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LOWERMOST MISSISSIPPI RIVER MANAGEMENT PROGRAM

Strategies and Scenarios Workplan

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PREFACE

This report summarizes a workplan to evaluate how various high-level strategies for managing water and sediment in the Lowermost Mississippi River (LMR) would potentially impact stakeholder concerns over the next 50 to 100 years. The evaluation framework would allow the intended and unintended consequences of these "what-if" strategies to be considered to help identify what changes in river management might warrant more detailed analyses. This work was conducted in support of the Louisiana Coastal Protection and Restoration Authority (CPRA) Lowermost Mississippi River Management Program (LMRMP).

The work described here builds on extensive expertise the Water Institute of the Gulf (the Institute) has developed in riverine hydrodynamic and sediment processes as well as in innovative techniques for working with stakeholders and decision-makers to co-produce actionable science. In addition, the evaluation framework design draws heavily upon extensive work that the Institute has conducted in collaboration with technical partners to understand and quantify the impacts of natural processes and human activities on the Mississippi River. The workplan was developed collaboratively with CPRA, which provided guidance on the needs of the evaluation framework to shape its development, helped refine the management strategies to be evaluated, ensured coordination with the other tasks of LMRMP and other CPRA programs, co-led the engagement of stakeholders, and helped drive the direction of the modeling framework development workplan. Royal Engineers & Consultants (Royal) also made substantial contributions to the effort through input on the needs of the evaluation framework, as well as coordination of stakeholder engagement and interaction with other LMRMP tasks.

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LIST OF ACRONYMS

Acronym	Term
BAU	Business as Usual
CPRA	Coastal Protection and Restoration Authority
CRCL	Coalition to Restore Coastal Louisiana
EDF	Environmental Defense Fund
ERDC	Engineer Research and Development Center
HDDA	Hopper Dredge Disposal Area
IPCC	Intergovernmental Panel on Climate Change
LASAAP	Louisiana Sediment Availability and Allocation Program
LASARD	Louisiana Sand Resource Database
LDNR	Louisiana Department of Natural Resources
LDWF	Louisiana Department of Wildlife and Fisheries
LMR	Lowermost Mississippi River
LMRMP	Lowermost Mississippi River Management Program
MVD	U.S. Army Corps of Engineers, Mississippi Valley Division
MVN	U.S. Army Corps of Engineers, New Orleans District
NGO	Non-governmental organization
NWF	National Wildlife Federation
NWR	National Wildlife Refuge
OMAR	U.S. Army Corps of Engineers Old, Mississippi, Atchafalaya, and Red River Assessment
ORCS	Old River Control Structure
PC	Pontchartrain Conservancy
PR&G	Principles, Requirements, and Guidelines
RCP	Representative Concentration Pathway
RSLR	Relative sea level rise
RSM	Regional Sediment Management
SDM	Structured decision-making
SLR	Sea level rise
SW Pass	Southwest Pass
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
WMA	Wildlife Management Area
WRDA	Water Resources Development Act

ACKNOWLEDGEMENTS

Several other members of the Institute provided conceptual input to the conceptual development of the LMRMP evaluation framework including Chris Esposito, Ioannis Georgiou, Francesca Messina, John Swartz, and Brendan Yuill; Mitch Andrus from Royal also provided input. Jordan Earls of the Coastal Protection and Restoration Authority (CPRA) participated in early meetings of framework development. Individuals from multiple entities provided input on stakeholder interests in the LMR region (see Appendix A for a list of representative agencies).

This report was reviewed by Jim Pahl of CPRA and Mitch Andrus of Royal, and edited by Charley Cameron of the Institute.

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INTRODUCTION

One of the primary goals of the Louisiana Coastal Protection and Restoration Authority (CPRA) Lowermost Mississippi River Management Program (LMRMP) is to identify and evaluate strategies for managing water and sediment within the Lowermost Mississippi River (LMR; Figure 1). Historically, the U.S. Army Corps of Engineers' (USACE) management of the LMR has focused on objectives that are each addressed independently of one another. These objectives include maintaining a navigable waterway, reducing flood risk to communities, and restoring and protecting ecosystems (e.g., use of riverine sediment and diversions to support marsh creation in the Mississippi River Delta; Figure 2). However, these objectives all rely on the effective management of river water and sediment. The use of a holistic approach for water and sediment management with mutual benefit across objectives, agencies (state and federal), and funding authorizations has the potential to be more cost effective, resilient, and sustainable for the Mississippi River and the communities, commerce, and ecosystems that rely on it. LMRMP aims to identify mutually beneficial holistic strategies for river management and assess what the outcomes of those potential approaches would be for the interests of CPRA and other stakeholders.

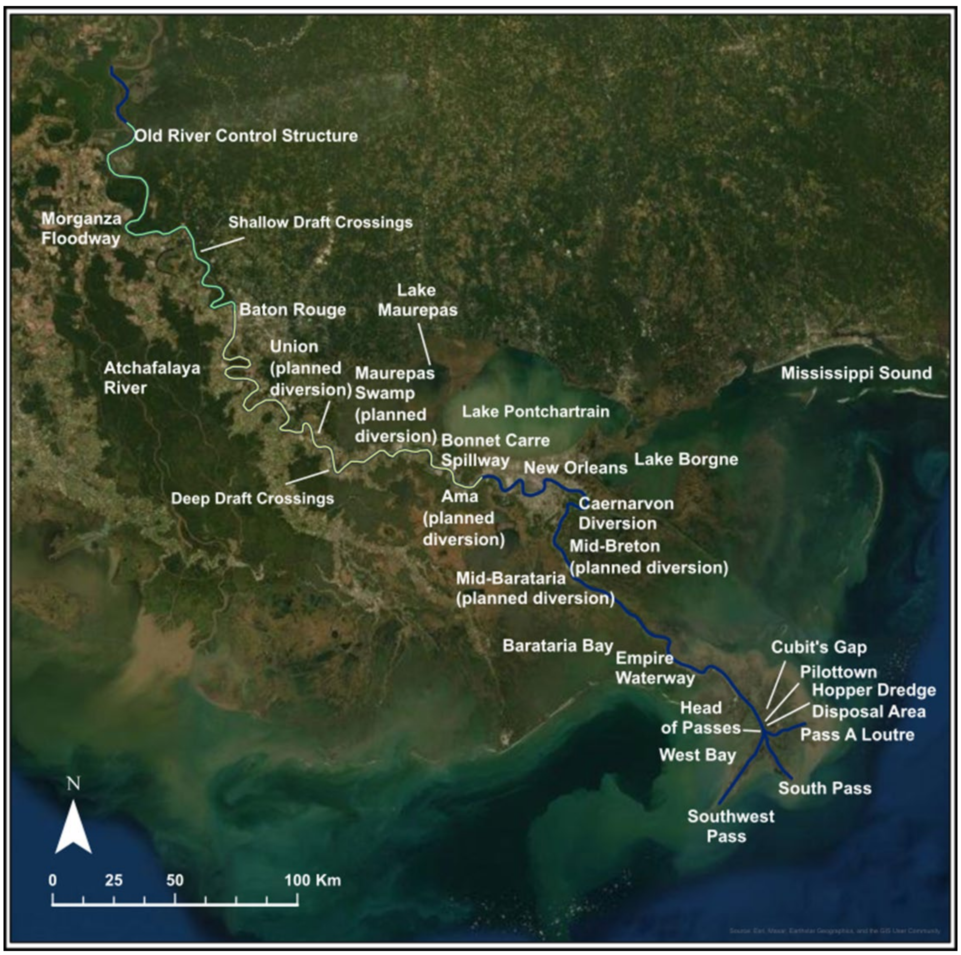

Figure 1. Lowermost Mississippi River (LMR) study area. Main river channel is shown in dark blue. The extent or reach in the river where the shallow draft crossings and deep draft crossings occur are drawn in green and yellow, respectively.

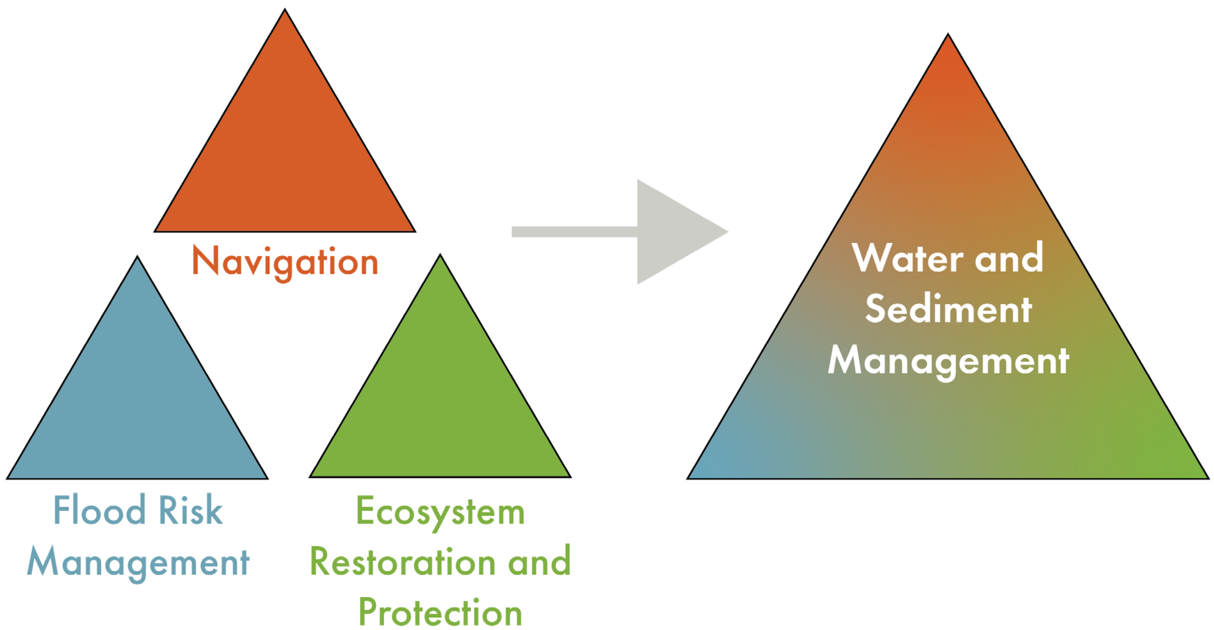

Figure 2. The Lowermost Mississippi River has historically been managed to independently achieve objectives such as navigation, flood risk management, and ecosystem restoration and protection (left). Each of these objectives relies on managing water and sediment in the LMR, however, and a holistic approach to river management could be a more resilient and sustainable way to address all concerns (right).

There are multiple tasks under LMRMP to support the overarching goal for holistic management of the LMR, one of which is a Strategies & Scenarios (S&S) task to identify specific alternate management strategies and develop an evaluation framework for assessing the likely outcomes of those strategies in the long-term (decadal time scales). In the first phase of the S&S task, described in this report, a structured decision-making (SDM) based approach was used to engage stakeholders and decision-makers, articulate objectives and desired outcomes for LMR management, and design the evaluation (modeling) framework for evaluating how the identified strategies would impact interests on the LMR. Key environmental factors that cannot be controlled, such as relative sea level rise (RSLR), were also identified so that the outcomes of management strategies across realistic (but uncertain) future scenarios can be considered. The final deliverable of this phase of the S&S task is the workplan which is provided herein. This LMRMP S&S Workplan describes the development of an evaluation framework for evaluating the outcomes of the alternate management strategies for stakeholder interests for the LMR identified as of April 2022 when this report was drafted. Once the workplan is executed, the evaluation framework can be used to investigate the implications of potential sediment and water management strategies on the range of federal/state decision-maker and stakeholder interests (ecosystem restoration and protection, flood risk management, maintaining navigation channels, etc.) over 50-year time scales.

This report is organized as follows. First, an overview of the process used to develop the LMRMP S&S Workplan is presented. The goal and objectives of LMR management—identified by CPRA and refined with input from external stakeholders—are then provided. This section is followed by a description of the management strategies and environmental scenarios that were identified and refined by the same groups. The components and design of the evaluation framework are then described, and lastly the proposed next steps of the S&S task are provided.

WORKPLAN DEVELOPMENT PROCESS

Because there are a large number of decision-makers and stakeholders with varying interests in the LMR, it was critical that a transparent and objectives-orientated approach be used for the identification of alternate management strategies, the design of the evaluation framework for those strategies, and for the selection of metrics that could be used in communicating the results. The process used in the development of the LMRMP evaluation framework, including identification of management strategies and environmental scenarios, was patterned after the "PrOACT" process used in Structured Decision Making (SDM; Figure 3). SDM is a formal technique used in decision framing and analysis that consists of a sequence of steps including:

- Identifying the **Pr**oblem: Articulating the scope of the Decision Context, i.e., the central issue or challenge that will be resolved and the potential decision-makers that would make those decisions.
- Articulating the **O**bjectives: Describing a set of objectives outlining the desired positive outcomes.
- Describing the **A**lternatives: Developing a list of potential options or choices for the decisions that could be made to achieve the objectives (in LMRMP, the term "strategies" is used).
- Evaluating **C**onsequences: Using a tool or model to systematically predict what the outcomes would be for the identified decision alternatives (herein "strategies").
- Considering **T**radeoffs: Identifying and/or quantifying what the positive and negative outcomes would be across all objectives for each alternative (herein "strategy").

SDM can help ensure that decision-making is transparent and objectives-orientated (Gregory et al., 2012), and can therefore be particularly beneficial when the decisions being made are complex or there are multiple stakeholders with potentially competing interests. The process used here was modeled after the overarching approach of PrOACT for the same reasons.

