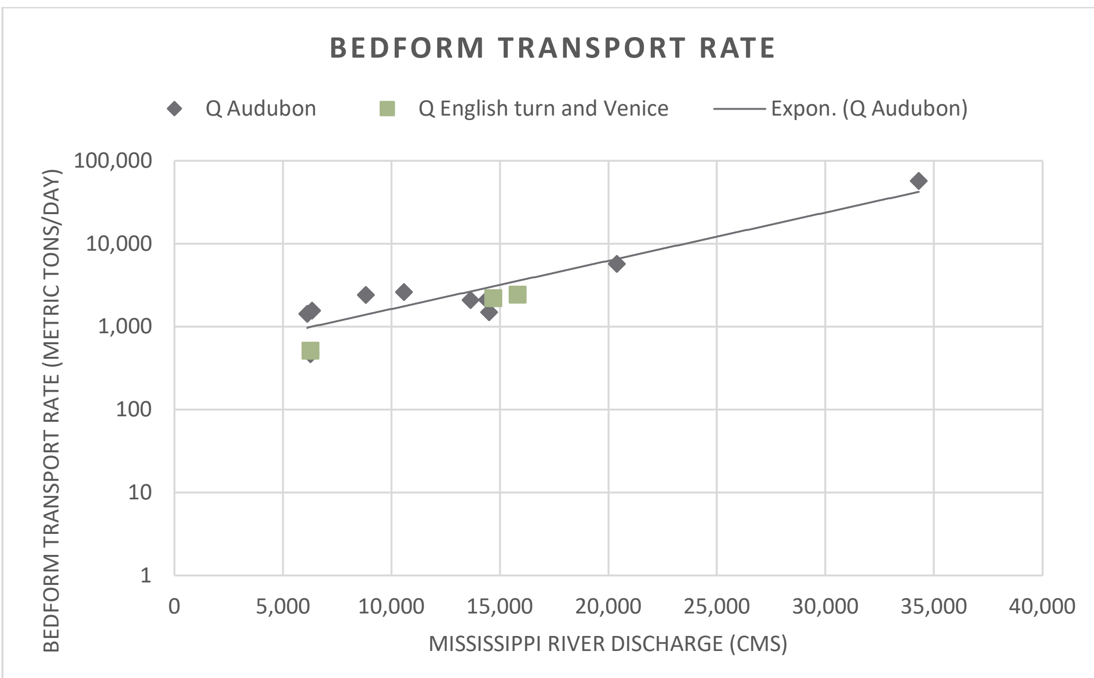


Figure 51 Bed transport rate recreated from (Nittrouer et al., 2008)

The Nittrouer study (Nittrouer et al., 2008) investigated the river channel bedform migration along four separate reaches between river miles 167 and 0 (Head of Passes) by collecting and analyzing multibeam swath daily bathymetry at each location. From this data, they formed an empirical exponential relationship that relates Mississippi River discharge to its bedform transport rate. To include the hydraulic effects of the entire system of operation plans, this study uses the exponential relationship between river discharge and bedform transport from Nittrouer et al. 2008 and applied the relationship to the model output for the Mississippi River near Venice, LA, approximately river mile 11. The Mississippi River near Venice is a primary dredging location of the USACE and is downstream of all management locations (diversion and outlet closures) tested in this study. There are some complexities in this reach of the river that should be considered when examining the transport rates. Namely, this is a significant degree of uncertainty in the backwater effects on sedimentation and dune migration in this reach of the river. There is a stronger tidal signal at Venice than in the locations surveyed by Allison and Ramirez in later studies (Allison et al., 2012b; Ramirez & Allison, 2013). Finally, there is a large degree of uncertainty in the remaining sediment concentration in the river channel that would result from these diversion operations. These uncertainties support the suggestion for future study and data collection of bedform transport in the lower most river to support and refine the empirical relationship used to relate discharge to transport rates.

4.5 Scenario Results Charts

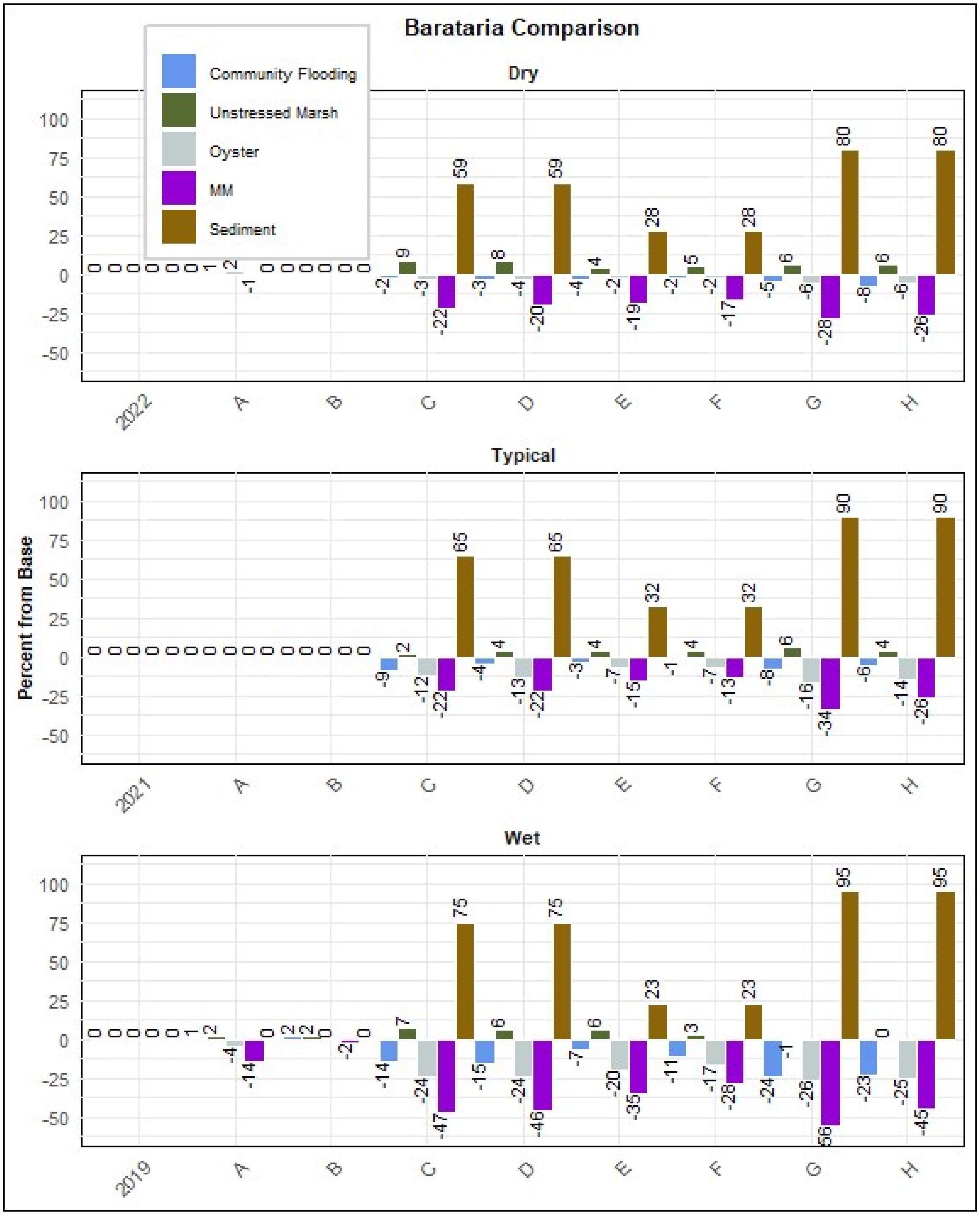


Figure 52 Barataria Basin Percent from Base Results for Dry (top), Typical (middle), and Wet (bottom) year analysis

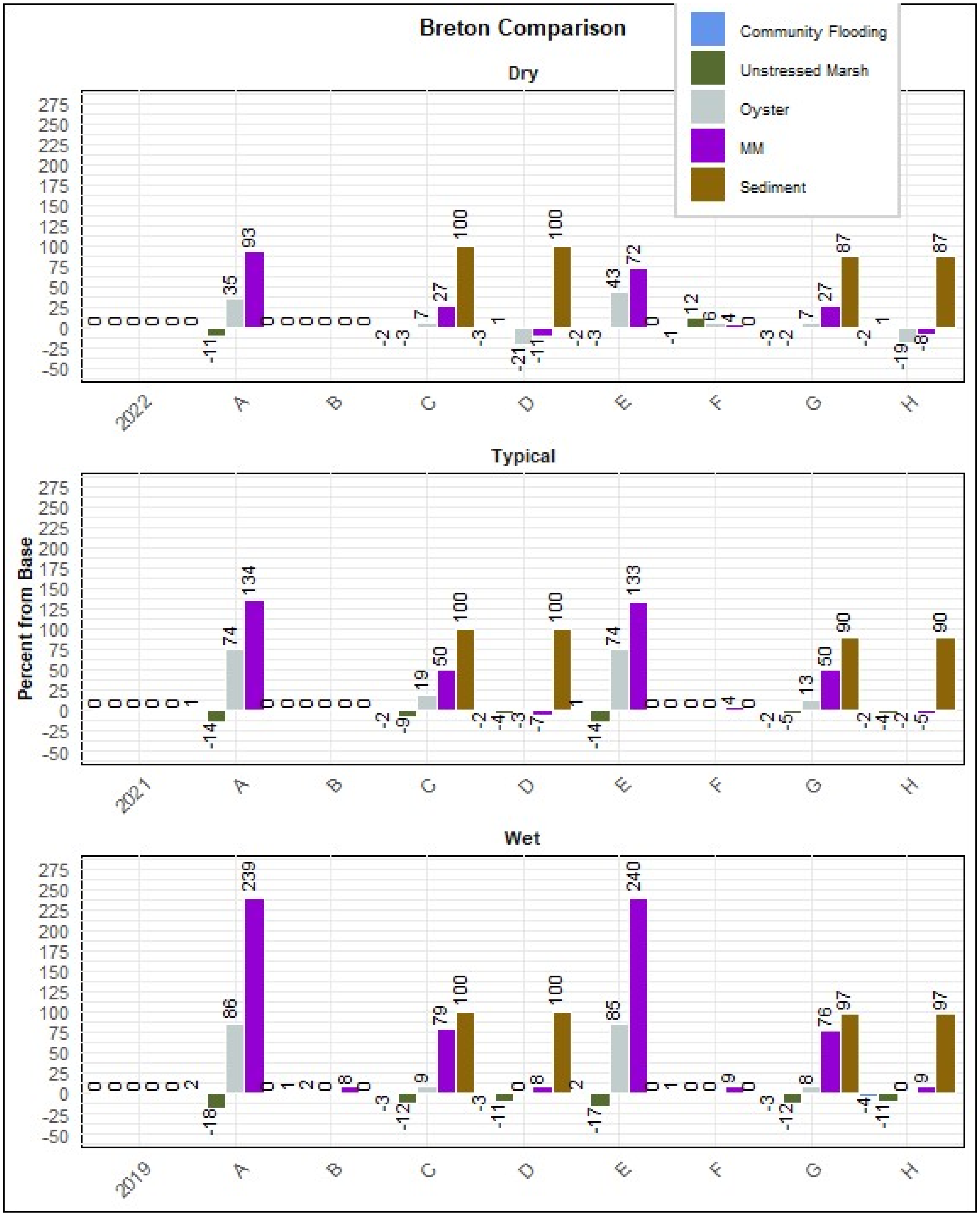


Figure 53 Breton Basin Percent from Base Results for Dry (top), Typical (middle), and Wet (bottom) year analysis

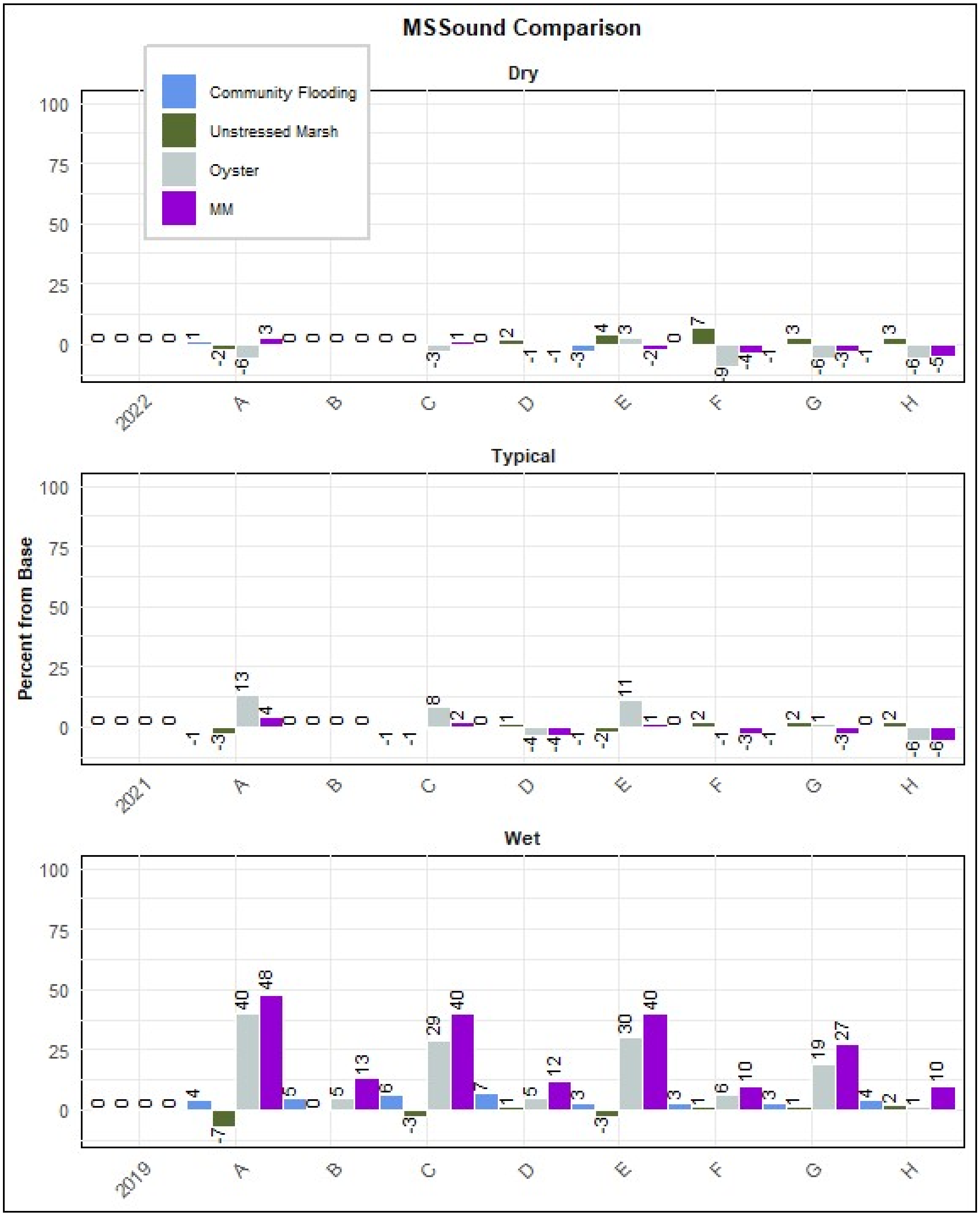


Figure 54 Mississippi Sound Basin Percent from Base Results for Dry (top), Typical (middle), and Wet (bottom) year analysis

