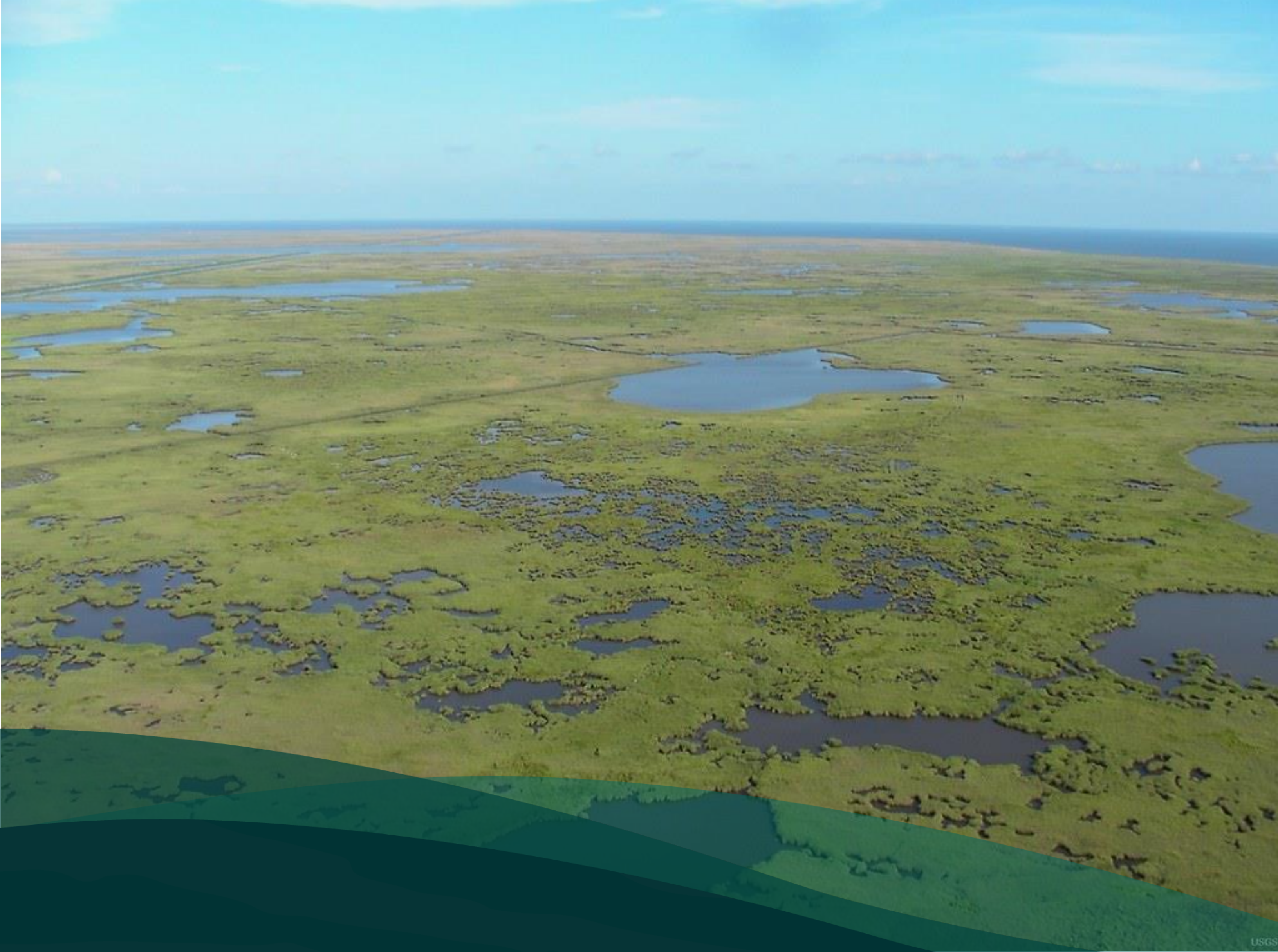

Conceptual Design for a Real-Time Sediment Diversion Operations Tool (SDOT) for the Mississippi River

January 19, 2021

RESTORE THE MISSISSIPPI RIVER DELTA

ESSA

Conceptual Design for a Real-Time Sediment Diversion Operations Tool (SDOT) for the Mississippi River

Prepared For:

Restore the Mississippi River Delta

and

Environmental Defense Fund

January 19, 2021

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Executive Summary

The Mississippi River Delta is a dynamic and substantially altered system where subsidence, winds, tides / currents, and extreme events like hurricanes influence coastal land loss. An extensive levee system has been constructed to support navigation and protect communities and property from flooding, yet these structures also disconnect the Mississippi River from coastal marshes and play a role in ongoing land losses. Moreover, the Delta is a highly valued ecosystem that supports economically significant commercial seafood and recreational fishing industries and is home to an array of waterfowl, migratory birds, and iconic Louisiana species. The Delta's wetlands also protect people and property from storm surge, filter pollutants from water, and support breeding, spawning, feeding, and nursery habitat for many fish species.

Land losses remain an ongoing threat to the coast. Between 1932 and 2016 Louisiana lost approximately 1,900 square miles of land, and without restoration the coast is predicted to lose an additional 1,200 to 4,100 square miles of land in the next 50 years. Federal and state agencies have recommended a portfolio of actions for maintaining and building land to mitigate these losses. Sediment diversions are one of the unique restoration actions designed to capture sediment from the river to build new and add to existing wetlands in the Delta. There are many scientific uncertainties, however, that affect the ability of operators to predict and understand how best to operate these diversions in a way that balances the many, varied social-ecological needs of decision-makers from various agencies and stakeholders across the state.

Given these unknowns, there is a strong rationale and there has been interest in developing a decision support tool that can inform seasonal operational strategies and real-time (within season) adjustments to operations in response to changes in the status of biophysical conditions that are directly and indirectly affected by diversions. This document proposes and describes a conceptual design for a Real-Time Sediment Diversion Operations Tool (SDOT) that would serve that role. This conceptual design document describes the proposed purpose and need, scope, candidate components, low fidelity mock-ups, and development steps to build such a tool. Currently, there is no commitment to develop it, but the intent with this document is to clarify how the tool could become a reality.

The envisioned purpose for the tool would be to couple existing Mississippi River flow forecasts, sediment transport, salinity, turbidity, and related hydrodynamic models to a representative suite of well-specified, valued ecological and social components inside a highly intuitive web-enabled software tool that allows decision-makers to explore within-year operational alternatives that best balance the multiple interests and constraints of relevance to their operations. Importantly, the SDOT would not provide a Delta-wide assessment of consequences on all valued components of interest to decision-makers and stakeholders, and it would not replace existing planning models used to project outcomes on multi-year or decadal time scales. This tool would also not serve as a data repository and visualization for reporting on the status and trends of key performance measures gathered as part of long-term monitoring or broader adaptive management efforts.

The proposed scope and boundaries of the tool include considerations that relate to the: (1) decisions that the tool would inform; (2) management objectives that operators would strive to balance through these decisions; and (3) spatial / temporal scales of relevance to diversion operations.

Regarding the scope of relevant decisions, the SDOT would be used to evaluate outcomes and trade-offs associated with the magnitude, duration, and frequency of gate openings and how these gate settings are adjusted through time in response to Mississippi River trigger flows, changes in the sediment / water efficiency ratio, and variations in the status of other important performance measures. Although the purpose of freshwater diversions is much different than sediment diversions, the architecture for the tool would be modular which would allow for the inclusion of multiple existing and planned freshwater and sediment diversions with the ultimate potential to support systemwide coordination of diversions and management across a broad spatial area encompassing the lower Mississippi River and Delta.

A foundational component to clarifying the scope and boundaries for the SDOT is based on the management objectives that operators are trying to achieve through their decisions. The 2017 Coastal Master Plan articulates five broad goals for restoring the Louisiana Coast around which the following six objectives are proposed to guide operations of sediment diversions (grouped according to three of the Coastal Master Plan goals):

- Deltaic Processes [DP]
    - maximize sediment capture by diversion
    - maximize extent of influence to build / sustain land
    - avoid or minimize stagnant water that could lead to hypoxic conditions
    - minimize induced wetland loss from elevated water levels
- Risk Reduction [RR]
    - avoid induced increased flood risk to basin communities
- Working Coast [WC]
    - maintain a balance of fresh and saltwater harvestable species populations

The spatial scale of the SDOT is expected to depend on the performance measures and physical variables listed below, but in general, the study area is proposed to include the Barataria and Pontchartrain Basins and nearshore Gulf which includes the mainstem Mississippi River downstream of Baton Rouge to the Gulf. The upstream boundary is proposed to also include the Old River Control Structure, to account for real-time operations of that facility during very high flow periods.

The anticipated temporal horizon for the SDOT is expected to be one year or less with the intent to combine real-time gauge data with forecasting models and make projections at the appropriate times scale (4-6 week advance forecasts, *repeatedly*) for relevant performance measures and physical variables listed below. The proposed temporal resolution of the SDOT is anticipated to involve a mixture of daily and weekly time-steps (i.e., run at least weekly during key diversion operation decision periods). As each operational water year (or multi-month phase) is completed, resource managers will be in a position to retrospectively “audit” what performance levels for different objectives were realized. As SDOT operators move through time, this should influence future priorities in terms of what objectives may need to be weighted higher or lower in the given year ahead (or other appropriate decision period). Specifically, we describe in this report the innovative concept and role of Turn Taking Optimization. Turn Taking is an effective antidote for the inability of structured decision-making consequence tables to identify solutions that balance trade-offs for resource management problems characterized by large suites (several dozen+) of objectives.

Next, specifying the SDOT components involves providing more clarity around the performance measures that are relevant to the management objectives described above and sufficiently well specified for inclusion in a quantitatively rigorous tool. Based on these considerations, inputs from technical experts, and a review of the literature the following performance measures are proposed:

- Sediment Capture [DP1]
- Sediment Distribution [DP2]
- Stagnant Water [DP3]
- Floodplain Inundation [DP4]
- Flood Risk to Basin Communities [RR1]
- Oyster Habitat Suitability [WC1]
- White Shrimp Habitat Suitability [WC2]
- Brown Shrimp Habitat Suitability [WC3]
- Alligator Habitat Suitability [WC4]

Given the important role of natural hydrodynamics (river, estuary, and ocean), water diversions, and entrainment in affecting the Delta’s processes, it is critical that the above performance measures be linked to physical driving variables at the appropriate temporal and spatial scale (e.g., flow, stage / elevation, salinity, temperature, and turbidity / sediment). To make projections for each of the above performance measures, the SDOT will need to forecast physical conditions (e.g., stage / elevation, salinity, temperature) using live linkages to available real-time data sources, coupled with a hydrodynamic simulation projection across the study area. The Delta’s existing real-time monitoring network will enable the inference of current conditions at many in-river and in-basin gauges. The simplicity or complexity necessary to forecast those physical variables into the future will greatly affect the level of effort required to make the SDOT a reality. Based on a survey of the hundreds of potential models described in the literature, we believe that the Integrated Compartment Model (ICM) and its underlying simulation tools (Delft3d) are the most suitable (probably with some modification) to support the SDOT. With enhancements, its simulations and forecasts would likely be able to incorporate data from real-time gauges.

Developing and building cross-disciplinary tools of this kind are best conducted through an iterative process. This conceptual design document outlines 5 stages for delivering a fully operational SDOT:

- Stage 1: Scoping & Conceptual Design (represented by this document, though subject to revisions from decision-makers)
- Stage 2: Sub-Model Vetting & Fully Specifying Performance Measures (proposed next stage)
- Stage 3: Final Feature Prioritization & Initial Proof-of-Concept Development
- Stage 4: Acceptance Testing, Refinement & Feature Enhancement
- Stage 5: As-Built Documentation, Training, & Long-term Operational Deployment

Beyond these development steps, supporting progress towards the SDOT also represents an opportunity to catalyze further synthesis of existing knowledge, multi-disciplinary coordination, and clarity around critical knowledge gaps that can ultimately improve decision-making, research, and monitoring across the Louisiana coast. To be successful, it will be important that the SDOT be aligned with related efforts to avoid duplication and take advantage of potential synergies such as:

- Coordinating with the regulatory review and development of planned sediment diversions;
- Integrating with existing diversions and spillways given the interrelated nature of decisions and outcomes in the outfall areas;
- Leveraging previous and future model development and application which would serve as the underlying quantitative engines for driving the SDOT; and
- Aligning with adaptive management efforts at a project and/or programmatic scale.

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The content and interpretations in this document represent the perspectives of the report authors. Should readers find any inaccuracies, omissions, or misrepresentations, such mistakes are our own and purely unintentional.

Glossary

Acronym	Full Name
AHPS	Advance Hydrologic Prediction Service
BICM	Barrier Island Comprehensive Monitoring
BOD	biological oxygen demand
cfs	cubic feet per second
CIMS	Coastal Information Management System
CORS	Continuously Operating Reference Stations
CMP	Coastal Master Plan
CPRA	Coastal Protection and Restoration Authority
CRMS	Coastwide Reference Monitoring System
DEM	Digital Elevation Model
DST	Decision Support Tool
ICM	Integrated Compartment Model
LDEQ	Louisiana Department of Environmental Quality
LDWF	Louisiana Department of Wildlife and Fisheries
MBSD	Mid-Barataria Sediment Diversion
MRD	Mississippi River Delta
NDBC	National Data Buoy Center
NHD	National Hydrology Dataset
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
PM	Performance Measures
RTO	Real-Time Operations
TBA	To be assessed
TTO	Turn-Taking Optimization (see https://doi.org/10.15447/sfews.2018v16iss1/art2)
USACE	US Army Corps of Engineers
USGS	US Geological Survey
VC	Valued Component

1 Introduction and Context

The Mississippi River Delta is a dynamic and substantially altered environment where geomorphic forces like subsidence, winds, tides / currents, and extreme events like hurricanes influence coastal land loss. While essential for maintaining river cargo transport and protecting communities and property from flooding, expansive levees disconnect the Mississippi River from coastal marshes and play a role in ongoing land losses. Furthermore, the Delta is also a highly valued ecosystem that supports economically significant commercial seafood and recreational fishing industries and is home to an array of waterfowl, migratory birds, and iconic Louisiana species. The Delta's wetlands protect people and property from storm surge, filter pollutants from water, and support breeding, spawning, feeding, and nursery habitat for many fish and wildlife species.

Between 1932 and 2016 Louisiana lost approximately 1,900 square miles of land along the coast.[1] Without restoration interventions, the coast could lose an additional 1,207 to over 4,100 square miles of land in the next 50 years, depending on future uncertain environmental conditions affected by sea level rise and increased storm activity (CPRA 2017). From 2004 through 2008 alone, more than 300 square miles of marshland were lost to Hurricanes Katrina (2005), Rita (2005), Gustav (2008) and Ike (2008) (Couvillion et al. 2011). Moreover, 2020 was a record-breaking storm season with 30 Atlantic storms, 5 of which made direct landfall with Louisiana (Cristobal, Laura, Marco, Delta, and Zeta).[2] For many years, federal and state agencies have recommended a mix of actions for maintaining and building land to mitigate the Delta's ongoing and projected land losses (Figure 1.1).

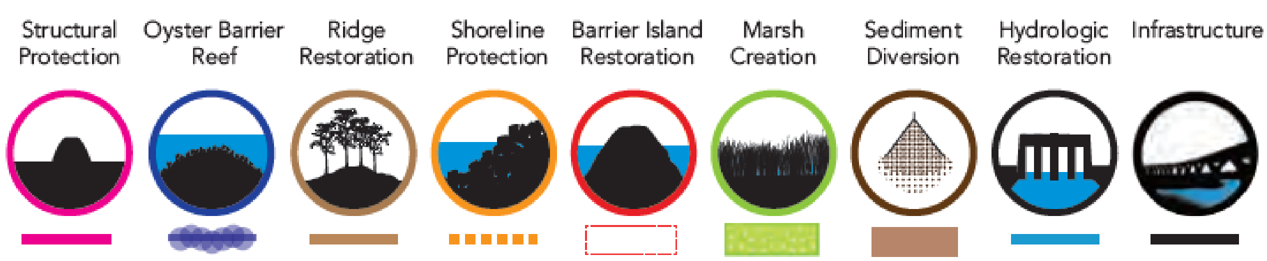

Figure 1.1: Types of management actions or projects to maintain and build land across Louisiana's coast (Source CPRA 2017).

Sediment and freshwater diversions are management actions currently in use or being proposed to help connect the Mississippi River to its deltaic ecosystem. Although the purpose of

[1] U.S. Geological Survey, National Wetlands Research Center. 2011. Land Area Change in Coastal Louisiana from 1932 to 2010. Retrieved from http://www.nwrc.usgs.gov/topics/landloss.htm and
Couvillion, B.R., Beck, H., Schoolmaster, D., and Fischer, M. 2017. Land area change in coastal Louisiana 1932 to 2016: U.S. Geological Survey Scientific Investigations Map 3381, 16 p. pamphlet, https://doi.org/10.3133/sim3381.
[2] https://www.cnn.com/2020/05/11/us/2020-atlantic-hurricane-season-fast-facts/index.html and
https://www.nola.com/news/hurricane/article_d9697294-16c1-11eb-abb3-2737fc665d10.html

freshwater diversions (which have a focus on maintaining a specific salinity regime) is much different than sediment diversions, the fundamental management action is the same – the magnitude and duration of gate openings and how this is adjusted through time. Sediment diversions are being designed and located along the Mississippi to capture the greatest amount of sediment during high river flows, with the goal of directly building new wetlands and adding sediment to existing wetlands in Barataria and Pontchartrain Basins. The idea is to mimic the river's historic land-building process, when by shifting course and through annual spring flooding, large quantities of sediment were deposited and created new land and wetlands. With rare exceptions, those processes ended 150 years ago when humans began locking the river in its present channel with levees and cut off flooding of the Delta in the spring. Once constructed and operational, the sediment diversion will quickly change the dynamics of the entire estuarine basin (Peyronnin et al. 2017).

There are many specific actions that can be taken to adjust construction, operation, and maintenance of such diversions. For instance, a control structure of gates built into the existing levee of the Mississippi River would allow river water, sediment, and nutrients to flow into degraded wetlands, mimicking the natural flood cycle, crevassing, and distributary sub-delta formation of the Mississippi River. Diversion operators would make decisions about gate openings and closings based on riverine and basin conditions to transfer sediment-laden water to target outfall areas. However, diversion operations and decisions around gate openings and closing will also need to balance sediment delivery and land building objectives with potential flood risk to coastal communities, erosion of adjacent marshes, and habitat needs for vegetation, fish, and wildlife species. Furthermore, there are many scientific uncertainties that affect the ability to control the effects of a diversion and understand how it can best operate to balance the needs of these many valued components of interest to decision-makers and stakeholders across coastal Louisiana. The operational strategies for diversions will be a critical factor that influences how valued ecological and human components change over time, and given the unknowns involved, these strategies should become an explicit part of ongoing adaptive management and monitoring programs (Hijuelos and Reed 2017; TWIG 2020; Carruthers et al. 2020).

Within this context, **the purpose of this document is to propose and describe a conceptual design for a Real-Time Sediment Diversion Operations Tool (SDOT).** This conceptual design includes a description of the proposed purpose and need, scope, candidate components, low fidelity mock-ups, and development steps to build such a tool. Currently, there is no commitment to develop it, but the intent with this document is to clarify how it could become a reality. If developed, this tool would be an integrated multi-objective decision support tool that would support operations and adaptive management of sediment diversions in the lower Mississippi River. Its ultimate intent would be to support the capabilities of diversion operators to evaluate alternative operational scenarios and diversions in a real-time operational context (i.e., within and across operational seasons) to better support success in achieving land building and improving restoration outcomes along the Louisiana coast.

1.1 Purpose of the Real-Time SDOT

As decision-makers move toward construction of large-scale sediment diversions in the lower Mississippi River, the development of a decision support tool or decision engine would support real-time (within year) operational strategies and respond to real-time status of relevant state variables directly and indirectly affected by diversions. Hence, the purpose of this tool would be:

To couple existing Mississippi River flow forecasts, sediment transport, salinity, turbidity and related hydrodynamic models to a representative suite of well-specified valued ecological and social components inside a highly intuitive web-enabled software tool that allows decision-makers to explore within-year operational alternatives that best balance interests and constraints.

A fundamental and unique aspect of the proposed SDOT is that it would deeply couple what are typically independent sub-models and performance measures (Figure 1.2) rather than run specific disciplinary models serially in isolation from one another. The later approach only offers model investigators a finite set of decision outcomes to choose from, while the advantages of SDOT are that it would explicitly couple and link flow, hydrodynamic, and ecosystem models together with two-way feedback to permit application of more advanced computing and optimization techniques, like Turn-Taking Optimization (TTO), to identify and improve (but not perfect) decision outcomes (see Alexander et al. 2018 and Box 1). A coupled modeling approach is superior to serial simulations, not only because it is orders of magnitude faster, it also fundamentally provides the ability to explore and evaluate many thousands more options than model practitioners who are stuck in traditional serial "*what if*" model run configurations.