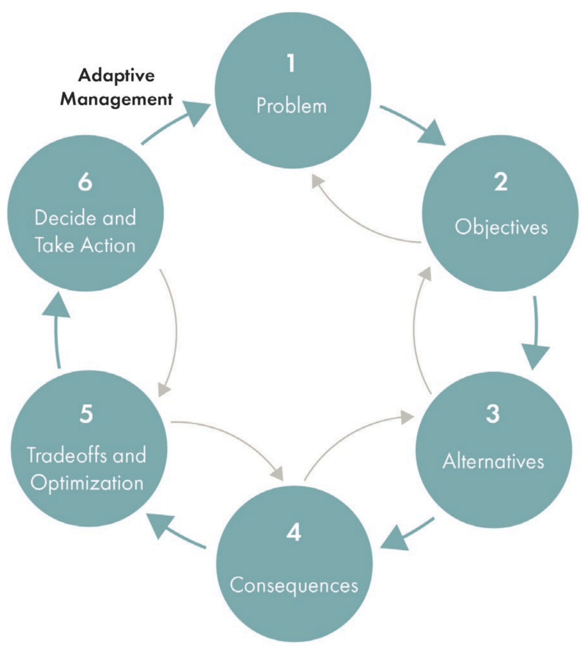

Figure 3. "PrOACT" process used in Structured Decision Making (SDM).

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The initial step in the S&S task was to use the principles of SDM to develop a workflow that would ultimately lead to the identification and evaluation of potential management strategies for more resilient, sustainable, and holistic management of the LMR (Figure 4). The S&S team, consisting of representatives from CPRA, the Institute, Royal, and others (Appendix A. Internal and External Engagement), then began execution of that workflow. The PrOACT cycle was adapted and applied to workflow development to ensure it advanced the objectives of CPRA and LMRMP.

The components of the LMRMP S&S task workflow include:

- Articulating the CPRA Decision Context (i.e., scope of what CPRA is trying to achieve) and Objectives.
- Evaluating synergy of CPRA interests with the Decision Context and Objectives of other agencies and stakeholders.
- Identifying potential alternate management strategies and future environmental scenarios for the LMR.
- Designing an evaluation framework for modeling the outcomes of the alternate management strategies across a range of environmental scenarios (i.e., future uncertainty in factors such as RSLR). This evaluation framework is the tool that will be used to predict the consequences and outcomes of alternate LMR management strategies.
- Evaluating the consequences and tradeoffs of alternate management strategies based on their outcomes (execution of this step is part of future work after the evaluation framework is developed).
- Implementing and adaptively managing LMRMP (execution of this step is part of future work and encompasses CPRA decision-making enabled by the S&S task).

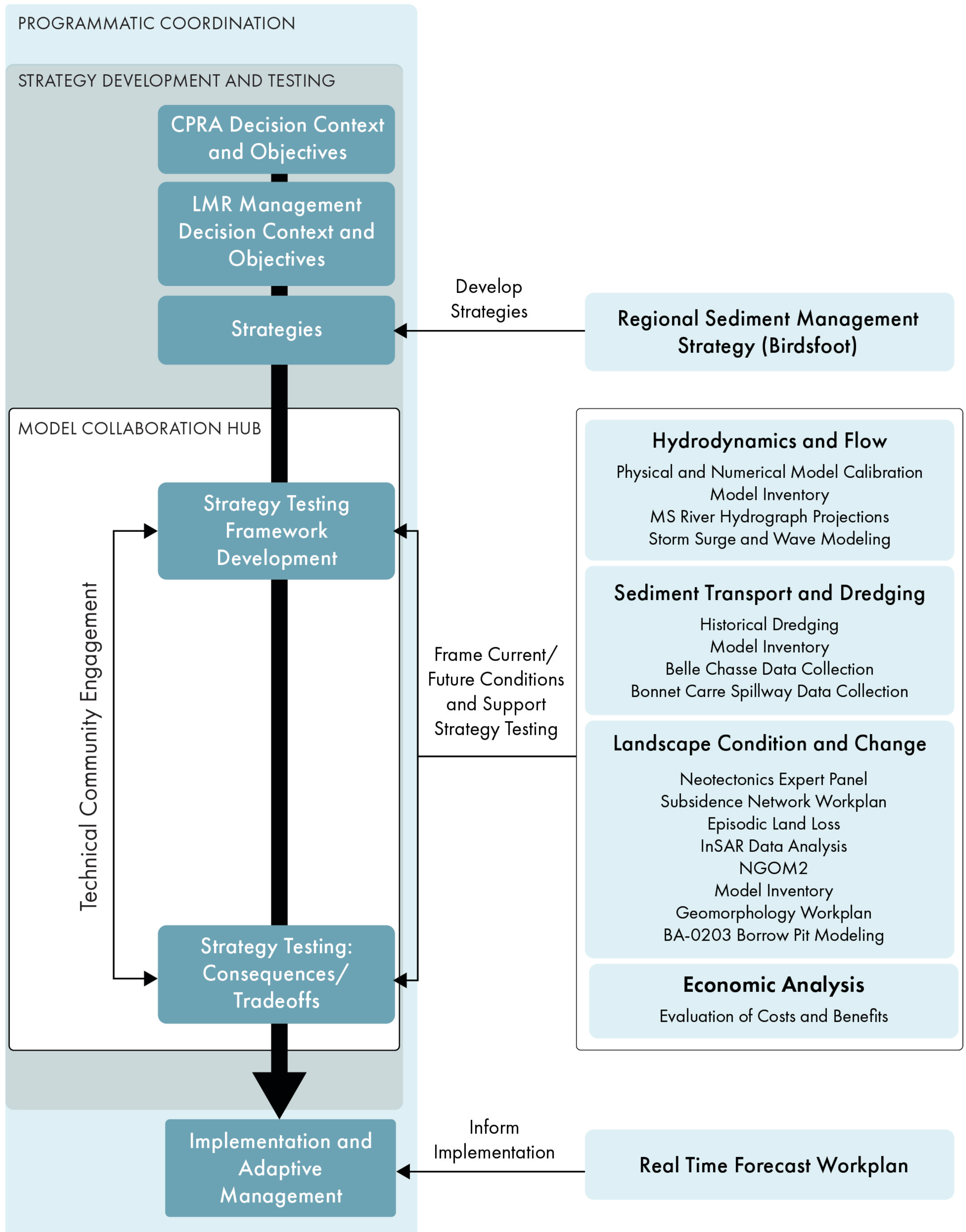

Figure 4. Workflow of the development of the LMRMP Strategies and Scenarios (S&S) task evaluation framework (dark blue boxes), as well as the interaction of that workflow with other tasks within the LMRMP program (light blue boxes).

The proposed LMRMP S&S Workplan is intentionally designed to connect with other tasks in the LMRMP (Figure 4) and ultimately has the potential to connect with other initiatives such as the Coastal Master Plan (Master Plan) and U.S. Army Corps of Engineers (USACE) planning efforts. Linkages to other LMRMP tasks include:

- **Regional Sediment Management (RSM) Strategy (bird's foot)**: Identification of alternative methods of managing the sediment dredges from the river downstream of Venice, LA. The approaches identified by this task will be included in the suite of management strategies to be tested with the S&S evaluation framework.
- **Model Inventory**: A list that is being created of existing numerical models and their outputs for the LMR. These models will be considered for use in parameterizing the S&S evaluation framework.
- **MS River Hydrographs**: Prediction of the river hydrograph for the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathways (RCPs) 4.5 and 8.5 (IPCC, 2014). The S&S evaluation framework will use these predictions as upstream boundary conditions for plausible future scenarios.
- **Storm Surge and Wave Modeling**: Modeling of storm conditions for a set of synthetic storms under varying river flow conditions. The S&S evaluation framework will use these predictions and downstream and lateral boundary conditions for plausible future scenarios.
- **Historical Dredging**: Synthesis and analysis of historical dredging activity in the LMR below Baton Rouge. This analysis will serve as input to the dredging operations and sediment budget for evaluating existing river management strategies and to an economic analysis for RSM and evaluation of alternative river management strategies.
- **Belle Chasse Data Collection**: Collection of sediment and flow data that the S&S evaluation framework will use for evaluating current conditions.
- **Economic Analysis of Current and Alternative Management Strategies**: Analysis of the costs and potential benefits of alternate LMR management strategies that will inform their viability under the LMRMP S&S Workplan.

The workflow began with identification of the CPRA Decision Context and Objectives for LMR management through a series of working sessions with the S&S team and other representatives from CPRA. These sessions were also used to develop a draft list of high-level management strategies for the LMR (i.e., "what-if" approaches) and environmental scenarios for consideration with the evaluation framework. After initial drafting, stakeholders were then engaged to elicit their input on objectives and desired outcomes for management of the LMR, as well as to provide feedback and input on the draft list of management strategies and environmental scenarios. Stakeholders were also asked to provide input on specific outputs that would be of concern to them (i.e., areas of the LMR where they had interests, such as land management) and to suggest quantifiable metrics that could potentially be valuable to compare in considering the impacts of alternate management strategies. In addition to providing valuable input to the S&S evaluation framework development process, this direct engagement—which will continue as the S&S evaluation framework is developed—facilitates transparency with stakeholders and ensures their interests are understood and considered. The list of stakeholders and decision-makers for engagement included representatives from:

- **Federal Regulatory Entities**
  - U.S. Army Corps of Engineers (USACE)
    - New Orleans District (MVN)
    - Mississippi Valley Division (MVD)

- **State Regulatory Entities**
  - Louisiana Department of Transportation and Development (DOTD)
  - Louisiana Department of Natural Resources (LDNR) Office of Coastal Management

- **Land Management Entities**
  - Louisiana Department of Wildlife and Fisheries (LDWF), Pass á Loutre Wildlife Management Area (WMA)
  - U.S. Fish and Wildlife Service (USFWS), Delta National Wildlife Refuge (NWR)

- **Ports**
  - Ports Association of Louisiana (primary coordination)
  - Secondary coordination may include outreach to individual ports, as needed

- **Navigation Community**
  - Big River Coalition
  - Associated Branch Pilots

- **Environmental Groups (Non-Governmental Organizations [NGOs])**
  - Environmental Defense Fund (EDF)
  - National Wildlife Federation (NWF)
  - Coalition to Restore Coastal Louisiana (CRCL)
  - Pontchartrain Conservancy (PC)
  - Secondary coordination may include additional entities if requested

- **Public and Other Stakeholders**
  - A public webinar was held through the National Academies of Sciences (NAS), Engineering and Medicine Gulf Research Program, and a second one may be held later in the project timeline.
  - Secondary coordination and direct outreach may include technical experts, practitioners, natural resource users, parishes, other landowners, and levee districts as needed.

As noted above, outreach for some entities has already occurred and is expected to continue during the evaluation framework development process. Engagement with external stakeholders was conducted through email, personal outreach, and meetings that were primarily held virtually due to the COVID-19 pandemic (Appendix A). This elicitation focused on refining (1) the objectives of LMR management; 2) the suite of management strategies; and 3) the types of output the evaluation framework should produce to be relevant to the needs of decision-makers and stakeholders. Questions asked included:

- What opportunities and/or concerns do you see relative to your entity's roles and responsibilities?

- Do you have guiding principles (e.g., long-term management plans, etc.,) for managing lands, flood risk management, ports, navigation and commerce, etc. that would be impacted or relate to the strategy? What can/should LMRMP consider?
- What parameters or information would be helpful for LMRMP to provide to inform your decision-making or investigate the impact of the strategy on your areas of interest?
- Are there specific strategies that would be beneficial for you to see investigated?

The LMRMP goal and objectives, management strategies, and environmental scenarios were refined by the S&S team based on the input of external decision-makers and stakeholders. This refinement included adding more specific variants of alternate management strategies and defining the underlying assumptions associated with each.

In addition to the entities listed above, the S&S team engaged other subject matter experts, agencies, and programs that could provide technical input to the development of the evaluation framework and/or that could potentially utilize its outputs in the longer term. These included Federal research entities engaged through the LMRMP Community of Practice and other tasks on LMRMP (the USACE Engineering Research and Development Center [ERDC], the U.S. Geological Survey) as well as the CPRA Diversions Program (staff and private design firms contracted for Mid-Barataria and Mid-Breton Sediment Diversions Engineering and Design) through the joint Mid-Diversions Tech Transfer Workshops.

LOWERMOST MISSISSIPPI RIVER OBJECTIVES

The following goal and objectives were articulated for LMR management by the CPRA representatives on the S&S task team (Table A-1) through a series of discussions facilitated by the Institute:

Goal of Lowermost River Management: Holistic approach to water and sediment management that supports the long-term sustainability and benefits of the LMR.

CPRA and State of Louisiana Objectives for Lowermost River Management:

1. Support the long-term sustainability of the coast, reducing land loss and collapse to the greatest degree possible.
2. Enhance the health of ecosystems associated with the LMR.
3. Mitigate threats to communities and infrastructure posed by flooding.
4. Maintain and enhance channels that support use of the LMR for navigation.
5. Manage the LMR holistically, maximizing the benefits across all objectives.

The goal and objectives above formed the basis for the development of the LMRMP's alternate management strategies. In addition, they are the underlying principles for selecting the outcomes that the evaluation framework will predict to inform which strategies to potentially pursue for more in-depth analysis in the longer-term.