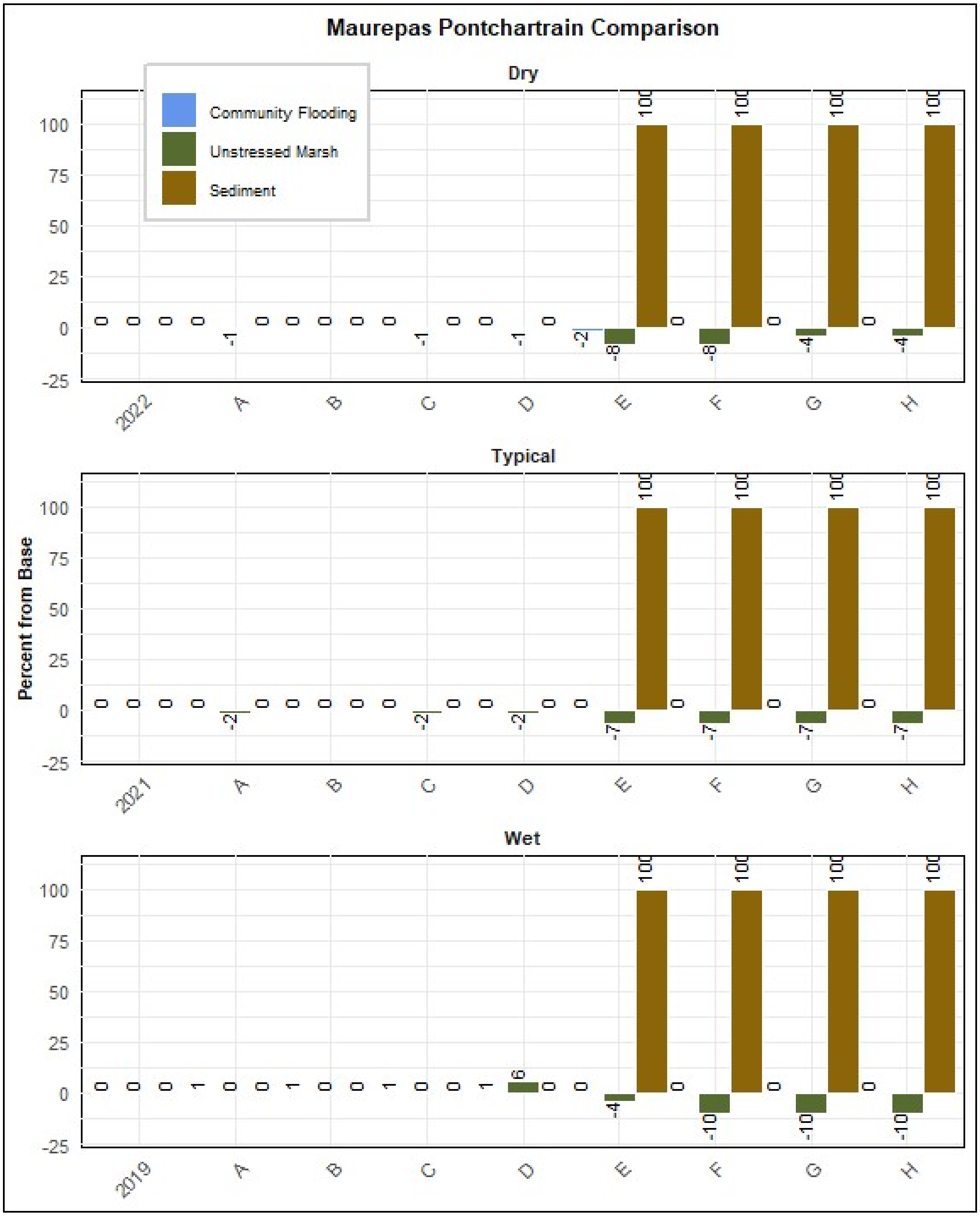


Figure 55Maurepas Pontchartrain Basin Percent from Base Results for Dry (top), Typical (middle), and Wet (bottom) year analysis

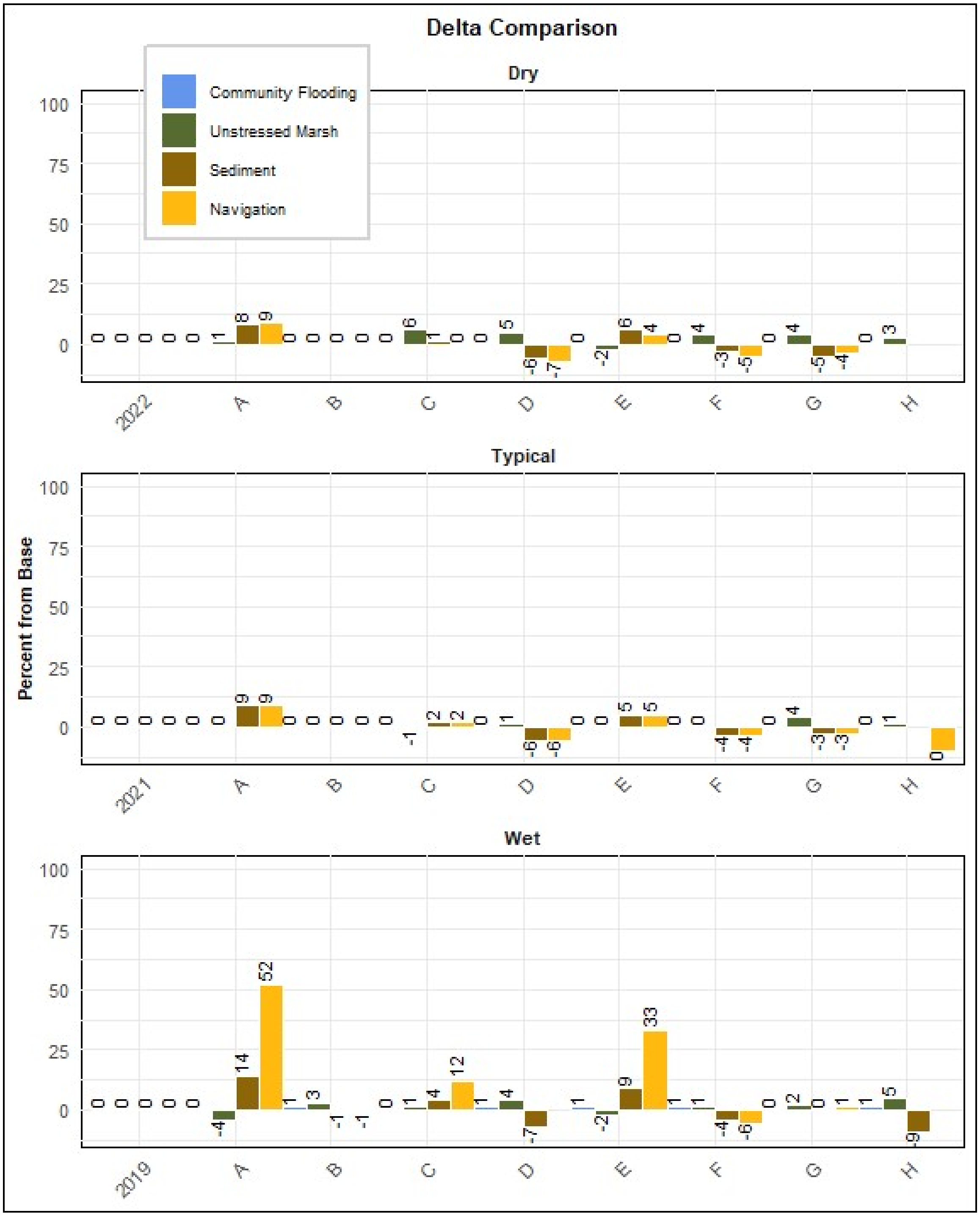


Figure 56 Delta Percent Target Results for Dry (top), Typical (middle), and Wet (bottom) year analysis

4.6 Scenario Results Maps

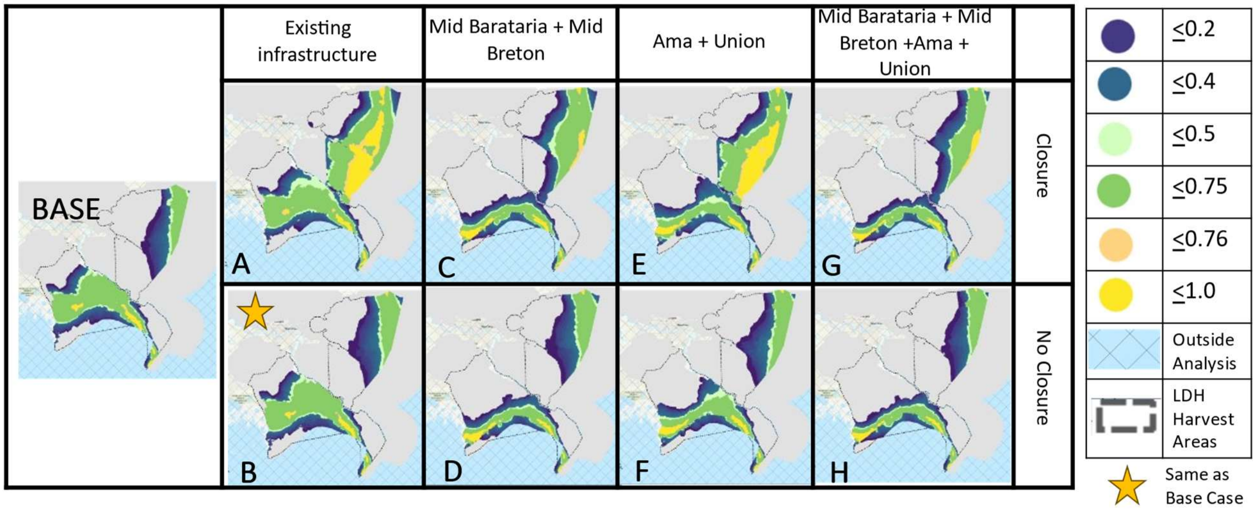


Figure 57 Eastern Oyster Habitat Suitability Indices (0-1) Results: Wet Year Disclaimer: The maps illustrate only HSIs within LDH zones.

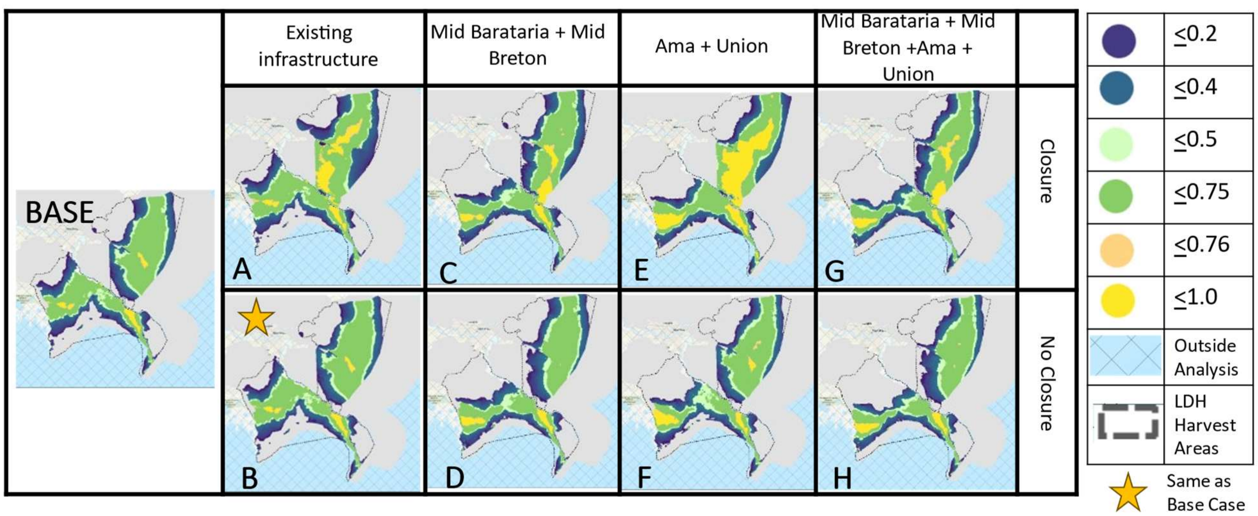


Figure 58 Eastern Oyster Habitat Suitability Indices (0-1) Results: Dry Year Disclaimer: The maps illustrate only HSIs within LDH zones.

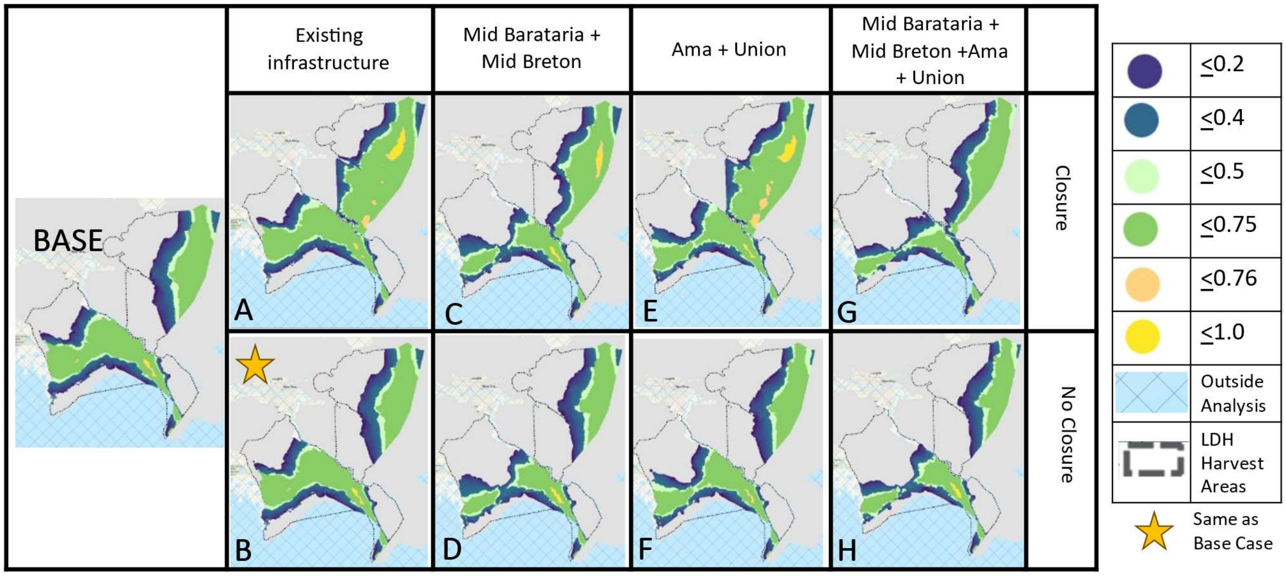
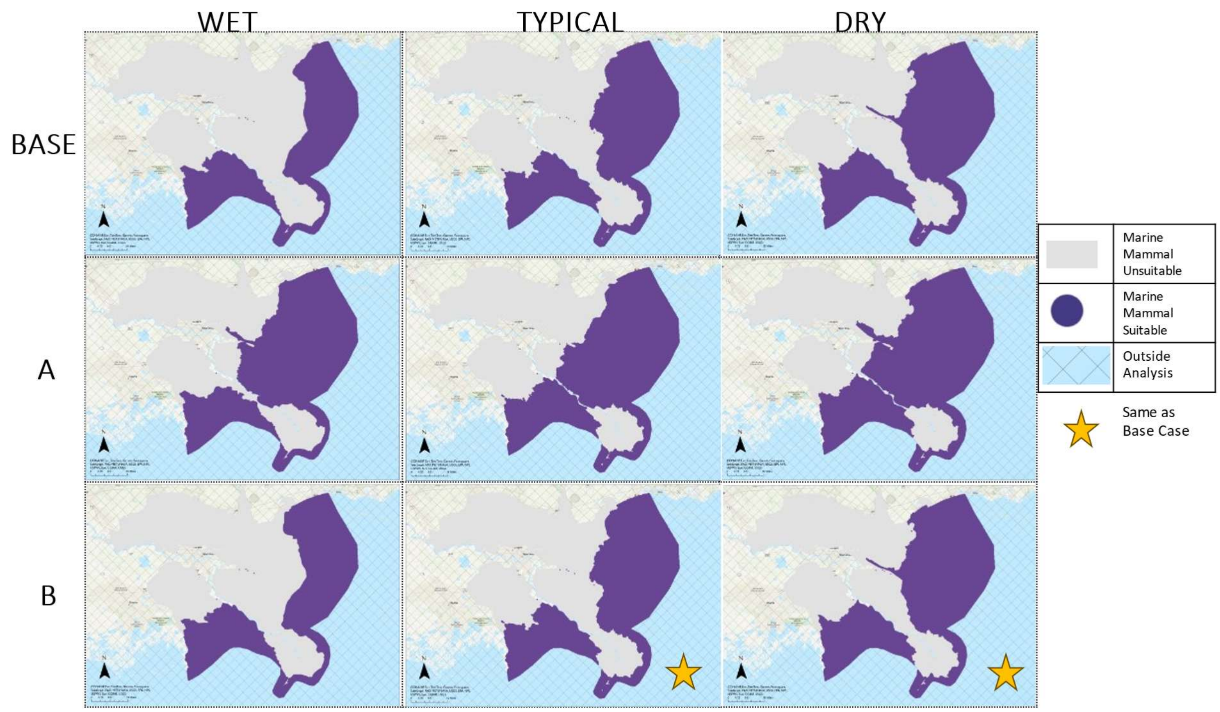
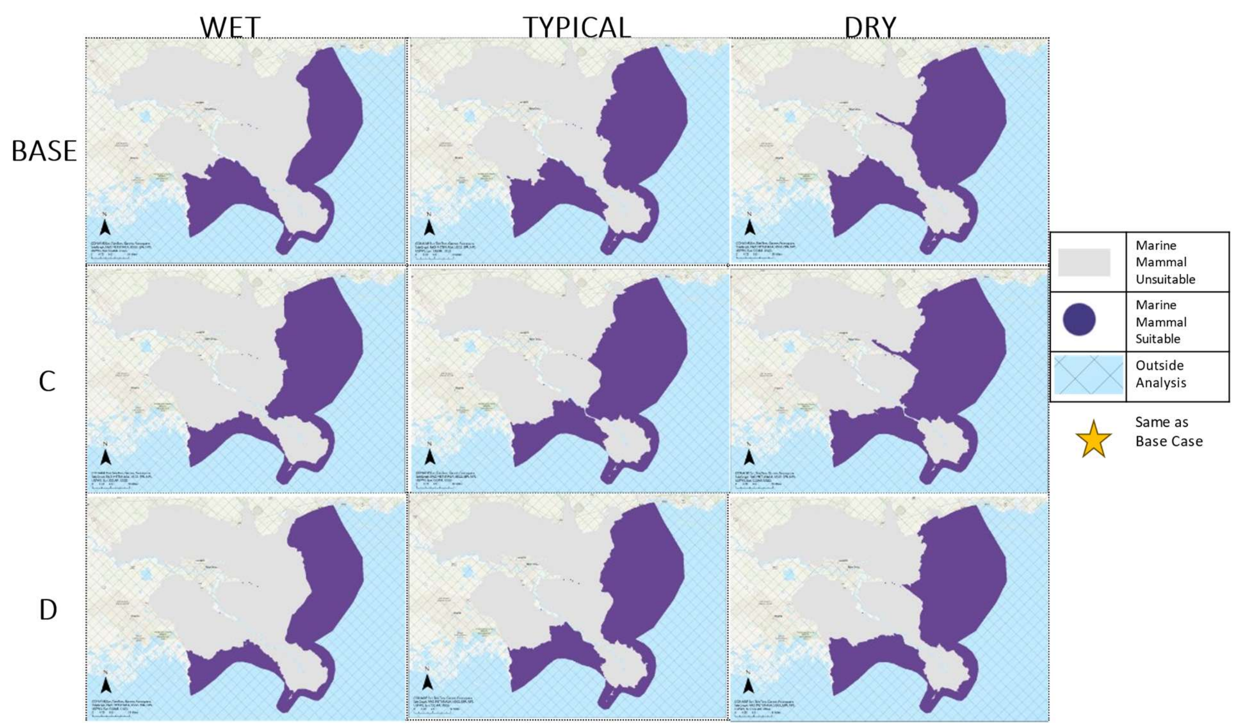