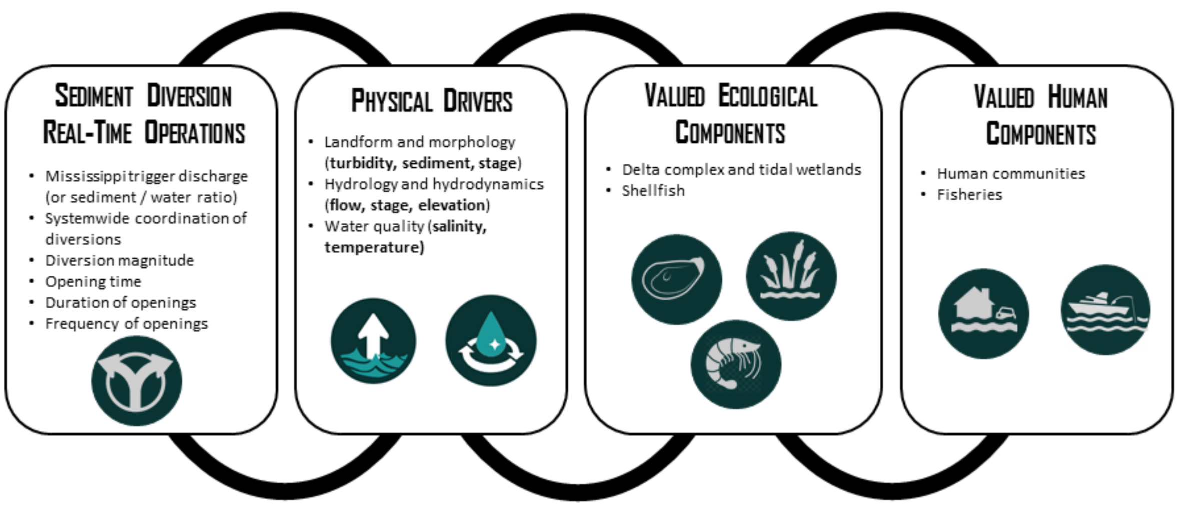

Figure 1.2: Simplified conceptual illustration of the coupled modeling involved in linking management actions along a cause-effect chain from real-time operations to changes in physical variables to influences on valued ecological and human components.

Model coupling enables the necessary model-to-model communication feedbacks and the package of coupled models can be ‘taught’ to make use of optimization algorithms to semi-automate the process of narrowing in on candidate diversion operations. This is why we sometimes use the term “*decision engine*”, as this approach automatically generates a smaller number of promising candidate operational scenarios for operators to choose from. However, operator’s expertise and knowledge ultimately must be involved as there will always remain value trade-offs that cannot be “*computed away*” with optimization nor cleverly devised operational scenarios.

1.2 Real-Time Operational Decision-Making

As noted above, the SDOT would support real-time operational decision-making (i.e., adjustments within a season) and aid in retrospective year-end evaluations of operational plans. It would not be designed to support long-term modeling and assessment of diversion operations over multiple years. Real-time operational computer simulations of diversion operations mean that the predictions made by the decision support tool would be relative to a real-world decision date. Forward of the current decision date, the SDOT would leverage forecasts of key physical inputs to make predictions for how different performance measures will respond to different operational scenarios. Prior to the current decision date, the SDOT would present actual real-world measured conditions for the same physical variables derived from real-time enabled gauging / monitoring stations. These data could also be overlaid with information about how performance measures in the historic period responded to comparable conditions. Every day the decision date marches forward in real-time, the time series of actual retrospective conditions grows, while the future forecast period typically diminishes in length until the end of the operational season. For example, an SDOT operational scenario that is run on June 16, 2022 would make forecasts for the period June 16, 2022 through to the end of the model’s simulation time horizon on July 13, 2022 (assuming a maximum 28-day forecasting period). The key performance measures of valued components (VCs) included in the decision support tool would likewise represent future predictions based on these forecasted datasets.

Prior to June 16, 2022, the tool would display actual values for all key driving physical variables (derived from web-linked real-time gauging stations / instruments) and these actual values would be used to determine results for key performance measures (see example illustration in Figure 1.3). Each of the relevant performance measures would include defined suitability thresholds or ranges (allowing for dashboard “*hazards bars*” to be plotted), as well as time periods of relevance (controlling the temporal span the hazard bar is plotted on the graph).

To begin to visualize what this might look like for a sediment diversion, imagine transferring appropriate performance metric hazard bars like those in Figure 1.3 onto the plot in Figure 1.4 (Section 3 discusses candidate performance measures for this conceptual design). Of course, there is no single sediment diversion operation that will simultaneously optimize conditions for all valued components at all key locations (Peyronnin et al. 2017). For this reason, the SDOT would need to identify opportunities for balanced achievement of objectives through time and space by encouraging decision makers to leverage the concept of Turn-Taking when evaluating and managing trade-offs among multiple objectives and related performance measures (See

Section 4.1.4, Alexander et al. 2018). Due to limitations of most flow forecasting models, simulations of real-time operations will most likely be constrained to the current water year (with opportunities to run prior individual water years as part of retrospective simulations to support operator training).

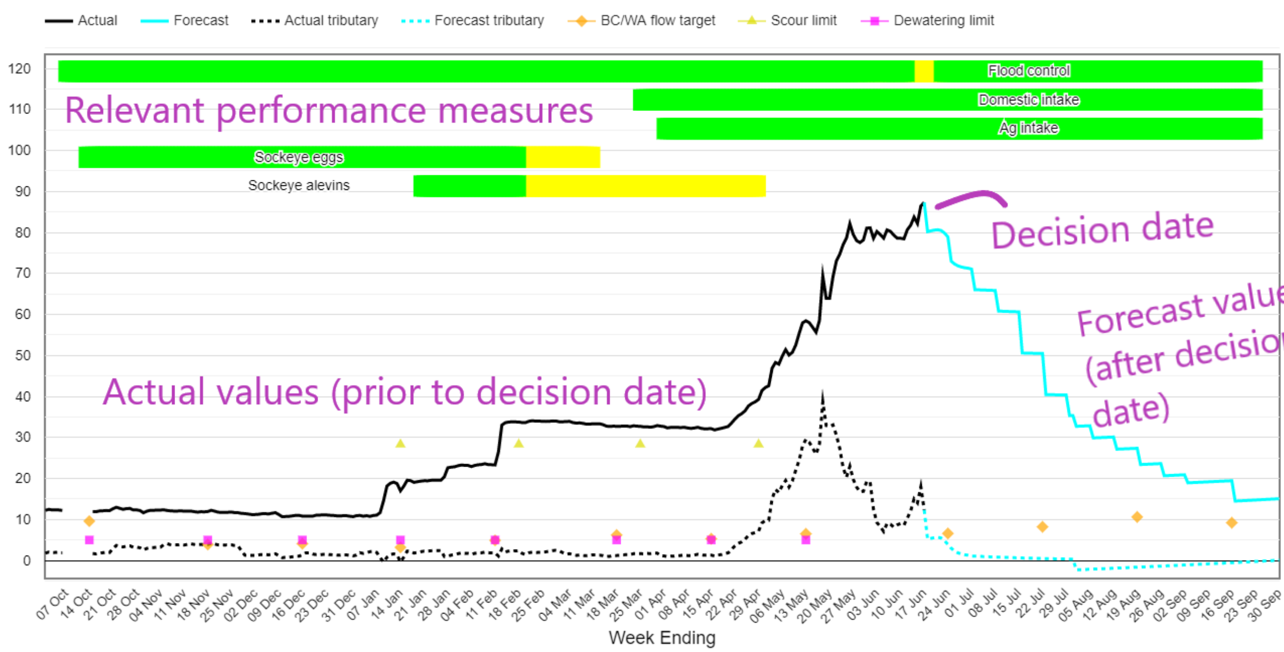

Figure 1.3: Example of DST dashboard output showing suitability of conditions for multiple objectives (green-yellow colored horizontally stacked bars) at one key location against actual values from gauging stations (black line) and forecast river flows (blue line) resulting from a particular time series of diversion operations. Square dots, diamonds, and triangles near the horizontal axis reflect ideal target flows for specific objectives. Similar graphs can exist for reporting at multiple locations with common and/or different performance measures. Analogous outputs could be generated for sediment diversion operations with a focus on gate settings and resultant sediment delivery and river stages. The goal of operators would be to find diversion operations that keep all core performance measures “green” (see Hyatt et al. 2015).

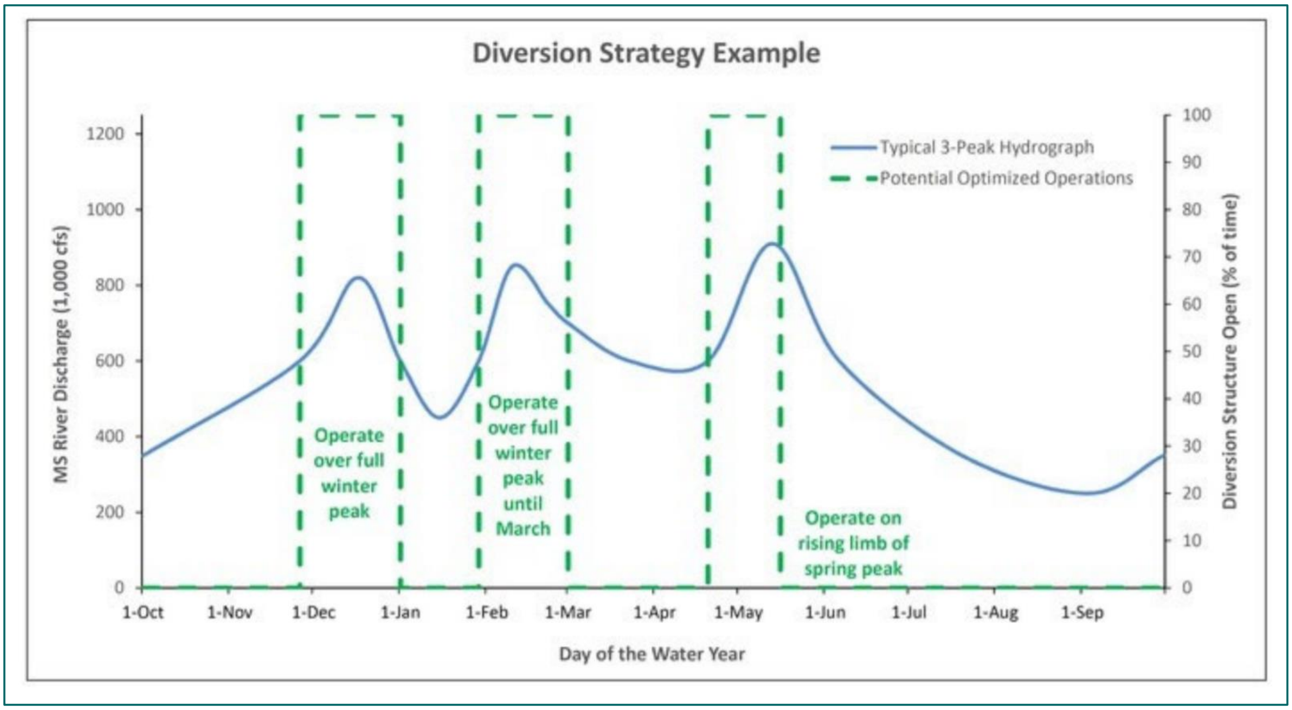

Figure 1.4: Simplified conceptual example of how a diversion could be operated to deliver sediment in consideration of its effects on fish and wildlife habitats. As noted in Peyronnin et al. (2017), an operation strategy can be developed and tested for each hydrograph typology (demonstrated here on a three-peak hydrograph typology) that effectively captures sediment for land building, while also balancing the needs of the ecosystem and communities.

Box 1: What is Turn-Taking Optimization (TTO)?

Balancing trade-offs among multiple-objectives is complicated–especially when there are *many* multiple objectives. These multiple objective trade-off balancing problems are common in intensively managed river systems and estuaries like the Mississippi River Delta, Columbia Basin, as well as the Sacramento Rivers and the Sacramento–San Joaquin Delta (SRD). Conventional approaches (e.g., consequence tables) often fall short by emphasizing a handful of objectives which can promote a world of "winners and losers". This winners and losers problem is further exacerbated when consequences are derived using disintegrated modeling that prevents sub-models from responding dynamically to conditions in other sub-models because the family of models are being run independently from one another (rather than in the manner shown in Figure 1.5). Even with creative identification of alternative actions, complex and large-scale decision problems can rarely be boiled down to a handful of choices capable of enduring over a range of exogenous conditions.

ESSA's scientists, in partnership with The Nature Conservancy, published a paper (Alexander et al. 2018) that demonstrates significant benefits of an innovative new solution to the perennial challenge of managing water for conflicting needs. The approach – coined 'Turn-Taking Optimization' (TTO) – draws inspiration from the song made famous by the Rolling Stones: "*You can't always get what you want*" (a.k.a. 'Jagger's Law'). This approach for managing water requires managers to embrace greater flexibility, real-time decision-support systems, the principle of taking turns through time and leveraging cloud computing and optimization to explore the thousands of scenarios necessary to find more balanced trade-off solutions in the face of many objectives.

The TTO approach hinges on the idea that humans and ecosystems have an innate resilience to disturbance and therefore do not need to achieve 'target' suitability conditions every year/season but can 'take turns' having their needs met. An underlying tenet is that natural selection and evolution confer on many species the ability to survive and persist during poor habitat conditions if there are enough periods with good conditions. The same premise can be applied to certain socio-economic objectives. Accepting this premise, our TTO approach allows past ecological benefits to be 'remembered' in the optimization procedure. For example, if a species' performance indicator was achieved in a prior set of years, its priority can be downgraded for an appropriate period, allowing other indicators to have a higher priority (see Figure 1.6). Put simply, as objectives 'get what they need' their priority is temporarily reduced, letting other objectives have their turn. Depending on the setting, these turn-taking priority adjustments can occur at different time-scales (not always annually).

Our in-depth study in California SRD demonstrated that **adopting a water allocation approach that incorporates shifting priorities and optimization of indicators across years leads to overall multi-objective and species benefits.**

Although a water-management paradigm that embraces TTO will not solve every trade-off, if it were tried, managers just might find that more values and objectives get what they need.

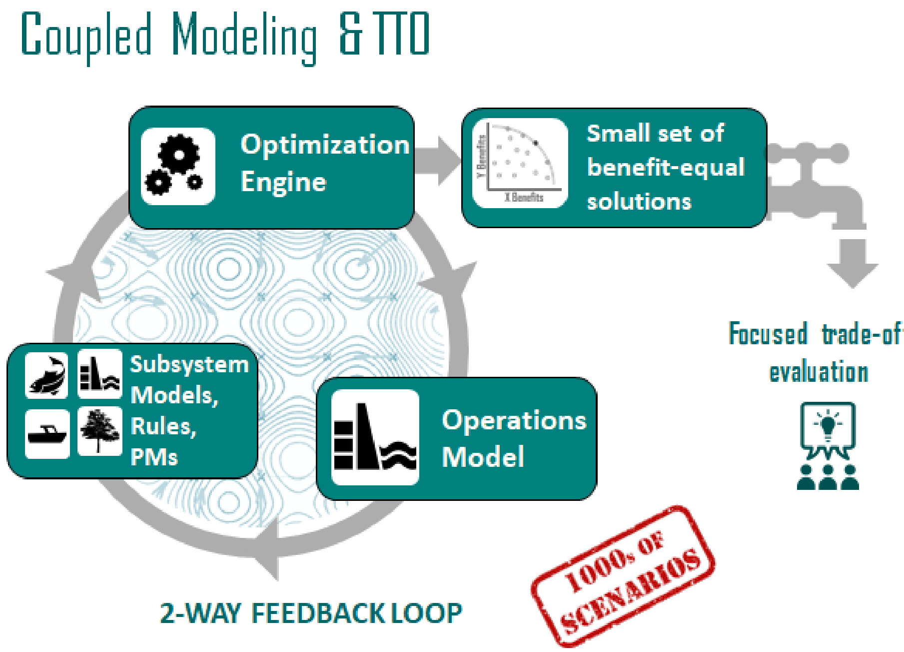

Figure 1.5: Example of an advanced tool feature, termed Turn-Taking Optimization. Illustration represents coupled decision support models and performance measures functioning within a two-way feedback loop and linked to optimization algorithms that help narrow down best candidate solutions for decision-makers.

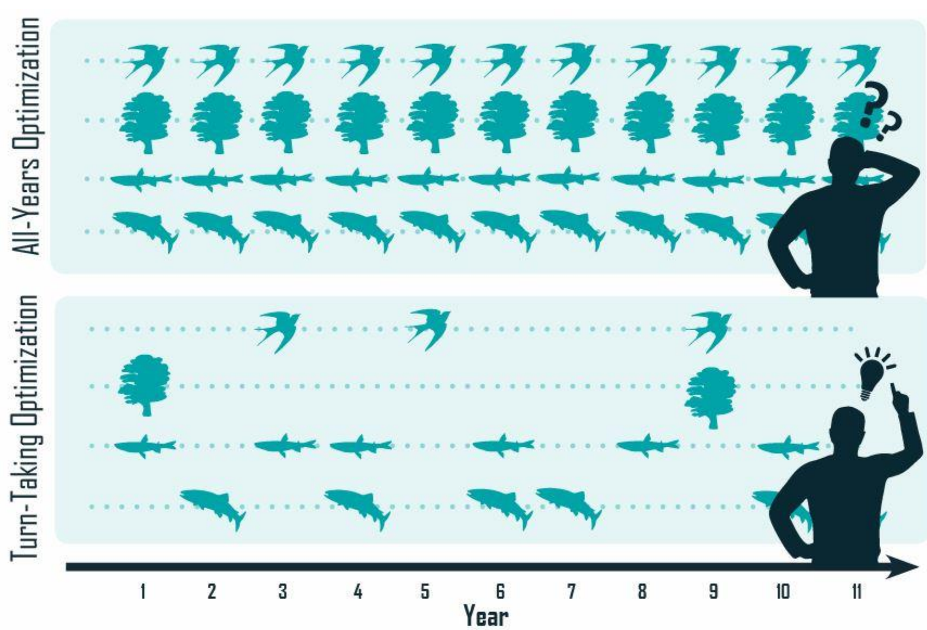

Figure 1.6: Illustration of Turn-Taking Concept in which the top panel seeks to optimize conditions for multiple objectives and performance measures across all years, while the bottom panel seeks to optimize conditions for different objectives and performances measures in different years. For more information see https://essa.com/explore-essa/tools/jaggers-law-Turn-Taking-optimization/.

What the SDOT Is Not

The SDOT would not provide a Delta-wide assessment of consequences on all valued components of interest to decision makers and stakeholders, and it would not replace the many and varied planning models used to project outcomes for other objectives that are assessed on multi-year or decadal time scales. Moreover, this tool would not serve as a data repository and visualization tool to report on the status and trends of key performance measures collected at annual (or less frequent) time intervals that are part of long-term monitoring and broader adaptive management efforts.

The SDOT we envision here is an operational, real-time system that will help raise visibility on current constraints associated with meeting multiple objectives on a seasonal to annual time horizon. It is intended to be a go-to system used weekly by engineers and resource managers. It is not intended as an 'academic' planning tool used occasionally to update master operating plans. Its power would be in enabling a deeper synthesis and coupling of physical and performance measure sub-models combined with real-time data from active field sensors to allow exploration of consequences associated with near-term and real-time operational decisions of one or more diversions.

1.3 Conceptual Mockups & Technology Platform

Please note that this section provides only a small number of examples of potential user interface components. As a static document the following images cannot convey the software interactivity that is intended.

Before presenting details around the scope and recommendations for technical underpinnings in Sections 2 and 3, we present some conceptual mock-ups here and elaborate upon the technology solution being envisioned through this conceptual design.

The Real-Time Sediment Diversion Operations Tool (SDOT) would be a secure, internet accessible, real-time web application that could be operated by multiple authorized users simultaneously. The tool would promote iterative running of diversion "scenarios" and sharing them with other authenticated managers to provide a highly transparent, efficient, and effective way to converge toward balanced operational strategies (see Figure 1.4 and Figure 1.7). As a real-time operational system, the software would also unify display of relevant alerts and conditions on a dashboard (e.g., weather alerts, real-world river flow, river elevation, salinity, and other gauges to continuously update forecast information with actual conditions of these same key state variables (stage, flow, salinity, etc.)). At its core, the SDOT would be a decision support software — advanced, custom computer code representing coupled biophysical submodels, their key performance measures, real-time databases, web services, and network software.