MANAGEMENT STRATEGIES AND ENVIRONMENTAL SCENARIOS

A draft suite of LMRMP "what-if" management strategies was developed based on the potential to advance the *Lowermost Mississippi River Objectives*. In addition, some draft strategies were included based on their potential to provide immediate benefit in advancing the objective of sustainably managing the LMR (for example, management of the Hopper Dredge Disposal Area [HDDA], an area near Southwest [SW] Pass used for disposing of sediment removed from that main navigation channel). The draft management strategies were developed with a tiered approach, with the S&S team first identifying six high-level strategies, then engaging stakeholders for their input and suggestions, and finally adding and refining specific variants for each strategy based on internal and external discussion.

The strategies and their variants will be refined and finalized as part of the ongoing S&S task and may include:

1. **Business as Usual (BAU):** Sediment/flow management based on USACE guidance and construction of projects identified in the 2023 Master Plan (White, 2021) and funded as of 2022. Variants may include:

    a. **Current landscape**: All flow/sediment operations as conducted under present conditions, as well as the funded River Reintroduction into Maurepas Swamp.
    b. **Reasonable foreseeable future**: Adds Mid-Barataria and Mid-Breton Sediment Diversions to the current landscape variant.

2. **Integration of Flow Considerations into Diversion Management or Diversions into Flood Fight:** Variation of the siting and operation of diversions to preserve ecological benefits while minimizing freshwater releases through floodways, specifically through the Bonnet Carré and Morganza spillways. The specific variations of this strategy will be refined and may include:

    a. **Diversion operations:** Varying operations of the Ama, Union, and Lake Maurepas (and possibly others) diversions based on seasonally variant flow triggers to evaluate the cumulative impact, including operation alternatives under consideration by CPRA.
    b. **Diversion siting:** Varying the location of planned diversions within a range that still allows for sediment delivery and benefits to the intended marsh and basin locations. Only diversions with locations that have not yet been finalized will be considered for these variations.

3. **Sediment Management Strategies for SW Pass and the HDDA:** alternate placement areas for sediment in the coastal system. May include:

    a. **Cut across:** Transport of material from the HDDA via cutterhead dredge to stockpile or staging area directly west of Head of Passes (south of West Bay). Sediment is then used for the Barrier Island System Management program along the Barataria Bight.

b. **Relocation of the HDDA:** Initial dredging of Pilottown Anchorage and establishing a HDDA at the present location of the Pilottown Anchorage.

4. **Alternate Navigation Channel Alignment (abandon SW Pass as Deep Draft Navigation Channel):** alternate courses for the main navigation channel for the southern LMR. The courses for evaluation are under development and may include:

    a. Establish a different course with shortest route to 60 ft isobath (approximately Empire). Flow and a shallow draft navigation channel would be maintained through the bird's foot delta.

5. **Adjust Flow Ratio at the Old River Control Structure (ORCS):** Remove constraint for diversion of 30 percent of flow to go down the Atchafalaya River and consider seasonal and dynamic flow split thresholds. The variants of this strategy will be refined based on available data and model output, as well as on external constraints (for example, flow needs associated with hydroelectric power generation). If available, the variants of this strategy may be based in part on:

    a. **USACE Old, Mississippi, Atchafalaya, and Red River (OMAR) Assessment:** Flow distribution changes considered by USACE in the ongoing OMAR technical assessment under the authority of the Mississippi River and Tributaries program.

Additional information about the underlying assumptions of each management strategy can be found in Appendix B.

The environmental scenarios that are tested with the evaluation framework will vary across factors that have significant potential influence on achieving the objectives of LMR management, such as variability in the LMR hydrograph and RSLR. In addition, the impacts of varying storminess and associated storm surge will be considered. The environmental scenarios will be selected, in part, based on the range of parameters used in the Master Plan and by USACE in project design. This approach creates synergy with existing planning tools and increases the likelihood the framework output will catalyze changes in management approaches.

Factors that will be considered in environmental scenarios and their sources:

- Eustatic (global) sea level rise (SLR), select scenarios taken from USACE planning guidance (USACE, 2019) and 2023 Master Plan modeling (White, 2021)
- Subsidence, select scenarios taken from 2023 Master Plan modeling (Fitzpatrick et al., 2021)
- Storminess, select scenarios taken from:
    - LMRMP USACE ERDC revised storm suite, which varies intensity and frequency (note, does not vary storm tracks; currently under development), and
    - The 2023 Master Plan (Johnson & Geldner, 2020)
- LMR hydrograph, select scenarios taken from:
    - LMRMP task predictions of Mississippi River hydrodynamics under IPCC scenarios RCP 4.5 and RCP 8.5 (currently under development), and

- Future assuming variability within the current LMR hydrograph, consistent with the 2023 Master Plan (White, 2021)

The evaluation framework will investigate the changes in LMR water and sediment flows and the likelihood of advancing the LMR objectives across the range of environmental scenarios by varying these factors. In addition, the framework will consider how the uncertainty associated with these environmental scenarios, as well as with the expected response of the LMR system, impacts outcomes of interest to CPRA and other stakeholders.

STRATEGY AND SCENARIO EVALUATION FRAMEWORK

A core component needed for the S&S evaluation framework is an environmental module that can predict the movement of water and sediment through the LMR under varying management strategies and environmental scenarios. Various one-, two-, and three-dimensional numerical modeling approaches have been previously applied to predict the response of the LMR to natural drivers and management alternatives, including Delft3D (e.g., Edmonds, 2012; Meselhe et al., 2016; Yuill et al., 2015), FVCOM (e.g., Georgiou et al., 2017), and HEC-6T and HEC-RAS (e.g., Allison & Pratt, 2013). In the case of 2D and 3D models, these frameworks are often computationally expensive to run and therefore the number of simulations that can be considered is limited. In addition, the use of a deterministic model precludes data-driven approaches such as machine learning and the use of ensemble techniques that leverage outputs from multiple sources of input, which can improve the accuracy in predicting outcomes for complex systems such as the LMR (Saleh et al., 2016; van der Wiel et al., 2019).

A series of facilitated working sessions with CPRA representatives on the S&S team were used to determine the environmental modeling approach to use for the evaluation framework (Appendix A). First, a set of guiding principles were developed for the evaluation framework structure and its components to help ensure they supported the overall objectives of the LMRMP program while also being feasible to create and implementable on a reasonable timeline (1–2 years).

The design principles of the evaluation framework were that it can:

1. Inform LMR outcomes under high-level management strategies over 50-to-100-year timescales and be practically useful in decision-making (i.e., feasible to run on existing computational resources, computationally efficient with a run-time of minutes to hours, capability of evaluating management strategies across a range of environmental scenarios) by
2. Leverage existing data, models, studies, planning tools (Master Plan), institutional knowledge, and lessons learned in previous efforts wherever possible (i.e., allows input source information from different agencies and institutions to be used as boundary and forcing conditions) to create
3. Be a 'living' model which can be continually improved and updated with new data, model output, and other information as it becomes available (as part of an adaptive management approach to the LMR).

Based on these criteria, it was determined that a system dynamics ("stock/flow") model would be appropriate for the environmental prediction component (Figure 5). Stock/flow models are mass-conserving approaches, originally developed for modeling complex industrial systems, that consist of a set of mass or volume containing stocks (i.e., cells or boxes) to describe the system of interest, with material moving between stocks via flows (fluxes of mass or volume; Ford, 2000; Forrester, 1958). Flows within the model are dictated by set of prescriptive relationships that can vary in complexity. System dynamics models have been applied to environmental management problems including water resource allocation, surface/groundwater systems, and flood risk management, and are applicable to complex systems where it may be challenging to fully parameterize traditional physics-based numerical models or where it is difficult to link other types of models to stakeholder engagement and management decisions (Madani & Mariño, 2009; Mashaly & Fernald, 2020; Mirchi et al., 2012; Sehlke & Jacobson, 2005; Stave, 2002).

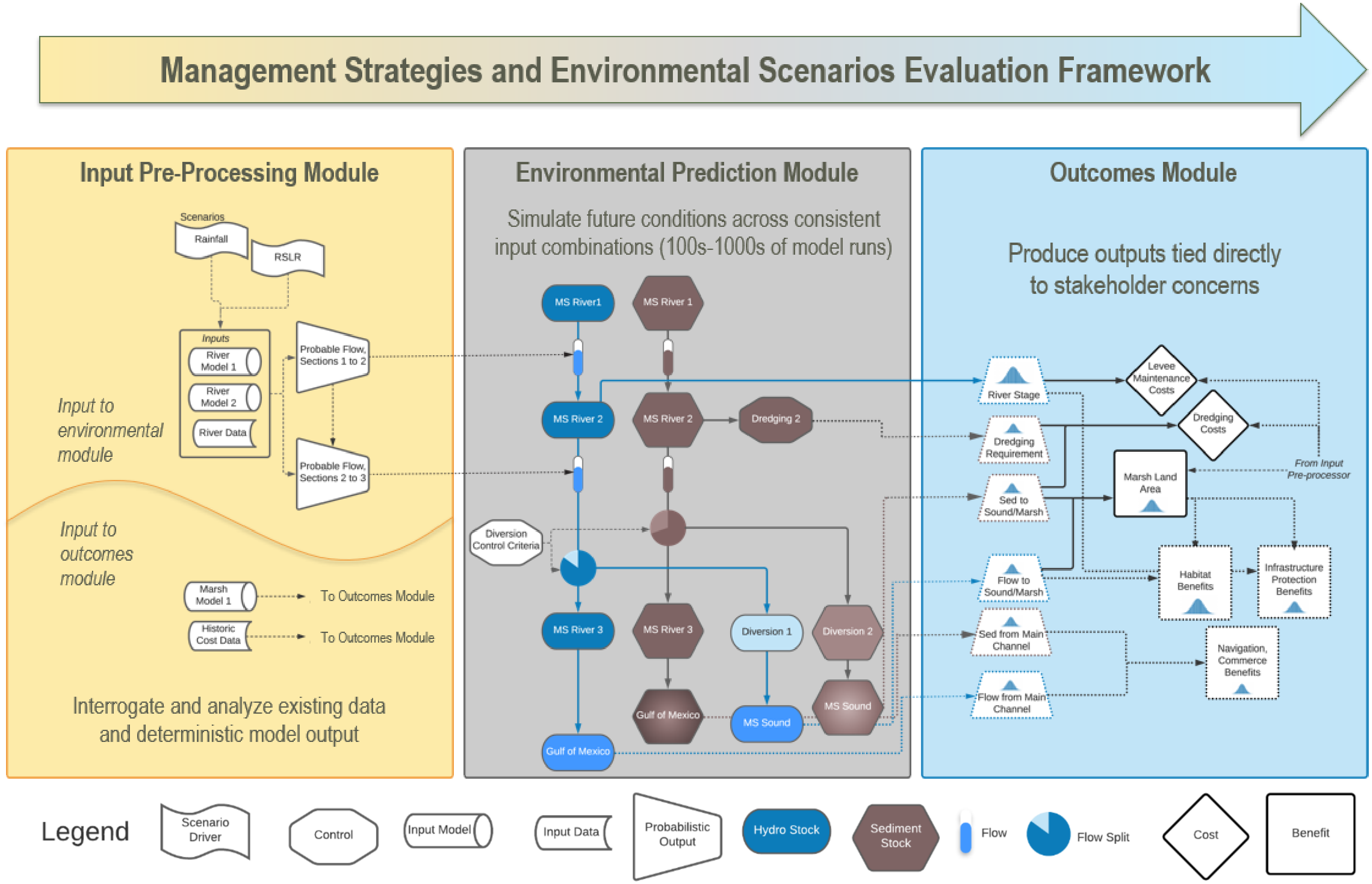

Figure 5. Components of the LMRMP evaluation framework for evaluating the outcomes of alternate management strategies for the LMR across a range of environmental scenarios (i.e., future conditions). Note this is a simplified example for communication purposes. The full evaluation framework would consider 100s of datasets and models and would have as many stocks and flows as needed for each strategy being evaluated. Flow chart elements created with LucidChart®.

A stock/flow model was selected as the best choice for the environmental prediction component of the evaluation framework because it will allow sediment and water to be tracked as it moves down the LMR; flows can be parameterized using a variety of input data sources and updated as new information becomes available; and individual simulations can be run quickly and efficiently for a range of management strategies and environmental scenarios (estimated computational time of minutes to hours on a desktop computer). In addition, a unique and powerful capability of the envisioned stock/flow model is that the domain and stocks can be dynamically adjusted based on the management strategies and environmental scenarios being simulated. Most environmental models rely on a grid that is finalized as part of calibration and validation. Because varying the grid requires the model be recalibrated, it typically remains fixed for all simulations even if that results in loss of computational efficiency (e.g., the grid size is determined based on the largest area of interest and the finest spatial resolution needed across all simulations, even if some of the simulations could be conducted with a smaller domain or coarser resolution at substantial savings of computational run time). In contrast, the stocks within a stock/flow can be dynamically allocated and readily adjusted to be as computationally efficient as possible. For example, simulations investigating strategies to vary the flow distribution of the Atchafalaya and Mississippi Rivers can include stocks that resolve the flow channels of the ORCS, while the domain for strategies that do not includes the ORCS can start downstream of this location. Lastly, system dynamics models are well-suited for conducting "what-if" scenarios on the time and spatial scales of interest to LMRMP and can produce outputs that link directly to stakeholder concerns.