Figure 59. Eastern Oyster Habitat Suitability Indices (0-1) Results Typical Year Disclaimer: The maps illustrate only HSIs within LDH zones.

Bottle Nose Dolphin Suitability





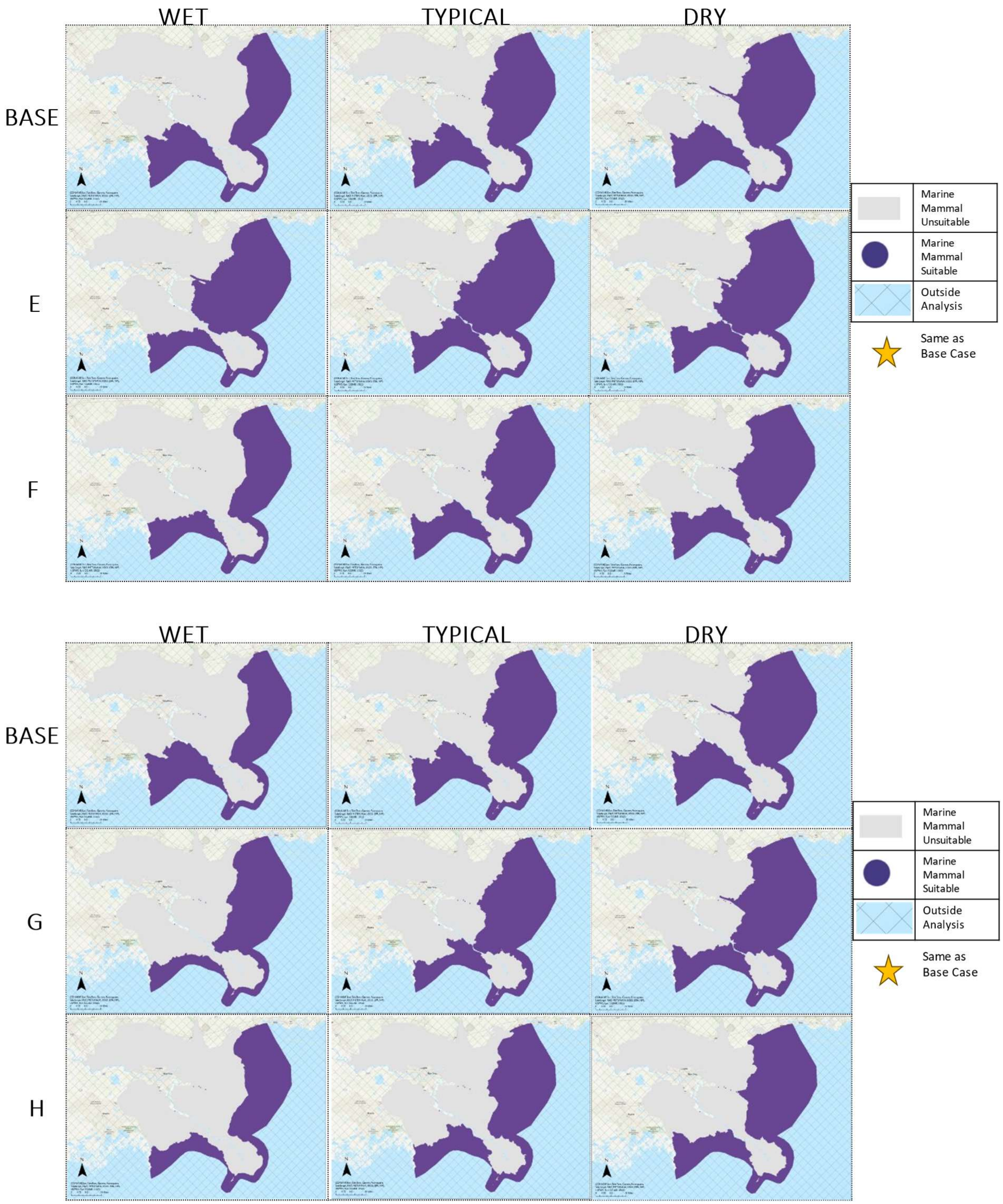


Figure 60 Marine Mammal Suitability Results: suitable areas in purple

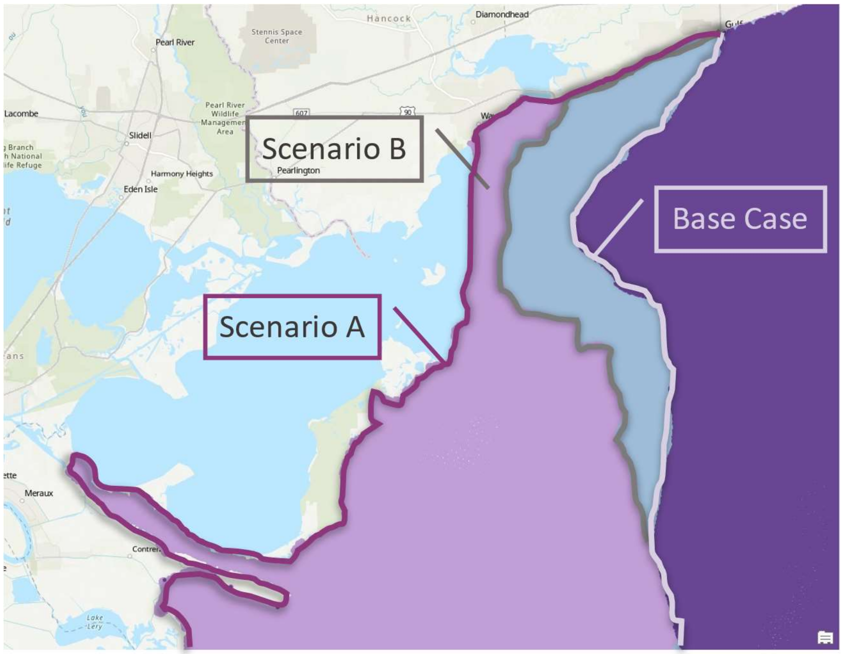
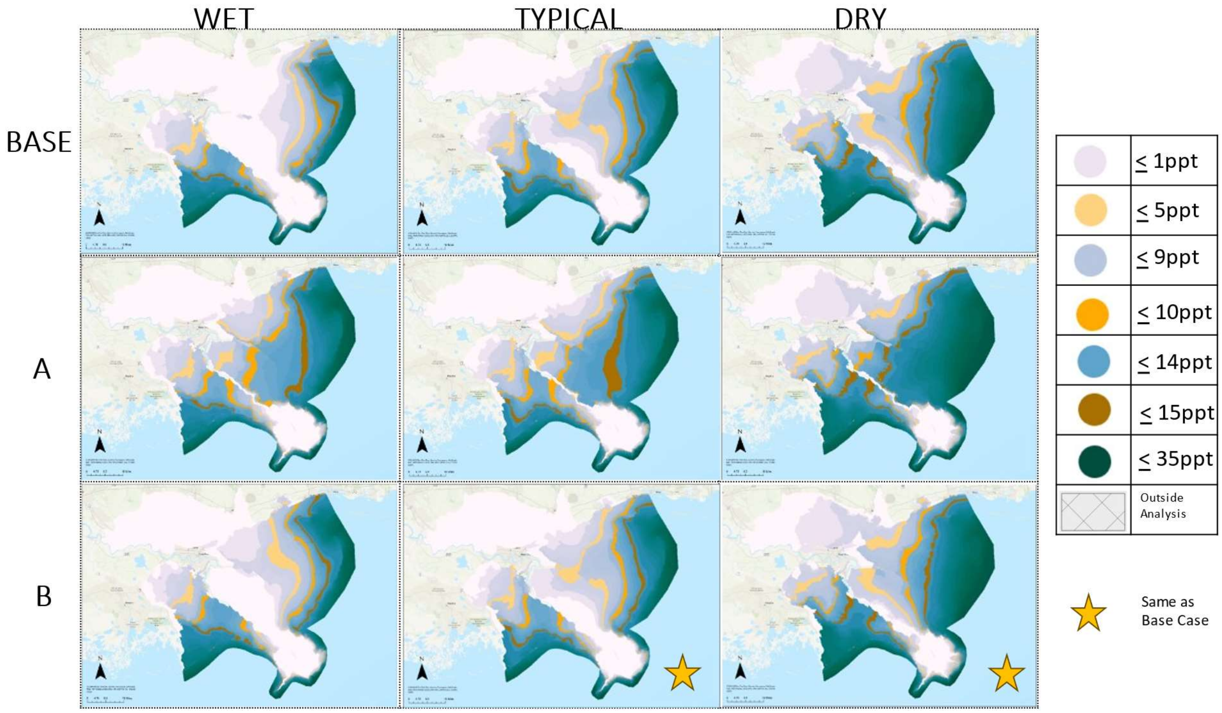
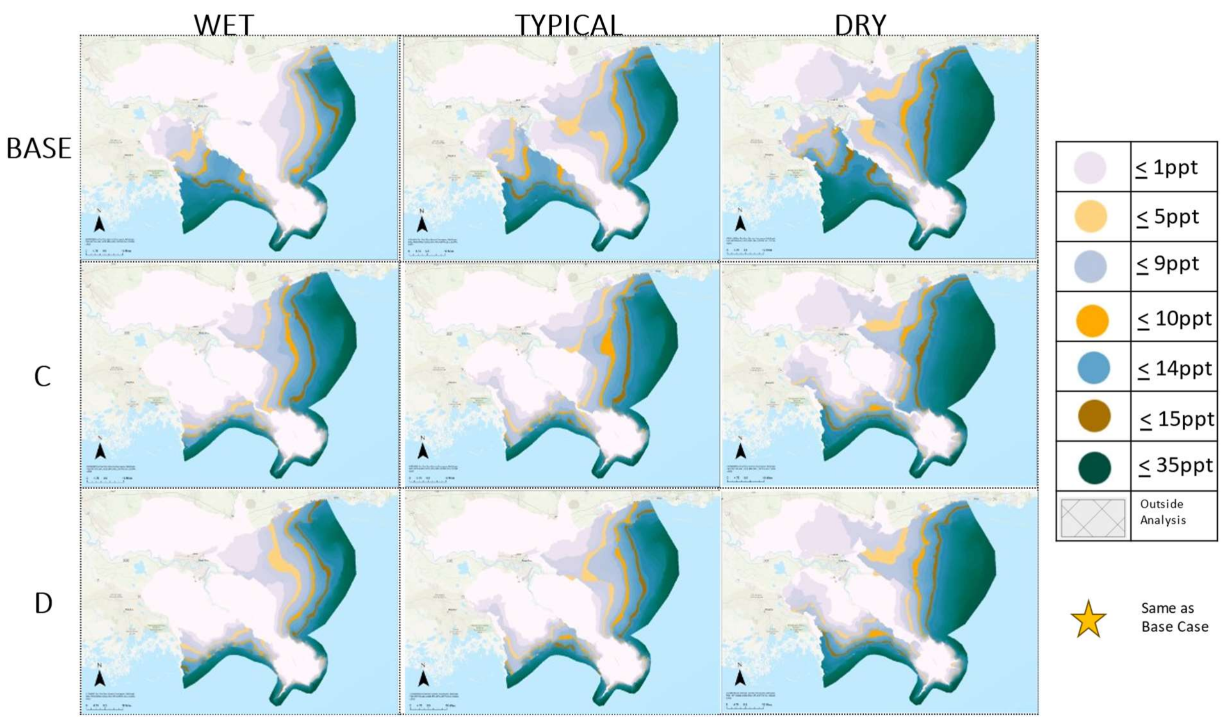


Figure 61 Marine mammal suitable region for wet year base case (purple) and scenario B (grey) with ~ 115,000 acres equating to 13% improved from base case and scenario A (pink) with ~ 430,000 acres equating to 48% improved from base case.

Mean April Salinity Maps: Growing season for marsh and wetlands.