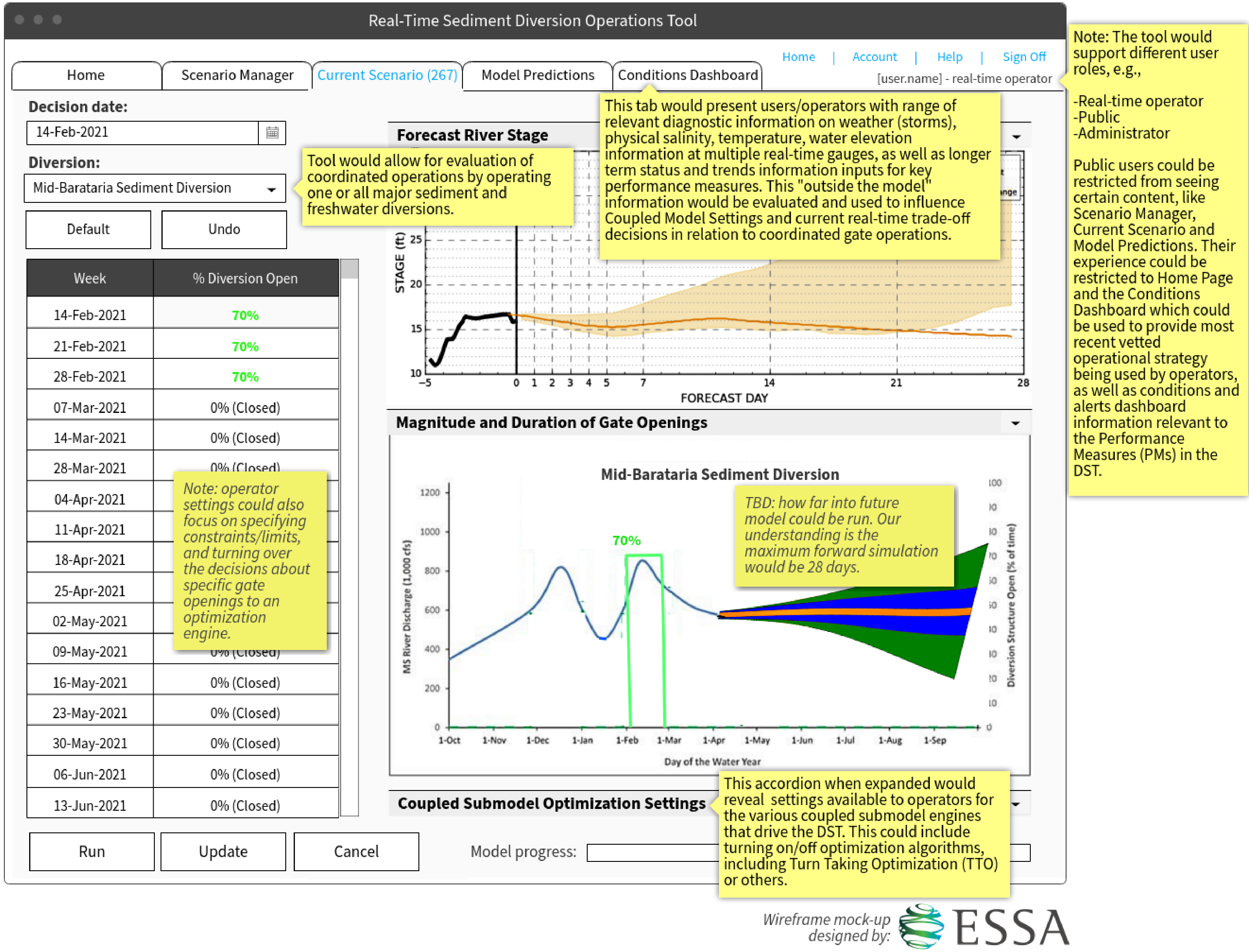

Figure 1.7: Early conceptual mockup of the SDOT web user interface, showing a hypothetical operations scenario that a manager is considering on February 14, 2021. The real-time operator selects one or more diversions to specify gate settings for, reviews weather and river forecasts, and runs simulations to determine outcomes on key performance measures (displayed on Model Predictions tab after the DST is run). Note: this is only an early illustration and does not contain actual data or model outputs. All implied data and results are purely hypothetical for example purposes only. <11x17 page>

The SDOT would be used to evaluate outcomes and trade-offs associated with the magnitude and duration of gate openings and how these gate settings are adjusted through time in response to Mississippi River trigger flows, sediment / water efficiency ratio triggers as well as the status of other important performance measures. Gate settings could involve choices around:

- magnitude of gate openings (diversion flow magnitude — e.g., effect of gates open 0%, 50%, 100% of maximum);
- duration of these openings (how long, when); and
- frequency of openings and closings (Figure 1.7).

Alternatively, users could specify constraints/thresholds for gate openings and turn over decisions about specific settings within the allowed flexibility range to an optimization engine (Figure 1.7).

1.3.1 User Interface Paradigm

The web user interface would be structured around a series of functionally interrelated tabs or pages that would allow users to advance from logging into the tool, encountering simple overview information on a "*Home*" landing page, and depending on the user's role and permissions, progressing towards evaluation of alternative diversion operation scenarios ("*Scenario Manager*") and related settings ("*Current Scenario*", see Figure 1.7) and predictions ("*Model Predictions*", see Figure 1.8). A critical component of the "*Current Scenario*" tab, which houses user configurable model settings and constraints, is integrated river flow and stage forecasts. While not the sole factor, river forecasts are the most important input driving decisions and outcomes related to diversion operations. Hence, the quality of the SDOT simulations will critically depend on the quality of these river forecasts.

A "*Conditions Dashboard*" tab would provide users with a range of relevant, highly integrated ("one stop") diagnostic information on weather (storms), physical salinity, temperature, water elevation information, etc. at multiple real-time gauges, as well as longer term status and trends information inputs for key performance measures being collected through long-term monitoring programs. This could also include value added features such as early warning diagnostics and anomaly detection algorithms that alert tool users to particularly unusual physical conditions. This part of the SDOT would house information that is relevant to how operators may wish to structure settings and constraints for the coupled physical and ecological models relevant to coordinated gate operations. However, the "*Conditions Dashboard*" information would typically be environmental variables that are not strongly under the control of diversion operations, but in the reverse, would be important to setting operational constraints, triggers and priorities for diversion operations. For example, weather alerts about storm surge conditions, as well as a variety of other lagged, slow response status and trend information driven by multiple factors.

In contrast, the "*Model Predictions*" tab (Figure 1.9) would house performance measure outputs that are significantly influenced by diversion operations and are largely determined / predicted by the coupled sub-models that would exist underneath the user interface (i.e., see performance measured described in Section 3 below).

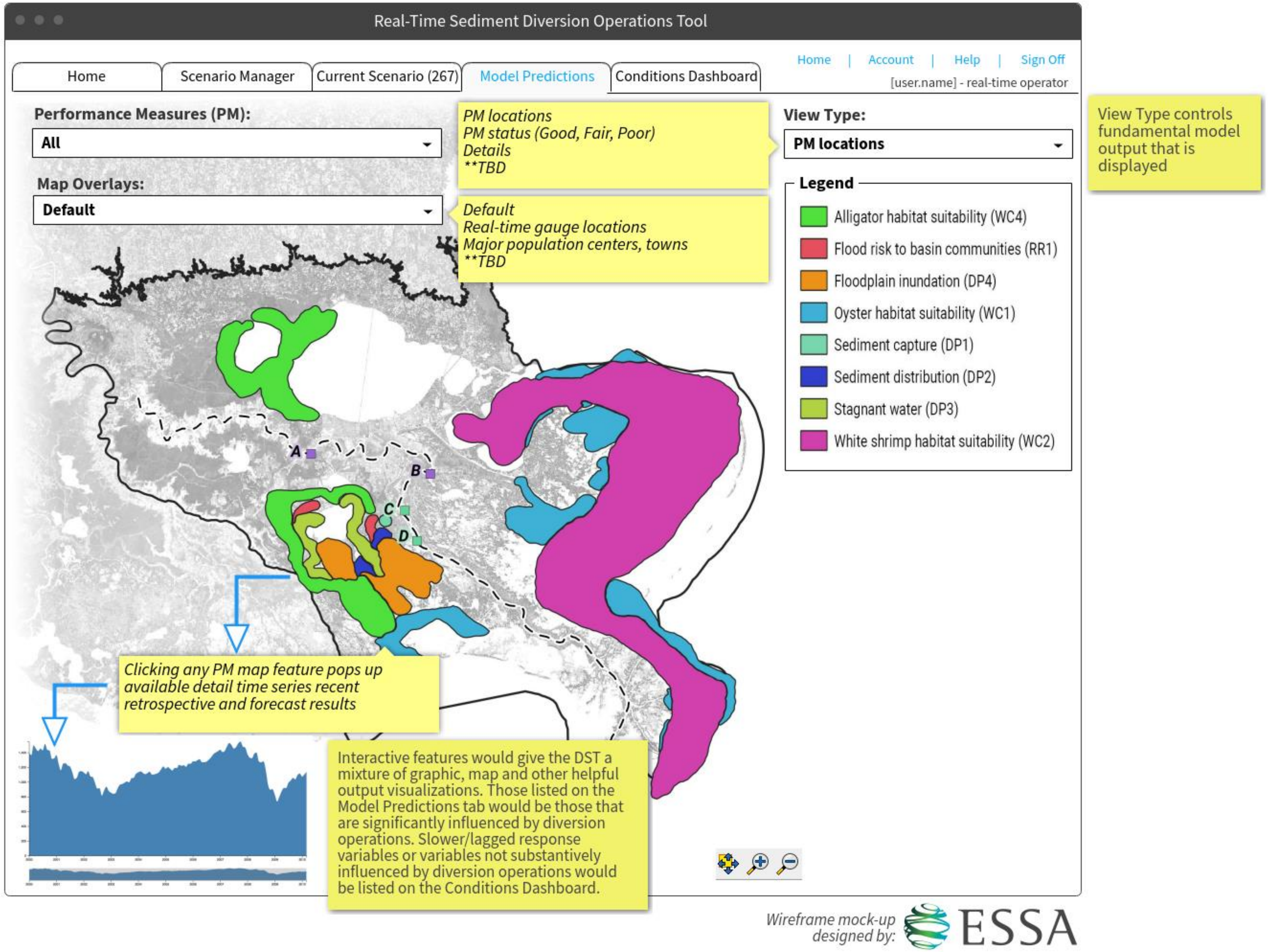

Figure 1.8: Early conceptual mockup of the SDOT web user interface, showing available visualizations associated with (hypothetical) model run 267 that was configured and run from the Current Scenario tab. In this example, the user is presented with the locations of various performance measures on a map. The controls on the page allow users to select a variety of view types, performance measures, and different map overlays. Note: this is only an early illustration and does not contain actual data or model outputs. All implied data and results are purely hypothetical for example purposes only. <11x17 page>

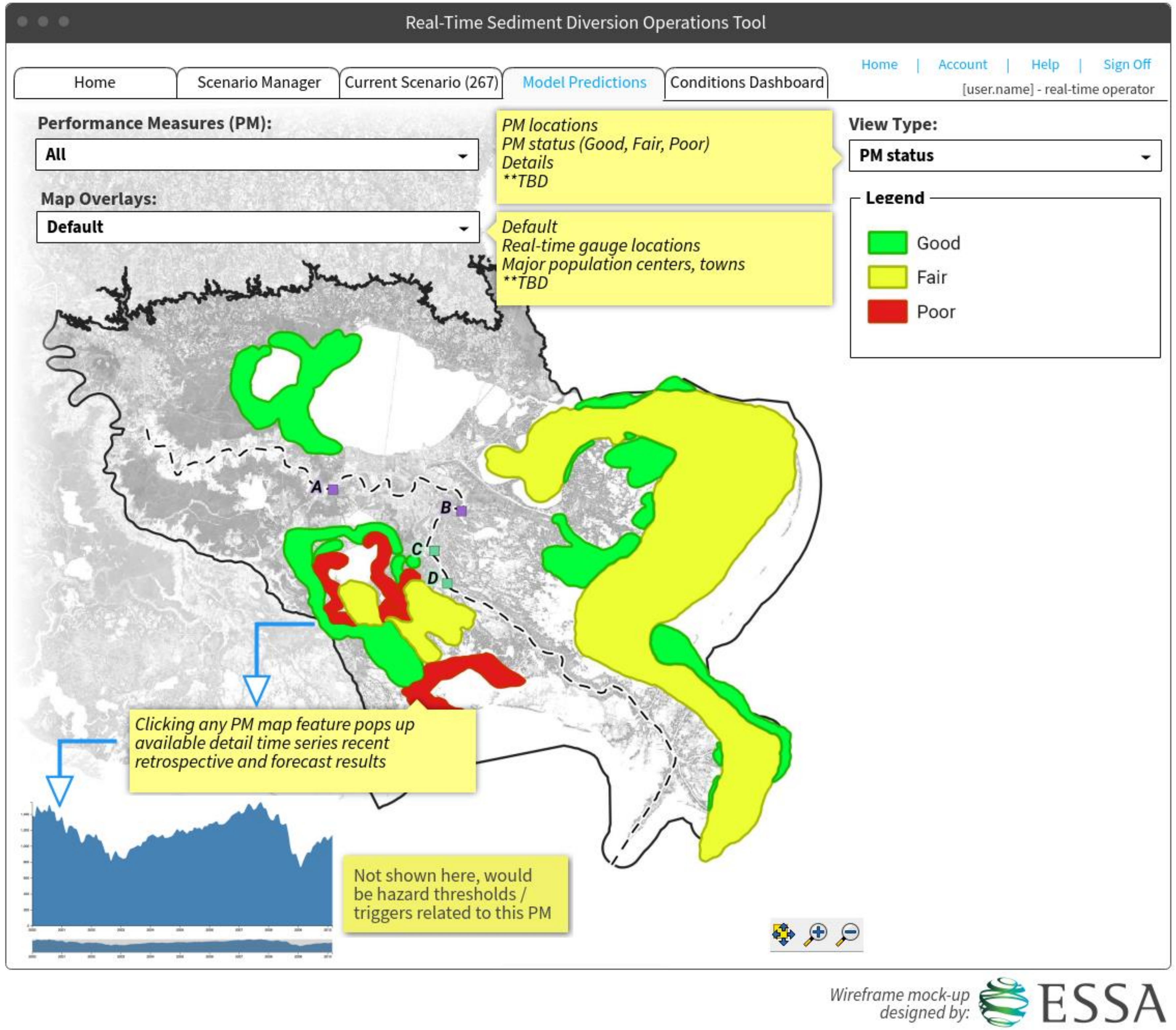

Figure 1.9: Early conceptual mockup of the SDOT web user interface, showing available visualizations associated with (hypothetical) model run 267 that was configured and run from the Current Scenario tab. In this example, the user has selected the PM status hazard assessment view type, which provides a rapid status assessment of performance measures that are under the influence of diversion operations. The controls on the page allow users to select a variety of view types, performance measures, and different map overlays. Note: this is only an early illustration and does not contain actual data or model outputs. All implied data and results are purely hypothetical for example purposes only. <11x17 page>

The "*Model Predictions*" tab (Figure 1.9) would center around map-based displays with interactive features that would give the SDOT a mixture of map, graphic, and other helpful kinds of output visualizations (discoverable from a map-centric user interface). A defined set of view types and map overlays would interact to provide users with essential context on the relationships amongst diversion operations, performance measures, external / ancillary ("conditions") variables, and important places of interest. Specific details of these various output visualizations would be developed following more detailed sub-model vetting and fully specifying the performance measures that are to be included.

Depending on user roles and privacy policies of SDOT owners, some of these tabs / components would not be available. There are a variety of options with regards to roles and access that still need to be discussed. This includes whether the tool would be structured to allow public access. From a technology perspective, often, public users are granted access to a smaller range of data and vetted / curated results as opposed to scenarios or data that are transient or in progress. For the time being, this remains an open discussion.

1.3.2 Overall Keys to Success

Based on our experience, the core features needed to implement a successful SDOT includes the following (based on insights from Greig et al. 2013 and Moran et al. 2020 among others):

- providing sufficiently specific performance measures that include instantaneous and annual suitability thresholds (clearly define favorable status values) along with annual recurrence frequencies (how many years out of y years a performance measure needs to yield a favorable status);
- coupling existing and new physical river flow / stage, salinity, turbidity, ecosystem, and human use sub-models so they can run simultaneously with two-way feedbacks;
- adding an appropriate machine learning / statistical optimization engine (like Turn-Taking Optimization; see description in Box 1) and configuring coupled models so they are capable of being run in an unattended fashion under direction of an overarching simulation engine;
- embedding the coupled and more computationally demanding set of models within a powerful, fast, yet inexpensive commercial cloud-based computing environment;
- providing highly intuitive multi-objective web user interface that allow multiple users to easily operate detailed models and visualize results using simplified dashboards and maps that transparently communicate trade-offs across multiple valued components; and
- ensuring decision support tools are integrated with appropriate, effective governance structures that can enable successful learning and decision making.

1.3.3 Design Principles

A main design aim for the SDOT is to allow exploration of trade-offs amongst key valued components in a way clear to non-specialists. The main technical product will be an integrated database, coupled model engine, optimization engine, and web user interface for presenting trade-offs among performance measures. Table 1.1 outlines some of the principles that will serve as the foundation to the design of the SDOT.

Table 1.1: Design principles for the Real-Time Sediment Diversion Operations Tool.

Principle	Notes
Flexible, extensible design	**Use a flexible model architecture that allows other tools, models and performance measures to be added and removed.** RTO will incorporate software development strategies that maximize adaptability and ease of revision. The system architecture will follow a tiered design that separates the database (first tier) from sub-model logic (middle tier) and any user interface (third tier) components (e.g., user reports). **Focus initially on a tight set of valued components.** Considering the scale of the Mississippi River Delta (MRD), the wide array of habitat units it encompasses and the many species it supports, it is necessary to focus on the most critical priority ecosystem and other valued socioeconomic attributes first. This will allow the team to demonstrate how real-time operations can be used to identify and visualize key ecological trade-offs rather than spending all resources cataloguing the entire ecosystem and attempting to integrate everything. This principle demands a modular approach which allows different performance measures and freshwater/sediment diversions to be added/removed.
Do not reinvent existing functionality	**Capitalize on existing tools and models.** To the extent possible, integrate existing quantitative models followed by existing qualitative models or other decision support tools. Selectively analyze existing data to build new performance measure models (e.g., regression relationships) for focal species, habitats, or habitat-forming processes where appropriate and feasible.
Generic, flexible relational data model	**Develop a custom relational database as the 'glue' holding all coupled model sub-model data and related data transfers together.** Linking together existing models with new ones to evaluate trade-offs for different scenarios requires a substantial level of data flow management. If the system includes an optimization engine and two-way feedbacks, then all the models also need to be able to talk to one another which typically requires an intermediary coordination database.
Intuitive and user friendly	**Real-time operations should be designed for users of low to moderate computer literacy.** The tool should not require any specialized or 'power' user skills such as coding or database design. Once logged in the system, it should be easy to self-learn and should emphasize dashboard style outputs with options to deliver increasingly sophisticated reports.
Number of users	As a web solution, **multiple users will be able to run the tool from a web browser simultaneously**.
Use error handling and logging	Invisible to users, SDOT application code will use structured error handling and by default all moderate and severe errors will be logged. This simple practice has been shown from experience to greatly simplify debugging and maintenance.

2 Scope and Boundaries for the SDOT

The scope and boundaries for the SDOT, as presented in this Section, were developed through a combination of desktop research and technical expert engagement occurring over approximately 18 months. Developing the scope and boundaries for this conceptual design involved the following efforts:

- engaging the Restore the Mississippi River Delta coalition of scientists and policy experts in a series of meetings to discuss relevant management actions, valued components, management objectives, and critical management uncertainties specifically related to the Mid-Barataria sediment diversion;
- developing a series of technical memos and summary outputs from these engagements to summarize:
    - **valued ecological and human components** of interest to stakeholders and decision makers in the region;
    - an **"objectives hierarchy"** representing hierarchal linkages, timing, and importance of objectives as they relate to diversion operations and the Coastal Master Plan (see Appendices B and C);
    - a preliminary set of **performance measures** that relate to the long list of identified objectives; and
    - **scientific and management uncertainties** associated with diversion operations that could be resolved through research and / or adaptive management;
- conducting additional background research to identify a narrower and more precise set of quantifiable performance measures for valued ecological and human components, alongside candidate physical models that could be used to represent quantitative relationships in the SDOT;
- convening a three-part remote workshop to receive feedback on the above content with a wider range of experts with specialized knowledge about quantitative modeling, hydrodynamics, and physical conditions in the lower Mississippi River and Delta, the valued human and ecological components of relevance to the study area, as well as operations and maintenance of diversions; and
- undertaking additional background research to further focus and clarify key components of the conceptual design for the SDOT based on feedback from workshop participants.