There are two other components of the evaluation framework that are designed to work in concert with the environmental prediction module. The first is an input pre-processing module to produce predictions of water and sediment flow as a function of LMR conditions through analysis of existing data and deterministic model output. The outputs of the input pre-processing module will be used to parameterize flows within the environmental prediction module. Lastly, there is an outcomes module that will analyze the output from the environmental prediction module and quantify a select set of metrics of interest to stakeholders (described in the "Quantitative Outcome Metrics" Section). The output of this module will be combined with qualitative analysis of evaluation framework predictions for assessing management strategy impacts. The module design will be refined during workplan implementation; however, specifics on the draft concept are provided below. The modeling platform will also be finalized during workplan implementation, but will likely be coded in an open source, open access platform such as Python.

INPUT PRE-PROCESSING MODULE

The input pre-processing module will consist of a set of tools for accessing and analyzing existing data and deterministic model output to provide input to the environmental module. The input pre-processing module will include an inventory (or database) of available source data and model output. A model inventory was begun as part of a separate task under LMRMP; this inventory is being expanded to include a broader list of deterministic model output and to include observational data. In addition to supporting the environmental prediction module, this inventory will identify and include, where possible, data that can be used to derive outcomes of stakeholder interest from the environmental prediction module. For example, the existing Master Plan Integrated Compartment Model (White, 2021) runs that predict the marsh land area creation may be used as the basis for using sediment outflow to sub-basins (output from the environmental prediction module) to estimate associate marsh land area created.

The second component of the pre-processing module will be a set of computational tools to analyze the input data and derive probabilistic relationships that calculate the hydrodynamic and sediment flow for each location within the environmental prediction module as a function of upstream conditions. These relationships will build, where possible, on prior analysis that has been done under other tasks within LMRMP and elsewhere. For example, the historical dredging analysis task provides high-frequency time-series bathymetric data that will be used to estimate bed sediment flux through the Crossings region of the LMR; this work will be functionalized as a predictive set of relationships. The form of these relationships will be refined as they are developed, but are likely to include both analytical and probabilistic approaches. In an analytical or semi-analytical approach, a specific formula would be developed that relates the flow at one point in a river to a set of specific upstream parameters (for example, the hydrodynamic flow between two stocks in the environmental prediction module might be a function of the head difference between the stocks). In some cases, probabilistic approaches and machine learning techniques that directly interrogate empirical data and deterministic model output may be used. This approach maximizes the use of data and existing information in the model framework. For example, machine learning approaches can be used to robustly predict outcomes over the range of historical conditions along with quantification of uncertainty based on historical variability if sufficient data are available for training the model, whereas analytical approaches are more appropriate to predict outcomes outside the range of historical conditions. The relationships that are developed within the pre-processing module will then be incorporated into the environmental prediction module to predict the flows between stocks for each model simulation.

Lastly, the pre-processing module will include algorithms that derive the range of environmental prediction module parameters associated with each management strategy and environmental scenario. This analysis allows the set of simulations that are run with the environmental prediction module to be robust, internally consistent, and representative of the strategies and scenarios. For example, one of the management strategies planned for modeling with the evaluation framework is variation of operating protocols of diversions to provide benefit in reducing flood risk while maintaining their benefit in marsh creation. The pre-processing module can use output from deterministic models that simulated the diversion outflows to identify the range of flows down each diversion to identify the realistic range of flow conditions that could be achieved by varying operations (and thus, what can be considered under that management strategy).

ENVIRONMENTAL PREDICTION MODULE

The core of the environmental prediction module is a stock/flow model that predicts river conditions over the range of management strategies and future environmental scenarios. Reaches of the river are represented as “stocks”, that is, control volumes capturing the amount of water and sediment within that section of the river. The transport of water and sediment down the river is represented by flows, which capture the volume of water and associated mass of sediment moving between stocks. The design of the stock/flow model will be finalized with the development of the evaluation framework; however, an initial conceptual design has been created and is included here. Each stock will include two vertical layers: a hydrodynamic cell capturing the water column and a bed cell capturing the river sediment bed (Figure 6). Flows between the hydrodynamic cells will represent volume of water movement, with suspended sediment mass flux captured based on the suspended sediment concentration parameter that can vary in space and time. Bedload sediment transport between bed cells can occur through direct mass transfer flow from one cell to the next. Sediment will also be allowed to move between hydrodynamic and bed cells, with vertical mass flux resulting in changes in suspended sediment concentration and sediment bed mass, respectively. Flows between stocks will be prescribed based on the relationships derived by the input pre-processing module. Each of the stocks can be associated with a set of parameters that can be predicted as a function of river conditions, such as river and navigational channel depth. The formulations to estimate these parameters will be developed as part of the input pre-processing module, with the same types of calculation methods (analytical formulation, machine learning, etc.) as those considered for the movement of water and sediment through the system.

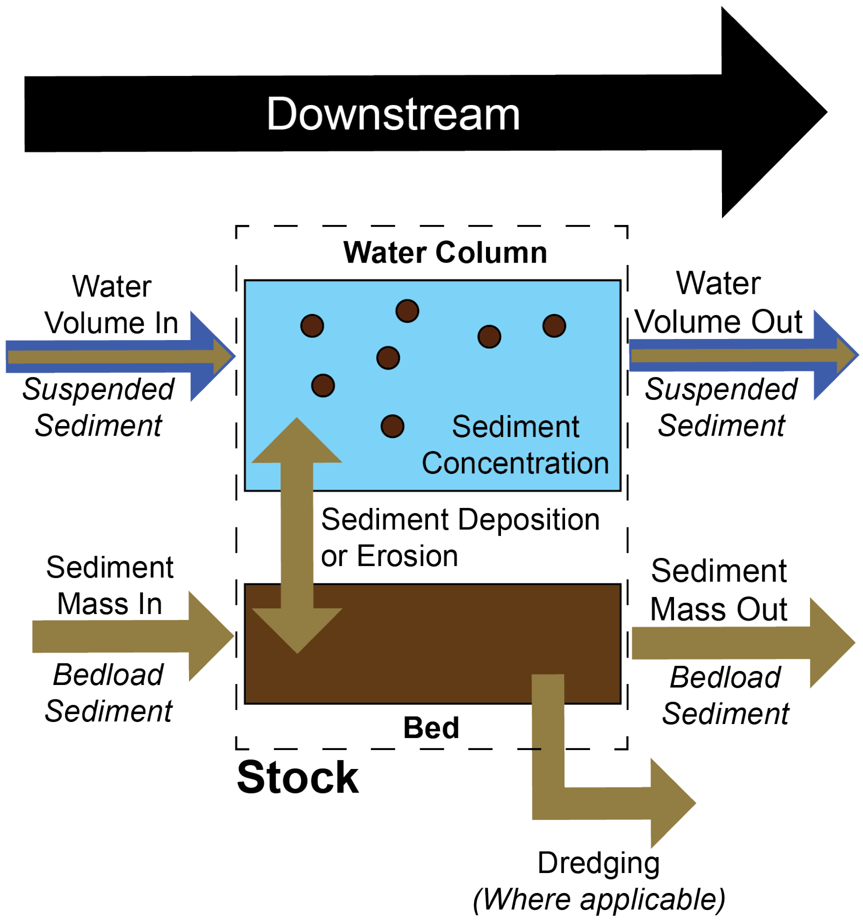

Figure 6. Diagram of the interaction between stocks within the environmental prediction module.

There are no constraints on the size of stocks within a systems dynamics model, therefore the S&S team will identify stocks based on identifying divisions in the river where the dynamics might vary, input data were known to be available to allow differentiation, and/or based on relevancy to LMR management (draft initial conceptual diagram shown in Figure 7). For example, dredging data are available for individual crossings in the LMR and resolving the frequency and magnitude of sediment deposition/removal for each of those crossings is of management relevance, so each crossing is included as a separate stock (Figure 8). Similarly, stock boundaries within the southernmost portion of the LMR may be dictated, in part, by the need to resolve diversions, siphons, and other LMR outflows (Figure 9).

The stock/flow model design is highly modular and adaptable, and may be varied somewhat for individual management strategies. For example, the internal structure of the ORCS may be resolved as needed to inform the outcomes of varying operation of that structure (Figure 10), whereas for other management strategies the entire ORCS may be resolved as a single stock with flows to the Atchafalaya and Mississippi rivers.

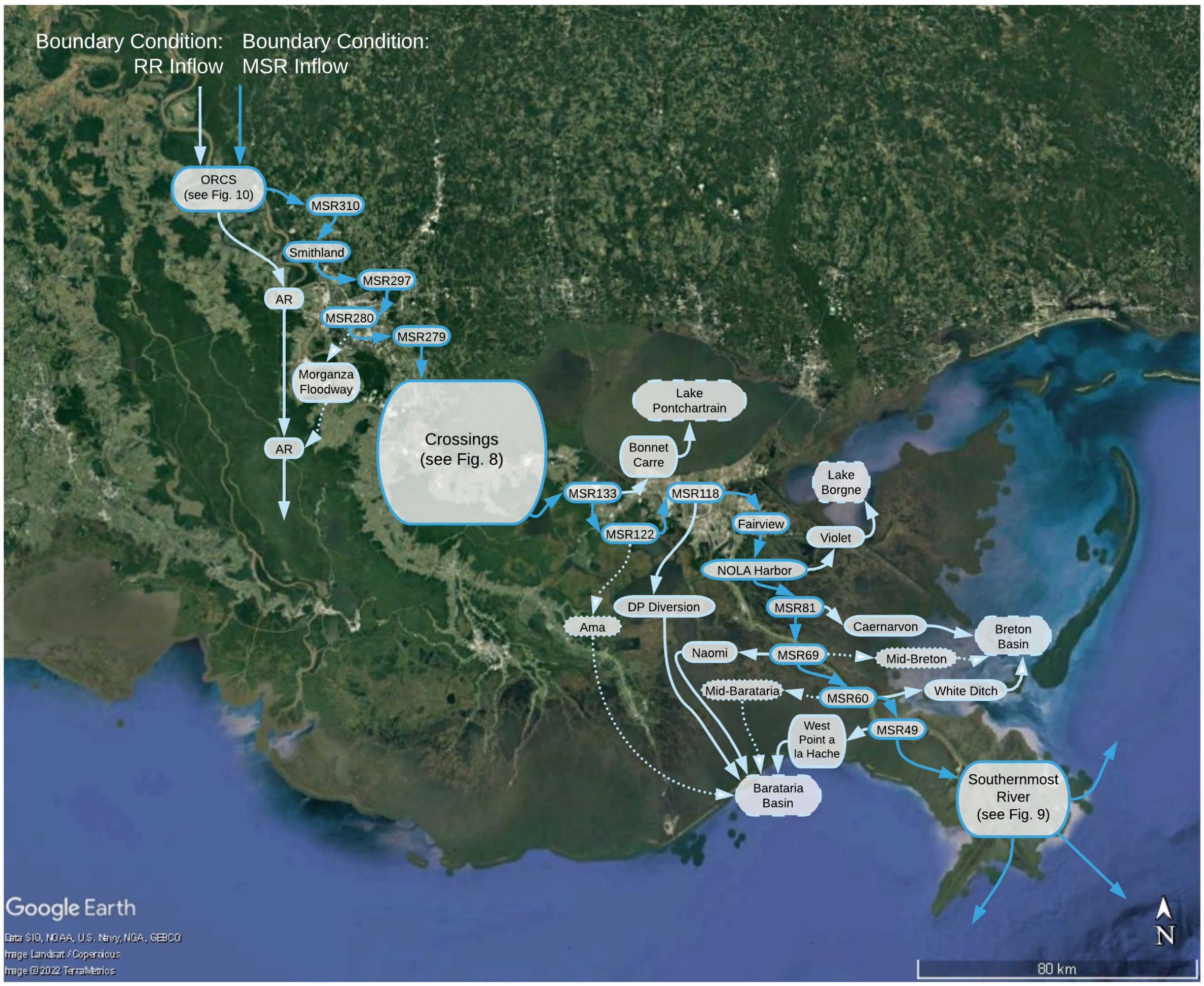

Figure 7. Draft stocks and flows that comprise the design of the environmental prediction module, which includes portions of the Mississippi River (MSR), Red River (RR), and Atchafalaya River (AR). Details of the Old River Control (ORCS) section of the LMR is shown in Figure 10; the Crossings section is shown in Figure 8; and the southernmost LMR section is shown in Figure 9. Dark blue borders indicate the main stem of the MSR model and light blue borders indicate outflows. Background imagery courtesy of Google Earth® and flow elements added with LucidChart®.

Figure 8. Mississippi River (MSR) stocks and flows that comprise the Crossings section of the environmental prediction module. Background imagery courtesy of Google Earth® and flow elements added with LucidChart®.