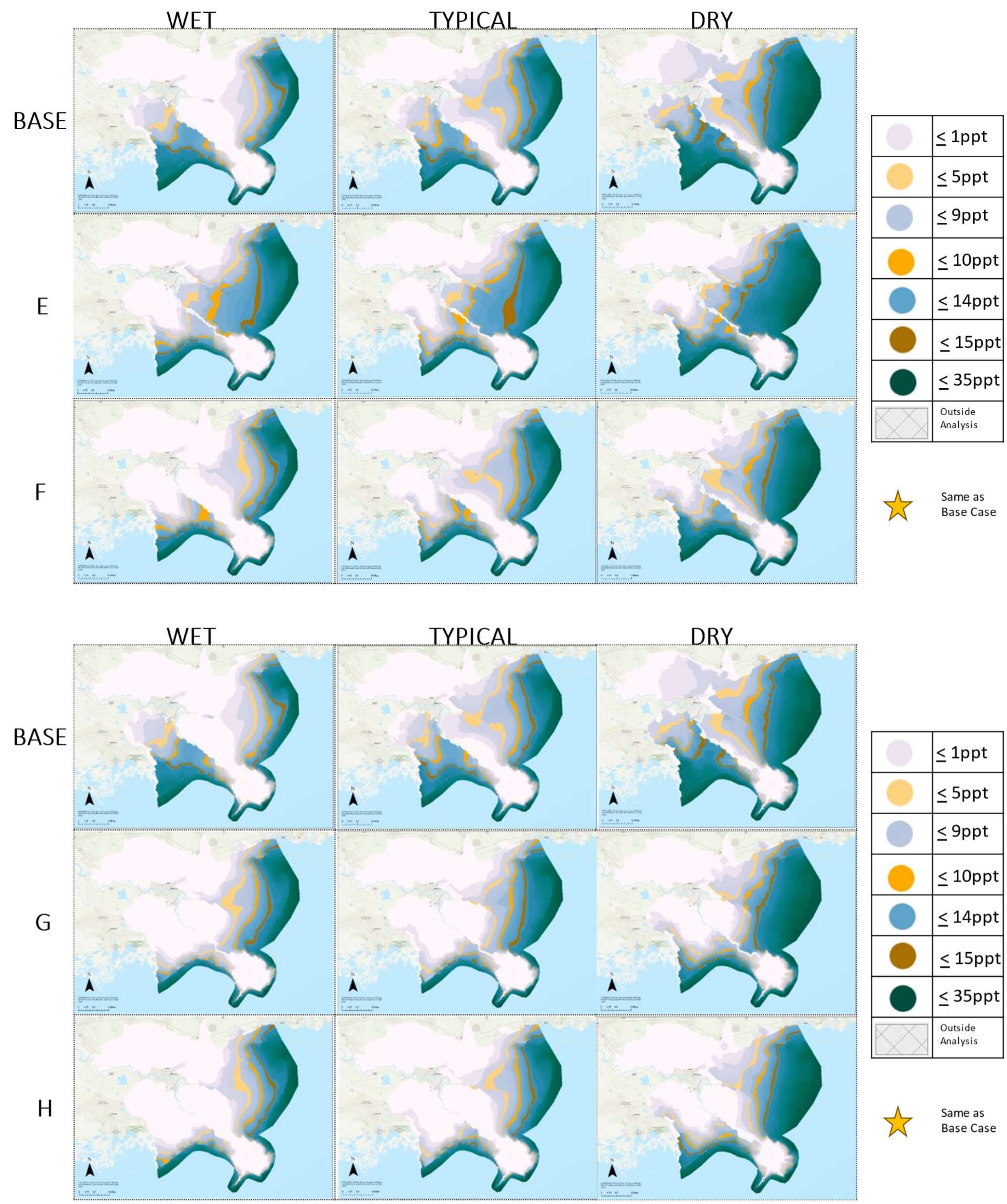
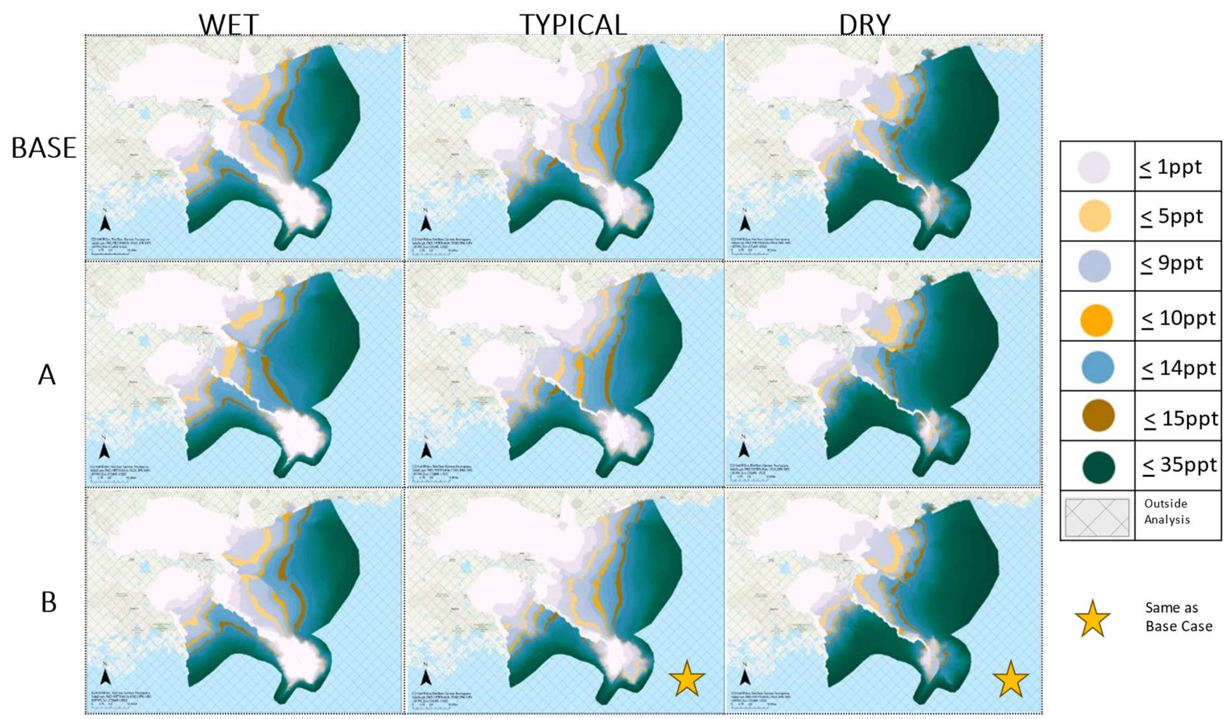
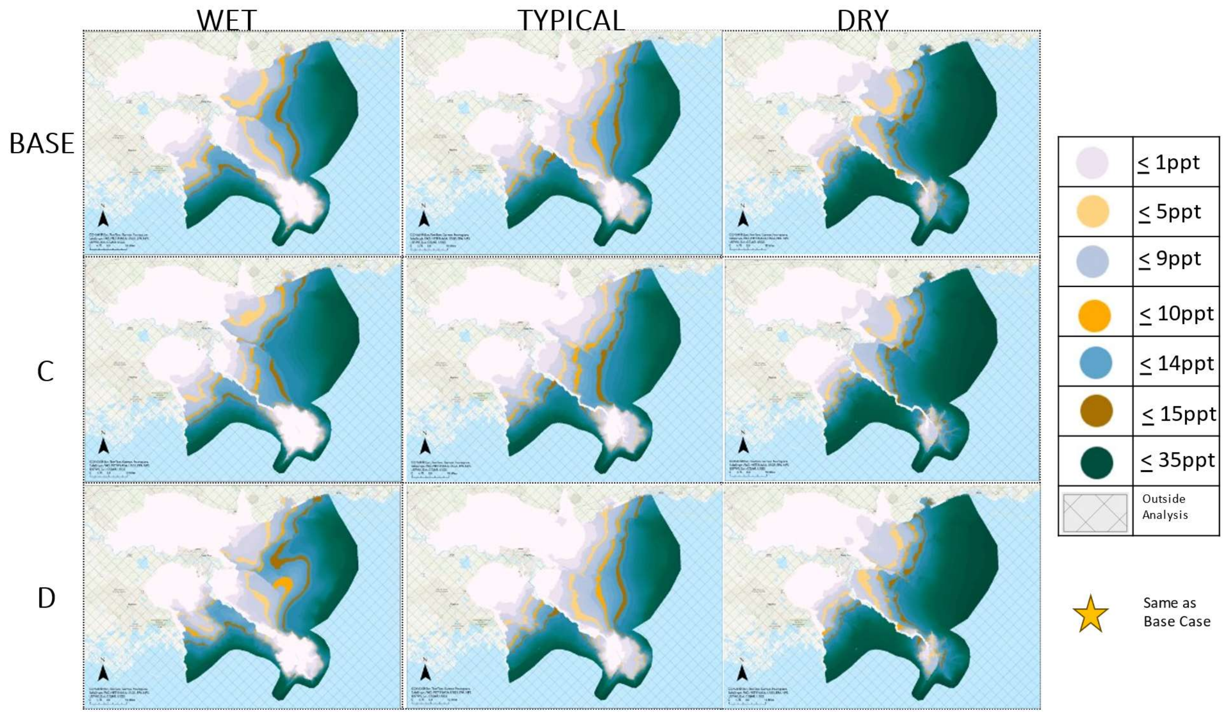


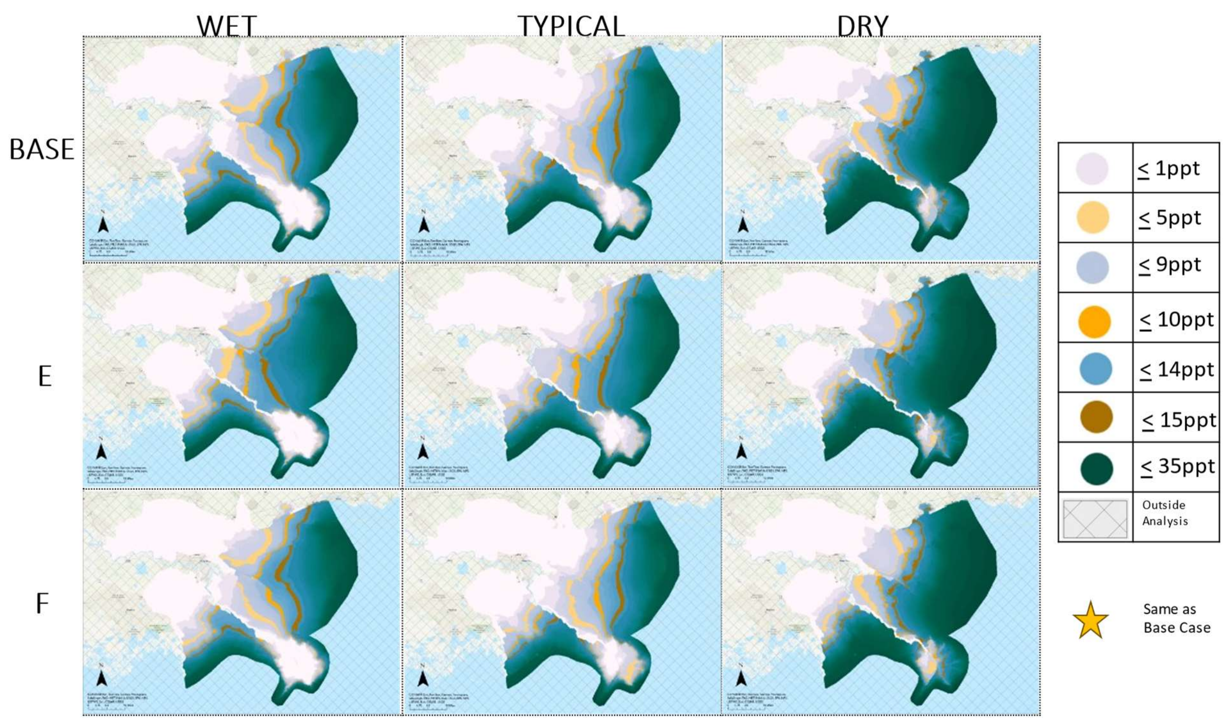
Figure 62 Mean April Salinity Results

\

Mean October Salinity Maps: Dormant season for marsh and wetlands.




WET
TYPICAL
DRY
BASE
C
D
≤ 1ppt
≤ 5ppt
≤ 9ppt
≤ 10ppt
≤ 14ppt
≤ 15ppt
≤ 35ppt
Outside Analysis
Same as Base Case


WET
TYPICAL
DRY
BASE
E
F
≤ 1ppt
≤ 5ppt
≤ 9ppt
≤ 10ppt
≤ 14ppt
≤ 15ppt
≤ 35ppt
Outside Analysis
Same as Base Case

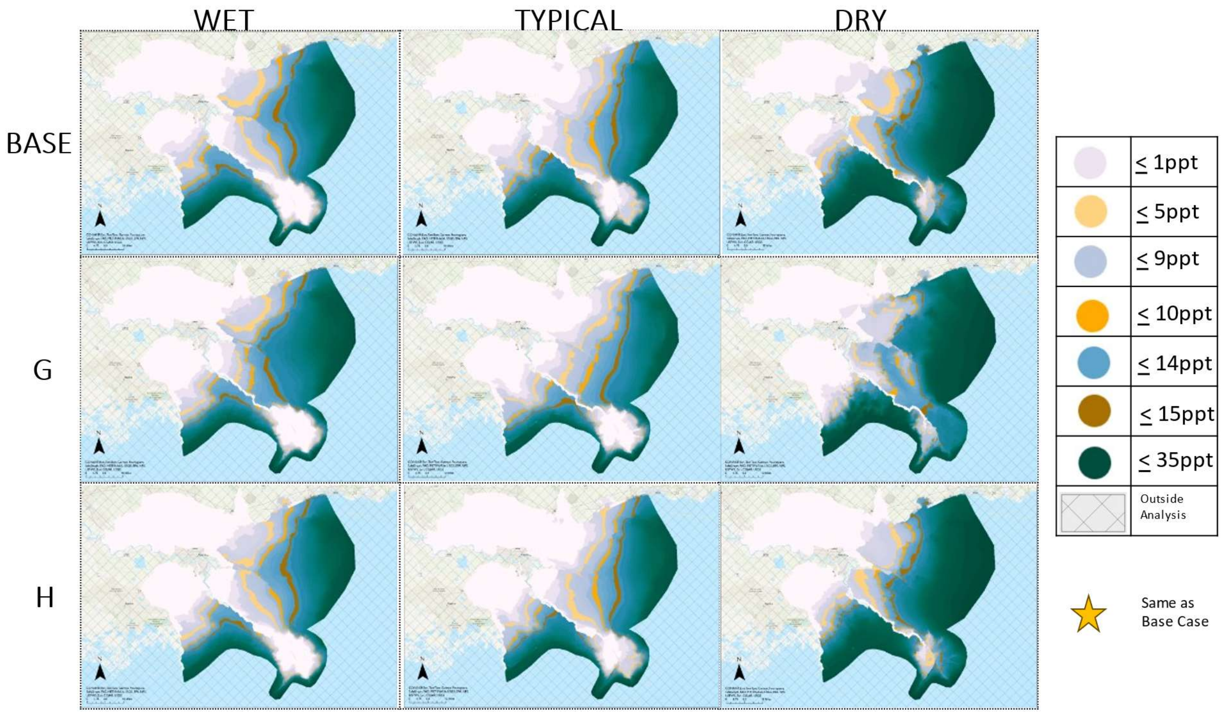


Figure 63 Mean October Salinity Results

4.7 Tabular Scenario Results

Table 9 Barataria Basin Actual Values

Barataria									
	Base	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
2019									
Flooding communities(days exceeding)	108	106	99	159	161	132	147	197	191
Marsh above Inundation threshold(acres)	210,938	214,264	214,241	226,118	223,782	222,647	217,360	208,417	211,594
Oyster (acres of HSI>0.5)	394,879	359,257	394,086	171,684	167,416	209,978	238,733	148,402	157,416
Marine Mammal(acres with streak <45 days)	550,606	474,229	537,794	291,457	298,136	359,758	393,879	241,384	303,486
Sediment Delivery (tons/year of sed delivered)	0	0	0	8	8	2	2	10	10
2021									
Flooding communities(days exceeding)	61	60	61	94	77	71	66	92	83
Marsh above Inundation threshold(acres)	236,094	235,319	236,094	240,614	245,696	244,752	245,819	250,493	246,257
Oyster (acres of HSI>0.75)	286,620	283,026	286,620	171,005	169,139	222,265	221,698	138,282	160,568
Marine Mammal(acres with streak <45 days)	527,733	528,917	527,733	409,111	413,813	450,732	459,765	346,170	388,646
Sediment Delivery (tons/year of sed delivered)	0	0	0	3	3	1	1	4	4
2022									
Flooding communities(days exceeding)	52	51	52	61	63	68	58	72	80
Marsh above Inundation threshold(acres)	235,188	236,521	235,188	256,420	254,847	244,752	245,819	248,313	249,901