The section that follows represents our best understanding of a feasible and useful scope and boundaries for the SDOT that would serve the interests of diversion operators and address some of the broader interests of stakeholders. We acknowledge that the proposed scope and boundaries could further evolve and be adjusted as the tool advances through future development steps and accommodates other perspectives.

2.1 Focal Management Actions

Sediment diversions are one engineering solution to support coastal protection and land building by diverting freshwater, sediment, and nutrients from the lower Mississippi River into adjacent wetlands in the Delta. With the right type of operations, they can provide long-term benefits that constructed marsh creation projects alone do not. For instance, the proposed Mid-Barataria Sediment Diversion near Myrtle Grove (Figure 2.1) would transfer sediment-laden water from the Mississippi River through a self-contained conveyance channel roughly 1.5 miles long, and discharge into mid-Barataria Basin. Located near River Mile 61, the diversion channel would divert a base flow of up to 5,000 cubic feet per second (cfs) when Mississippi River flows are less than 450,000 cfs at the USGS gage at Belle Chasse, divert variable flows of 5,000 to 75,000 cfs when Mississippi River flow is between 450,000 and 1,000,000 cfs, and divert 75,000 cfs when the river flow exceeds 1,000,000 cfs. Over a 50-year period the diversion is expected to build and nourish up to 47 square miles of new critical coastal wetland (or up to 30,000 acres)[3]. In contrast, over the same period without the benefits of restoration, the Barataria Basin is projected to lose 550 square miles of land with a sea level rise of two feet (CPRA 2017).

Sediment diversions can be operated over winter peak flows to capture the highest sediment concentration, reduce losses of dormant vegetation, and reduce detrimental effects to fish and wildlife. Operations during the spring / summer need to occur over shorter periods to capture the highest sediment load during the rising limb of the flood peak while minimizing impacts to the ecosystem (Peyronnin et al. 2017). Figure 1.4 shows a simplified example in which a 3-peak year is operated with 3 diversion-openings.

The SDOT would be used to evaluate outcomes and trade-offs associated with the magnitude and duration of gate openings and how these gate settings are adjusted through time in response to Mississippi River trigger flows, sediment / water efficiency ratio triggers and status of other important performance measures. Gate settings involve choices around:

- magnitude of gate openings (diversion magnitude — e.g., effect of gates open 0%, 50%, 100% of maximum);
- duration of these openings (how long, when); and
- frequency of openings and closings.

[3] http://coastal.la.gov/wp-content/uploads/2020/03/BA-0153-Mid-Barataria-Sediment-Diversion.pdf

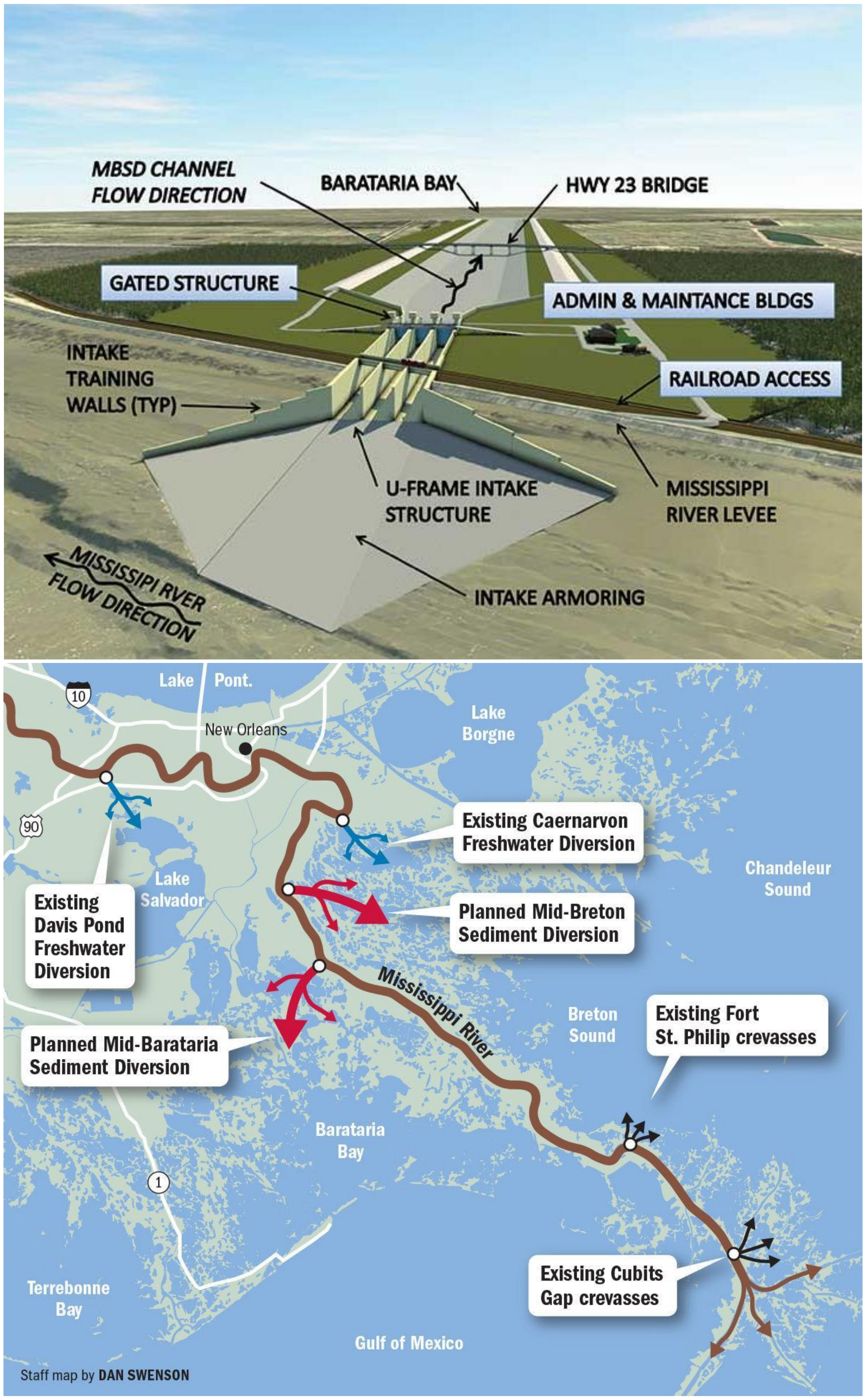

Figure 2.1: Upper illustration shows an artist rendition of the Mid-Barataria Sediment Diversion. Source: Engineering News-Record (https://www.enr.com/articles/44968-mississippi-river-diversions-could-save-louisianas-drowning-coast). The lower map shows the general layout and outfall areas of influence for the Mid-Breton and Mid-Barataria Diversions (image used by kind permission of Dan Swenson and The Times-Picayune/New Orleans Advocate). The size of the arrows does not represent the relative magnitude of discharge from these diversions.

As a computer simulation tool, some of the operational strategies being explored may or may not be consistent with existing permits and constraints. This reality creates an opportunity to identify new operational approaches or procedures that may better serve decision makers' needs and can be evaluated as part of ongoing adaptive management and monitoring.

Although the purpose of freshwater diversions is much different than sediment diversions (having a focus on maintaining a specific salinity regime), the fundamental management action is the same – the magnitude and duration of gate openings and how this is adjusted through time. As such, the architecture for the tool would be modular to include multiple existing and planned freshwater and sediment diversions, which could ultimately support systemwide coordination of diversions and management of a broad spatial area encompassing the lower Mississippi River and lower Mississippi River Delta. Ideally, a prototype (or proof of concept) system would be built first for one or more existing freshwater diversions to introduce the core concepts and capabilities of the system, then sediment diversions could be added once they are constructed (see Section 4.1 for more discussion about development steps). This is a practical and efficient suggestion because of the time required to create the underlying foundations for these systems and the need to overcome various technical hurdles involved with coupling disciplinary models. In essence, the development principle would be to "*start small and get bigger*" by testing smaller scale prototypes to help efficiently enable staged, modular expansion of additional diversions and inclusion of features like Turn Taking Optimization.

2.2 Valued Components and Management Objectives

A foundational component to clarifying the scope and boundaries for the SDOT is based on the management objectives that decision-makers are trying to achieve through the operations of sediment diversions of the lower Mississippi River. Management objectives are concise statements about "what matters"; they speak to the fundamental issues or "valued components" of interest to people which can include ecological and human considerations (Gregory et al. 2012). Objectives can also be a disaggregation of broader goals into a clearer representation of the suite of desired attributes for a system and typically represent a desired outcome alongside a preferred direction of change. Management objectives, for the purposes of the SDOT, are not and should not be confused with targets. Rather, they provide the management context and relevance for the more quantifiable performance measures that serve as the focus of real-time monitoring and forecasting in the SDOT (see Section 3.1). Management objectives also serve as fundamental markers for adaptive management to ensure that decision makers are striving towards desired outcomes and resolving uncertainties that cloud their understanding about how best to achieve those outcomes (Lee 1993). Experience has shown that in the absence of a clear set of management objectives, decision-makers and stakeholders can be left with an adaptive management approach in which everything matters (i.e., all valued components and all uncertainties) or the desired outcomes of decision-makers are ambiguous or unclear (Greig et al. 2013).

A series of research and engagement steps were used to iteratively develop, refine, and filter the set of management objectives included in this scope of this conceptual design. These steps are described below, but included:

- Developing a preliminary scope around management actions, valued components, management objectives, and critical uncertainties;
- Clarifying time relevance and perceived importance of management objectives to decision makers;
- Identifying candidate performance measures and potential data sources related to preliminary set of management objectives;
- Drafting a discussion document that described details for a potentially feasible set of management objectives, performance measures, and physical sub-models;
- Gathering input from broad group of experts on valued components, management objectives, performance measures, and physical sub-models (see Acknowledgement Section); and
- Narrowing the list of management objectives and related performance measures based on lessons from above steps (i.e., time relevance, importance, responsiveness, and level of decision influence).

The first step noted above involved developing a long list of potential management objectives based on the five broad goals for restoring the Louisiana Coast as laid out in the 2017 Coastal Master Plan: Increase Flood Protection, Use Natural Processes, Provide Coastal Habitats, Protect Cultural Heritage, and Support a Working Coast (CPRA 2017). Given the real-time operational needs for this tool, valued components and management objectives related to protecting our cultural heritage were not considered within scope of this conceptual design since they were not seen as being directly influenced and responsive at the time-scale of diversion operations.

These management objectives were then organized into an objective hierarchy (see Appendix A) and further distinguished based on the anticipated time-period over which they would be most relevant to diversion operations and their importance to decision makers (see Appendix B). Objectives were distinguished according to their relevance to one of three time periods: early warning (EW) objective (0-3 years), a near-term (NT) objective (4-10 years), and/or a long-term (LT) objective (>10 years). Objectives with a high importance were denoted as being directly or closely related to the purpose and need of the diversion project. Objectives with a medium importance were denoted as being fundamentally important to the approval of the project and could reflect a legal mandate that they be considered or potential legal / political risk to the project if they were not achieved. Objectives of low importance were denoted as having a legal mandate that they be considered for approval of the project, but they did not carry as significant a litigation / political risk as medium priority objective.

Next, feedback on the long list of management objectives from several groups of experts was used to inform multiple rounds of refinement and filtering which led to a narrow list of six management objectives for sediment diversions. Although this final list does not represent everything that was discussed at an expert workshop, this narrow list of management objectives represents a minimum number that are (A) representative of high priority purposes and needs for diversion operations; (B) directly influenced by diversion operations (as opposed to changes being mediated or confounded by many other factors); and (C) likely sensitive at the time scales consistent with adjustments in operational decisions (i.e., sensitive to within season operational changes and relevant within the first few years of operations).

These steps and considerations resulted in a short list of the following six objectives for inclusion in the conceptual design of the SDOT (grouped by three of the Coastal Master Plan goals):

- Deltaic Processes
    - maximize sediment capture by diversion
    - maximize extent of influence to build / sustain land
    - avoid or minimize stagnant water that could lead to hypoxic conditions (nutrients, HABs, DO)
    - minimize induced wetland loss from elevated water levels
- Risk Reduction
    - avoid induced increased flood risk to basin communities (i.e., vulnerable populations)
- Working Coast
    - maintain a balance of fresh and saltwater harvestable species populations

Although there are many other management objectives of interest and relevance to decision makers and stakeholders (see Appendix B), these six reflect a bare minimum of considerations that could be considered within scope of the SDOT. A summary of the proposed objectives for the SDOT is provided in Table 3.1 and aligned with the related performance measures described in Section 3.1.

2.3 Spatial Domain & Resolution

An essential issue for bounding the SDOT and its components is to define the spatial boundaries of the system (both the spatial domain / extent[4] and spatial resolution[5]) over which operations managers wish to consider the effects of their decisions. Spatial scale usually depends on the performance measures (see Section 3.1) and physical variables of interest (see Section 3.2), but in general, the study area horizon for the SDOT includes the Barataria and Pontchartrain Basins and nearshore Gulf as defined by White et al. (2017) which tentatively includes the mainstem Mississippi River downstream of Baton Rouge to the Gulf (Figure 2.2), although the spatial extent could be extended to include other basins along the Louisiana coast if there was an interest and need. On the Mississippi River, the upstream boundary could be as far upstream as the Old River Control Structure, to provide the potential to account for real-time operation of that facility during very high flow periods.

[4] **Spatial domain (def.):** The geographic scope and boundary limits of the study area that will be included in the model. Areas outside of these bounds will not be considered.
[5] **Spatial resolution (def.):** The most appropriate discrete spatial reporting unit for a performance measure or physical variable (e.g., reach segment, cross-section, specific gauge location). Typically, this involves making decisions about suitable levels of aggregation for specific variables as well as choices about subsets of index locations to include in order to show representative trends and patterns of variation.

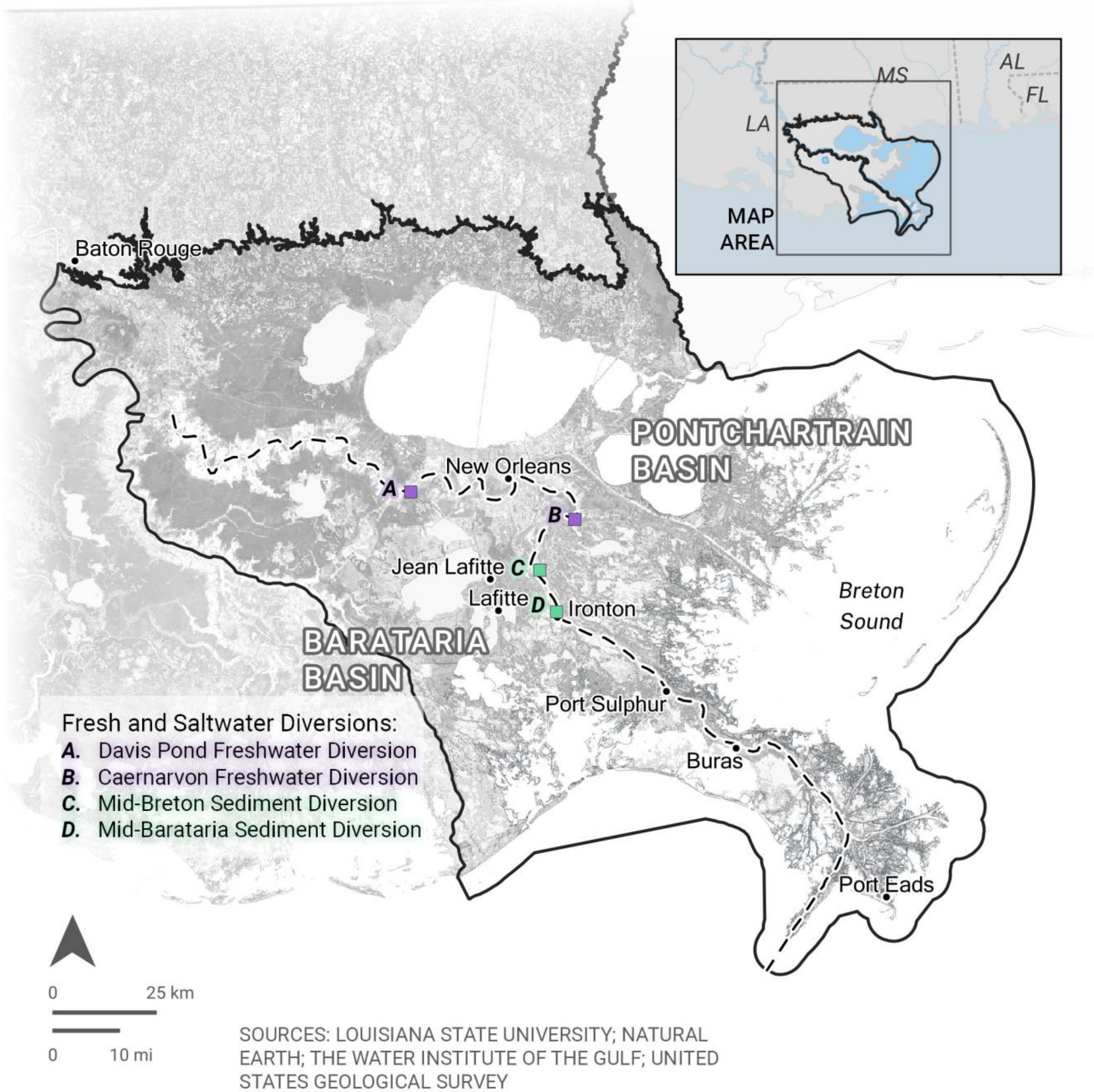

Figure 2.2: The two main basins and the discharge locations of planned (green) and existing (purple) freshwater and sediment diversion projects.

A fundamental consideration with clarifying the spatial horizon of the tool also depends on the ultimate boundary conditions or practical areas of influence around freshwater and sediment diversions that are sensitive to riverine inputs before ocean influences clearly dominate. A credible simulation and forecasting model must include a combination of reliable boundary conditions and spatial resolution that includes enough of the physical system to have plausible hydrologic behavior.

Gathering more clarity and precision around the spatial horizon of the SDOT also requires understanding:

- areas of interest for the performance measures that are integrated into the SDOT (some priority locations that people care about are provided in Section 3.1);
- points of interest that can be commonly quantitatively / qualitatively modeled for key physical variables and their alignment with the above areas of interest for performance measures. This information is important because the locations of physical model predictions may or may not coincide with where ecologists are most interested in having information on flows, salinity, turbidity, water temperature, etc.; and
- representative locations with real-time monitoring stations that can be used to support predictions of key physical variables (see real-time monitoring locations in Section 2.5).

The spatial complexity of deltaic systems typically needs to be greatly simplified to avoid crippling detail in the tool and unrealistic expectations that the tool must provide predictions at every possible location. As a first step to clarify the spatial resolution of the SDOT developers need to understand:

- locations where managers would most like to know about a particular performance measure (e.g., hot spots, representative index sites);
- portions of the areas of interest where relevant input data exist to calculate the performance measure; and
- representative sites that can be simulated in the quantitative models to produce physical driving variables necessary for calculation of the performance measures.

The overlap between these three considerations would determine the spatial resolution for each performance measure throughout the SDOT study area.

2.4 Temporal Horizon & Resolution

Equally important for bounding the SDOT is to define the temporal horizon[6] or future period over which managers wish to consider the effects of their decisions and the temporal resolution[7] necessary for predictions. For example, simulation scenarios using the Integrated Compartment Model (ICM) in the 2017 Coastal Master Plan used a temporal horizon of 50 years and included storm events and hurricanes which are important to many processes. However, with a real-time operational tool, the anticipated temporal horizon for the SDOT is expected to be one year or less (e.g., the water year from October 1st of year n to September 30th of year n+1 (12 months)), with the ultimate goal of being able to combine real-time gauge data with forecasting models

[6] **Temporal horizon (def.):** The retrospective and prospective temporal limits of typical model simulations. For example, whether simulations will run for one month or 100 years.

[7] **Temporal resolution (def.):** The temporal unit of measure that is to be associated with each incremental estimate or prediction for a modelled performance measure or variable, at a specific location. This is also commonly referred to as model time-step (e.g., hourly, daily, weekly, monthly, annually).

(e.g., the National Weather Service 28-day forecasts of river-stage), to make projections for performance measures. Within this time horizon each performance measure will have time periods to which changes in key physical variables may or may not be of interest to decision makers (e.g., critical habitat needs at a specific time of year during an important life history stage).