Figure 9. Mississippi River (MSR) stocks and flows that comprise the Southernmost LMR section of the environmental prediction module. Background imagery courtesy of Google Earth® and flow elements added with LucidChart®

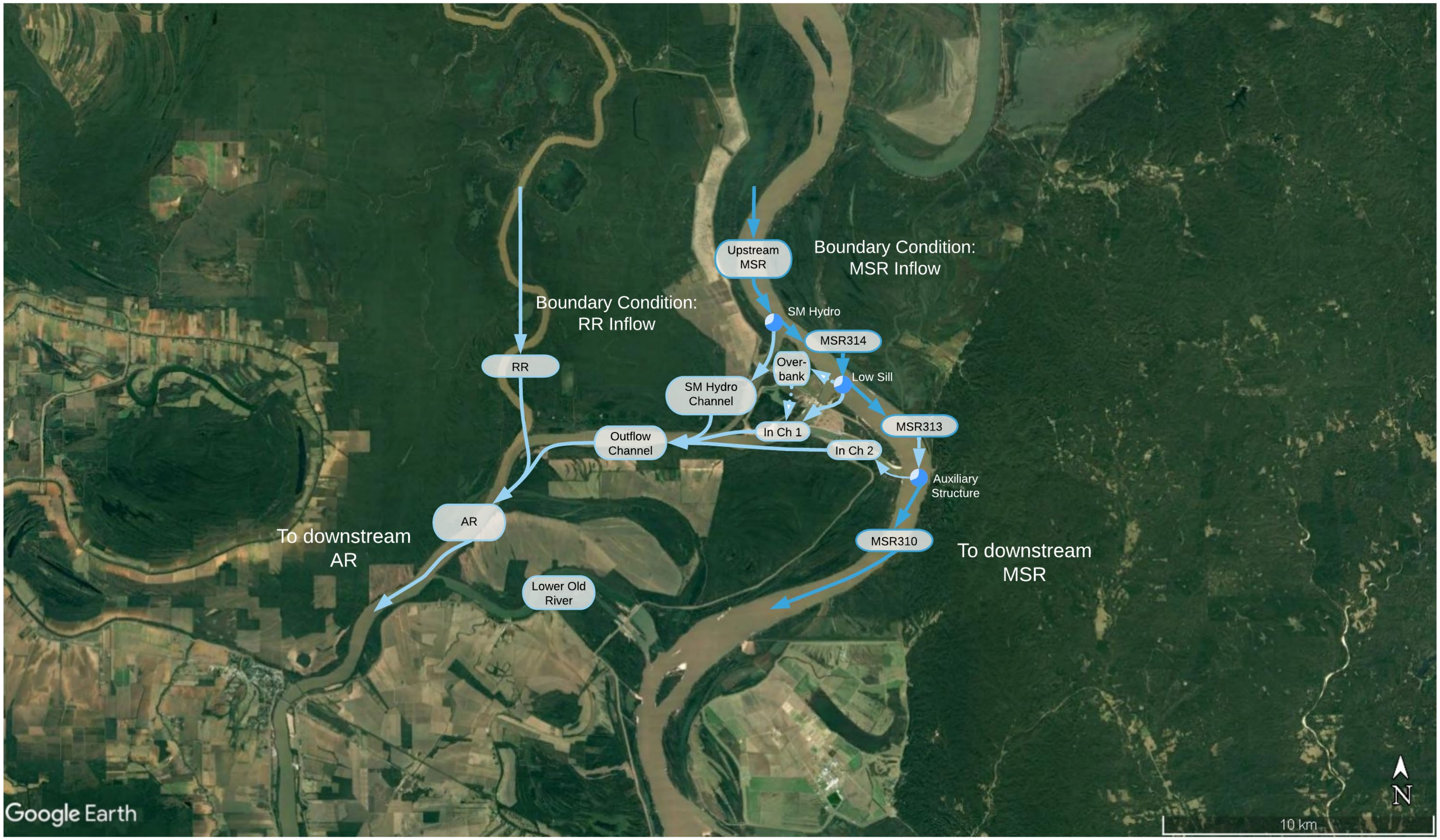

Figure 10. Stocks and flows that comprise the Old River Control Structure (ORCS) section of the environmental prediction module, which includes portions of the Mississippi River (MSR), Red River (RR), and Atchafalaya River (AR), as well as the Sydney Murray (SM) Hydroelectric Station. Background imagery courtesy of Google Earth® and flow elements added with LucidChart®.

The rapid computational time associated with stock/flow models allows many (hundreds to thousands) simulations to be run across a variety of conditions, thus allowing the environmental prediction module to consider a broad range of uncertainty when evaluating the outcomes of management strategies. For each management strategy, the range of parameters associated with the environmental scenarios (RSLR, variations in the LMR hydrograph, etc.) will be sampled to develop the range of plausible combinations. The environmental prediction module (Miner, 2007) will simulate these combinations to predict a range of possible outcomes for each management strategy across the uncertainties. In doing so, the outcome of each strategy can be considered under varying potential futures. For example, one management strategy may perform well under a moderate rate of RSLR but result in much poorer outcomes if RSLR is on the higher end of predicted values.

OUTCOMES MODULE

After the environmental prediction module has simulated a range of future LMR conditions across varying environmental scenarios, the output will be passed to an outcomes module for translating that output into decision-relevant information.

The trajectory and outcome analysis within the outcomes module will include two components:

1. Calculation of select quantitative outcome metrics
2. Qualitative and scenario-based evaluation of the impacts of management strategies to interests and priorities of CPRA, USACE, and other stakeholders

These components will be incorporated into illustrative narratives that describe the feasibility and sustainability of the management strategies and the expected impacts on decision-maker and stakeholder priorities. A draft list of quantitative outcome metrics, described below, was developed as part of the creation of this workplan; however, they will continue to be refined through CPRA and stakeholder engagement as the evaluation framework is developed.

Quantitative Outcome Metrics

A select set of quantitative metrics will be calculated from the environmental prediction module output. The selection of these metrics will be based on CPRA and stakeholder priorities and their potential to inform and adjust USACE management of the LMR. The S&S team developed a draft set of metrics through a series of facilitated working sessions during this phase of the task (Figure 11, Table 1). In these workshops, the team reviewed the input from stakeholder engagement to identify metrics of value (Appendix A). The type of metric, spatial location for calculation, and frequency (or time scale) of interest were identified. In addition, the S&S team identified high-priority “primary” metrics and lower-priority “secondary” metrics. This list will continue to evolve through ongoing stakeholder engagement and identification of input data to calculate derived metrics.

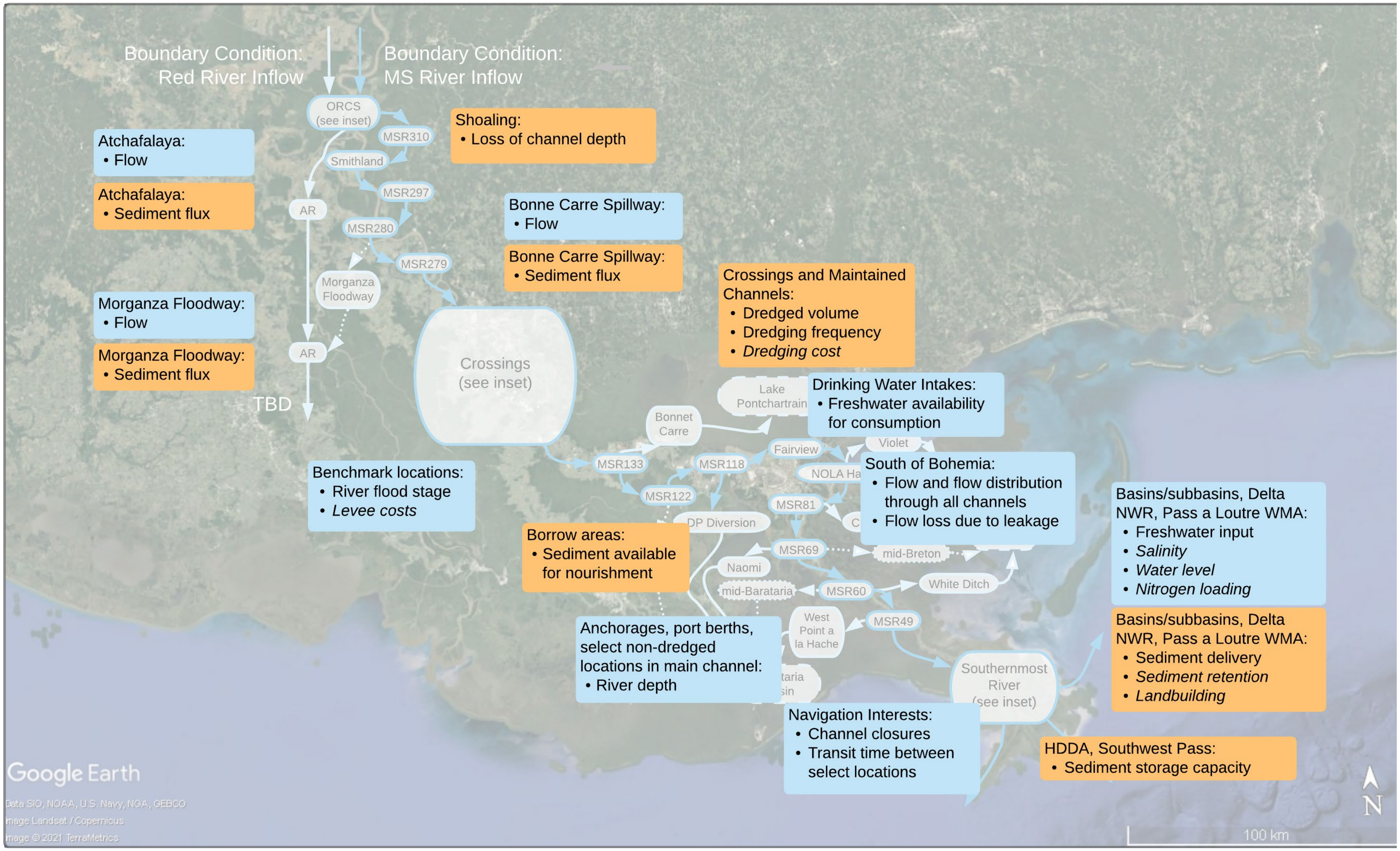

Figure 11. Map showing the quantitative output metrics of the outcomes module. Boxes in blue indicate metrics associated with hydrodynamic parameters, boxes in orange indicate metrics associated with sediment parameters. Italics are used to indicate secondary metrics (i.e., derived metrics for which there is uncertainty if sufficient data are available to calculate from the environmental prediction module outputs). Background image from Google Earth®.

Table 1. Quantitative outcome metrics that will be considered for calculation by the S&S evaluation framework. The list of metrics will be finalized by the S&S team as the evaluation framework is developed, with additional input from stakeholders through continued engagement.

Metric	Area of Interest
Sediment available for dedicated restoration dredging (cubic yards/year) and distance to benchmark locations of need (miles) on an annual basis	Identified borrow areas, and use borrow area selection criteria to identify new potential borrow areas where possible
Sediment delivery to the basins and marshes (cubic yards/year) on a seasonal and annual basis	Basins or sub-basins, with particular interest in Delta NWR and Pass a Loutre WMA. If possible, also consider calculating sediment retention potential and/or land building.
Dredged sediment volume (cubic yards/year) and frequency (occurrence/year) on an annual basis	By crossing if possible or aggregate as needed. If possible, also consider conversion to dredging costs
Sediment storage capacity (cubic yards/year) on an annual basis	Initially SW Pass and the HDDA, but note may need to move upstream over time
River (flood) stage (feet) for average annual river flows and select flooding (1973, 2011, 2019) and storm events	Benchmark locations TBD (dictated by flowline analysis) at decadal intervals, and consider conversion to levee maintenance costs if possible
Navigation transit time (hours)	Time of transit, including dependency on discharge, between ports or other waypoints frequently traversed by vessels utilizing the LMR
Navigation closure time (days unavailable) on an annual basis	Time that the LMR is closed to navigation due to parameters predictable by the model
River depth (feet) on a seasonal and annual basis	Locations where dredging has historically occurred or may be required in the future, at anchorages, and at port berth locations
Freshwater available for consumption and industry (days unavailable due to exceedance of salinity thresholds)	Locations of drinking water intakes
Freshwater input to the basins from diversions, leakage, etc. (cfs) on a seasonal and annual basis	Basins or sub-basins, with particular interest in Delta NWR and Pass a Loutre WMA. Also consider calculating salinity, basin water level, and nitrogen loading/delivery if possible
Mean flow (cfs) and sediment flux (cfs) on a seasonal and annual basis	Atchafalaya River, Morganza Floodway, Bonnet Carré Spillway, all channels and passes below Mardi Gras Pass, main channel of the LMR
Flow loss due to leakage (cfs) on a seasonal and annual basis	Main channel south of Mardi Gras Pass (loss due to overbank leakage)

The calculation method for the outcome metrics will be refined during the execution of this workplan and will likely include a range of varying approaches. For metrics such as the flow and sediment flux in the river, the environmental module will be able to predict those quantities directly. In other cases, analysis from other LMRMP tasks and/or analytical formulations may be used to calculate the metric from the environmental module output; for example, the RSM and economics analysis tasks may produce methods for calculating the cost of alternate dredging strategies. Lastly, analytical or machine-learning based approaches may be used to estimate outcome metrics as a function of parameters predicted by the environmental module by developing (training) the method using the outputs of existing models such as the Master Plan. The formulations can then be applied to calculate the outcome metrics for the management strategies and environmental scenarios.