Oyster (acres of HSI>0.5)	238,351	253,324	238,351	207,238	202,395	222,265	221,698	178,355	180,549
Marine Mammal(acres with streak <45 days)	564,732	559,234	564,732	441,408	449,713	458,079	470,475	408,060	417,748
Sediment Delivery (tons/year of sed delivered)	0	0	0	3	**3**	**1**	**1**	**3**	**3**

Table 10 Breton Basin Actual Values

	Breton								
	Base	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
2019									
Flooding communities(days exceeding)	30	24	26	40	41	24	27	40	44
Marsh above Inundation threshold(acres)	103,656	85,026	105,597	90,819	92,703	85,836	103,992	90,763	92,428
Oyster (acres of HSI>0.5)	0	258,151	0	26,972	0	254,311	576	25,249	0
Marine Mammal(acres with streak <45 days)	127,583	432,914	137,613	228,205	137,473	433,387	139,424	224,518	139,082
Sediment Delivery (tons/year of sed delivered)	0	0	0	5	5	0	0	5	5
2021									
Flooding communities(days exceeding)	24	22	24	31	31	22	24	30	31
Marsh above Inundation threshold(acres)	113,763	98,198	113,763	103,467	108,974	98,198	113,805	108,229	109,485
Oyster (acres of HSI>0.5)	7,683	229,329	7,683	64,781	0	229,388	7,680	46,975	2,575
Marine Mammal(acres with streak <45 days)	186,630	436,357	186,630	279,132	174,470	435,779	194,870	280,737	176,568

Sediment Delivery (tons/year of sed delivered)	0	0	0	2	2	0	0	2	2
2022									
Flooding communities(days exceeding)	17	17	17	24	29	25	19	28	25
Marsh above Inundation threshold(acres)	101,559	90,596	101,559	98,399	102,212	98,198	113,805	99,896	102,546
Oyster (acres of HSI>0.5)	142,029	245,783	142,029	164,370	78,555	270,548	158,614	162,168	83,798
Marine Mammal(acres with streak <45 days)	245,099	473,048	245,099	310,818	219,259	421,345	254,536	312,468	224,779
Sediment Delivery (tons/year of sed delivered)	0	0	0	2	2	0	0	2	2

Table 11 Mississippi Sound Basin Actual Values

	Mississippi Sound								
	Base	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
2019									
Flooding communities (days exceeding)	183	167	164	161	159	172	171	172	167
Marsh above Inundation threshold(acres)	162,354	151,696	162,506	156,926	163,518	157,089	164,343	163,195	166,293
Oyster (acres of HSI>0.5)	114,543	385,796	151,918	314,570	151,918	317,703	155,133	242,611	123,508
Marine Mammal(acres with streak <45 days)	893,505	1,323,657	1,008,230	1,253,498	999,568	1,252,377	984,026	1,136,371	986,098
2021									
Flooding communities (days exceeding)	116	119	116	119	115	120	116	119	117

Marsh above Inundation threshold(acres)	161,724	156,743	161,724	160,029	163,261	159,298	164,413	164,930	165,212
Oyster (acres of HSI>0.5)	237191.54	327,892	237191.54	289,689	209592.34	314,083	232,296	241024.14	199213.91
Marine Mammal(acres with streak <45 days)	1,222,311	1,269,100	1,222,311	1,246,849	1,179,474	1,231,474	1,181,095	1,179,954	1,146,781
2022									
Flooding communities (days exceeding)	108	106	108	107	107	118	109	111	111
Marsh above Inundation threshold(acres)	153,681	151,270	153,681	154,194	156,447	159,298	164,413	157,835	158,897
Oyster (acres of HSI>0.5)	290492.17	248,904	290492.17	268,774	283627.59	314,083	232,296	250908.36	252341.57
Marine Mammal(acres with streak <45 days)	1,325,965	1,365,591	1,325,965	1,335,936	1,312,151	1,299,646	1,279,377	1,292,481	1,260,782

Table 12 Maurepas Pontchartrain Actual Values

	Maurepas Pontchartrain								
	Base	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
2019									
Flooding communities(days exceeding)	2	0	0	0	0	1	1	2	2
Marsh above Inundation threshold(acres)	328,176	328,258	328,504	328,577	348,990	314,935	294,775	294,519	294,305
Sediment Delivery (tons/year of sed delivered)	0	0	0	0	0	2	2	2	2
2021									
Flooding communities(days exceeding)	6	6	6	6	6	7	7	7	7

Marsh above Inundation threshold(acres)	331,606	326,176	331,606	326,244	326,015	308,753	308,595	306,807	308,593
Sediment Delivery (tons/year of sed delivered)	0	0	0	0	0	2	2	2	2
2022									
Flooding communities(days exceeding)	0	0	0	0	0	0	0	0	0
Marsh above Inundation threshold(acres)	334,081	331,506	334,081	331,657	331,470	308,753	308,595	321,148	320,941
Sediment Delivery (tons/year of sed delivered)	0	0	0	0	0	1	1	1	1

Table 13 Delta Actual Values.

	Delta								
	Base	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
2019									
Flooding communities(days exceeding)	9	9	7	8	6	7	5	10	6
Marsh above Inundation threshold(acres)	33,847	32,528	34,748	34,075	35,302	33,261	34,085	34,489	35,591
Navigation (metric tons/year *10^4)	135	257	133	164	102	214	120	138	91
Sediment Delivery (tons/year of sed delivered)	90	105	90	95	83	100	86	91	81
2021									
Flooding communities(days exceeding)	2	2	2	2	2	2	2	2	2
Marsh above Inundation threshold(acres)	42,042	42,030	42,042	41,704	42,574	41,919	42,119	43,794	42,644
Navigation (metric tons/year *10^4)	53	75	53	56	44	65	48	51	40

Sediment Delivery (tons/year of sed delivered)	53	58	53	54	50	56	51	51	47
2022									
Flooding communities(days exceeding)	2	2	2	1	1	2	3	3	3
Marsh above Inundation threshold(acres)	35,104	35,292	35,104	37,137	36,823	34,280	36,386	36,410	36,056
Navigation (metric tons/year $*10^4$)	43	54	43	43	36	48	39	39	33
Sediment Delivery (tons/year of sed delivered)	41	44	41	41	38	43	39	39	36

4.8 Bedform Transport Scenario Results

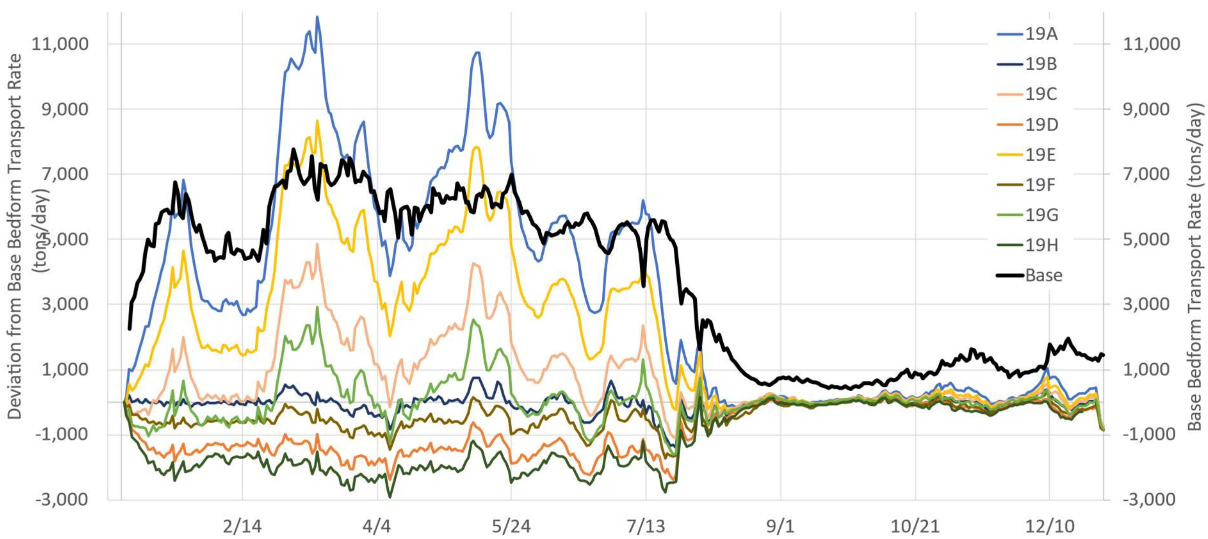


Figure 64Wet year. Base case bedform transport rate (black) plotted to right hand axis and scenario deviation from base case bedform transport rate plotted to left hand axis.

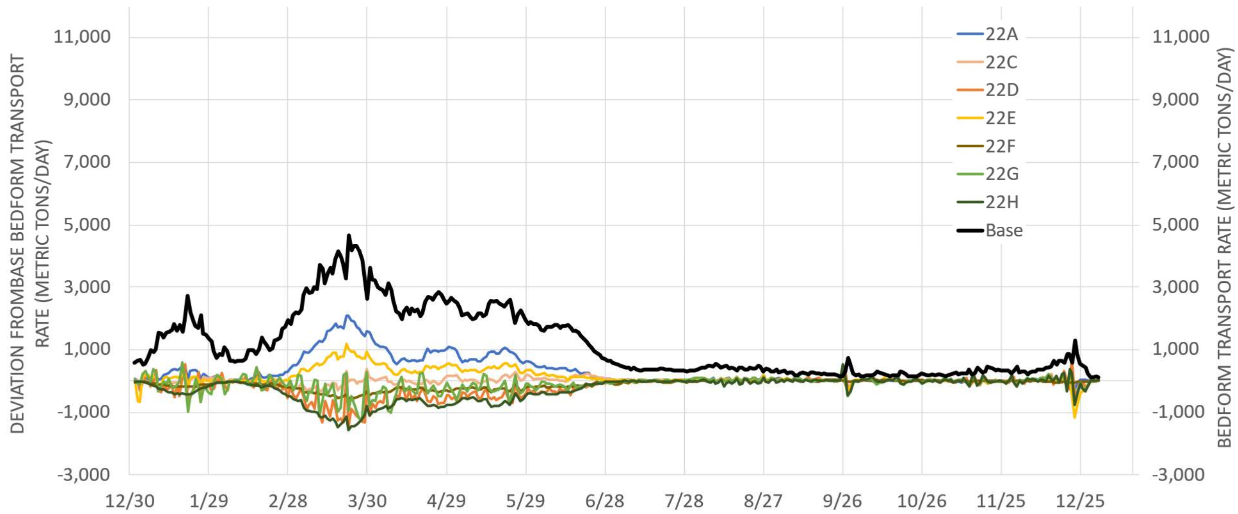


Figure 65 . Dry year. Base case bedform transport rate (black) plotted to right hand axis and scenario deviation from base case bedform transport rate plotted to left hand axis.

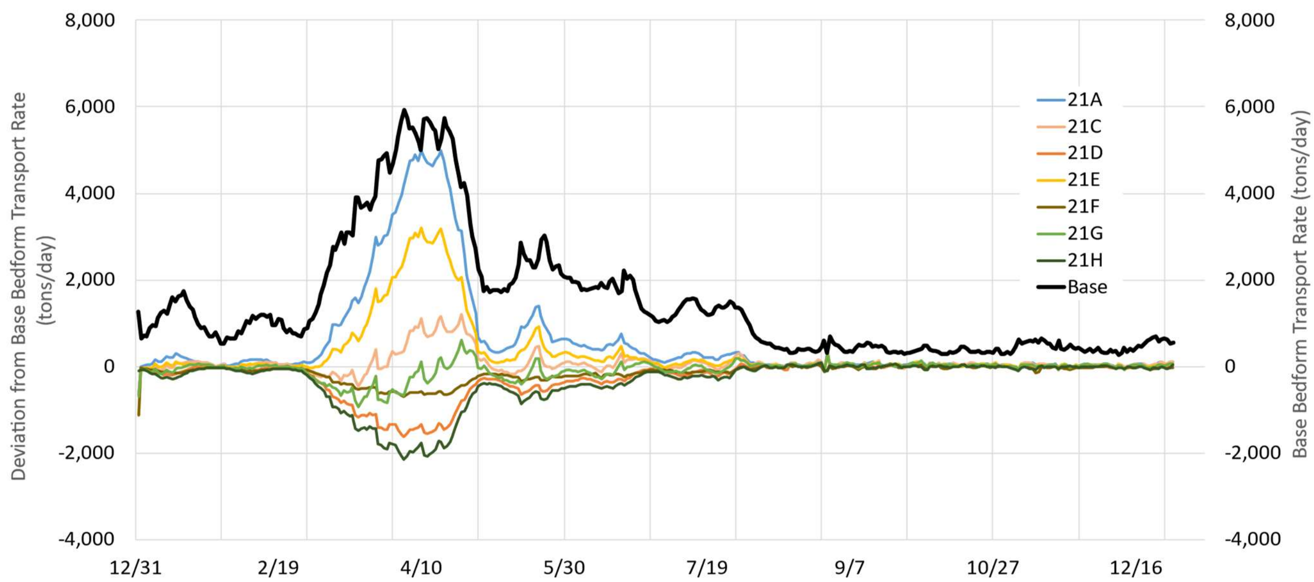


Figure 66 Typical year. Base case bedform transport rate (black) plotted to right hand axis and scenario deviation from base case bedform transport rate plotted to left hand axis.

4.9 Total Suspended Load Results

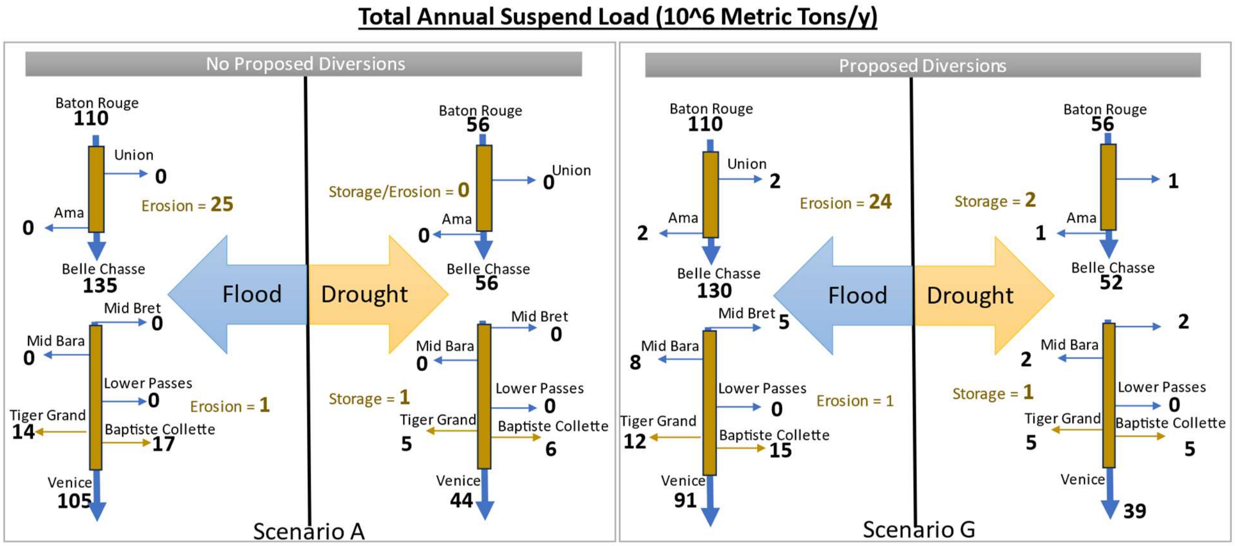


Figure 67 Average annual total suspended sediment discharge (in 10^6 tons/y) for the flood and drought years (2019 and 2022)scenarios A and G discussed in the present study for natural and man-made water exits from the Mississippi River below Baton Rouge, Louisiana. Also shown are annual channel storage rates (in 10^6 tons/y) for two sub-reaches of the channel between Baton Rouge to Belle Chasse and Belle Chasse to Venice. Rates were calculated via rating curve application to discharge at respective outlets.

5. References

2006. Louisiana Charrettes Move to Arabi. Available: http://archive.cnu.org/cnu-news/2006/03/louisiana-charrettes-move-arabi.