To clarify temporal resolution, we need to understand the time step, given both the rates of change of system components, and the current state of knowledge for the performance measures and physical variables being integrated into the decision support tool. Temporal resolution usually varies, but in general for real-time systems typically occurs daily or sub-daily, with some outputs rolled up to other temporal reporting units (e.g., most often weeks). The proposed temporal resolution of the SDOT is anticipated to involve a mixture of daily and weekly time-steps (e.g., prior to a given decision date, outcomes for all variables will likely be displayed daily; when forecasting, the temporal resolution may be weekly).

As noted in Section 1.2, a fundamental concept in real-time operations is that of a "*decision date*." By design, the SDOT will use the best information available for any particular decision date that is specified. A decision date is the specific calendar date beyond which a model user wishes to see a forecast of diversion decision impacts. A diversion manager is not able to influence what has already happened, so real-time operations focus on diversion management decisions and related forecasts forward of this date, while information prior to the decision date shows the actual real-time river flows, salinity, turbidity, and water temperatures (etc.) that actually occurred. Actual values would be obtained from real-time monitoring stations and other real-time enabled field loggers freely available through automated web services. As the diversion managers make decisions during each decision increment, they may also consider recent history of success for different objectives and performance measures and use this history to influence their priority weightings on different objectives (i.e., using a turn-taking philosophy). Note that in more advanced algorithm implementations turn-taking could suggest to the diversion manager a small number of equally optimal decisions for the decision period.

2.5 Real-Time Physical Monitoring Stations

The SDOT would integrate real-time sensor data feeds on daily or sub-daily time-scales in support of important predictions and model outputs that must be generated on sub-monthly usually weekly or sub-weekly time-frames. Real-time sensor data inputs must be leveraged to update various default sub-model algorithms used to generate key performance measures (e.g., to support real-time corrections to forecast models, provide trend / anomaly detection). Real-time feeds of sensor data will also provide information to show users actual status of key state variables near the time when the next decisions must be made. These real-time monitoring stations are typically accessed automatically via scheduled web services and other interfaces that allow a decision support tool to directly copy the data needed from the real-time station (i.e., without need for human action). Typically, such real-time systems are run in under 5-10 minutes and will often include attended and unattended optimization (machine learning) routines to cut down on the number of "what-if" manual simulations users need to perform. If integrated and designed well, diversion operation managers will save massive amounts of time by having real-time monitoring results readily available. This ability will help them make more informed and balanced decisions, and they will likely never want to go back to more heuristic methods of decision-making.

Three federal agencies regularly collect real-time data from a variety of gauges in the lower Mississippi River, Barataria Basin, and Pontchartrain Basin (see Table 2.1, Figure 2.3, Figure 2.4, and Figure 2.5). An example of the summary information available for individual stations is provided in Table 2.2. USGS gauges are the largest group by number and by the scope of measurements. The USGS data portal groups Louisiana by sub-basin. We included the following 6 sub-basins: Mississippi River Delta Basin, Mississippi-Atchafalaya River Basins, Mississippi River-Barataria Basin, New Orleans HGMS, Mississippi River-Breton Sound Basin, and Lake Pontchartrain Basin, as well as the Coastwide Reference Monitoring System (CRMS[8]) which is run by USGS. Typically for these stations, stage and flow are monitored at a 15-minute frequency and salinity at an hourly frequency. Some stations provide a broad range of 15- or 60-minute real-time data: stage, water temperature, salinity, chlorophyll-a, and turbidity. The period of record may extend back by 4-20 years depending on the variable being monitored and gauged. These maps represent the broad set of real-time stations that are readily available. Ultimately, a narrower list of real-time monitoring stations could be integrated into the SDOT once further specificity can be provided about critical locations of interest to the performance measures described in Section 3.1. It may also be useful to understand and leverage the aggregation methods already used by the Pontchartrain Conservancy to create its Hydrocoast maps:[9] salinity contour maps for Barataria Basin and Pontchartrain Basin produced every two weeks, using gauge data from federal and state agencies.

Table 2.1: Summary of sources of real-time physical monitoring stations in the lower Mississippi River, Barataria, and Pontchartrain Basins.

Source	Website	No.	Type	Frequency (min)
National Weather Service (NWS)	water.weather.gov	>10	Stage	60
US Army Corps of Engineers (USACE)[10]	water.usace.army.mil	>20	Stage	60
US Geological Survey (USGS)	waterdata.usgs.gov https://www.lacoast.gov/crms_viewer/Map/CRMSViewer	>25	Stage, flow, temperature, salinity	15 or 60

[8] https://www.usgs.gov/centers/wetland-ad-aquatic-research-center/science/louisiana%E2%80%99s-coastwide-reference-monitoring?qt-science_center_objects=0#qt-science_center_objects
[9] https://scienceforourcoast.org/pc-programs/coastal/hydrocoast-maps/

[10] Select: Water level by Basin; Basin: Mississippi River & Passes

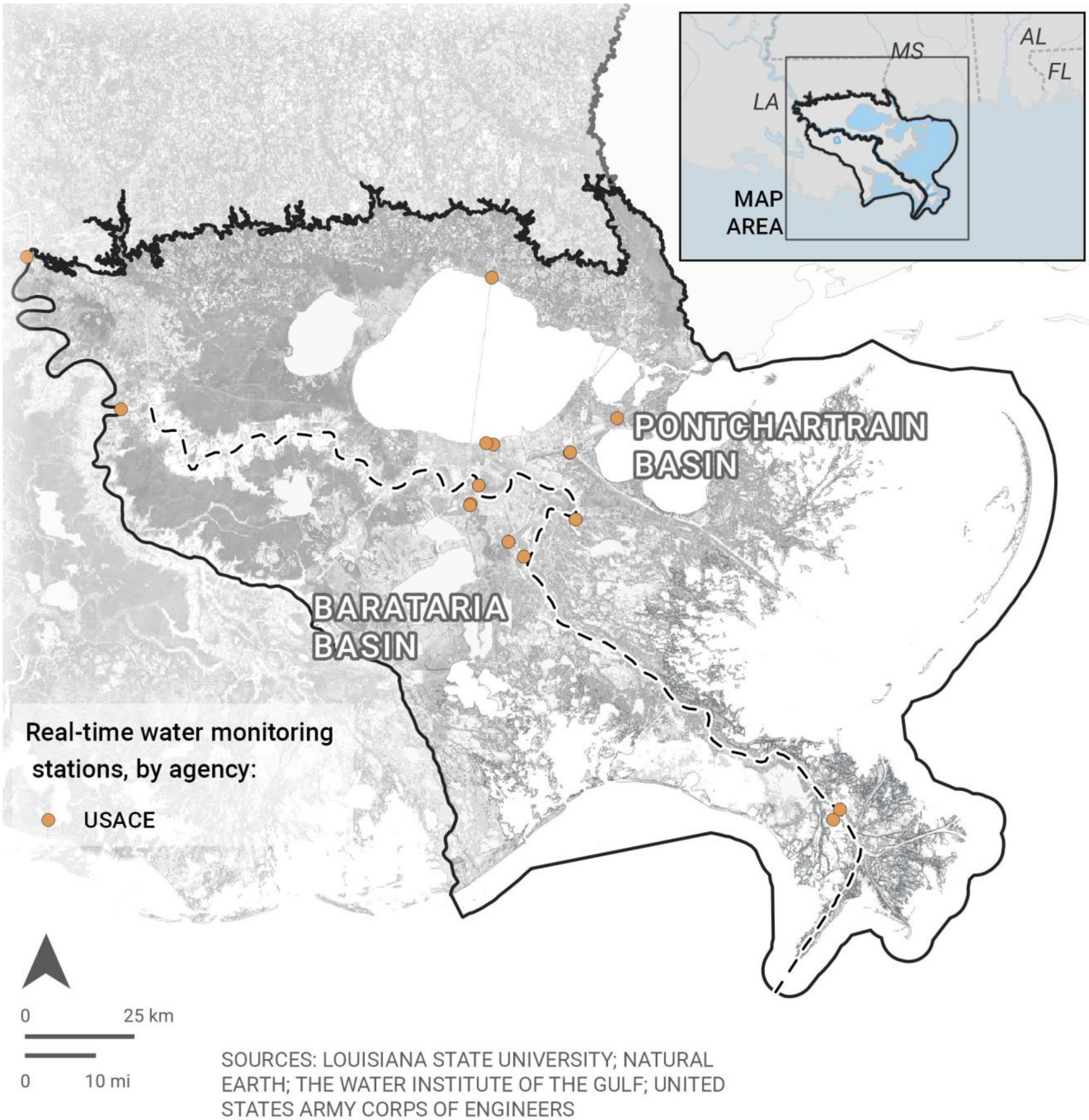

Figure 2.3: Locations in the lower Mississippi River, Barataria, and Pontchartrain Basins with a subset of **real-time** monitoring by the US Army Corps of Engineers.

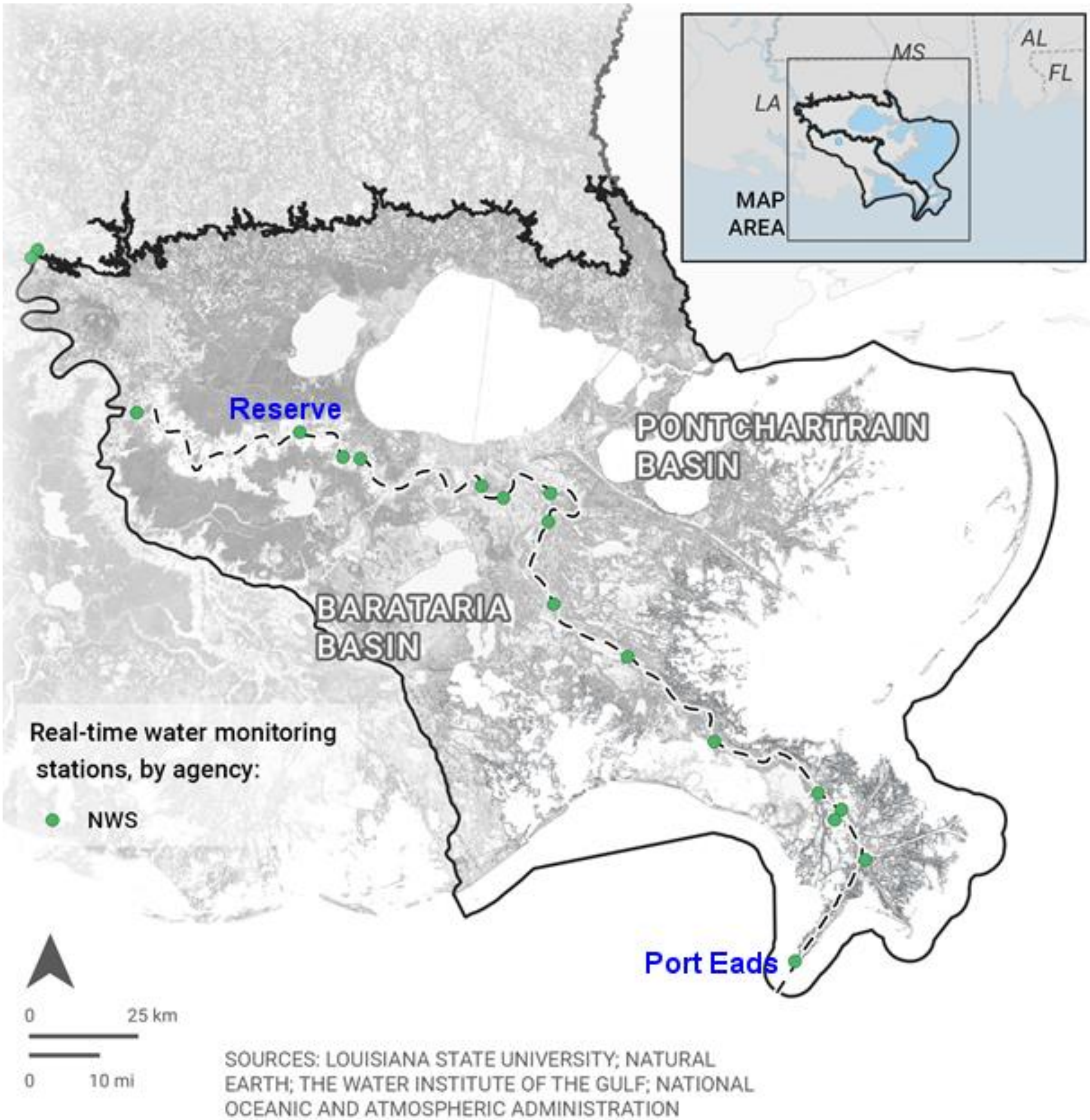

Figure 2.4: Locations in the lower Mississippi River with **real-time** monitoring by the National Weather Service (NWS).

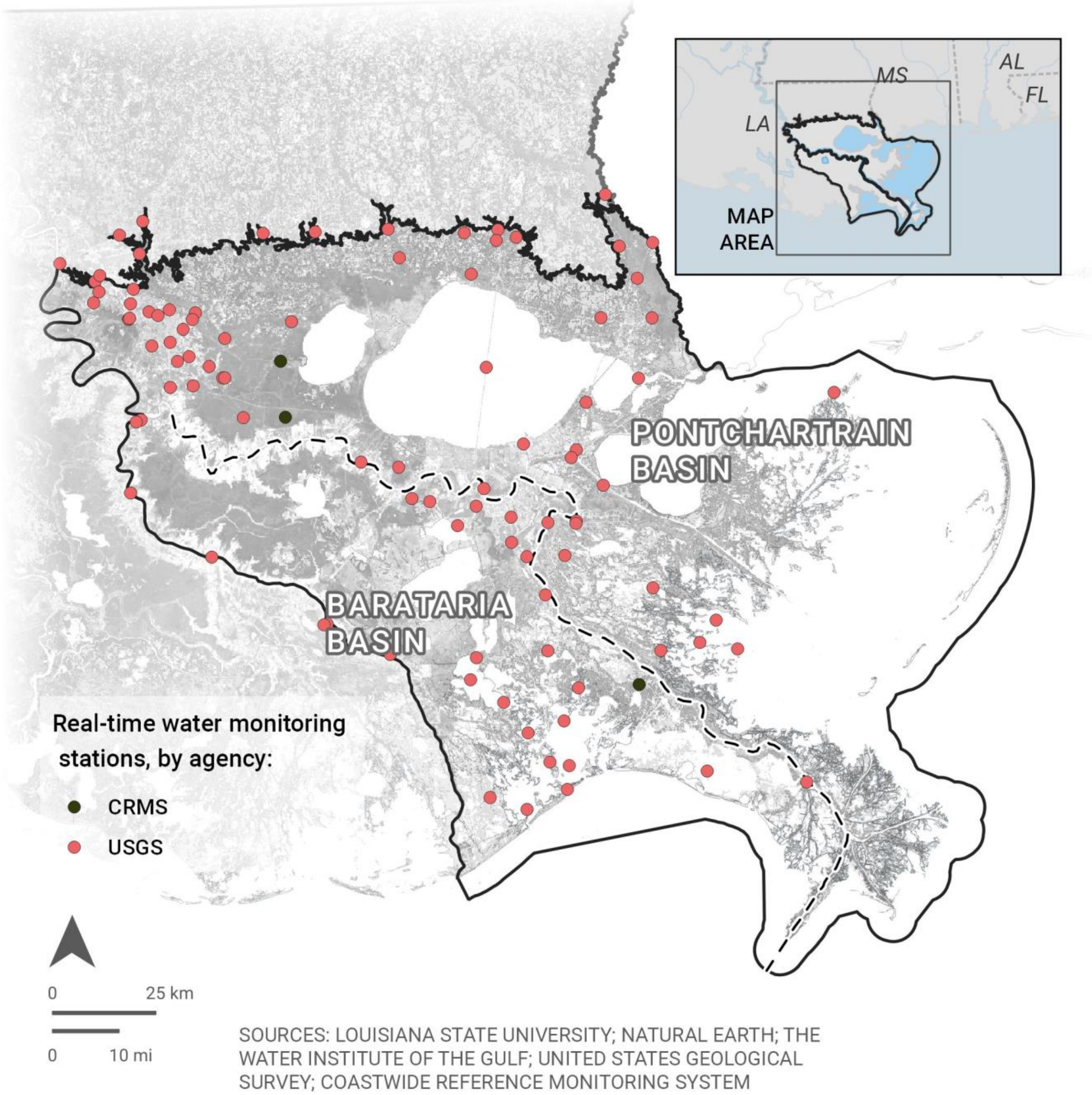

Figure 2.5: Locations in the lower Mississippi River, Barataria Basin, and Pontchartrain Basin with a subset of **real-time** monitoring by U.S. Geological Survey (USGS) broadly (red dots) and specifically within the Coastwide Reference Monitoring System (CRMS) (black dots).

Table 2.2: Summary of real-time monitoring data that might be required by Performance Measures, based on an example USGS gauge.[11]

Information	Example		
Station Number(s)	USGS 295231093100100		
Station Name	CRMS2418-H01-RT		
Latitude	29°52’31”		
Longitude	93°10’01” NAD83		
Gage datum (ft)	-0.17 ft above NAVD88		
	Frequency	First Date	Last Date
Stage (ft NAVD)	15-min	1996-03-14	Current
T°	15-min	1996-03-14	Current
Salinity	15-min	1996-03-14	Current
TDS	Monthly	“	“
Other 1 (e.g. BOD)	“	“	“
Other 2 (e.g. Chl-a)	“	“	“

[11] This information is available for USGS stations by (a) selecting “Map location”; (b) “Time Series Daily Data”

3 Recommendations and Technical Underpinnings of the SDOT

3.1 Recommended Performance Measure Sub-Models for Valued Components

3.1.1 What Makes a Good Performance Measure?

The scoping of every decision support tool must rely on assumptions and choices about what is included and excluded to keep the effort tractable. A clear and focused scope is important to ensure that the decisions and trade-off evaluations being supported by a decision support tool are tractable given the inherent and inevitable cognitive limitations and bias of decision makers. Maintaining a clear focus in a decision support tool involves seeking a balance of (1) representative performance measures given the relevant valued components of interest to decision makers, the state of scientific knowledge about the performance measure and its related valued component, the types of decisions the tool is meant to support, budgetary resources and whether knowledge surrounding the representative indicators themselves possess, and (2) sufficiently well-specified properties for inclusion in a rigorous DST. Creating a narrowly focused tool in no way suggests that performance measures screened out are unimportant; rather the universe of concern in supporting decision makers and developing a tool must, for practical reasons, be selective.

The first filtering component that helps resource managers side-step the paralysis that comes with trying to cover everything involves agreeing on some criteria to help distinguish what may be worth including (i.e., representativeness). Section 2.2 clarifies the process and focus around a narrower set of valued components and management objectives that guided the conceptual design for the SDOT in this document. Tool developers must also go beyond tests of importance or relevance like those discussed in Section 2.2 and consider the available knowledge base related to understanding, rigor, and feasibility when deciding whether to include a performance measure in a tool. When deploying modern machine learning and optimization techniques like Turn-Taking to overcome difficult trade-offs, performance measures must possess minimum specificity standards (see Figure 3.1 and Box 2). Although the final list of management objectives and performance measures presented here does not represent everything that could be within scope of SDOT, the proposed set of PMs strikes a reasonable balance of what is technically feasible in the near term, is linked to changes in diversion operations, and is more strongly linked to the purpose and need of the diversion (and other directly relevant valued components).

The adherence to the above filters and specificity criteria ensures standardized comparisons can be drawn from a pool of candidate VC considerations. For the focal management objectives summarized in Section 2.2, candidate Performance Measures are proposed below based on our current understanding of (a) critical life history requirements, and (b) the critical information sources needed to quantify the link between flow-centered management actions and habitat or biological performance. Table 3.1 provides an overview of the performance measures discussed in the sections that follow and which are recommended as initial candidates for inclusion in the conceptual design of the SDOT. The goal with these multi-focal species performance measures is to improve quantitative analysis capabilities so decision makers can better assess how water operations mesh with the management objectives described in Section 2.2 and better elucidate tradeoffs among them.