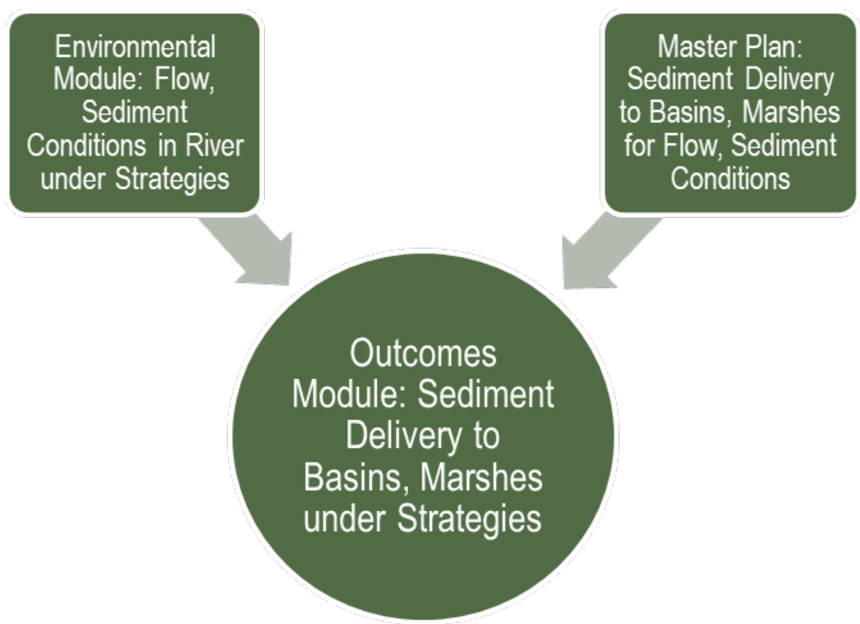

Figure 12. Conceptual diagram illustrating the calculation of quantitative outcome metrics by parameterizing the dependency of that metric on outputs of the environmental module by using existing model output (i.e., from the Master Plan).

Output metrics will continue to be refined through CPRA and stakeholder engagement. The linkage of the draft set of metrics to select stakeholder interests includes:

- **Sediment available for dedicated restoration dredging (cubic yards/year) and distance to benchmark locations of need (miles) on an annual basis.** Stakeholders include CPRA, parishes, environmental groups, the navigation industry, and USACE. These stakeholders have interest in environmental restoration, for which sediment is needed. Data from LMRMP can be incorporated into existing CPRA tools and programs for RSM, such as the Louisiana Sediment Availability and Allocation Program (LASAAP) and the Louisiana Sand Resource Database (LASARD). The choice of borrow areas is also of interest to USACE and the navigation industry due to the potential of sediment dredging to interrupt operations.
- **Sediment delivery to the basins and marshes (cubic yards/year) on a seasonal and annual basis.** Stakeholders include CPRA, USFWS, and LDWF. Sediment delivery to the marshes

through natural and man-made channels may reduce the need for future restoration projects, including for NWRs and WMAs.

- **Dredged sediment volume (cubic yards/year) and frequency (occurrence/year) on an annual basis.** Stakeholders include the navigation industry, ports, and DOTD and others with direct interest in the navigation channel being maintained. In addition, LDNR and the U.S. Coast Guard have regulatory authorities relevant to dredging, while USACE is directly responsibility for the dredging. Lastly, environmental groups have concerns related to the sustainability of dredging to maintain the deep draft navigation channel beyond Head of Passes.
- **Sediment storage capacity (cubic yards/year) on an annual basis.** Stakeholders include USACE, which requires dredge disposal areas; the navigation industry, which has concerns about the impacts of dredge disposal on anchorage capacity; and CPRA and other entities that require sediment for use in restoration projects.
- **River (flood) stage (feet) for average annual river flows and select flooding (1973, 2011, 2019) and storm events.** Multiple stakeholders have concerns about the potential for future flooding, including USACE, parishes, and CPRA. In addition, CPRA and environmental groups have indirect interests due to the impacts that river flood state has on diversion operations and thus, delivery of sediment and water to the basins. USACE also has interest in the future cost of levee maintenance.
- **Navigation transit time (hours).** Potential delays to navigation and the associated costs are of interest to USACE, DOTD, the navigation community, and ports.
- **Navigation closure time (days unavailable) on an annual basis.** Closures of the navigation channel impact operations for the shipping industry and thus are of interest to USACE, DOTD, the navigation community, and ports. Because one of the potential causes of navigation channel closures is for dredging to support restoration, CPRA is also a stakeholder.
- **River depth (feet) on a seasonal and annual basis.** Changes in river depth may change when, where, and how frequently dredging may need to occur, which is of interest to USACE. In addition, the navigable depth of the river is of concern to DOTD, the navigation community, and ports.
- **Freshwater available for consumption and industry (days unavailable due to exceedance of salinity thresholds).** Industrial users, land owners (e.g., cattle ranchers, farmers), and communities (parishes, cities) have a stake in the availability of drinking water. In addition, increases in salinity may lead to USACE needing to build a new sill to prevent saltwater incursion upstream.
- **Freshwater input to the basins from diversions, leakage, etc. (cfs) on a seasonal and annual basis.** Freshwater input influences the health and viability of marshes, which is of interest to USFWS and LDWF due to the potential impact to NWRs and WMAs, respectively. In addition, CPRA has interest due to its role in maintaining and restoring coastal basins and marshes.
- **Mean flow (cfs) and sediment flux (cfs) on a seasonal and annual basis.** Mean flow and sediment flux through diversions, spillways, and the main stem of the LMR impacts multiple stakeholders including ports located downstream of the Atchafalaya River and Morganza Spillway; the state of Mississippi, with particular interest in the Bonnet Carré Spillway; and CPRA due to its responsibility for management of the coastal region.

- **Flow loss due to leakage (cfs) on a seasonal and annual basis.** As with flow through diversions and natural channels, overbank leakage can impact basins and marshes and is therefore of interest to CPRA, USFWS, and LDWF.

Qualitative and Scenario-Based Outcome Evaluation

Quantitative metrics will be calculated whenever possible to capture the interests of CPRA, USACE, and other stakeholders. In addition, outputs from the environmental prediction module may be combined with reasonable assumptions about the future of the region to benchmark outcomes against the BAU management strategy. For example, the model framework will predict the flood stage of the LMR during events but quantifying (i.e., calculating) the impacts of changes of management strategies on flooding risk to infrastructure behind the levees is beyond the scope of LMRMP. However, benchmarking the river flood stage from the environmental prediction module for alternate management strategies against the BAU case can allow some qualitative conclusions to be drawn. If the frequency at which the river flood stage exceeds the current levee heights continues to increase under BAU, the levees will need to be raised (and widened to accommodate the height increase) or the risk to infrastructure will increase. Strategies that reduce the frequency of river flood stage exceeding the current levee heights can be expected to have lower costs, volume of sediment and setback space needed for levee construction, and associated risk to infrastructure. The focus of the qualitative analysis will be guided by continued input from CPRA and stakeholders with interests in the LMR.

Sustainability and Feasibility: Illustrative Narratives

The quantitative metrics and qualitative outcome evaluation will be incorporated into a set of illustrative narratives that capture the predicted impacts of different management strategies to decision-makers and stakeholders in the LMR. The narratives will also use the metric analysis and understanding of LMR operations to provide a synopsis of the feasibility and sustainability of the management strategies, including concerns such as:

- Feasibility concerns:
    - Short-term cost of execution
    - Physically possible to execute the management actions from an engineering standpoint
    - Executable from a policy and regulatory standpoint
    - Decision-maker buy-in (USACE, state, etc.)
    - Implementation timelines

- Environmental and Economic Sustainability concerns:
    - Long-term maintenance cost
    - Sediment availability
    - Ecosystem sustainability
    - Preventing the collapse of the system in the face of SLR, subsidence, precipitation changes, etc.

Background literature review of prior studies and historical conditions will be used to identify what the potential impacts of the management strategies will be given the results of the evaluation framework. These narratives will form a high level "report card" evaluating the pros and cons (likely positive and negative outcomes) of potential alternate management strategies. They will include the predicted outcomes of interest to CPRA, USACE, and other stakeholder groups, along with the quantitative metrics and descriptions of the outcome drivers and variability across the environmental scenarios. Specific areas of potential concern, such as likelihood of substantial increase in cost to maintain the navigation channel or levees, will be highlighted and quantified with quantitative metrics. The variability in those metrics and outcomes across future uncertainty will also be quantified.

NEXT STEPS

WORKPLAN EXECUTION

The next step of the LMRMP S&S task will be the execution of the rest of the evaluation (model) framework development workplan (Figure 13). The immediate next step will be the expansion of the model inventory currently under development in another task of LMRMP; in addition to adding other models to the inventory, it will be expanded to include observational data that can be used in parameterizing the environmental prediction module. The management strategies and environmental scenarios, as well as the quantitative metrics calculated by the outcomes module, will be refined as needed based on a gap analysis of available source data identified in the inventory. The environmental module prediction framework (i.e., the model architecture itself, which will be coded in the open-source Python programming language), will begin development concurrent with the expansion of the input pre-processing module inventory. This development process will include the design and implementation of dynamic stock allocation routines; this unique approach will allow the evaluation framework to be modular, adaptable, and very computationally efficient when compared to numerical modeling approaches that rely on a fixed grid.

From there, the formulations to predict the river flows as a function of conditions will be developed and incorporated into the environmental prediction module. The calculation methodology of derived quantitative outcome metrics will be finalized as part of development of the outcomes module. Included will be a combination of empirical formulations, where data are used to develop simple predictive formulas for flow or sediment flux; look-up tables, where the conditions within the stock/flow model are matched to corresponding conditions within an existing deterministic model, which then provides the corresponding flow or sediment flux; and machine learning, where multiple sources of data and model output are used to simulate flow or sediment flux based on correlation with predictive variables (e.g., upstream flow, water level, etc.). The selection of numerical models and data to use in the parameterization of the stock/flow model will depend on the LMR conditions under which they were developed and validated (models) or collected (data).

After the evaluation framework has been developed, simulations will be conducted for baseline (existing) conditions and used to calibrate and assess the environmental prediction module outputs. A series of simulations will then be conducted to assess the outcomes of the alternate management strategies. Each of the strategies has a vast number of potential variations that could produce different outcomes (e.g., three or four diversions can produce hundreds of individual variations when combining the range of possible operations for each across seasons and flow conditions). Simulations will first be conducted to identify the outcomes of the BAU strategy, with a particular focus on identifying future environmental scenarios that result in negative outcomes (e.g., insufficient sediment supply through the diversions to maintain marshes in the receiving basins; substantial cost to maintain the levees or navigation channels). These “negative future” scenarios will be used to identify variations of the alternate management strategies that produce the most positive outcomes, such as the specific combination of operating guidelines for diversions that maximize both flood risk reduction and sediment delivery to the basins. This ‘optimized’ set of management strategy variations will then be simulated across the full range of future conditions to identify which strategies are the most robust to environmental scenario uncertainty and produce the most positive outcomes for CPRA and other stakeholders.

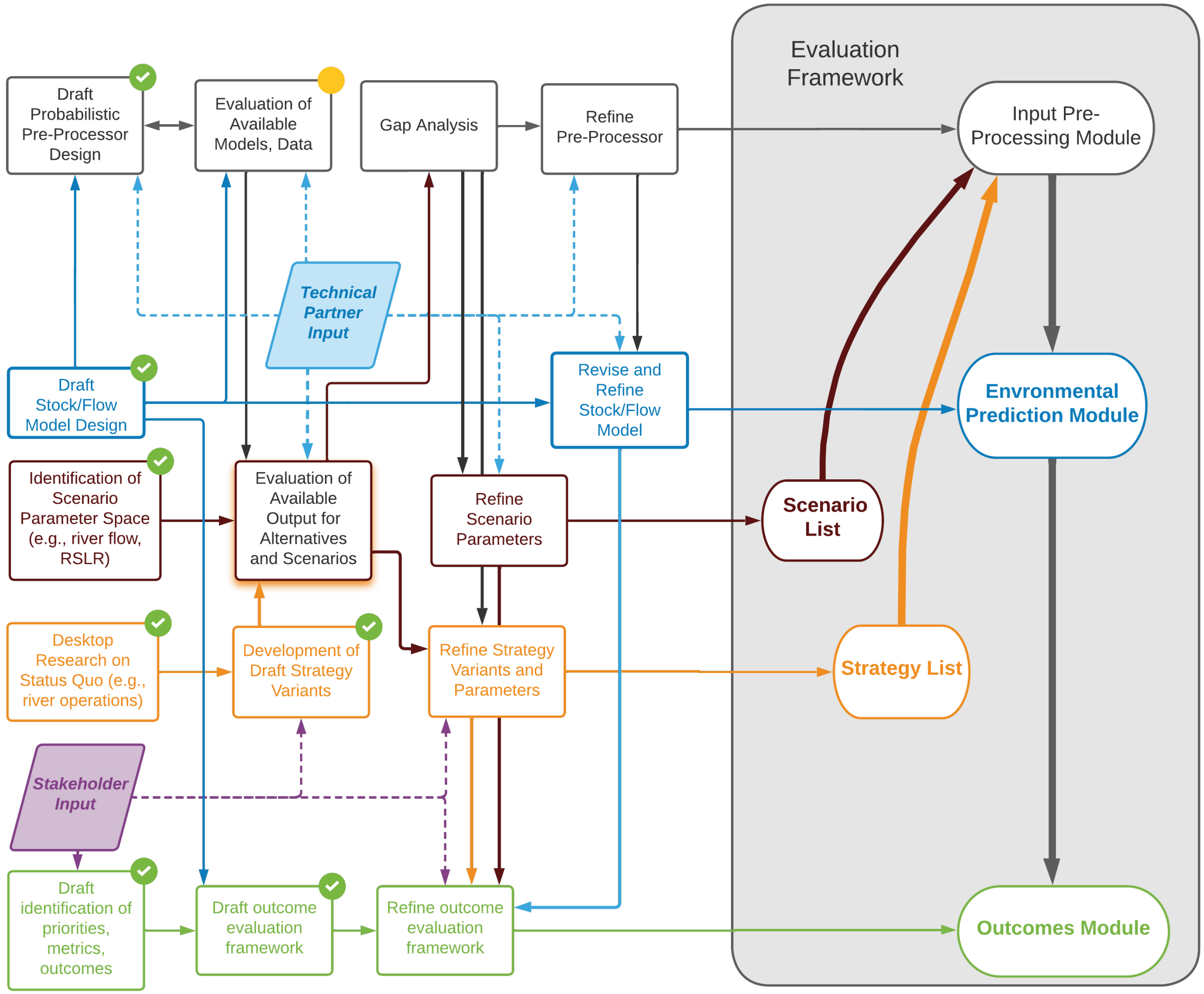

Figure 13. Workflow to develop LMRMP evaluation framework. Green checks indicate steps completed in this phase of the project; the orange circle indicates ongoing work. The formulations used within the evaluation framework will be developed based on the availability of input data and models. The flexibility of the approach, including the potential for inclusion of analytical formulations, will enable the strategies and scenarios of interest to be modeled.