ARMITAGE, D. R., PLUMMER, R., BERKES, F., ARTHUR, R. I., CHARLES, A. T., DAVIDSON-HUNT, I. J., DIDUCK, A. P., DOUBLEDAY, N. C., JOHNSON, D. S., MARSCHKE, M., MCCONNEY, P., PINKERTON, E. W. & WOLLENBERG, E. K. 2009. Adaptive co-management for social–ecological complexity. *Frontiers in Ecology and the Environment,* 7**,** 95-102.

ARNOTT, J. C., NEUENFELDT, R. J. & LEMOS, M. C. 2020. Co-producing science for sustainability: Can funding change knowledge use? *Global Environmental Change,* 60**,** 101979.

BARNES, E. 2010. Charrettes: Laying the foundation for project success. Available: https://www.tam.usace.army.mil/Media/News-Stories/Article/483554/charrettes-laying-the-foundation-for-project-success/.

BEAUNOYER, E., DUPÉRÉ, S. & GUITTON, M. J. 2020. COVID-19 and digital inequalities: Reciprocal impacts and mitigation strategies. *Computers in Human Behavior,* 111**,** 106424.

BEDNAREK, A. T., WYBORN, C., CVITANOVIC, C., MEYER, R., COLVIN, R. M., ADDISON, P. F. E., CLOSE, S. L., CURRAN, K., FAROOQUE, M., GOLDMAN, E., HART, D., MANNIX, H., MCGREAVY, B., PARRIS, A., POSNER, S., ROBINSON, C., RYAN, M. & LEITH, P. 2018. Boundary spanning at the science–policy interface: the practitioners' perspectives. *Sustainability Science,* 13**,** 1175-1183.

CASH, D. 2006. Countering the Loading-Dock Approach to Linking Science and Decision Making: Comparative Analysis of El Nino/Southern Oscillation (ENSO) Forecasting

Systems. *Science Technology & Human Values - SCI TECHNOL HUM VAL,* 31**,** 465-494.

CASH, D., ADGER, W., BERKES, F., GARDEN, P., LEBEL, L., OLSSON, P., PRITCHARD, L. & YOUNG, O. 2006. Scale and Cross-Scale Dynamics: Governance and Information in Multilevel World. *ECOLOGY AND SOCIETY,* 11.

CHARLES E. YOE, K. B.-C., MARTIN T. SCHULTZ, BURTON C. SUEDEL 2010. Addressing Risk and Uncertainty in Planning Ecological Restoration Projects. *In:* ENGINEER, U. S. A. & CENTER, R. A. D. (eds.) *EMRRP Technical Notes Collection.* Vicksburg, MS: ERDC TN EMRRP-ER-13. COUNCIL, N. R. 2009. *Informing Decisions in a Changing Climate,* Washington, DC, The National Academies Press.

CROWLEY, S., EIGENBRODE, S., O'ROURKE, M. & WULFHORST, J. D. 2010. MultiLingual Cross-disciplinary localization: a philosophical approach. *Multilingual,* 4.

CVITANOVIC, C., HOBDAY, A. J., VAN KERKHOFF, L., WILSON, S. K., DOBBS, K. & MARSHALL, N. A. 2015. Improving knowledge exchange among scientists and decision-makers to facilitate the adaptive governance of marine resources: A review of knowledge and research needs. *Ocean & Coastal Management,* 112**,** 25-35.

CVITANOVIC, C., SHELLOCK, R. J., MACKAY, M., VAN PUTTEN, E. I., KARCHER, D. B., DICKEY-COLLAS, M. & BALLESTEROS, M. 2021. Strategies for building and managing 'trust' to enable knowledge exchange at the interface of environmental science and policy. *Environmental Science & Policy,* 123**,** 179-189.

DALE, P., SPORNE, I., KNIGHT, J., SHEAVES, M., ESLAMI-ANDERGOLI, L. & DWYER, P. 2019. A conceptual model to improve links between science, policy and practice in coastal management. *Marine Policy,* 103**,** 42-49.

DJENONTIN, I. N. S. & MEADOW, A. M. 2018. The art of co-production of knowledge in environmental sciences and management: lessons from international practice. *Environmental Management,* 61**,** 885-903.

ENGINEERS, U. A. C. O. 2003. ENGINEERING AND CONSTRUCTION BULLETIN. *In:* CECW-E, C.-M. (ed.) *Subject: DD Form 1391 Preparation Planning Charrette Process.* USACE.

GIBSON, F. L., ROGERS, A. A., SMITH, A. D. M., ROBERTS, A., POSSINGHAM, H., MCCARTHY, M. & PANNELL, D. J. 2017. Factors influencing the use of decision support tools in the development and design of conservation policy. *Environmental Science & Policy,* 70**,** 1-8.

GUSTAFSSON, K. M. & LIDSKOG, R. 2018. Boundary organizations and environmental governance: Performance, institutional design, and conceptual development. *Climate Risk Management,* 19**,** 1-11.

GUSTON, D. H. 1999. Stabilizing the Boundary between US Politics and Science:: The Rôle of the Office of Technology Transfer as a Boundary Organization. *Social Studies of Science,* 29**,** 87-111.

HAASNOOT, M., KWAKKEL, J. H., WALKER, W. E. & TER MAAT, J. 2013. Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change,* 23**,** 485-498.

HOWARD, Z. & SOMERVILLE, M. M. 2014. A comparative study of two design charrettes: implications for codesign and participatory action research. *CoDesign,* 10**,** 46-62.

JASANOFF, S. S. 1987. Contested Boundaries in Policy-Relevant Science. *Social Studies of Science,* 17**,** 195-230.

KARCHER, D. B., CVITANOVIC, C., VAN PUTTEN, I. E., COLVIN, R. M., ARMITAGE, D., ASWANI, S., BALLESTEROS, M., BAN, N. C., BARRAGÁN-PALADINES, M. J., BEDNAREK, A., BELL, J. D., BROOKS, C. M., DAW, T. M., DE LA CRUZ-MODINO, R., FRANCIS, T. B., FULTON, E. A., HOBDAY, A. J., HOLCER, D., HUDSON, C., JENNERJAHN, T. C., KINNEY, A., KNOL-KAUFFMAN, M., LÖF, M. F., LOPES, P. F. M., MACKELWORTH, P. C., MCQUATTERS-GOLLOP, A., MUHL,

E.-K., NEIHAPI, P., PASCUAL-FERNÁNDEZ, J. J., POSNER, S. M., RUNHAAR, H., SAINSBURY, K., SANDER, G., STEENBERGEN, D. J., TUDA, P. M., WHITEMAN, E. & ZHANG, J. 2022. Lessons from bright-spots for advancing knowledge exchange at the interface of marine science and policy. *Journal of Environmental Management,* 314**,** 114994.

KIRCHHOFF, C., LEMOS, M. & DESSAI, S. 2013. Actionable Knowledge for Environmental Decision Making: Broadening the Usability of Climate Science. *Annual Review of Environment and Resources,* 38**,** 393-414.

KÖPSEL, V., DE MOURA KIIPPER, G. & PECK, M. A. 2021. Stakeholder engagement vs. social distancing—how does the Covid-19 pandemic affect participatory research in EU marine science projects? *Maritime Studies,* 20**,** 189-205.

LANG, D. J., WIEK, A., BERGMANN, M., STAUFFACHER, M., MARTENS, P., MOLL, P., SWILLING, M. & THOMAS, C. J. 2012. Transdisciplinary research in sustainability science: practice, principles, and challenges. *Sustainability Science,* 7**,** 25-43.

LAWRENCE, M. G., WILLIAMS, S., NANZ, P. & RENN, O. 2022. Characteristics, potentials, and challenges of transdisciplinary research. *One Earth,* 5**,** 44-61.

LEMOS, M. C. & MOREHOUSE, B. J. 2005. The co-production of science and policy in integrated climate assessments. *Global Environmental Change,* 15**,** 57-68.

LEMPERT, R. J. 2019. Robust Decision Making (RDM). *In:* MARCHAU, V. A. W. J., WALKER, W. E., BLOEMEN, P. J. T. M. & POPPER, S. W. (eds.) *Decision Making under Deep Uncertainty: From Theory to Practice.* Cham: Springer International Publishing.

LEMPERT, R. J., POPPER, S. W. & BANKES, S. C. 2003. *Shaping the Next One Hundred Years New Methods for Quantitative, Long-Term Policy Analysis*, RAND Corporation.

LOUISIANA, C. P. A. R. A. O. 2017. Louisiana's Comprehensive Master Plan for a Sustainable Coast. *In:* LOUISIANA, C. P. A. R. A. O. (ed.). Baton Rouge, LA.

MACHER, C., STEINS, N. A., BALLESTEROS, M., KRAAN, M., FRANGOUDES, K., BAILLY, D., BERTIGNAC, M., COLLOCA, F., FITZPATRICK, M., GARCIA, D., LITTLE, R., MARDLE, S., MURILLAS, A., PAWLOWSKI, L., PHILIPPE, M., PRELLEZO, R., SABATELLA, E., THÉBAUD, O. & ULRICH, C. 2021. Towards transdisciplinary decision-support processes in fisheries: experiences and recommendations from a multidisciplinary collective of researchers. *Aquat. Living Resour.,* 34**,** 13.

MASSON-DELMOTTE, V., P. ZHAI, A. PIRANI, S.L., CONNORS, C. P., S. BERGER, N. CAUD, Y. CHEN, L. GOLDFARB, M.I. GOMIS, M. HUANG, K. LEITZELL, E. LONNOY, J.B.R. MATTHEWS, T.K. & MAYCOCK, T. W., O. YELEKÇI, R. YU, AND B. ZHOU (EDS.) 2021. IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. , United Kingdom and New York, NY, USA: Cambridge University Press, Cambridge.

MAUSER, W., KLEPPER, G., RICE, M., SCHMALZBAUER, B. S., HACKMANN, H., LEEMANS, R. & MOORE, H. 2013. Transdisciplinary global change research: the co-creation of knowledge for sustainability. *Current Opinion in Environmental Sustainability,* 5**,** 420-431.

MCCLENACHAN, G. 2016. *Coastal Ecosystem Resiliency after Major Disturbances.* PhD Dissertation, Louisiana State University.

MEADOW, A., FERGUSON, D., GUIDO, Z., HORANGIC, A., OWEN, G. & WALL, T. 2015. Moving Toward the Deliberate Co-Production of Climate Science Knowledge. *Weather, Climate, and Society,* 7.

NATIONAL ACADEMIES OF SCIENCES, E., AND MEDICINE 2020. Gulf Research Program Annual Report 2019(2020). Washington, DC.

NATIONAL ACADEMIES OF SCIENCES, E., AND MEDICINE 2022. An Approach for Assessing U.S. Gulf Coast Ecosystem Restoration: A Gulf Research Program Environmental Monitoring Report. *The National Academies Press.* Washington, DC.

NITTROUER, C., MULLARNEY, J., ALLISON, M. & OGSTON, A. 2017. Introduction to the Special Issue on Sedimentary Processes Building a Tropical Delta Yesterday, Today, and Tomorrow: The Mekong System. *Oceanography,* 30**,** 10-21.

RAYMOND, C., FAZEY, I., REED, M., STRINGER, L., ROBINSON, G. & EVELY, A. 2010. Integrating local and scientific knowledge for environmental management. *Journal of environmental management,* 91**,** 1766-77.

SCHNAPP, L., ROTSCHY, L., HALL, T., CROWLEY, S. & O'ROURKE, M. 2012. How to talk to strangers: Facilitating knowledge sharing within translational health teams with the Toolbox dialogue method. *Translational behavioral medicine,* 2**,** 469-79.

SUTTON, S. & KEMP, S. 2006. Integrating Social Science and Design Inquiry Through Interdisciplinary Design Charrettes: An Approach to Participatory Community Problem Solving. *American journal of community psychology,* 38**,** 125-39.

TOMPKINS, E. L., FEW, R. & BROWN, K. 2008. Scenario-based stakeholder engagement: Incorporating stakeholders preferences into coastal planning for climate change. *Journal of Environmental Management,* 88**,** 1580-1592.

WALKER, W. 2000. Policy Analysis: A Systematic Approach to Supporting Policymaking in the Public Sector. *Journal of Multi-criteria Decision Analysis,* 9**,** 11-27.

Aberle, J., & Järvelä, J. (2013). Flow resistance of emergent rigid and flexible floodplain vegetation. *Journal of Hydraulic Research*, *51*(1), 33-45. https://doi.org/10.1080/00221686.2012.754795

Adams, T. E. (2016). Chapter 10 - Flood Forecasting in the United States NOAA/National Weather Service. In T. E. Adams & T. C. Pagano (Eds.), *Flood Forecasting* (pp. 249-310). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-801884-2.00010-4

Allen, A. L., Brown, C. W., Lewitus, A. J., & Sandifer, P. A. (2015). The Roles of Emerging Technology and Modeling Techniques in Operational Ecological Forecasting at NOAA. *Marine Technology Society Journal*, *49*(2), 193-203. https://doi.org/10.4031/MTSJ.49.2.18

Allison, M., Demas, C., Ebersole, B., Kleiss, B., Little, C., Meselhe, E., Powell, N., Pratt, T., & Vosburg, B. (2012a). A water and sediment budget for the lower Mississippi–Atchafalaya River in flood years 2008–2010: Implications for sediment discharge to the oceans and coastal restoration in Louisiana. *Journal of Hydrology*, *s 432–433*, 84–97. https://doi.org/10.1016/j.jhydrol.2012.02.020

Allison, M., Demas, C., Ebersole, B., Kleiss, B., Little, C. D., Meselhe, E. A., Powell, N. J., Pratt, T. C., & Vosburg, B. M. (2012b). A water and sediment budget for the lower Mississippi–Atchafalaya River in flood years 2008–2010: Implications for sediment discharge to the oceans and coastal restoration in Louisiana. *Journal of Hydrology*, *432-433*, 84-97. https://doi.org/https://doi.org/10.1016/j.jhydrol.2012.02.020

Allison, M., Demas, C., Ebersole, B., Kleiss, B. A., Little, C. D., Meselhe, E. A., Powell, N. J., Pratt, T. C., & Vosburg, B. M. (2012c). A water and sediment budget for the lower Mississippi–Atchafalaya River in flood years 2008–2010: Implications for sediment discharge to the oceans and coastal restoration in Louisiana. *Journal of Hydrology*, *432-433*, 84-97. https://doi.org/10.1016/j.jhydrol.2012.02.020

Allison, M., Meselhe, E., & Kleiss, B. (2023). Impact of Water Loss on Sustainability of the Mississippi River Channel in its Deltaic Reach. *Authorea*. DOI: 10.22541/au.167929277.71582944/v1

Allison, M. A., & Meselhe, E. A. (2010). The use of large water and sediment diversions in the lower Mississippi River (Louisiana) for coastal restoration [Review]. *Journal of Hydrology*, *387*(3-4), 346-360. https://doi.org/10.1016/j.jhydrol.2010.04.001

Allison, M. A., Ramirez, M. T., & Meselhe, E. A. (2014). Diversion of Mississippi River Water Downstream of New Orleans, Louisiana, USA to Maximize Sediment Capture and Ameliorate Coastal Land Loss [Article]. *Water Resources Management*, *28*(12), 4113-4126. https://doi.org/10.1007/s11269-014-0731-y

Amer, R., Kolker, A. S., & Muscietta, A. (2017). Propensity for erosion and deposition in a deltaic wetland complex: Implications for river management and coastal restoration. *Remote Sensing of Environment*, *199*, 39-50. https://doi.org/https://doi.org/10.1016/j.rse.2017.06.030

Armstrong, B. N., Cambazoglu, M. K., & Wiggert, J. D. (2021, 20-23 Sept. 2021). Modeling the impact of the 2019 Bonnet Carré Spillway opening and local river flooding on the Mississippi Sound. OCEANS 2021: San Diego – Porto, Bagnold, R. A. (1960). *Sediment Discharge and Stream Power: A Preliminary Announcement*. United States Department of the Interior, Geological Survey. https://books.google.com/books?id=Vpxb5TjS3SQC

Bagnold, R. A. (1997). An empirical correlation of bedload transport rates in flumes and natural rivers. *Proceedings of the Royal Society of London. A. Mathematical and Physical Sciences*, *372*(1751), 453-473. https://doi.org/10.1098/rspa.1980.0122