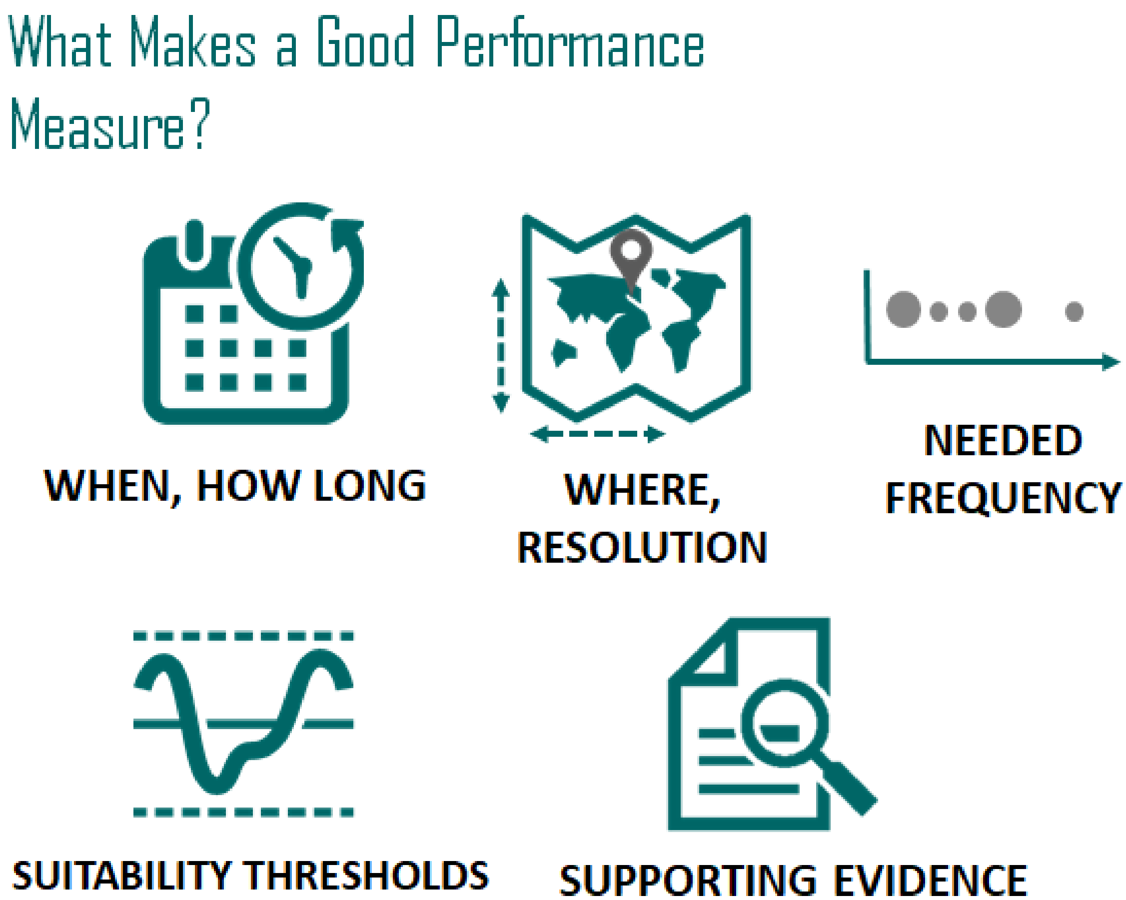

Figure 3.1: Overview of minimum specificity standards to aid in the selection of performance measures and their integration into a decision support tool.

Box 2: Description of minimum specificity standards for performance measures.

- Performance measures used in decision support tools must specify instantaneous and annual **suitability thresholds** or benchmarks (i.e., clearly defined favorable status values). Suitability thresholds are quantitative or qualitative ranges within which most observers would agree that a performance measure value is poor, fair, and good (or preferred). Additionally, these ranges remove the need to use continuous value scales in optimization settings which come with *punishing* computational penalties. The key is to determine rules that guide how instantaneous performance accumulates through a season or year to generate an annual suitability rating (e.g., the number or proportion of days within an indicator's critical period that daily suitability thresholds must be met to be considered a 'good' year).
- Every performance measure must be accompanied by an annual **target recurrence frequency** (how many years out of *y* years the indicator needs to yield a favorable status). The concept of recurrence frequency recognizes that most valued components do not require preferred conditions every year. For example, many aquatic species are adapted to sustain viable populations even in the face of variable flows and periodic extreme conditions (e.g., periods of drought and flood) (Tollrian and Harvell 1999; Hilborn et al. 2003, Waples et al. 2008). When the recurrence frequency is defined for each performance measure, such rules provide a powerful tool that facilitates Turn-Taking (i.e., "*indicator j should achieve a favorable or 'good' outcome in at least 2 out of 4 years,*" see Section 4.1.4). Note that both target recurrence frequencies and suitability thresholds are leveraged via aggregation and roll-up schemes to service multi-year implementation of Turn-Taking Optimization (i.e., separate and distinct multi-year habitat suitability thresholds / indices are not required).
- Performance measure must have clearly defined **critical periods** of relevance to the valued components being represented (e.g., a specific season or all-year).
- The **locations of primary interest** for performance measures must be clear and must sufficiently align in space and time with the available driving physical sub-models that supply needed inputs on physical conditions. Additionally, some areas are of more concern than others for a variety of social and ecological reasons. Identifying these geographic 'hotspots' and focusing efforts there can generate comparatively high benefits. Spatial and temporal looking outward matrices can be useful for validating needed space / time alignment. A key step is to generate a "master register" of input and output locations of importance to physical, social, and ecological sub-models.
- Driving physical sub-models (e.g., river flow, stage, salinity, turbidity) that are to be coupled within a decision support tool need to provide interfaces that (with some additional work) **allow for unattended simulation** (i.e., do not require manual interventions by a human user). Often, this means tools that are command-line based or query-driven. Other technology implementations like R-language and Excel-based models are also compatible with unattended simulation.

Table 3.1: Proposed focal management objectives for the SDOT. Time periods of relevance to each objective are denoted as EW (Early Warning, 0-3 years), NR (Near-Term, 4-10 years), and LT (Long-Term, 10+ years). Ratings of importance of objectives are denoted as H (High), M (Medium), and L (Low). Driving variables, locations and relevant time periods for each proposed objective are based on current literature and discussions at a workshop for conceptual development of the tool and are all subject to revision. Locations for shrimp [WC2, WC3] represent the adult life stage.

Master Plan Goal	Related Valued Components	Management Objective	EW	NT	LT	Driving Variables	Locations	Relevant Time Periods	Performance Measure
Deltaic Processes	Land loss building & tidal wetlands	Maximize sediment capture by diversion	H	H	H	flow, turbidity	Diversion outfall areas	Dec-May	Sediment Capture [DP1]
		Maximize extent of influence to build / sustain land		H	H	discharge, turbidity, tide, weather	Diversion outfall and deposition area	Dec-May	Sediment Distribution [DP2]
	Delta complex	Avoid or minimize stagnant water that could lead to hypoxic conditions (nutrients, HABs, DO)	L	L	L	discharge, tide, weather, bathymetry	Shallow water protected areas	Jul-Dec	Stagnant Water [DP3]
		Minimize induced wetland loss from elevated water levels	H	H		discharge, tide, weather, bathymetry	Upper Barataria and Pontchartrain Basins (with mid-Breton Diversion)	Dec-May	Floodplain Inundation [DP4]
Risk Reduction	Protection of human communities	Avoid induced increased flood risk to basin communities (i.e., vulnerable populations)	H	H	M	flow into Barataria Bay, tide, weather, diversion operations	Lafitte, Grand Bayou	Dec-May	Flood Risk to Basin Communities [RR1]
Working Coast	Harvestable species & reliant industry	Maintain a balance of fresh and saltwater harvestable species populations		M	M	salinity, temperature, flow velocity turbidity	numerous locations in Pontchartrain Basin	May-Nov	Oyster Habitat Suitability [WC1]
						salinity, temperature, tide	Lake Pontchartrain, Breton Sound	May-Nov	White Shrimp Habitat Suitability [WC2]
						salinity, temperature, tide	Lake Pontchartrain, Breton sound	Apr-Nov	Brown Shrimp Habitat Suitability [WC3]
						salinity, temperature	all areas	Jan-Dec	Alligator Habitat Suitability [WC4]

3.1.2 Sediment Capture [DP1]

The Sediment Capture [DP1] performance measure is intended to measure the efficiency of sediment capture by the operation of the diversion. It is a high priority to "*maximize sediment capture by the diversion structure*" in the Early Warning, Near-term, and Long-Term time periods. The objective as stated needs, however, careful interpretation, since maximizing sediment capture is not intended to supersede all other goals and must be balanced with other objectives (Peyronnin et al. 2017). The ultimate purpose of sediment capture is to contribute to the vertical accretion of the marsh surface, building and sustaining land and reducing land loss. DP1 is concerned only with the suspended and bedload sediment budget and does not consider the ultimate beneficial purpose of the sediment. Changes to the water budget of the basin could have an impact on communities and infrastructure which are already vulnerable to flooding during storm surge periods.

The indicator is based on near real-time monitoring of flow and turbidity (NTU) of diverted water coupled with 14-day projected flow and turbidity of diverted water. When integrated over time and calibrated with the empirical sediment concentration of known samples of diverted water, including an empirical relationship for bedload transport, this provides an estimate of the overall transport of suspended and bedload material. In the case of the transport of bedload sediment, the relationship is complex and will need to be provided through empirically based relationships and / or the substantial fluvial geomorphology literature. Definition of Good / Fair / Poor thresholds for annual sediment capture will require further discussion but might use a sediment-water ratio of 1 as a threshold to delineate Good / Fair conditions (i.e., capturing a higher proportion of sediment to freshwater when compared to what is in the river). Application and interpretation of the PM must also consider the evolution of the distributary system created by the discharge, which is expected to evolve over the first decade of operation, as well as within-year considerations, such as the higher concentration of sand found in the first peak flow (winter and early spring) of the water year (Allison et al. 2012).

Table 3.2: Definition for the Sediment Capture [DP1] performance measure.

<table>
<tr><th colspan="13">Sediment Capture [DP1]</th></tr>
<tr><td>Indicator (and units)</td><td colspan="12">Product of daily diversion discharge X turbidity, with empirical relationship to sediment and bedload tranport; converted to sediment-water ratio or tonnes / day</td></tr>
<tr><td>Management Objective</td><td colspan="12">Maximize sediment capture by the diversion</td></tr>
<tr><td>Driving physical variable(s)</td><td colspan="12">(a) hourly diversion discharge, (b) hourly NTU turbidity at diversion</td></tr>
<tr><td>Critical time period</td><td>J</td><td>F</td><td>M</td><td>A</td><td>M</td><td>J</td><td>J</td><td>A</td><td>S</td><td>O</td><td>N</td><td>D</td></tr>
<tr><td></td><td colspan="12">These are likely key months; potentially any period of high flow</td></tr>
<tr><td>Key Locations</td><td colspan="12">Mid-Barataria Sediment Diversion, Mid-Breton Diversion, and related outfall areas</td></tr>
<tr><td>Physical models generating values at key locations & time-frames</td><td colspan="12">Real-time discharge and turbidity at diversion; supplemented by 2-week forecast of stage (converted to discharge) and forecast turbidity under planned diversion operation. Requires empirical relationship between NTU and sediment load and bedload to calculate sediment-water ratio or tonnes / day</td></tr>
<tr><td rowspan="2">Daily / instantaneous suitability</td><td colspan="4">Preferred / Good</td><td colspan="4">Fair</td><td colspan="4">Poor</td></tr>
<tr><td colspan="4">>1.0</td><td colspan="4">–</td><td colspan="4">–</td></tr>
<tr><td rowspan="2">Critical period / Annual suitability</td><td colspan="4">Preferred / Good</td><td colspan="4">Fair</td><td colspan="4">Poor</td></tr>
<tr><td colspan="4">TBA</td><td colspan="4">TBA</td><td colspan="4">TBA</td></tr>
<tr><td>Desired annual recurrence frequency</td><td colspan="12">TBA</td></tr>
<tr><td>Algorithm functional details & potential improvements</td><td colspan="12">Relationship of turbidity to actual sediment and bedload transport is important but not yet clarified in this document.</td></tr>
<tr><td rowspan="2">Potential trade-offs</td><td colspan="6">Positively correlated indicators</td><td colspan="6">Negatively correlated indicators</td></tr>
<tr><td colspan="6">• Increased wetland area
• Additional habitat for nesting birds
• Additional habitat for marsh vegetation
• Improved low-salinity regime for Phragmites and Sagittaria</td><td colspan="6">• Potential for elevated water levels and inundation for marshes and Barataria Basin communities
• Potential for induced shoaling for traffic in Barataria Waterway
• Reduced higher-salinity regime which currently favors Spartina, brown shrimp.</td></tr>
</table>

Foundational references / evidence / data Sources	Peyronnin et al. (2017), McCorquodale et al. (2017)

3.1.3 Sediment Distribution [DP2]

The Sediment Distribution [DP2] performance measure represents the location and amount of suspended sediments which settle to become deposited. The performance measure is related to the DP1 indicator but extends the information to explicitly modeling sediment and the potential marsh-formation that accompanies sediment deposition. DP2 would require a spatially explicit hydrodynamic model that is able to combine the current suite of mass-balance calculations (e.g., flow and salinity) to include the mass balance of sediments that are carried by the diversion into Barataria Basin (and potentially Pontchartrain Basin) and distributed through the outfall region, including mixing and suspension processes and the role of weather systems and tides to the dynamics of sedimentation. DP2 would be a simplification of actual sedimentation processes since it would probably not include the role of vegetation in securing sediments and reducing resuspension. The DP2 model would make use of the hydrodynamic model used by other indicators, and likely include the empirical relationship linking turbidity and sediment size distribution as a means of estimating the real-time composition of suspended solids and bed load sediment from existing gauges, along with forecasts of future conditions and the settling dynamics of sediments. The model would require forecast weather and flow from the diversion, and the forecast sediment load; both of which would be inputs to the hydrodynamic model. Model results could be checked and refined (e.g., annually) through sampling methods using the beryllium-7 isotope, which has been used to create sediment deposition timelines elsewhere in the Delta (Henkel et al. 2017, 2018).

Quantifying the benefit of sediment deposition will depend on establishing a spatially explicit profile of the desired locations for deposition, probably including a separate map for each size category in the sediment size profile. This multidimensional map would be used as the benchmark reference to measure against the modeled patterns of depositions and allow a spatially integrated "*goodness of fit*" score as the indicator.

Table 3.3: Definition for the Sediment Distribution [DP2] performance measure.

<table>
<tr><th colspan="13">Sediment Distribution [DP2]</th></tr>
<tr><td>Indicator (and units)</td><td colspan="12">Spatially integrated average departure between desired sediment distribution (by size category) and the modeled equivalent</td></tr>
<tr><td>Management Objective</td><td colspan="12">Maximize sediment desposition from the diversion operation</td></tr>
<tr><td>Driving physical variable(s)</td><td colspan="12">(a) hourly diversion discharge, (b) NTU turbidity, (c) tidal and weather contributions to water movement and sediment distribution</td></tr>
<tr><td rowspan="2">Critical time period</td><td>J</td><td>F</td><td>M</td><td>A</td><td>M</td><td>J</td><td>J</td><td>A</td><td>S</td><td>O</td><td>N</td><td>D</td></tr>
<tr><td colspan="12">These are likely key months; potentially any period of high flow</td></tr>
<tr><td>Key Locations</td><td colspan="12">Mid-Barataria Sediment Diversion, Mid-Breton Sediment Diversion, and related outfall areas</td></tr>
<tr><td>Physical models generating values at key locations & time-frames</td><td colspan="12">Real-time discharge and turbidity at diversion; supplemented by 2-week forecast of stage (converted to discharge) and forecast turbidity under planned diversion operation. Requires empirical relationship between NTU and sediment load and bedload; includes hydrodynamic simulation of sediment transport and dynamics of sediment settling and mixing.</td></tr>
<tr><td rowspan="2">Daily / instantaneous suitability</td><td colspan="4">Preferred / Good</td><td colspan="4">Fair</td><td colspan="4">Poor</td></tr>
<tr><td colspan="4">–</td><td colspan="4">–</td><td colspan="4">–</td></tr>
<tr><td rowspan="2">Critical period / Annual suitability</td><td colspan="4">Preferred / Good</td><td colspan="4">Fair</td><td colspan="4">Poor</td></tr>
<tr><td colspan="4">TBA</td><td colspan="4">TBA</td><td colspan="4">TBA</td></tr>
<tr><td>Desired annual recurrence frequency</td><td colspan="12">TBA</td></tr>
<tr><td>Algorithm functional details & potential improvements</td><td colspan="12">Relationship of turbidity to actual sediment and bedload transport is important but not yet clarified in this document. Sediment dynamics are not clarified in this document and are expected to be complex.</td></tr>
<tr><td rowspan="2">Potential trade-offs</td><td colspan="6">Positively correlated indicators</td><td colspan="6">Negatively correlated indicators</td></tr>
<tr><td colspan="6">• Increased wetland and marsh accretion, with associated improved resilience
• Additional habitat for nesting birds and alligators
• Additional habitat for marsh vegetation</td><td colspan="6">• Potential for elevated water levels and inundation for marshes and communities in Barataria Basin and Pontchartrain Basin
• Potential for induced shoaling for commercial shipping in MR and waterways of Barataria Basin and Pontchartrain Basin</td></tr>
</table>

Foundational references / evidence / data Sources	Peyronnin et al. (2017)

3.1.4 Stagnant Water [DP3]

The Stagnant Water [DP3] performance measure is focused on stagnation, which is a common and major contributor to hypoxia. Hypoxic conditions (usually <2mg / L oxygen concentration) are typically driven by excess nutrients (e.g., from agricultural sources) which cause eutrophication and algal blooms. Oxygen is consumed as the algal bloom overgrowth decays and sinks to the bottom, potentially made worse by salinity and temperature gradients in the water column, which inhibit mixing of oxygen-rich surface water with oxygen-depleted deeper water. Marine hypoxia has been monitored for over 30 years by systematic surveys in the Gulf of Mexico seaward of the Barataria Bay barrier islands and extending west over 200 miles into Texas. Within Barataria Bay, stagnation has been raised as an issue because of health concerns from mosquitos, harmful algal blooms and possibly other ecological concerns. Development of a hypoxia model based directly on first principles (photosynthesis, nutrients, mixing, phytoplankton, and all major ecosystem categories) is not feasible because of the complexity of the overall biophysical system. In shallow water environments, the development of hypoxia would probably be dominated by the contribution of stagnation (low flow) and the role of nutrients would be of less importance. Therefore, a PM that quantifies stagnation in shallow water need not include assumptions about the contribution of physiological processes that contribute to oxygen-depletion.

Although computationally intensive, the simulation of stagnant water conditions can be made through hydrodynamic models of the spatial and temporal processes of water movement. We assume that modeling capabilities like the ICM (2D) or Delft3d (3D) simulation tools will be necessary for any PM developed for stagnation, including a DEM that is updated annually and linkage to near real-time weather (with projections of weather and river flow), tides and diversion operation. A requirement of the hydrodynamic simulation is its ability to simulate “particle tracking” as a method of computing water movement at a daily resolution, probably simulated at an hourly timestep. We think that low total travel distance will provide a spatially explicit measure which is correlated with stagnation-driven hypoxia. It is not clear whether a fully depth-sensitive hydrodynamic model is required, or if a 2D model will be sufficient for shallow water. It is also not clear whether there is a strong relationship between the diversion operation and stagnation. This may be assessed in previous modeling work and could be resolved by creating a few simple scenarios which added extra flow in the location of the diversion, comparing the amount of stagnation at critical times of the year. Assigning DP3 thresholds for Good / Fair / Poor travel distance will require additional work, probably determined through expert interviews and a literature review to provide guidance which allows the PM to be linked with observed hypoxia locations and times.

Even if the PM is concerned with shallow water zones only, the hydrodynamic simulation will require complete coverage of the study area. An hourly time-step is probably the necessary temporal resolution needed to track water movement and include the tidal cycle, but integration at a daily scale is probably sufficient to quantify changes in shallow water stagnation related to discharge from the operation of the SDOT. Given the high temporal uncertainty in meteorological inputs, forecasts beyond 24 hours may need to incorporate historical results or models.

Table 3.4: Definition for the Stagnant Water [DP3] performance measure.

Stagnant Water [DP3]														
Indicator (and units)	Integrated value of water movement: daily sum of surface "particle" motion on a map grid.													
Management Objective	Minimize shallow water hypoxia, strongly correlated with stagnation													
Driving physical variable(s)	(a) discharge at diversion; (b) forecast tides; (c) current and forecast weather; (d) DEM updated annually; (e) hourly forecast													
Critical time period	J	F	M	A	M	J	J	A	S	O	N	D	Low flow periods	
							■	■	■	■	■	■		
Key Locations	Upper areas of Barataria and Pontchartrain Basins													
Physical models generating values at key locations & time-frames	Current real-time discharge at diversion, 2-week forecast of daily stage (converted to discharge) under current diversion operation; combined with particle-tracking of parcels of surface water. Timestep TBA; perhaps 15min													
Daily / instantaneous suitability	Preferred / Good	Fair	Poor											
	TBA	TBA	TBA											
Critical period / Annual suitability	Preferred / Good	Fair	Poor											
	NA	NA	NA											
Desired annual recurrence frequency	TBA													
Algorithm functional details & potential improvements	The empirical link between shallow water hypoxia and stagnation needs to be quantified, along with proposed daily threshold values. This would help to inform the definition of plausible Good / Fair / Poor thresholds. The assumption that hourly timesteps are the appropriate temporal resolution also needs to be reviewed, as does the spatial resolution of the hydrodynamic simulation.													
Potential trade-offs	*Positively correlated indicators*	*Negatively correlated indicators*												
	• TBA	• TBA												
Foundational references / evidence / data Sources	The potential for the diversion to affect stagnation needs to be clarified through literature and previous modeling, and possibly aided by scenarios which include/exclude the diversion discharge at times of the year when stagnation is thought to be present.													