MANAGEMENT APPLICATION

The LMRMP evaluation framework is designed to assess how management strategies for the LMR may impact stakeholder interests in the region on a 50-year time scale, and to understand how the uncertainty in those outcomes relates to predictive modeling uncertainties and unknowns in how the system will respond to management strategies and environmental scenarios. It is intended to be used for answering high-level "what-if" questions, producing quantitative and qualitative outcome assessments that can identify the intended and unintended potential consequences of alternate strategies. If the evaluation framework identifies strategies that could potentially enhance the feasibility and sustainability of the LMR in the long-term while also providing positive outcomes for CPRA and other stakeholders, these strategies can then be pursued for more in-depth analysis.

The LMRMP evaluation framework is intended to be complementary and synergistic with the Master Plan. During the initial development and application, output from Master Plan models will be used to parameterize the environmental river and outcomes modules. For example, the one-dimensional river model used in the 2023 Coastal Master Plan can be used to parameterize flows over the reaches of the LMR that it includes, while the outputs of the Integrated Compartment Model can provide estimates of sediment delivery to the basins under varying flow conditions. The design and computational efficiency of the LMRMP framework, however, enables hundreds of future simulations to be conducted while also leveraging data and models from USACE and other entities. This capacity allows the range of outcomes for CPRA and other stakeholders under varying management strategies to be predicted, providing actionable information that considers uncertainty in a way that a deterministic and computationally expensive model system cannot. This type of "screening tool" complements and extends the value of deterministic models such as those used in the Master Plan and by USACE during project engineering and design. Once identified by the LMRMP evaluation framework as having the potential to produce positive outcomes, promising management strategies can be refined into projects and design alternatives and moved forward for more detailed modeling with tools such as those used in the Master Plan.

The LMRMP S&S analysis is also particularly timely given the 2020 Water Resources Development Act (WRDA). Under the 2020 WRDA, USACE is directed to issue new agency Principles, Requirements, and Guidelines (PR&G), which govern the evaluation of project costs and benefits, ultimately dictating what projects are approved by the agency. WRDA emphasizes the advancement of "future water resources development projects that produce multiple project benefits," aligning with the objectives of—and management strategies being evaluated under—LMRMP. WRDA also authorized USACE to conduct the ongoing comprehensive study of the Lower Mississippi River to evaluate management strategies for enhancing outcomes across flood risk management, navigation, ecosystem restoration and protection, water supply, hydropower production, recreation, and other uses of the LMR. Guidance for the study includes a charge to make use of existing data provided by external entities including State agencies. The new WRDA, associated PR&G, and LMR Comprehensive Study provide an avenue through which LMRMP analyses can inform and the evaluation framework adopted for USACE management of the LMR.

SUMMARY AND CONCLUSION

The primary goal of the LMRMP is to identify and consider how holistic management of water and sediment in the LMR might enhance the feasibility and sustainability of LMR management in the long-term while improving outcomes for stakeholders across a wide range of interests including ecosystem restoration and protection, flood risk management, and navigation. As part of advancing that goal, the S&S task identified a set of alternate, holistic management strategies; determined a range of environmental scenarios (factors beyond management control, such as RSLR); and developed a workplan for creating an evaluation framework to assess the outcomes of those potential strategies on a 50- to 100-year time frame.

Six high-level strategies were identified, each of which has multiple variants and underlying assumptions as described elsewhere in this report:

1. BAU
2. Integration of Flow Considerations into Diversion Management or Diversions into Flood Fight
3. Sediment Management Strategies for SW Pass and the HDDA
4. Alternate Navigation Channel Alignment (abandon SW Pass for Deep Draft Navigation)
5. Adjust Flow Ratio at Old River Control Structure (ORCS)

The evaluation framework design consists of three components (an input pre-processing module; an environmental prediction module; and an outcomes module) that will use existing deterministic model output and observational data to predict how these strategies will impact stakeholder interests in the LMR. In the next phases of the project, the workplan developed here will be implemented and the strategies evaluated for use in determining what holistic LMR management strategies to pursue with more detailed analysis.

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APPENDICES

APPENDIX A. INTERNAL AND EXTERNAL ENGAGEMENT

Table A-1. Internal S&S team and cross-team LMRMP working sessions used in developing the high-level evaluation framework (Figure 4), identifying management strategies and environmental scenarios for testing with the framework, and coordinating stakeholder engagement. Meetings are ongoing and shown as of February 10, 2022. Meetings at which specific decisions were made relative to the this workplan are shown in bold.

Dates	Attendees	Description
Recurrent	Carol Parsons Richards, Mike Miner, Soupy Dalyander, Alaina Grace, Mandy Green, Jordan Earls[1], Jason Curole	Weekly to biweekly project team meetings; working sessions focused on advancing framework development and/or preparing materials for the meetings below
11/5/2020	Carol Parsons Richards, Brian Lezina, Mike Miner, Soupy Dalyander	Development of overall approach for strategy and scenario development; outcomes of finalizing the overall approach of the S&S task (Figure 4) and identification of preference for a reduced complexity environmental model
12/2/2020	Carol Parsons Richards, Brian Lezina, Mike Miner, Soupy Dalyander, Alaina Grace, Mandy Green	Development of draft objectives for CPRA for LMRMP and LMR Management
2/3/2021	Carol Parsons Richards, Brian Lezina, Greg Grandy, Bren Haase	Presentation of LMRMP objectives (WI slide development)
2/22/2021	Carol Parsons Richards, Brian Lezina, Mike Miner, Soupy Dalyander, Alaina Grace, Mandy Green	Development of a strategy for stakeholder engagement; outcome of a draft list of stakeholders to provide feedback on the strategies and workplan
3/15/2021	Carol Parsons Richards, Brian Lezina, Mike Miner, Soupy Dalyander, Jason Curole, Alaina Grace, Mandy Green	Development of LMRMP decision-maker and stakeholder engagement strategy; outcome of a refined list of strategies to be vetted with stakeholders
4/7/2021	Carol Parsons Richards, Mike Miner, Soupy Dalyander, Rex Caffey, Hua Wang	Discussion of linkages of the strategies and scenarios task to the economic analysis task
4/13/2021	Carol Parsons Richards, Brian Lezina, Mike Miner, Soupy Dalyander, Alaina Grace, Mandy Green, Jordan Earls, Jason Curole	Updates on engagement of USACE leadership; walkthrough of pilot model and first draft concept of evaluation framework design; outcome of selection of systems dynamics (stock/flow) model as basis of environmental module
5/5/2021	Carol Parsons Richards, Mike Miner, Soupy Dalyander, Rex Caffey, Hua Wang	Discussion of indices, potential quantification of outcomes in the evaluation framework

[1] Jordan Earls left CPRA in the summer of 2021 and did not participate in calls after that time.

Dates	Attendees	Description
5/17/2021	Carol Parsons Richards, Brian Lezina, Mike Miner, Soupy Dalyander, Alaina Grace, Mandy Green, Jordan Earls, Jason Curole	Continued refinement of stakeholder engagement plan; outcome of a refined list of management strategies and associated assumptions
5/20/2021	Carol Parsons Richards, Mike Miner, Soupy Dalyander, Rex Caffey, Hua Wang	Discussion of indices, potential quantification of outcomes in the evaluation framework
5/26/2021	Carol Parsons Richards, Jordan Earls, Ahmad Tavakoly, Sara Lytle, Mike Miner, Soupy Dalyander, Ioannis Georgiou, Alaina Grace, Many Grain	Update on the LMRMP Mississippi River hydrograph tasks to inform environmental scenario development
5/27/2021	Carol Parsons Richards, Ronald Heath, Travis Dahl, Gary Brown, Mike Miner, Soupy Dalyander, Ioannis Georgiou, Mandy Green, Alaina Grace	Discussion of USACE Engineering Research and Development Center (ERDC) engagement in strategy and scenario development
6/7/2021	Carol Parsons Richards, Brian Lezina, Mike Miner, Soupy Dalyander, Alaina Grace, Mandy Green, Jordan Earls, Jason Curole	Refinement of desired level of input from stakeholders on outcomes analysis; refinement of preferred strategies and scenarios
6/28/2021	Carol Parsons Richards, Brian Lezina, Mike Miner, Alaina Grace, Mandy Green, Jordan Earls, Jason Curole	Discussion of stakeholder input plans; assessment and refinement of BAU strategy set; discussion of workplan and deliverables
7/8/2021	Carol Parsons Richards, Soupy Dalyander, Hua Wang	Continued discussion of cost/benefit components of model framework
8/4/2021	Carol Parsons Richards, Mike Miner, Soupy Dalyander, Alaina Grace, Mandy Green, Jason Curole	Planning and preparation for engagement of USACE MVN leadership
8/6/2021	Carol Parsons Richards, Mike Miner, Soupy Dalyander, Alaina Grace, Mandy Green, Jason Curole, Ioannis Georgiou, Chris Massey, Margaret Owesnby	Discussion of output from LMRMP storm surge modeling and leveraging within the strategy and scenario framework
8/25/2021	Carol Parsons Richards, Rudy Simoneaux, Russ Joffrion, Dain Gillen, Mike Miner, Soupy Dalyander, Francesca Messina, Brett McMann, Brendan Yuill, John Swartz, Chris Esposito, Ioannis Georgiou, Alaina Grace, Mandy Green	Update and discussion with the CPRA Engineering team
8/26/2021	Carol Parsons Richards, Mike Miner, Soupy Dalyander, Ioannis Georgiou, Chris Esposito, Francesca Messina, Alaina Grace, Mandy Green, Travis Dahl	Check-in and discussion with USACE ERDC; cross-team task coordination
9/20/2021	Carol Parsons Richards, Brian Lezina, Mike Miner, Alaina Grace, Mandy Green, Jason Curole	Finalization of the management strategies and environmental scenarios

Dates	Attendees	Description
9/30/2021	Soupy Dalyander, Francesca Messina, Christopher Esposito, Ioannis Georgiou, Travis Dahl, Alaina Grace, Mandy Green	Check-in and discussion with USACE ERDC; cross-team task coordination
10/4/2021	Carol Parsons Richards, Mike Miner, Soupy Dalyander, Ioannis Georgiou, Chris Esposito, John Swartz, Mandy Green, Alaina Grace, Rob Nairn, Qimiao Lu	Discussion of the Baird Box model and potential for input to the stock/flow model
10/21/2021	Carol Parsons Richards, Chris Massey, Margaret Owensby, Mike Miner, Soupy Dalyander, Jason Curole, Alaina Grace, Mandy Green	Check-in and discussion with USACE ERDC on storm surge modeling
10/25/2021	Carol Parsons Richards, Mike Miner, Soupy Dalyander, Jason Curole, Alaina Grace, Mandy Green, and the CPRA Planning and Research Division (open invitation to webinar)	Update to, and engagement of, the CPRA Planning and Research Division on the LMRMP strategies and scenarios task
11/15/2021	Carol Parsons Richards, Brian Lezina, Mike Miner, Soupy Dalyander, Jason Curole, Ioannis Georgiou, Chris Esposito, Brendan Yuill, John Swartz, Brett McMann, Alaina Grace, Mandy Green, Mitch Andrus	Identification and refinement of strategy and scenario outcome metrics (Part 1 of 2)
11/18/2021	Carol Parsons Richards, Ahmad Tavakoly, Sara Lytle, Ronnie Heath, James Lewis, Mike Miner, Ioannis Georgiou, John Swartz, Chris Esposito, Brendan Yuill, Alaina Grace	Updates on the hydrographs and S&S tasks; discussion of potential use of the hydrographs within the S&S evaluation framework
11/29/2021	Carol Parsons Richards, Mike Miner, Soupy Dalyander, Jason Curole, Alaina Grace, Mandy Green, Mitch Andrus	Discussion of the RSM costing tool
11/29/2021	Carol Parsons Richards, Mike Miner, Soupy Dalyander, Jason Curole, Ioannis Georgiou, Chris Esposito, Brendan Yuill, John Swartz, Brett McMann, Alaina Grace, Mandy Green, Mitch Andrus	Identification and refinement of strategy and scenario outcome metrics (Part 2 of 2)
12/2/2021	Carol Parsons Richards, Mike Miner, Soupy Dalyander, Francesca Messina, Ioannis Georgiou, Chris Esposito, Travis Dahl, Alaina Grace, Mandy Green	Check-in and discussion with USACE ERDC; cross-team task coordination
12/3/2021	Carol Parsons Richards, Mike Miner, Soupy Dalyander, Rex Caffey, Hua Wang	Refinement and discussion of strategy and scenario outcome metrics
01/13/2022	Carol Parsons Richards, Mike Miner, Soupy Dalyander, Francesca Messina, Ioannis Georgiou, Chris Esposito, Travis Dahl, Alaina Grace, Mandy Green	Check-in and discussion with USACE ERDC; cross-team task coordination