Barnes, E. (2010). Charrettes: Laying the foundation for project success. https://www.tam.usace.army.mil/Media/News-Stories/Article/483554/charrettes-laying-the-foundation-for-project-success/

Bentley, S. J., Freeman, A. M., Willson, C. S., Cable, J. E., & Giosan, L. (2014). Using What We Have: Optimizing Sediment Management in Mississippi River Delta Restoration to Improve the Economic Viability of the Nation. In J. W. Day, G. P. Kemp, A. M. Freeman, & D. P. Muth (Eds.), *Perspectives on the Restoration of the Mississippi Delta: The Once and Future Delta* (pp. 85-97). Springer Netherlands. https://doi.org/10.1007/978-94-017-8733-8_6

Biedenharn, D. S., Thorne, C. R., & Watson, C. C. (2000). Recent morphological evolution of the Lower Mississippi River. *Geomorphology*, *34*(3), 227-249. https://doi.org/https://doi.org/10.1016/S0169-555X(00)00011-8

Cash, D. (2006). Countering the Loading-Dock Approach to Linking Science and Decision Making: Comparative Analysis of El Nino/Southern Oscillation (ENSO) Forecasting Systems. *Science Technology & Human Values - SCI TECHNOL HUM VAL*, *31*, 465-494. https://doi.org/10.1177/0162243906287547

Chapman, E. L. (2019). *Assessment of Off-Bottom Oyster (Crassostrea Virginica) Aquaculture Techniques on Biofouling in the Northern Gulf of Mexico* (Publication Number 29114404) [M.Sc., Louisiana State University and Agricultural & Mechanical College]. ProQuest Dissertations & Theses Global. United States -- Louisiana. http://libproxy.tulane.edu:2048/login?url=https://www.proquest.com/dissertations-theses/assessment-off-bottom-oyster-crassostrea/docview/2665133528/se-2?accountid=14437

https://library.search.tulane.edu/openurl/01TUL_INST/01TUL_INST:Tulane?genre=dissertations&atitle=&author=Chapman%2C+Ellis+Leroy&volume=&issue=&spage=&date=2019&rft.btitle=&rft.jtitle=&issn=&isbn=9798438706021&sid=ProQuest+Dissertations+%26+Theses+Global_

Coleman, J. M., Roberts, H. H., & Gregory, W. S. (1998). Mississippi River Delta: An Overview. *Journal of Coastal Research*, *14*(3), 699-716. http://www.jstor.org/stable/4298830

Council, N. R. (2009). *Informing Decisions in a Changing Climate*. The National Academies Press.

CPRA. (2012). Louisiana comprehensive master plan for a sustainable coast. *Coastal Protection and Restoration Authority of Louisiana*.

CPRA. (2017). *Louisiana's Coastal Master Plan for a Sustainable Coast*.

CPRA. (2023). *Louisiana's Coastal Master Plan for a Sustainable Coast*.

Crowley, S., Eigenbrode, S., O'Rourke, M., & Wulfhorst, J. D. (2010). MultiLingual Cross-disciplinary localization: a philosophical approach. *Multilingual*, *4*.

Dasgupta, S., Islam, M. S., Huq, M., Huque Khan, Z., & Hasib, M. R. (2019). Quantifying the protective capacity of mangroves from storm surges in coastal Bangladesh. *PLOS ONE*, *14*(3), e0214079. https://doi.org/10.1371/journal.pone.0214079

Day, J. W., Lane, R. R., D'Elia, C. F., Wiegman, A. R. H., Rutherford, J. S., Shaffer, G. P., Brantley, C. G., & Kemp, G. P. (2016). Large infrequently operated river diversions for Mississippi delta restoration. *Estuarine, Coastal and Shelf Science*, *183*, 292-303. https://doi.org/10.1016/j.ecss.2016.05.001 (Estuar. Coast. Shelf Sci. (Netherlands))

Day, J. W., Lane, R. R., D'Elia, C. F., Wiegman, A. R. H., Rutherford, J. S., Shaffer, G. P., Brantley, C. G., & Paul Kemp, G. (2018). Large Infrequently Operated River Diversions for Mississippi Delta Restoration. In J. W. Day & J. A. Erdman (Eds.), *Mississippi Delta Restoration: Pathways to a sustainable future* (pp. 113-133). Springer International Publishing. https://doi.org/10.1007/978-3-319-65663-2_8

De Mutsert, K., Lewis, K., Milroy, S., Buszowski, J., & Steenbeek, J. (2017). Using ecosystem modeling to evaluate trade-offs in coastal management: Effects of large-scale river diversions on fish and fisheries. *Ecological Modelling*, *360*, 14-26. https://doi.org/10.1016/j.ecolmodel.2017.06.029

Deltares (Ed.). (2011). *D-Flow Flexible Mesh Computational Cores and User Interface User Manual* (SVN Revision: 76991 ed., Vol. 1) [User Manual]. Deltares.

Djenontin, I. N. S., & Meadow, A. M. (2018). The art of co-production of knowledge in environmental sciences and management: lessons from international practice. *Environmental Management*, *61*(6), 885-903. https://doi.org/10.1007/s00267-018-1028-3

Engineers, U. A. C. o. (2003). *ENGINEERING AND*

CONSTRUCTION BULLETIN (Subject: DD Form 1391 Preparation Planning Charrette Process, Issue. https://www.wbdg.org/FFC/ARMYCOE/COEECB/ARCHIVES/ecb_2003_8.pdf

Gagliano, S. M., Meyer-Arendt, K. J., & Wicker, K. M. (1981). Land loss in the Mississippi River Deltaic Plain.

Galler, J. J., & Allison, M. A. (2008). Estuarine controls on fine-grained sediment storage in the Lower Mississippi and Atchafalaya Rivers. *GSA Bulletin*, *120*(3-4), 386-398. https://doi.org/10.1130/B26060.1

Garrison, L. P., Litz, J., & Sinclair, C. (2020). Predicting the effects of low salinity associated with the MBSD project on resident common bottlenose dolphins (Tursiops truncatus) in Barataria Bay, LA [Technical Memorandum]. https://doi.org/https://doi.org/10.25923/53z9-nn54 (NOAA Technical Memorandum NMFS-SEFSC ; 748)

Gaweesh, A., & Meselhe, E. (2016). Evaluation of Sediment Diversion Design Attributes and Their Impact on the Capture Efficiency. *Journal of Hydraulic Engineering*, *142*(5), 04016002. https://doi.org/10.1061/(ASCE)HY.1943-7900.0001114

Gledhill, J. H., Barnett, A. F., Marc, S., Kristine, L. W., Gregory, L. E., Stephanie Showalter, O., & Deborah, J. G. (2020). Mass Mortality of the Eastern Oyster <i>Crassostrea virginica</i> in the Western Mississippi Sound Following Unprecedented Mississippi River Flooding in 2019. *Journal of Shellfish Research*, *39*(2), 235-244. https://doi.org/10.2983/035.039.0205

Gough, L., & Grace, J. B. (1998). Effects of flooding, salinity and herbivory on coastal plant communities, Louisiana, United States. *Oecologia*, *117*(4), 527-535. https://doi.org/10.1007/s004420050689

Gustafsson, K. M., & Lidskog, R. (2018). Boundary organizations and environmental governance: Performance, institutional design, and conceptual development. *Climate Risk Management*, *19*, 1-11. https://doi.org/https://doi.org/10.1016/j.crm.2017.11.001

Guston, D. H. (1999). Stabilizing the Boundary between US Politics and Science:: The Rôle of the Office of Technology Transfer as a Boundary Organization. *Social Studies of Science*, *29*(1), 87-111. https://doi.org/10.1177/030631299029001004

Haasnoot, M., Kwakkel, J. H., Walker, W. E., & ter Maat, J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change*, *23*(2), 485-498. https://doi.org/https://doi.org/10.1016/j.gloenvcha.2012.12.006

Howard, Z., & Somerville, M. M. (2014). A comparative study of two design charrettes: implications for codesign and participatory action research. *CoDesign*, *10*(1), 46-62. https://doi.org/10.1080/15710882.2014.881883

Hu, K., Meselhe, E., & Reed, D. J. (2023). Understanding Drivers of Salinity and Temperature Dynamics in Barataria Estuary, Louisiana. *Journal of Geophysical Research: Oceans*, *128*(7), e2023JC019635. https://doi.org/https://doi.org/10.1029/2023JC019635

Hu, K., Reed, D., & Meselhe, E. (2023). *Modeling Habitat Suitability for Common Bottlenose Dolphins (Tursiops truncatus) and Eastern Oyster (Crassostrea virginica) in the Breton Sound and Pontchartrain-Chandeleur Basin with the Mid-Breton Sediment Diversion*.

Hu, K., Reed, D., & Meselhe, E. (2023). Understanding Drivers of Salinity and Temperature Dynamics in Barataria Estuary, Louisiana. *Journal of Geophysical Research: Oceans*, *128*(7), e2023JC019635. https://doi.org/https://doi.org/10.1029/2023JC019635

Hupp, C. R., Demas, C. R., Kroes, D. E., Day, R. H., & Doyle, T. W. (2008). Recent sedimentation patterns within the central Atchafalaya Basin, Louisiana. *Wetlands*, *28*(1), 125-140. https://doi.org/10.1672/06-132.1

Iles, R. L., Walker, N. D., White, J. R., & Rohli, R. V. (2020). Impacts of a Major Mississippi River Freshwater Diversion on Suspended Sediment Plume Kinematics in Lake Pontchartrain, a Semi-enclosed Gulf of Mexico Estuary [Article; Early Access]. *Estuaries and Coasts*, 18. https://doi.org/10.1007/s12237-020-00789-y

Jain, V., Preston, N., Fryirs, K., & Brierley, G. (2006). Comparative assessment of three approaches for deriving stream power plots along long profiles in the upper

Hunter River catchment, New South Wales, Australia. *Geomorphology*, *74*(1), 297-317. https://doi.org/https://doi.org/10.1016/j.geomorph.2005.08.012
Khalifa, A. M. (2023). *Development and Applications of Morphodynamic Model to Study Deltaic and Coastal Ecosystems* (Publication Number 30528181) [Ph.D., Tulane University]. ProQuest Dissertations & Theses Global. United States -- Louisiana. http://libproxy.tulane.edu:2048/login?url=https://www.proquest.com/dissertations-theses/development-applications-morphodynamic-model/docview/2849727387/se-2?accountid=14437

https://library.search.tulane.edu/openurl/01TUL_INST/01TUL_INST:Tulane?genre=dissertations&atitle=&author=Khalifa%2C+Ahmed+M.&volume=&issue=&spage=&date=2023&rft.btitle=&rft.jtitle=&issn=&isbn=9798380102933&sid=ProQuest+Dissertations+%26+Theses+Global_
Kirchhoff, C., Lemos, M., & Dessai, S. (2013). Actionable Knowledge for Environmental Decision Making: Broadening the Usability of Climate Science. *Annual Review of Environment and Resources*, *38*, 393-414. https://doi.org/10.1146/annurev-environ-022112-112828
Knighton, A. D. (1999). Downstream variation in stream power. *Geomorphology*, *29*(3), 293-306. https://doi.org/https://doi.org/10.1016/S0169-555X(99)00015-X
Kopecki, I., Schneider, M., & Tuhtan, J. A. (2017). Depth-dependent hydraulic roughness and its impact on the assessment of hydropeaking. *Science of the Total Environment*, *575*, 1597-1605. https://doi.org/https://doi.org/10.1016/j.scitotenv.2016.10.110
Kordzadze, A. A., Demetrashvili, D. I., & Demetrashvili, D. I. (2017). Some Results of Forecast of Hydrodynamic Processes in the Easternmost Part of the Black Sea. *Journals of Georgian Geophysical Society*, *14*(2). https://ggs.openjournals.ge/index.php/GGS/article/view/1773
Lemos, M. C., & Morehouse, B. J. (2005). The co-production of science and policy in integrated climate assessments. *Global Environmental Change*, *15*(1), 57-68. https://doi.org/https://doi.org/10.1016/j.gloenvcha.2004.09.004
Lempert, R. J. (2019). Robust Decision Making (RDM). In V. A. W. J. Marchau, W. E. Walker, P. J. T. M. Bloemen, & S. W. Popper (Eds.), *Decision Making under Deep Uncertainty: From Theory to Practice* (pp. 23-51). Springer International Publishing. https://doi.org/10.1007/978-3-030-05252-2_2
Leonhardt, J. M., Casas, S., Supan, J. E., & La Peyre, J. F. (2017). Stock assessment for eastern oyster seed production and field grow-out in Louisiana. *Aquaculture*, *466*, 9-19. https://doi.org/https://doi.org/10.1016/j.aquaculture.2016.09.034
Lesser, G. R., Roelvink, J. A., van Kester, J. A. T. M., & Stelling, G. S. (2004). Development and validation of a three-dimensional morphological model. *Coastal Engineering*, *51*(8), 883-915. https://doi.org/https://doi.org/10.1016/j.coastaleng.2004.07.014
Levine, C. M., & Stromberg, J. C. (2001). Effects of flooding on native and exotic plant seedlings: implications for restoring south-western riparian forests by

manipulating water and sediment flows. *Journal of Arid Environments*, *49*(1), 111-131. https://doi.org/https://doi.org/10.1006/jare.2001.0837
Lewis, J., Ashley, J., Lauth, T., & David S. Biedenharn, T. A. D., Ronald R. Copeland, Gaurav Savant, Gary L. Brown, James R. Leech, Patrick I. Donohue, Kathleen E. Harris, Casey M. Mayne, Keaton E. Jones, David A. Fertitta, David A. Ramirez, Steven Ayres, Maxwell E. Agnew, Charles D. Little, Jr., Joseph B. Dunbar, Samantha L. Lucker, and Nalini Torres (2022). *Technical Assessment of the Old, Mississippi, Atchafalaya, and Red (OMAR) Rivers: Main Report*. U. MVD.
Li, X., Liu, J. P., Saito, Y., & Nguyen, V. L. (2017). Recent evolution of the Mekong Delta and the impacts of dams. *Earth-Science Reviews*, *175*, 1-17. https://doi.org/https://doi.org/10.1016/j.earscirev.2017.10.008
Lindquist, D. C., Sable, S. E., D'Acunto, L., Hijuelos, A. C., Johnson, E.I., Langlois, S.R.M., Michel,, & N.L., N., L., O'Connell, A.M., Percy, K., & Robinson, E.M. . (2020). *2023 Coastal Master Plan: Habitat Suitability Index Model Improvements. Draft Final*.
Linhoss, A., Mickle, P., & Osorio, R. J. (2023). Simulating How Freshwater Diversions Impact Salinity Regimes in an Estuarine System. *Journal of Marine Science and Engineering*, *11*(12).
Littles, C. J., Jackson, C. A., DeWitt, T. H., & Harwell, M. C. (2018). Linking people to coastal habitats: A meta-analysis of final ecosystem goods and services on the coast. *Ocean & Coastal Management*, *165*, 356-369. https://doi.org/https://doi.org/10.1016/j.ocecoaman.2018.09.009
Louisiana Charrettes Move to Arabi. (2006). http://archive.cnu.org/cnu-news/2006/03/louisiana-charrettes-move-arabi
Louisiana, C. P. a. R. A. o. (2017). *Louisiana's Comprehensive Master Plan*

for a Sustainable Coast.
Magilligan, F. J. (1992). Thresholds and the spatial variability of flood power during extreme floods. *Geomorphology*, *5*(3), 373-390. https://doi.org/https://doi.org/10.1016/0169-555X(92)90014-F
Mahmood, A., Han, J.-C., Ijaz, M. W., Siyal, A. A., Ahmad, M., & Yousaf, M. (2022). Impact of Sediment Deposition on Flood Carrying Capacity of an Alluvial Channel: A Case Study of the Lower Indus Basin. *Water*, *14*(20).
Mann, K. H. (1988). Production and use of detritus in various freshwater, estuarine, and coastal marine ecosystems. *Limnology and Oceanography*, *33*(4part2), 910-930. https://doi.org/https://doi.org/10.4319/lo.1988.33.4part2.0910
Masson-Delmotte, V., P. Zhai, A. Pirani, S.L., Connors, C. P., S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K., & Maycock, T. W., O. Yelekçi, R. Yu, and B. Zhou (eds.). (2021). *IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I*

to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.
McAnally, W. H., & Nail, G. H. (1995). Freshwater diversion to reduce estuarine salinities.*International Water Resources Engineering Conference - Proceedings*

Proceedings of the 1st International Conference on Water Resources. Part 1 (of 2), August 14, 1995 - August 18, 1995, San Antonio, TX, USA.