3.1.5 Floodplain Inundation [DP4]

The Floodplain Inundation [DP4] performance measure is based on a dynamic and spatially explicit model of water elevation during the operation of the diversion, in addition to regular tidal cycles and transient storm surge and weather effects (Figure 3.2). The PM provides a quantitative measure to address a high priority objective in the Early Warning and Near-Term time periods – "*minimize induced wetland loss from extensive elevated water levels over the marsh surface*."

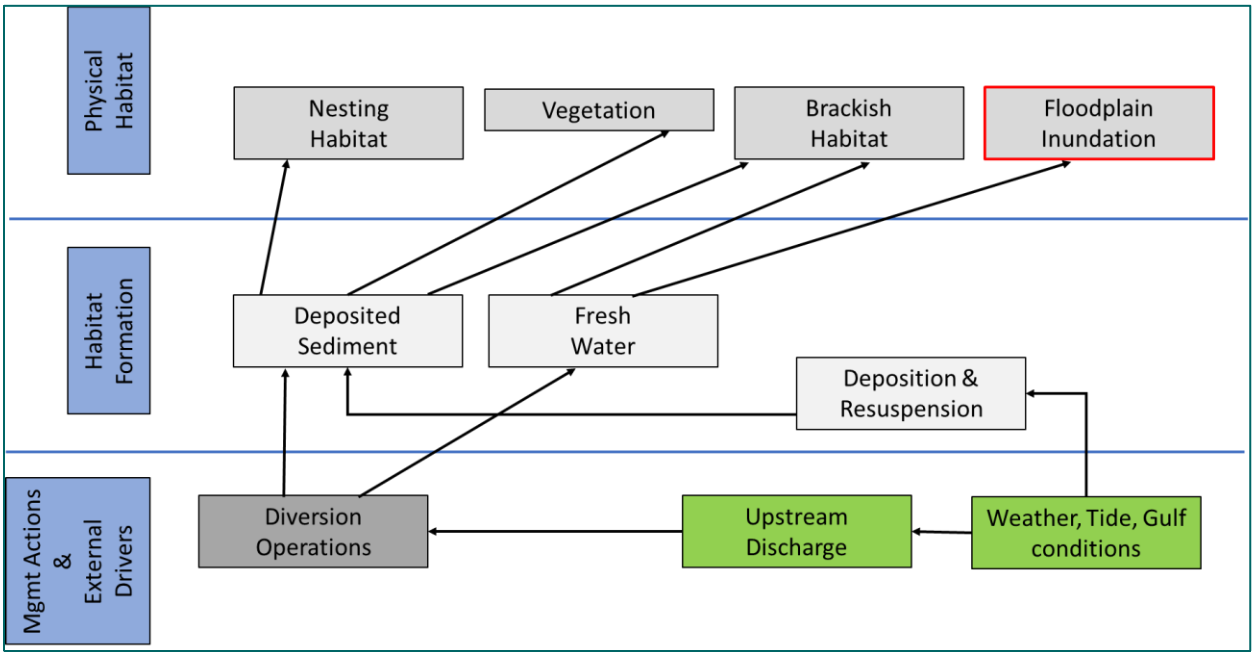

Figure 3.2: Simple representation of the conceptual relationships between the input of fresh water at the diversion which can lead to floodplain inundation.

Transient increases in marsh inundation have the potential to harm existing vegetation such as *Phragmites* or *Spartina,* two grass species that have been identified by some workshop participants as being important indicators of marsh status. If inundation persists too long compared to current patterns of inundation, the marsh vegetation may be damaged, potentially leading to a cascade of consequences as plants decline and the muddy substrate is bound together less securely by root systems and becomes more vulnerable to erosion and resuspension (particularly during storms), leading to the induced loss of marshland.

Simulating the spatial and temporal processes of water movement is computationally intensive and complex, and sensitive to short term changes in flow and weather (see Figure 3.3). We assume that modeling capabilities like the ICM (2D) or Delft3d (3D) simulation tools will be necessary for this PM, including a DEM that is updated annually. The key result needed by DP4 is the change in the duration of inundation across the Barataria and Pontchartrain Basins integrated over the day, compared to a baseline measure of inundation. The PM might be restricted to key point- or area-locations, although the hydrologic modeling requires and produces complete coverage. The hydrologic simulation results would allow forecasts of water elevation (e.g., using an hourly resolution) so the length of inundation could be incorporated into the magnitude of the inundation effect and could include projections of flow and weather. Such an approach is needed if the SDOT is to provide meaningful projections over time scales up to a month. Given the high temporal uncertainty in meteorological inputs, projections beyond 24 hours may need to incorporate historical results or models.

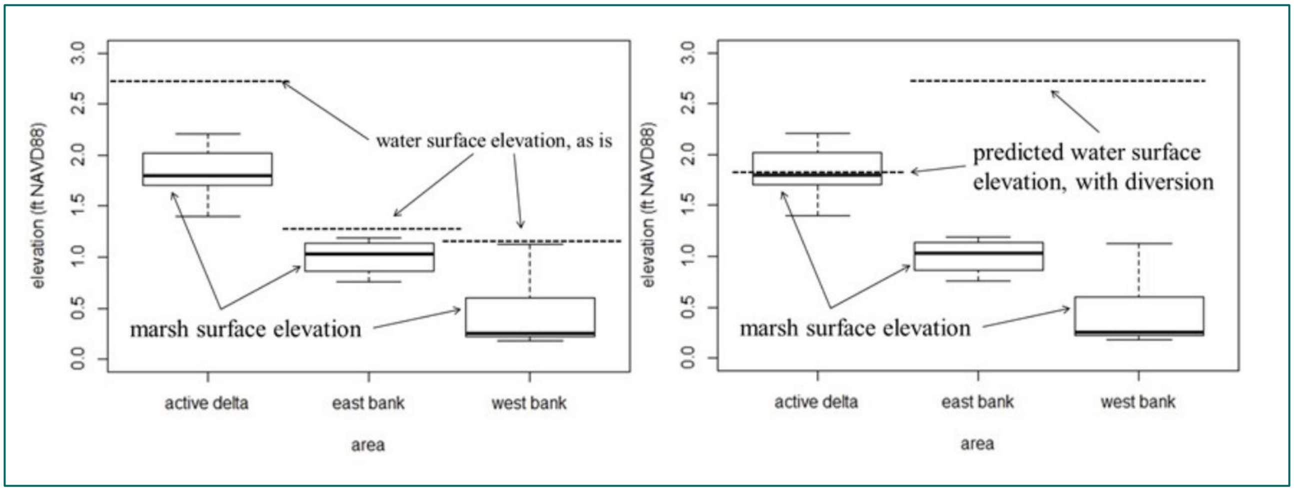

Figure 3.3: Example of hypothetical changes in water elevation with (right) and without (left) multiple diversions in operation on both sides of the river. In this hypothetical example, surface elevation in Barataria Bay (west bank) increases by about 2 feet when the diversions are active (Peyronnin et al. 2016).

An important aspect of this PM is the difference – relative to current patterns – in the daily (or other time-period) integrated measure of inundation which is attributable to the diversion. The definition of current patterns is itself not yet clear. To provide more clarity a baseline would be needed against which the diversion operation can be compared, but which is also sensitive to the real-time and forecast state of the entire study area, including Barataria and Pontchartrain Basins. The baseline could consist of a no-diversion-operation simulation against which the effects of a diversion are compared. The inputs which will contribute to calculating the baseline and the change attributable to a diversion will need to account for such factors as:

- the current DEM structure of the Barataria and Pontchartrain Basins, which may change over longer timescales in response to subsidence, accretion or storm alteration;
- short-term forecasts of discharge from a diversion;
- short-term forecasts of weather effects on water elevation;
- predictable tidal patterns;
- “typical” weekly-to-monthly average patterns of floodplain inundation resulting from seasonal changes in flow in the Mississippi River, and average climatic patterns; and
- identification of key locations or areas in the Barataria and Pontchartrain Basins which can be used as reference points for the PM.

These considerations would then need to be combined to develop a profile that can be used as a reference condition.

Table 3.5: Definition for the Floodplain Inundation [DP4] performance measure.

<table>
<tr><th colspan="16">Floodplain Inundation [DP4]</th></tr>
<tr><td>Indicator (and units)</td><td colspan="15">Difference in forecast inundation hours relative to a no-diversion baseline, at key locations in Barataria and Pontchartrain Basins.</td></tr>
<tr><td>Management Objective</td><td colspan="15">Minimize induced wetland loss that may result from extensive elevated water levels over marsh surface</td></tr>
<tr><td>Driving physical variable(s)</td><td colspan="15">(a) discharge at diversion; (b) forecast tides; (c) current and forecast weather; (d) historic annual-average inundation profile (d) DEM updated annually</td></tr>
<tr><td rowspan="2">Critical time period</td><td>J</td><td>F</td><td>M</td><td>A</td><td>M</td><td>J</td><td>J</td><td>A</td><td>S</td><td>O</td><td>N</td><td>D</td><td colspan="3" rowspan="2">There are differences in suitability of inundation between dormant months and the growing season</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Key Locations</td><td colspan="15">Upper areas of Barataria and Pontchartrain Basins; possibly inventoried locations for Phragmites, Spartina and Sagittaria based on periodic vegetation survey. Contribution of Mid-Breton Diversion also possible</td></tr>
<tr><td>Physical models generating values at key locations & time-frames</td><td colspan="15">Current real-time discharge at diversion, 2-week forecast of daily stage (converted to discharge) under current diversion operation including forecast weather and flow; combined with forecast of simulated water elevation from a hydrologic simulation model</td></tr>
<tr><td rowspan="2">Daily / instantaneous suitability</td><td colspan="7">Preferred / Good</td><td colspan="6">Fair</td><td colspan="2">Poor</td></tr>
<tr><td colspan="7">TBA</td><td colspan="6">TBA</td><td colspan="2">TBA</td></tr>
<tr><td rowspan="2">Critical period / Annual suitability</td><td colspan="7">Preferred / Good</td><td colspan="6">Fair</td><td colspan="2">Poor</td></tr>
<tr><td colspan="7">TBA</td><td colspan="6">TBA</td><td colspan="2">TBA</td></tr>
<tr><td>Desired annual recurrence frequency</td><td colspan="15">TBA</td></tr>
</table>

<table>
<tr><td>Algorithm functional details & potential improvements</td><td colspan="2">If Phragmites and Spartina are key drivers of marsh stability in the bays, it would be useful to determine the relationship between their presence and current inundation patterns. We need to know what they require to persist and remain healthy. This would help to inform the definition of plausible Good / Fair / Poor thresholds.</td></tr>
<tr><td rowspan="2">Potential trade-offs</td><td>Positively correlated indicators</td><td>Negatively correlated indicators</td></tr>
<tr><td>Additional habitat for nesting birds and alligators
More low-salinity regime for Phragmites australis and Sagittaria lancifolia
Improved habitat for manatees (in terms of temperature and salinity)</td><td>Potential for elevated water levels and inundation for marshes and Barataria Bay communities
Potential for induced shoaling for commercial shipping in MR and Barataria Waterway
Less high-salinity regime for Spartina patens, brown shrimp, white shrimp, and bottlenose dolphin</td></tr>
<tr><td>Foundational references / evidence / data Sources</td><td colspan="2">McCorquodale et al. (2017), Brown et al. (2017), Peyronnin et al. (2016)</td></tr>
</table>

3.1.6 Flood Risk to Basin Communities [RR1]

The Flood Risk to Basin Communities [RR1] performance measure is a model of water elevation at Lafitte and other communities in the Barataria Basin such as Myrtle Grove and Grand Bayou. Water elevation is driven by upstream flow and weather and could be affected by the operation of freshwater and sediment diversions (in a way similar to Figure 3.3). Tidal influences also affect water elevation in predictable ways. The temporary increase in water elevation when diversions are in operation has the potential to increase flood risk during periods of high river flow, storms and heavy upstream rain. RR1 has the same driving variables as DP4 (Figure 3.4), but with different threshold criteria and locations of relevance. Simulating the spatial and temporal processes of water movement is computationally intensive and complex, with many sources of uncertainty. The NWS currently produces a 28-day forecast of river stage, but it is not yet clear how the projection of Mississippi River stage and diversion discharge could be projected forward outside the river using simple relationships. Especially for flood risk, temporal resolution at an hourly scale can be critical to decision-makers. This will require a more complex approach making use of hydrologic simulation results that would allow site-specific projection of water elevation so the flooding risk threshold could be incorporated into the PM. Detail about the resolution of a driving simulation mode can be found in the DP4 description.

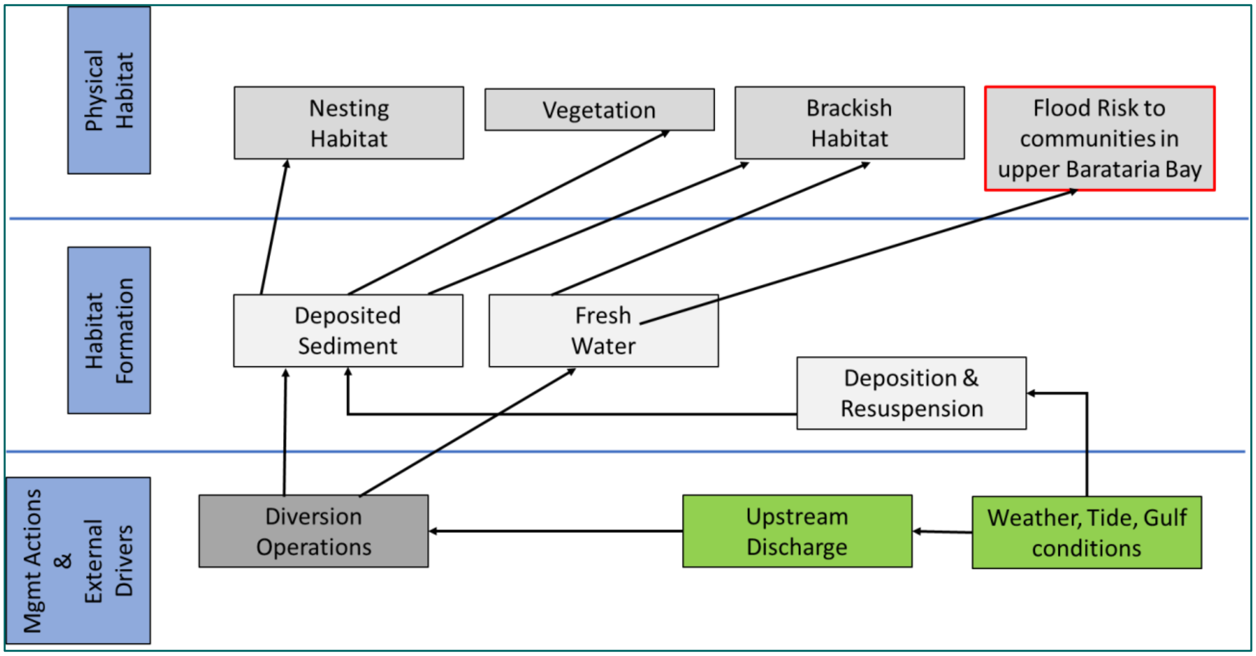

Figure 3.4: Simple representation of the conceptual relationship between the input of fresh water at the diversion potentially leading to flooding of communities in upper Barataria Bay.

Table 3.6: Definition for the Flood Risk to Basin Communities [RR1] performance measure.

Flood Risk to Basin Communnities [RR1]			
Indicator (and units)	Water elevation (feet) at Lafitte and other Basin communities		
Management Objective	Avoid induced increased flood risk to basin communities		
Driving physical variable(s)	(a) Upstream flow into Barataria Bay; (b) weather; (c) tide; (d) Diversion operation		
Critical time period	J F M A M J J A S C N D	These are likely key months	
Key Locations	Lafitte, Grand Bayou		
Physical models generating values at key locations & time-frames	Simulated water elevation from a hydrologic simulation model at Lafitte, Myrtle Grove, and Grand Bayou.		
Daily / instantaneous suitability	Preferred / Good	Fair	Poor
	< NWS Minor risk	NWS Moderate risk	NWS Major risk[12]
Critical period / Annual suitability	Preferred / Good	Fair	Poor
	Tercile of daily score?	Tercile of daily score?	Tercile of daily score?
Desired annual recurrence frequency	TBA		
Algorithm functional details & potential improvements	If a hydrologic simulation is linked, projections of *exceedance* of threshold water elevation could be used, based on key locations		
Potential trade-offs	*Positively correlated indicators*	*Negatively correlated indicators*	
	• Improved low-salinity regime for *Phragmites australis* • Additional habitat for nesting birds and alligators • Improved habitat for manatees (in terms of temperature and salinity)	• Potential for induced shoaling for commercial shipping in MR and Barataria Waterway • Reduction in higher-salinity regime for *Spartina patens,* brown shrimp, white shrimp and bottlenose dolphin	
Foundational references / evidence / data Sources	McCorquodale et al. (2017), Brown et al. (2017), Peyronnin et al. (2016)		

[12] For example, see https://water.weather.gov/ahps2/hydrograph.php?wfo=lix&gage=rrvl1

3.1.7 Oyster Habitat Suitability [WC1]

The Oyster Habitat Suitability [WC1] performance measure relates to the objective of "*maintaining a balance of fresh and saltwater harvestable species populations, to the extent that is practicable*". This objective is of medium importance in the near and long-term. In practice this objective will involve maintaining a suitable estuarine gradient (with seasonal patterns) to support populations of both fresh and saltwater harvestable species. This desired estuarine gradient may be more representative of historic conditions rather than current ones, and therefore the current habitats (e.g., associated fishing grounds) of the harvestable species may shift.

Eastern oyster (*Crassostrea virginica*) is a saltwater mollusk found in the northern Gulf of Mexico. The Eastern oyster is highly valued economically and ecologically (LaPeyre et al. 2009), and salinity and temperature play primary roles for all life stages (La Peyre et al. 2009, Lowe et al. 2017). Optimal salinity and temperature regimes and the location and timing of abundant populations vary by life stage (Figure 3.5), therefore two or more indicators may be needed to adequately manage diversion operations for all life stages. Aside from considering optimal conditions for spawning, development, feeding, and growth, the WC1 model should also reflect optimal conditions for reducing parasitism (e.g., "dermo" disease cause by *Perkinsus marinus*) and predation (e.g., from oyster drills). In considering freshwater diversions, LaPeyre et al. (2009) found pulsed freshwater (<5 ppt) events every 2-3 weeks reduced parasite infection. These results suggest that varying low and high salinity conditions may be beneficial for maximizing oyster production following implementation of the diversion. Remaining uncertainties about the effects of pulsed freshwater could be resolved through the Adaptive Management program. It may also be possible to maintain harvestable populations of oysters through a multi-year management approach that varies years of low and high salinity and accepts those difference, an approach that is complementary with TTO.

A simple performance measure relating to oysters would be a habitat suitability model that links salinity on a scale from 0 (poor) to 1 (optimum), following the work by Hijuelos et al. (2017) in the 2017 CMP. A more complex model that incorporates additional variables such as water temperature may be possible (e.g., Sehlinger et al. 2019), and it will be worth investigating whether flow velocity and suspended sediment could also be incorporated into habitat needs through different stages of their life cycle. Besides these HIS models, the Pontchartrain Conservancy has developed two modified oyster HSI approaches based on Chatry et al. (1983) and Soniat et al. (1988, 2004, 2012, 2013). These HSI's have been applied from 2013 to 2019 with salinity mapping in Pontchartrain Basin and 2017 and 2018 in Barataria Basin. HSI modifications were due to biological considerations and analysis of initial HSI results with directly observed oyster fleet activity for the corresponding years' of HSI analysis (Denapolis and Lopez 2019, 2020).

Given that optimal salinity and temperature regimes vary by oyster life stage, two or more indicators may be needed to adequately manage operations for all life stages. An indicator for juveniles would focus on May through November (Figure 3.6) when juvenile densities are highest in the bays and lakes of the Pontchartrain and Barataria Basins (Hijuelos et al. 2017). During this time, an hourly model time step may be needed to ensure that salinity and temperature conditions are maintained within the tolerance range of juvenile oysters. An indicator for adults would need to operate year-round, however a coarser daily resolution would likely be sufficient to ensure appropriate conditions for adult oysters.