Dates	Attendees	Description
1/27/2022	Carol Parsons Richards, Erin Vidrine, Brad Miller, Kazi Sadid, Alicia Mcalhaney, Eric White, Jim Pahl, Brandon Champagne, Krista Jankowski, Wes Leblanc, Angelia Freeman, Soupy Dalyander, Mike Miner, Jason Curole, Ioannis Georgiou, Brett McMann, Chris Esposito, John Swartz, Alaina Grace; Mandy Green	First meeting of the CPRA "Strategies & Scenarios Working Group," created to ensure continuity between LMRMP, the Coastal Master Plan, and other CPRA efforts, and to provide a forum for input on the S&S evaluation framework
2/3/2022	Carol Parsons Richards, Alicia Mcalhaney, Brandon Champagne, Mike Miner, Soupy Dalyander, Jason Curole, Nick Howes, Ioannis Georgiou, Alaina Grace, Mandy Green, Travis Dahl, Ronald Heath, James Lewis	First working sessions of the Strategies & Scenarios Team with USACE
2/3/2022	Carol Parsons Richards, Angelina Freeman, Dain Gillen, Wes Leblanc, Scott Mize, Aub Ward, James Rigby, Todd Baumann, Lane Simmons, Garron Ross, Matthew Hoy, Alaina Grace, Mandy Green, Guerry Holm, Mike Miner, Jason Curole, Ioannis Georgiou, Francesca Messina, Maricel Burgos	Update on the status of the Belle Chase data collection task
2/10/2022	Carol Parsons Richards, Brandon Champaign, Jim Pahl, Joseph 'Wes' Leblanc, Chris Massey, Margaret Owensby, Mike Miner, Soupy Dalyander, Ioannis Georgiou, Nick Howes, Jason Curole, Alaina Grace, Mandy Green	Updates from the storm surge modeling and S&S task and discussion of potential for use of the storm surge outputs in the evaluation framework

Table A-2. Webinars conducted as part of engagement of external decision-makers and stakeholders for eliciting input on management strategies and environmental scenarios for testing with the LMRMP evaluation framework as of February 10, 2022. Additional engagement of the navigation community, ports, and the general public – along with follow-up with the entities in the table – will be conducted as LMRMP continues.

Agency/Entity	Date	Attendees
Louisiana Department of Natural Resources (LDNR)	06/03/2021	Feedback elicited via email from Charles Reulet (LDNR, Office of Coastal Management)
U.S. Fish and Wildlife Service (USFWS)	06/11/2021	Barret Fortier (USFWS); Carol Parsons Richards, Brian Lezina, Jordan Earls (CPRA); Mike Miner, Soupy Dalyander, Jason Curole (the Institute); Alaina Grace, Mandy Green (Royal)
Non-Governmental Organizations	07/21/2021	Steve Cochran, Natalie Snider (EDF); David Muth, Alisha Renfro (NWF); Michael Hopkins (PC); Emily Vuxton (CRCL); Carol Parsons Richards (CPRA); Mike Miner, Soupy Dalyander (WI); Alaina Grace, Mandy Green (Royal)
U.S. Army Corps of Engineers, MVN	08/09/2021	Brad Inman, Jeff Varisco (USACE MVN); Brian Lezina, Carol Parsons Richards (CPRA); Soupy Dalyander (WI); Alaina Grace, Mandy Green (Royal)
Louisiana Department of Transportation & Development	08/17/2021	Molly Bourgoyne, Randall Withers (DOTD); Carol Parsons Richards (CPRA); Soupy Dalyander, Jason Curole (WI); Alaina Grace, Mandy Green (Royal)
Louisiana Department of Wildlife and Fisheries	09/09/2021	Vaughan McDonald (LDWF); Carol Parsons Richards, Todd Baker (CPRA); Soupy Dalyander, Jason Curole (WI); Alaina Grace, Mandy Green (Royal)
National Academy of Science (NAS) Gulf Research Program (GRP)	09/15/2021	Presentations by Carol Parsons Richards (CPRA) and Soupy Dalyander (WI). Webinar was publicly available and attended predominantly by members of the academic community.
Navigation Community	09/30/2021	Sean Duffy (Big River Coalition); Michael T.D. Miller (Associated Branch Pilots); Carol Parsons Richards, Brian Lezina (CPRA)
U.S. Army Corps of Engineers, MVN	10/06/2021	Brad Inman, Jeff Varisco, David Ramirez, Ann Hijuelos, Travis Creel (USACE); Carol Parsons Richards, Brian Lezina (CPRA); Mike Miner, Soupy Dalyander, Jason Curole (WI); Alaina Grace (Royal)
Non-Governmental Organizations	10/22/2021	Devyani Kar (EDF); David Muth, Alisha Renfro (NWF); Michael Hopkins (PC); Emily Vuxton (CRCL); Carol Parsons Richards, Erin Vidrine (CPRA); Mike Miner, Soupy Dalyander, Jason Curole, Donna Averion (WI); Alaina Grace (Royal)
U.S. Army Corps of Engineers, MVN	11/05/2021	Brad Inman, Dave Ramirez, Travis Creel, Ann Hijuelos (USACE); Carol Parsons Richards (CPRA); Mike Miner, Soupy Dalyander, Jason Curole (WI); Alaina Grace, Mandy Green (Royal)
U.S. Army Corps of Engineers, MVN	01/10/2022	Ann Hijueolos, David Shulman, Luis Flores, Travis Creel, Travis Dahl, Rachel Calico (USACE); Carol Parsons Richards (CPRA); Mike Miner, Soupy Dalyander, Jason Curole, Chris Esposito, John Swartz, Brett McMann (WI); Alaina Grace, Mandy Green (Royal)

APPENDIX B. LMRMP MANAGEMENT STRATEGIES AND UNDERLYING ASSUMPTIONS

Included below is a draft list of LMRMP management strategies, variants, and underlying assumptions; this list will continue to be refined through CPRA and stakeholder engagement as the S&S task continues.

1. Business as Usual

The BAU strategy is likely to consist of two variants. The first variant, "current landscape," captures the LMR under current management practice (e.g., dredging operations and flood risk management). Existing diversions, canals, siphons, spillways, and other controlled features are operated under their current protocol and assumptions, consistent with the modeling approach used in the 2023 Master Plan. The River Reintroduction into Maurepas Swamp project, which is funded for construction, is also included, and assumed to operate under the protocols used within the Master Plan. The second variant, "reasonable foreseeable future," adds the Mid-Barataria and Mid-Breton Sediment Diversions. These diversions would operate under the conditions included in the permits, and all other aspects of the LMR follow the "current landscape" variant.

Additional assumptions used in modeling both variants of the BAU strategy are likely to include:

- **Dredging**
    - Dredging strategy of clearing the Crossings and SW Pass to maintain a 50' deep navigation channel does not change over the time period of evaluation.
    - Material dredged from the Crossings is dumped to the side or placed downstream in the thalweg (not removed from the LMR).
    - Sediment dredged from SW Pass is placed in HDDA or offshore disposal area.
    - Sediment in the HDDA is removed and placed in wetlands in the bird's foot delta or used for channel stabilization.
    - No sediment from the LMR is used in Master Plan projects except those projects already identified in the Master Plan (White, 2021), including diversions and limited dedicated dredging projects.

- **Flow control**
    - Flood fight plan does not change. Existing triggers at the Carrollton gauge are used to control opening of the Bonnet Carré Spillway and Morganza Floodway.
    - Process of evaluating flood lines and managing the levee heights remains the same.
    - Flow at ORCS is maintained at 70/30 in the main channel vs. the Atchafalaya River.

2. Integration of Flow Considerations into Diversion Management or Diversions into Flood Fight

The focus of this strategy is evaluating if and how holistic management of multiple Mississippi River diversions can reduce the negative impacts of flood risk management by reducing the volume of water released through the Bonnet Carré Spillway into Lake Pontchartrain. Two potential variants of this strategy have been identified, including modifications to diversion operations (i.e., the amount of water released during different seasons and flow conditions) and the siting of diversions that have yet to enter the engineering and design phase. In all cases, the intended environmental and land-building benefits of the diversions must be preserved, with the intent being identification of opportunities to achieve those benefits while also diverting water that might have otherwise been released through the Bonnet Carré Spillway. These variants will leverage and build upon ongoing planning efforts for the Union Diversion, which consider how operations might vary seasonally and with flow conditions to maximize co-benefits to land-building and flood risk management.

Additional assumptions that may be used in modeling variants under this strategy include:

- **Dredging**
  - Because this strategy would have a significant impact on flow and sediment movement, there may be an impact to dredging operations (e.g., maintenance of diversions). This impact will be evaluated to the degree possible with the evaluation framework.
  - Potential dredging scenarios for the maintained channel will be considered in conjunction with evaluating the outcomes of this scenario if possible (i.e., if outputs can be parameterized with available input data).

- **Flow Control**
  - Triggers for operations of the spillways for flood risk management purposes will be assumed to follow the current protocols.

3. Sediment Management Strategies for SW Pass and HDDA

Sediment dredged by USACE from the navigation channel of the main stem of the LMR and portions of SW Pass is placed in the HDDA at Head of Passes. The action of disposing large volumes of sand at the heads of Pass á Loutre and South Pass reduces flow and sediment transport capacity in those passes. Removal of sediment from the HDDA by natural processes is minimal, leading to infilling and the need to frequently dredge the HDDA so that it retains capacity for subsequent hopper dredge disposal events and draft clearance for loaded hopper dredges. Sediment dredged from the HDDA is currently placed in various disposal areas within the bird's foot delta. Variants of this potential strategy include alternate methods of managing the HDDA and/or the sediment that is disposed there. One variant under consideration would evaluate a beneficial use of dredge material approach wherein the sediment dredged from the existing HDDA would be used to nourish and restore barrier islands within Barataria Basin under the Barrier Island System Management Program. Another variant under consideration would consider an alternate location of the HDDA itself, namely relocating it across the channel to the Pilottown Anchorage. This location could minimize the impact of disposed sediment on the flow and sediment transport within Pass á Loutre and South Pass, and pipelines used to convey sediment from this location to restoration projects will not interfere with navigation activities on the LMR. This RSM approach is being refined in a separate task within LMRMP, and the results of that task will be used to finalize the variants of this strategy and used in their evaluation.

Additional assumptions used in modeling variants under this strategy may include:

- **Dredging**
    - Sediment/sand from the HDDA that is currently being placed in the bird's foot delta would instead be used to construct Master Plan restoration projects at barrier islands, marsh, ridges, etc. outside of the bird's foot.
    - Sediment would be used for nourishing the coastal system (barrier islands, headlands, and marsh restoration) east from Caminada Headland to the bird's foot delta.

- **Flow control**
    - HDDA is maintained at clearance to allow flow down bird's foot delta distributaries.

4. Alternate Navigation Channel Alignment (abandon SW Pass for Deep Draft Navigation)

This management strategy encompasses rerouting the main (deep draft) navigation channel of the Mississippi River. One potential variant has been identified so far, namely the main channel following a more direct route to the 60' contour. Some flow to the existing bird's foot may be retained. Some sediment available within the bird's foot (and channel) can be mined to nourish the coast in other locations. The variants of this strategy will be refined as the evaluation framework is developed and may include components of three "Changing Course" design team concepts, all of which follow the same overarching approach of channel rerouting. These concepts may be refined or combined based on model output availability and preliminary evaluation framework results, and/or the original design teams may be consulted.

Additional assumptions used in modeling variants under this strategy may include:

- **Dredging**
    - Establish alternate course for deep draft navigation to the Gulf that terminates above the bird's foot delta, impacting the location of future dredging.
    - Mine the sediment supply south of the new location of the deep draft navigation channel.
    - Because this strategy would have a significant impact on flow and sediment movement, dredging operations will be parameterized based on dredging occurring for the current navigation channel.

- **Water management**
    - Maintain freshwater flow at major intake locations (e.g., Alliance).

5. Adjust Flow Ratio at Old River Control Structure (ORCS)

Under this management strategy, the current constraint of 30 percent flow down the Atchafalaya River at the ORCS will be removed. USACE is the decision-making authority for the ORCS and is currently conducting the Old, Mississippi, Atchafalaya, and Red River (OMAR) assessment under the authorization of the Mississippi River and Tributaries program to evaluate potential alternatives for ORCS management that would still meet other constraints (such as flow through the Sidney Murray Hydroelectric Station). The evaluation framework will consider the broader impacts of the alternatives considered under OMAR if available, and/or will conduct a sensitivity analysis to determine how a seasonally variable ORCS operational strategy might impact the Mississippi River. Although evaluating specific impacts of ORCS operating protocols to the Atchafalaya River, Basin, and Delta (i.e., downstream of the ORCS) are beyond the scope of LMRMP, changes in flow down the Atchafalaya will be noted and, if possible, the potential implications noted.

Additional assumptions used in modeling variants under this strategy may include:

- **Dredging**
  - Mining of available sediment supply in any potential sediment source areas downstream of the ORCS.
  - Because this strategy would have a significant impact on flow and sediment movement, dredging will follow parameterizations consistent with current operations.

- **Water management**
  - Achieve USACE benchmarks for flood risk management.
  - Maintain flow and river head at Sidney Murray Hydroelectric Station as necessary for operations.
  - Optimize flow within the Mississippi and Atchafalaya rivers (from an environmental sustainability perspective) during low-flow conditions.

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