McClain, A., Daniels, R., Gomez, F., Ridgway, S., Takeshita, R., Jensen, E., & Smith, C. (2020). Physiological Effects of Low Salinity Exposure on Bottlenose Dolphins (Tursiops truncatus). *Journal of Zoological and Botanical Gardens*, *1*. https://doi.org/10.3390/jzbg1010005

McClenachan, G. (2016). *Coastal Ecosystem Resiliency after Major Disturbances* [Dissertation, Louisiana State University].

Meade, R. H., & Moody, J. A. (2010). Causes for the decline of suspended-sediment discharge in the Mississippi River system, 1940–2007. *Hydrological Processes*, *24*(1), 35-49. https://doi.org/https://doi.org/10.1002/hyp.7477

Meadow, A., Ferguson, D., Guido, Z., Horangic, A., Owen, G., & Wall, T. (2015). Moving Toward the Deliberate Co-Production of Climate Science Knowledge. *Weather, Climate, and Society*, *7*. https://doi.org/10.1175/WCAS-D-14-00050.1

Meselhe, E., Costanza, K. E., & Ainsworth, C., Chagaris, D., Addis, D., Simpson, E., Rodrigue, M., Hoonshin, J., and Smits, J. (2015). *Models Performance Assessment Metrics for the LCA Mississippi River Hydrodynamic and Delta Management Study*.

Meselhe, E., Hu, K., Reed, D. (2019). *Interaction of Intra-Basin Ridge Restoration with Mid-Barataria Diversion Outflow.*

Meselhe, E. A., Hu, K., & Reed, D. (2019). *Interaction of Intr-Basin Ridge Restoration with Mid-Barataria Diverion Outflow.* (Report to the National Wildlife Federation, Issue.

Meselhe, E. A., Sadid, K. M., & Allison, M. A. (2016). Riverside morphological response to pulsed sediment diversions. *Geomorphology*, *270*, 184-202. https://doi.org/https://doi.org/10.1016/j.geomorph.2016.07.023

Ming, X., Liang, Q., Xia, X., Li, D., & Fowler, H. J. (2020). Real-Time Flood Forecasting Based on a High-Performance 2-D Hydrodynamic Model and Numerical Weather Predictions. *Water Resources Research*, *56*(7), e2019WR025583. https://doi.org/https://doi.org/10.1029/2019WR025583

Mishra, D. R., & Mishra, S. (2010). Plume and bloom: effect of the Mississippi River diversion on the water quality of Lake Pontchartrain. *Geocarto International*, *25*(7), 555-568. https://doi.org/10.1080/10106041003763394 (Geocarto Int. (UK))

Mize, S. V., & Demcheck, D. K. (2009). Water quality and phytoplankton communities in Lake Pontchartrain during and after the Bonnet Carré Spillway opening, April to October 2008, in Louisiana, USA [Article]. *Geo-Marine Letters*, *29*(6), 431-440. https://doi.org/10.1007/s00367-009-0157-3

Mossa, J. (1996). Sediment dynamics in the lowermost Mississippi River. *Engineering Geology*, *45*(1), 457-479. https://doi.org/https://doi.org/10.1016/S0013-7952(96)00026-9

Mukai, A. Y., Westerink, J. J., & Luettich, R. A. (2002). Guidelines for Using Eastcoast 2001 Database of Tidal Constituents within Western North Atlantic Ocean, Gulf of Mexico and Caribbean Sea.

Nanson, G. C., & Hickin, E. J. (1986). A statistical analysis of bank erosion and channel migration in western Canada. *GSA Bulletin*, *97*(4), 497-504. https://doi.org/10.1130/0016-7606(1986)97<497:ASAOBE>2.0.CO;2

National Academies of Sciences, E., and Medicine. (2020). *Gulf Research Program Annual Report 2019*

(2020). T. N. A. Press. https://doi.org/10.17226/25959.

National Academies of Sciences, E., and Medicine. (2022). *An Approach for*

Assessing U.S. Gulf Coast Ecosystem Restoration: A Gulf Research Program

Environmental Monitoring Report (The National Academies Press, Issue.

Nittrouer, C., Mullarney, J., Allison, M., & Ogston, A. (2017). Introduction to the Special Issue on Sedimentary Processes Building a Tropical Delta Yesterday, Today, and Tomorrow: The Mekong System. *Oceanography*, *30*, 10-21. https://doi.org/10.5670/oceanog.2017.310

Nittrouer, J. A., Allison, M. A., & Campanella, R. (2008). Bedform transport rates for the lowermost Mississippi River. *Journal of Geophysical Research: Earth Surface*, *113*(F3). https://doi.org/https://doi.org/10.1029/2007JF000795

NOLA.com. (2023). *Lafitte breaks ground on $14 million levee project. 'We cannot afford to sit by.'* https://www.nola.com/news/jefferson_parish/lafitte-breaks-ground-on-14-million-levee-project/article_a832ca6c-4c16-11ee-8d7c-9b5377a0c51a.html

Parra, S., Sanial, V., Boyette, A. D., Cambazoglu, M. K., Soto, I. M., Greer, A. T., Chiaverano, L. M., Hoover, A., & Dinniman, M. S. (2020). Bonnet Carré Spillway freshwater transport and corresponding biochemical properties in the Mississippi Bight. *Continental Shelf Research*, *199*, 104114. https://doi.org/https://doi.org/10.1016/j.csr.2020.104114

Parra, S. M., Sanial, V., Boyette, A. D., Cambazoglu, M. K., Soto, I. M., Greer, A. T., Chiaverano, L. M., Hoover, A., & Dinniman, M. S. (2020). Bonnet Carre Spillway freshwater transport and corresponding biochemical properties in the Mississippi Bight [Article]. *Continental Shelf Research*, *199*, 19, Article 104114. https://doi.org/10.1016/j.csr.2020.104114

Peters-Lidard, C. D., Clark, M., Samaniego, L., Verhoest, N. E. C., van Emmerik, T., Uijlenhoet, R., Achieng, K., Franz, T. E., & Woods, R. (2017). Scaling, similarity, and the fourth paradigm for hydrology. *Hydrology and Earth System Sciences*, *21*(7), 3701-3713. https://doi.org/10.5194/hess-21-3701-2017

Peyronnin, N. S., Caffey, R. H., Cowan, J. H., Justic, D., Kolker, A. S., Laska, S. B., McCorquodale, A., Melancon, E., Nyman, J. A., Twilley, R. R., Visser, J. M., White, J. R., & Wilkins, J. G. (2017a). Optimizing Sediment Diversion Operations: Working Group Recommendations for Integrating Complex Ecological and Social Landscape Interactions. *Water*, *9*(6), 368. https://www.mdpi.com/2073-4441/9/6/368

Peyronnin, N. S., Caffey, R. H., Cowan, J. H., Justic, D., Kolker, A. S., Laska, S. B., McCorquodale, A., Melancon, E., Nyman, J. A., Twilley, R. R., Visser, J. M., White,

J. R., & Wilkins, J. G. (2017b). Optimizing Sediment Diversion Operations: Working Group Recommendations for Integrating Complex Ecological and Social Landscape Interactions. *Water*, *9*(6). https://doi.org/10.3390/w9060368

Phillips, J. D., & Slattery, M. C. (2007). Downstream trends in discharge, slope, and stream power in a lower coastal plain river. *Journal of Hydrology*, *334*(1), 290-303. https://doi.org/https://doi.org/10.1016/j.jhydrol.2006.10.018

PontchartrainConservancy. (2022, 19 Sept. 2022). *Caernarvon Freshwater Diversion and Delta*. scienceforourcoast.org/pc-programs/coastal/coastal-projects/archive-caernarvon-freshwater-diversion-and-delta/

Ramirez, M. T., & Allison, M. A. (2013). Suspension of bed material over sand bars in the Lower Mississippi River and its implications for Mississippi delta environmental restoration. *Journal of Geophysical Research: Earth Surface*, *118*(2), 1085-1104. https://doi.org/https://doi.org/10.1002/jgrf.20075

Rowiński, P. M., Västilä, K., Aberle, J., Järvelä, J., & Kalinowska, M. B. (2018). How vegetation can aid in coping with river management challenges: A brief review. *Ecohydrology & Hydrobiology*, *18*(4), 345-354. https://doi.org/https://doi.org/10.1016/j.ecohyd.2018.07.003

Schnapp, L., Rotschy, L., Hall, T., Crowley, S., & O'Rourke, M. (2012). How to talk to strangers: Facilitating knowledge sharing within translational health teams with the Toolbox dialogue method. *Translational behavioral medicine*, *2*, 469-479. https://doi.org/10.1007/s13142-012-0171-2

Seitz, R. D., Wennhage, H., Bergström, U., Lipcius, R. N., & Ysebaert, T. (2014). Ecological value of coastal habitats for commercially and ecologically important species. *ICES Journal of Marine Science*, *71*(3), 648-665. https://doi.org/10.1093/icesjms/fst152

Shih, J. T., Henville, A., & Vossen, J. (2019). Two mississippi river diversion structures two different floodway scour rehabilitation designs.*Scour and Erosion IX - Proceedings of the 9th International Conference on Scour and Erosion, ICSE 2018* 9th International Conference on Scour and Erosion, ICSE 2018, November 5, 2018 - November 8, 2018, Taipei, Taiwan.

Smagorinsky, J. (1963). GENERAL CIRCULATION EXPERIMENTS WITH THE PRIMITIVE EQUATIONS: I. THE BASIC EXPERIMENT. *Monthly Weather Review*, *91*(3), 99-164. https://doi.org/https://doi.org/10.1175/1520-0493(1963)091<0099:GCEWTP>2.3.CO;2

Snedden, G. A., Cable, J. E., Swarzenski, C., & Swenson, E. (2007). Sediment discharge into a subsiding Louisiana deltaic estuary through a Mississippi River diversion. *Estuarine, Coastal and Shelf Science*, *71*(1), 181-193. https://doi.org/https://doi.org/10.1016/j.ecss.2006.06.035

Snedden, G. A., Cretini, K., & Patton, B. (2015). Inundation and salinity impacts to above- and belowground productivity in Spartina patens and Spartina alterniflora in the Mississippi River deltaic plain: Implications for using river diversions as restoration tools. *Ecological Engineering*, *81*, 133-139. https://doi.org/https://doi.org/10.1016/j.ecoleng.2015.04.035

Sutton, S., & Kemp, S. (2006). Integrating Social Science and Design Inquiry Through Interdisciplinary Design Charrettes: An Approach to Participatory Community Problem Solving. *American journal of community psychology*, *38*, 125-139. https://doi.org/10.1007/s10464-006-9065-0

Temmerman, S., Horstman, E. M., Krauss, K. W., Mullarney, J. C., Pelckmans, I., & Schoutens, K. (2023). Marshes and Mangroves as Nature-Based Coastal Storm Buffers. *Annual Review of Marine Science*, *15*(1), 95-118. https://doi.org/10.1146/annurev-marine-040422-092951

Titze, D., Beletsky, D., Feyen, J., Saunders, W., Mason, L., Kessler, J., Chu, P., & Lee, D. (2023). Development and skill assessment of a real-time hydrologic-hydrodynamic-wave modeling system for Lake Champlain flood forecasting. *Ocean Dynamics*, *73*(5), 231-248. https://doi.org/10.1007/s10236-023-01550-2

Tompkins, E. L., Few, R., & Brown, K. (2008). Scenario-based stakeholder engagement: Incorporating stakeholders preferences into coastal planning for climate change. *Journal of Environmental Management*, *88*(4), 1580-1592. https://doi.org/https://doi.org/10.1016/j.jenvman.2007.07.025

Turner, R. E. (2006). Will lowering estuarine salinity increase Gulf of Mexico oyster landings? [Article]. *Estuaries and Coasts*, *29*(3), 345-352. https://doi.org/10.1007/bf02784984

USACE. (2022). *Final Environmental Impact Statement for the proposed Mid-Barataria Sediment Diversion Project Plaquemines Parish, Louisisana*. https://www.mvn.usace.army.mil/Missions/Regulatory/Permits/Mid-Barataria-Sediment-Diversion-EIS/

USACE. (2023). *Lower Mississippi River Comprehensive Management Study*. https://www.mvn.usace.army.mil/About/LMRComp/#:~:text=The%20Lower%20Mississippi%20River%20%28LMR%29%20Comprehensive%20Management%20Study,from%20Cape%20Girardeau%2C%20to%20the%20Gulf%20of%20Mexico.

USACE, Engineers, U. S. A. C. o., & District, M. V. D. R. P. a. E. D. S. N. O. (2022). *DRAFT ENVIRONMENTAL ASSESSMENT MISSISSIPPI RIVER, BATON ROUGE TO THE GULF OF MEXICO, LOUISIANA, NEPTUNE PASS ROCK CLOSURE, PLAQUEMINES PARISH, LOUISIANA EA #589*.

Walker, W. (2000). Policy Analysis: A Systematic Approach to Supporting Policymaking in the Public Sector. *Journal of Multi-criteria Decision Analysis*, *9*, 11-27. https://doi.org/10.1002/1099-1360(200001/05)9:1/33.3.CO;2-V

Walling, D. E. (2011). Human impact on the sediment loads of Asian rivers.

Wang, H., Chen, Q., La Peyre, M. K., Hu, K., & La Peyre, J. F. (2017). Predicting the impacts of Mississippi River diversions and sea-level rise on spatial patterns of eastern oyster growth rate and production. *Ecological Modelling*, *352*, 40-53. https://doi.org/https://doi.org/10.1016/j.ecolmodel.2017.02.028

Werner, M., Schellekens, J., Gijsbers, P., van Dijk, M., van den Akker, O., & Heynert, K. (2013). The Delft-FEWS flow forecasting system. *Environmental Modelling & Software*, *40*, 65-77. https://doi.org/https://doi.org/10.1016/j.envsoft.2012.07.010

White, E., Messina, F., Moss, L., & Meselhe, E. (2018). Salinity and Marine Mammal Dynamics in Barataria Basin: Historic Patterns and Modeled Diversion Scenarios. *Water*, *10*. https://doi.org/10.3390/w10081015

White, E. D., Meselhe, E., Reed, D., Renfro, A., Snider, N. P., & Wang, Y. (2019). Mitigating the Effects of Sea-Level Rise on Estuaries of the Mississippi Delta Plain Using River Diversions. *Water*, *11*(10).

Yang, S. L., Zhang, J., Dai, S. B., Li, M., & Xu, X. J. (2007). Effect of deposition and erosion within the main river channel and large lakes on sediment delivery to the estuary of the Yangtze River. *Journal of Geophysical Research: Earth Surface*, *112*(F2). https://doi.org/https://doi.org/10.1029/2006JF000484

Yoe, C. E., Burkes-Copes, K., & Schultz, M. T. B. C. S. (2010). *Addressing Risk and Uncertainty*

in Planning Ecological

Restoration Projects (EMRRP Technical Notes

Collection, Issue. http://el.erdc.usace.army.mil/emrrp/

emrrp.html

6. BIOGRAPHY

Laura Manuel is an Acadiana native of Ville Platte, LA. She pursued her B.S. in Civil Engineering from the University of Louisiana at Lafayette before moving to New Orleans to work towards her PhD in River Coastal Science and Engineering at Tulane University. Under the advising of Dr. Ehab Meselhe, she has experienced a period rich with education and invaluable experiences in a budding department. With the utmost integrity and wisdom, he has mentored her in engineering, ethics, and professionalism that she hopes will resonate throughout her career. Her graduate studies have been incredibly formative, equipping her with a deepened understanding of river and coastal processes. Her education has continued to foster a deep love of her home state and a continued desire to provide for the communities that have supported her throughout her life. She enjoys baking, painting, and any outdoor recreation, but her time best spent is with her loved ones, especially her 5 little nieces and nephews. Following graduation, she is blessed to be accepting a job in New Orleans, LA to continue engineering work for river and coastal applications.