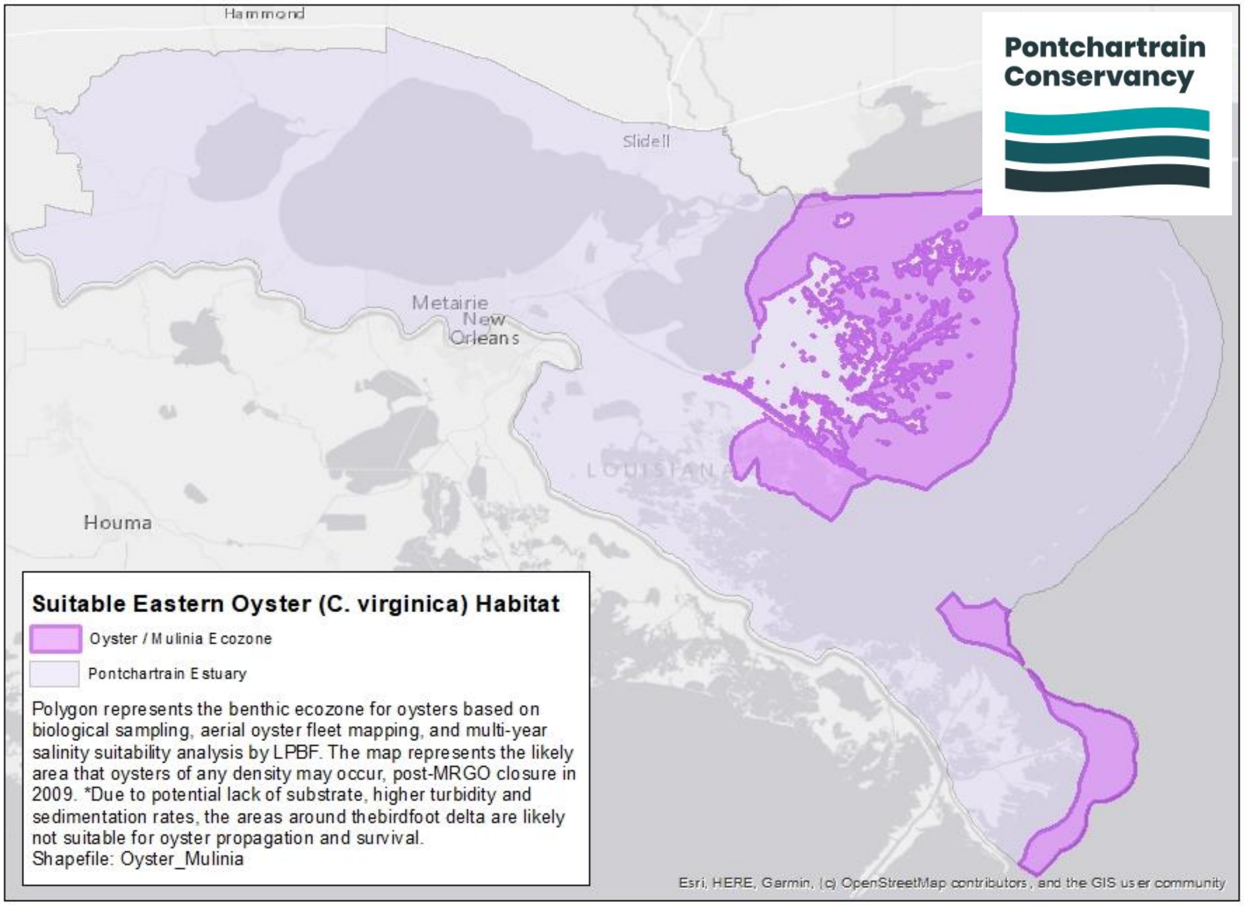

Figure 3.5: Suitable benthic ecozone for adult oysters (dark purple) in the Pontchartrain Basin (light purple), based on biological sampling, oyster fleet mapping, and multi-year salinity suitability analysis (John Lopez, Pontchartrain Conservancy, personal communication, 2020).

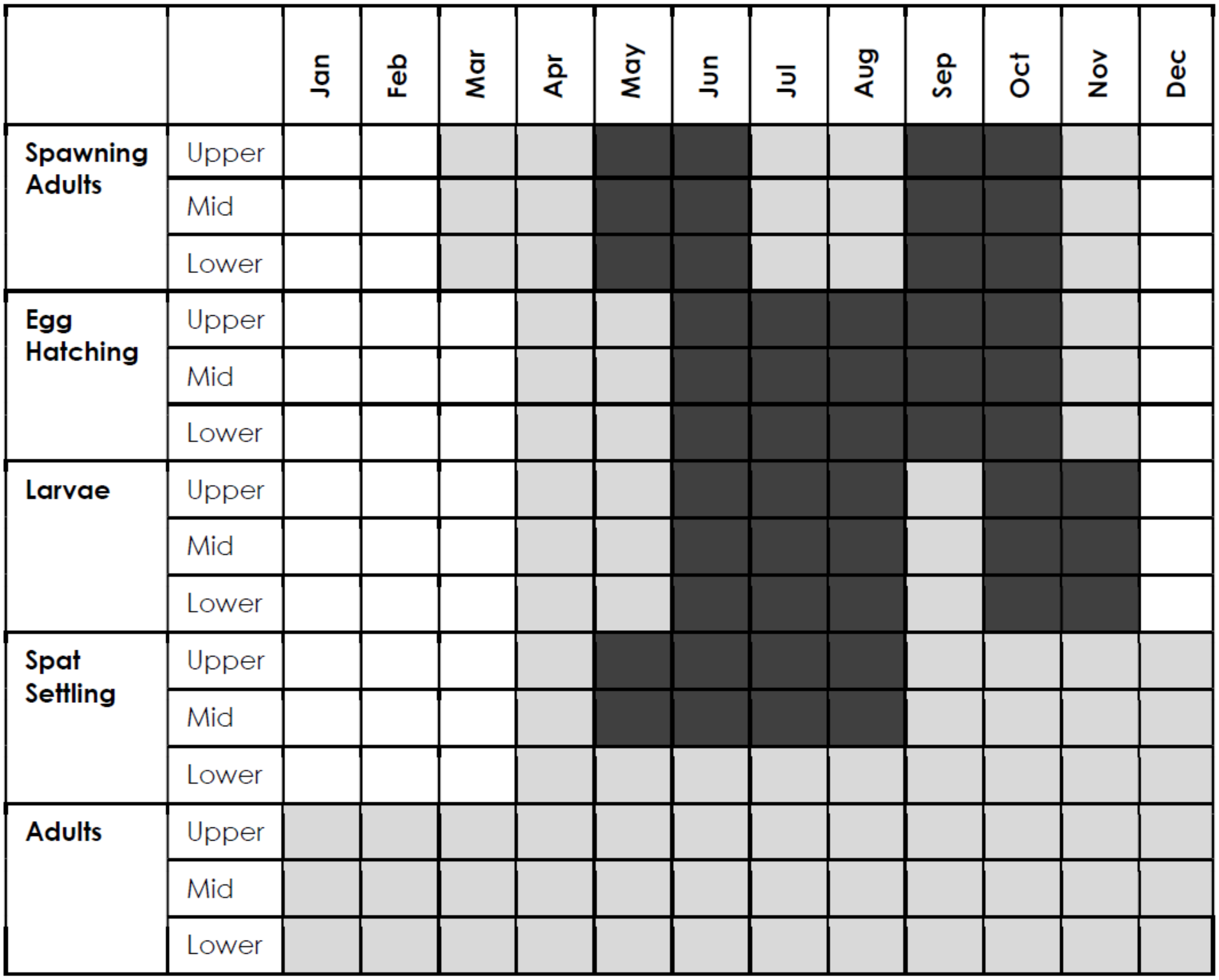

Figure 3.6: Spatial (upper, middle and lower estuary) and temporal (monthly) distribution of oysters by life stage. White cells indicate the life stage is generally not present; light grey cells indicate low abundance; dark grey cells indicate high abundance (Hijuelos et al. 2017).

Table 3.7: Definition for the Oyster Habitat Suitability [WC1] performance measure.

Oyster Habitat Suitability [WC1]			
Indicator (and units)	Index: Salinity (ppt) x Temperature (°C) using 0-1 scales		
Management Objective	Maintain a balance of fresh and saltwater harvestable species populations		
Driving physical variable(s)	(a) salinity; (b) temperature; (c) suspended sediment (d) flow velocity		
Critical time period	J F M A M J J A S O N D	period of juveniles from May - November	
Key Locations	Pontchartrain Basin: Bay Boudreau, Drum Bay, Eloi Bay / Lake Eloi, Lake Coquille, Lake Machias, Lake Fortuna, Lake Calebasse, approaching Lake Borgne Barataria Basin: Grand Isle? Equivalent information is being sought for Barataria Bay.		
Physical models generating values at key locations & time-frames	Real-time salinity and temperature gauges in Barataria Basin – May to November? Year-round?		
Daily / instantaneous suitability	Preferred / Good	Fair	Poor
	e.g. Salinity: 8-22 ppt e.g. Temp: 12-18° C	e.g. 5-8 ppt or 22-30 ppt e.g. 18-30°C	e.g. <5 or >30 ppt e.g. >30°C
Critical period / Annual suitability	Preferred / Good	Fair	Poor
	TBA	TBA	TBA
Desired annual recurrence frequency	TBA		
Algorithm functional details & potential improvements	A trade-off exists between best growing conditions and reduced mortality (from parasites / predators) – this trade-off results in a wide range of reported “optimal” conditions for Eastern Oysters.		
Potential trade-offs	*Positively correlated indicators*	*Negatively correlated indicators*	
	• Uncertain due to complexity of needs	• Uncertain due to complexity of needs	
Foundational references / evidence / data Sources	Denapolis & Lopez (2019, 2020); Hijuelos et al. (CMP appendix) (2017); La Peyre et al. (2009); Lowe et al. (2017); Sehlinger et al. (2019); Watson et al. (2015)		

3.1.8 White Shrimp Habitat Suitability [WC2]

The White Shrimp Habitat Suitability [WC2] performance measure relates to the objective of maintaining a balance of fresh and saltwater harvestable species populations, to the extent that is practicable. This objective is of medium importance for the near and long-term. In practice, this objective will involve maintaining a suitable estuarine gradient (with seasonal variation) to support populations of both fresh and saltwater harvestable species. This estuarine gradient may be more representative of historic conditions rather than current ones, and therefore the current habitats (and associated fishing grounds) of the harvestable species may shift (Figure 3.8 and Figure 3.9).

The Louisiana shrimp fishery accounts for 43% of all shrimp landings in the Gulf of Mexico. It is the second largest commercial fishery in Louisiana, as well as the most valuable for the state (Bourgeois et al. 2016). On average, white shrimp (*Litopenaeus setiferus*) make up 58-68% of the landings (pounds) in Louisiana (Bourgeois et al. 2016), and about the same percentage of the dollar value of shrimp landings. White shrimp are resilient to fishing pressure and populations can rebound from years of low abundance if the environmental conditions are suitable for growth and survival. Population modeling and other research suggests that suitable habitat conditions (e.g., appropriate salinity, water temperature, dissolved oxygen) for postlarvae and juvenile life stages are a critical factor in predicting white shrimp population size and potential harvest for the following season (Baker et al. 2014; Mace III and Rozas 2016). Therefore, a PM designed to meet optimal conditions for postlarvae and juveniles may be most sensitive option. Rozas and Minello (2011) also suggest that timing diversion operations to coincide with years when shrimp populations are already expected to be low (e.g., El Niño, La Niña events) could help alleviate any adverse effects (or enhance positive effects) of operations.

Simulating the spatial and temporal process of salinity is computationally intensive and complex, with many sources of uncertainty. Recognizing that white shrimp occupy different salinity and geographic areas depending on their age. The 2017 CMP adopted a habitat suitability model (O’Connell et al. 2017a) for juveniles which incorporates water temperature and salinity (Figure 3.7). An hourly resolution may be needed to ensure that salinity and temperature conditions are maintained within the tolerance range of juvenile white shrimp. The critical period for ensuring good nursery habitat conditions for juvenile white shrimp is from May to November, with postlarvae migration peaks into inshore estuaries in June and September (Figure 3.10) (Bourgeois et al. 2016).

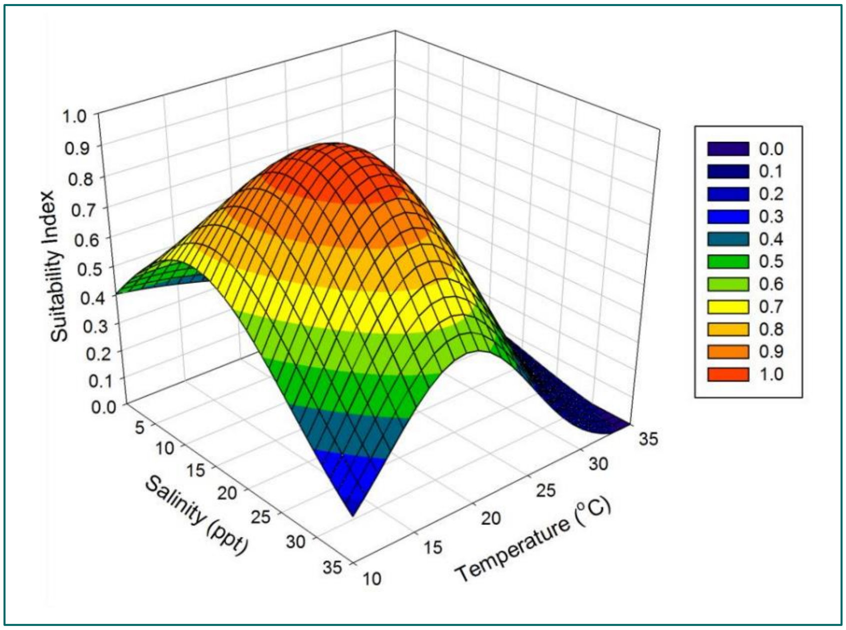

Figure 3.7: White shrimp habitat suitability model used by the 2017 CMP (O'Connell et al. 2017a).

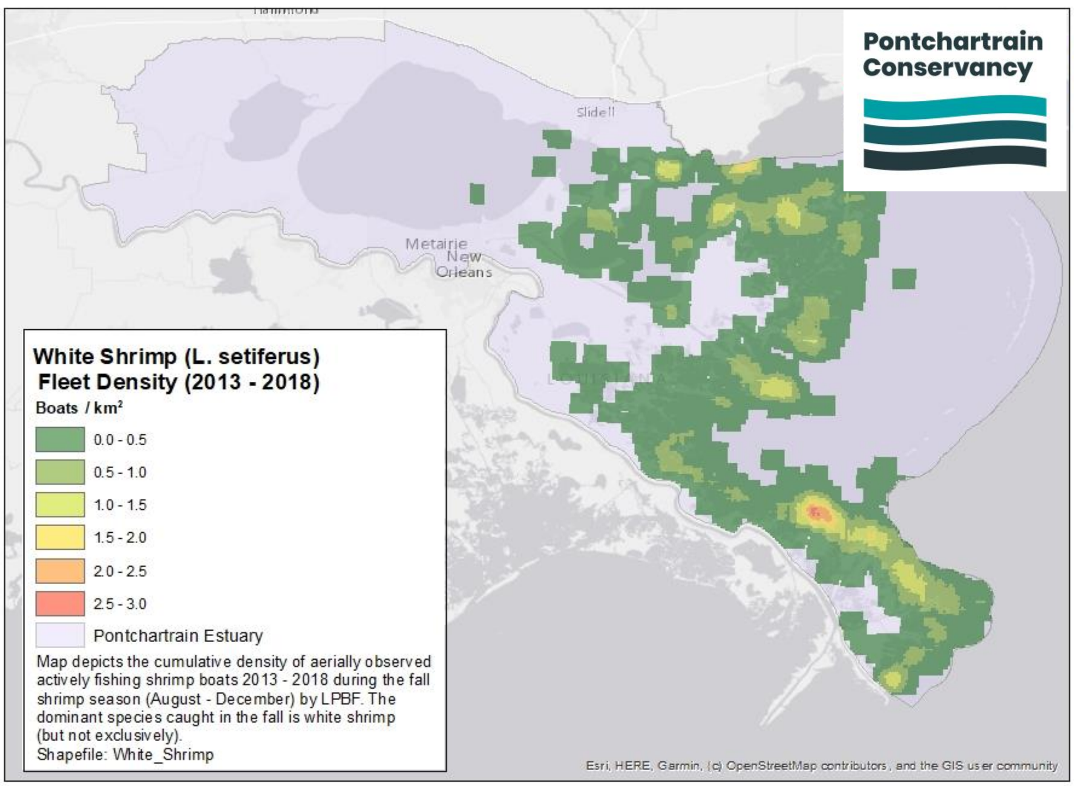

Figure 3.8: White shrimp fleet density (dark green = lowest density; red = highest density) in the Pontchartrain Basin (light purple) from 2013-2018; a proxy for the distribution of adult white shrimp (John Lopez, Pontchartrain Conservancy, personal communication, 2020).

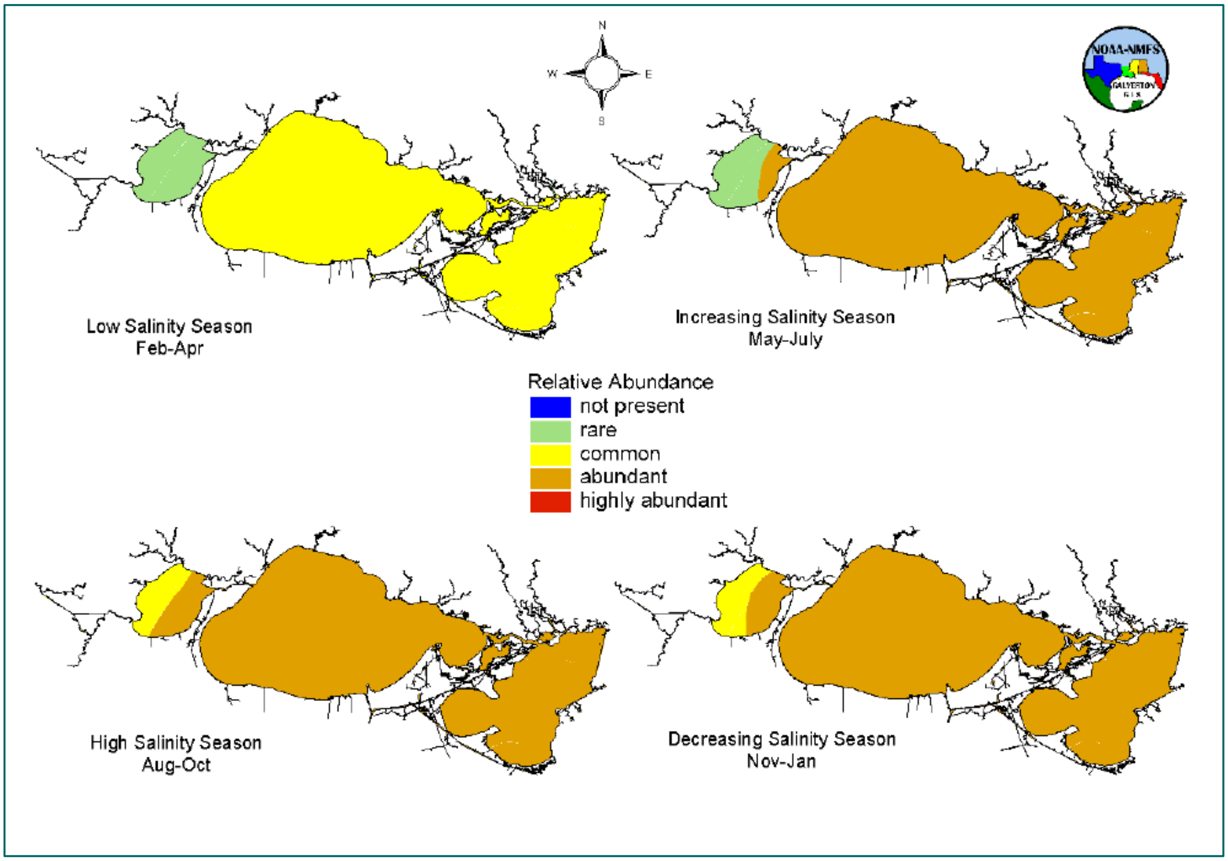

Figure 3.9: Juvenile white shrimp abundance in Lake Pontchartrain by season (NMFS 1998). Conditions have likely hanged due to the closure of the Mississippi River Gulf Outlet in 2009.

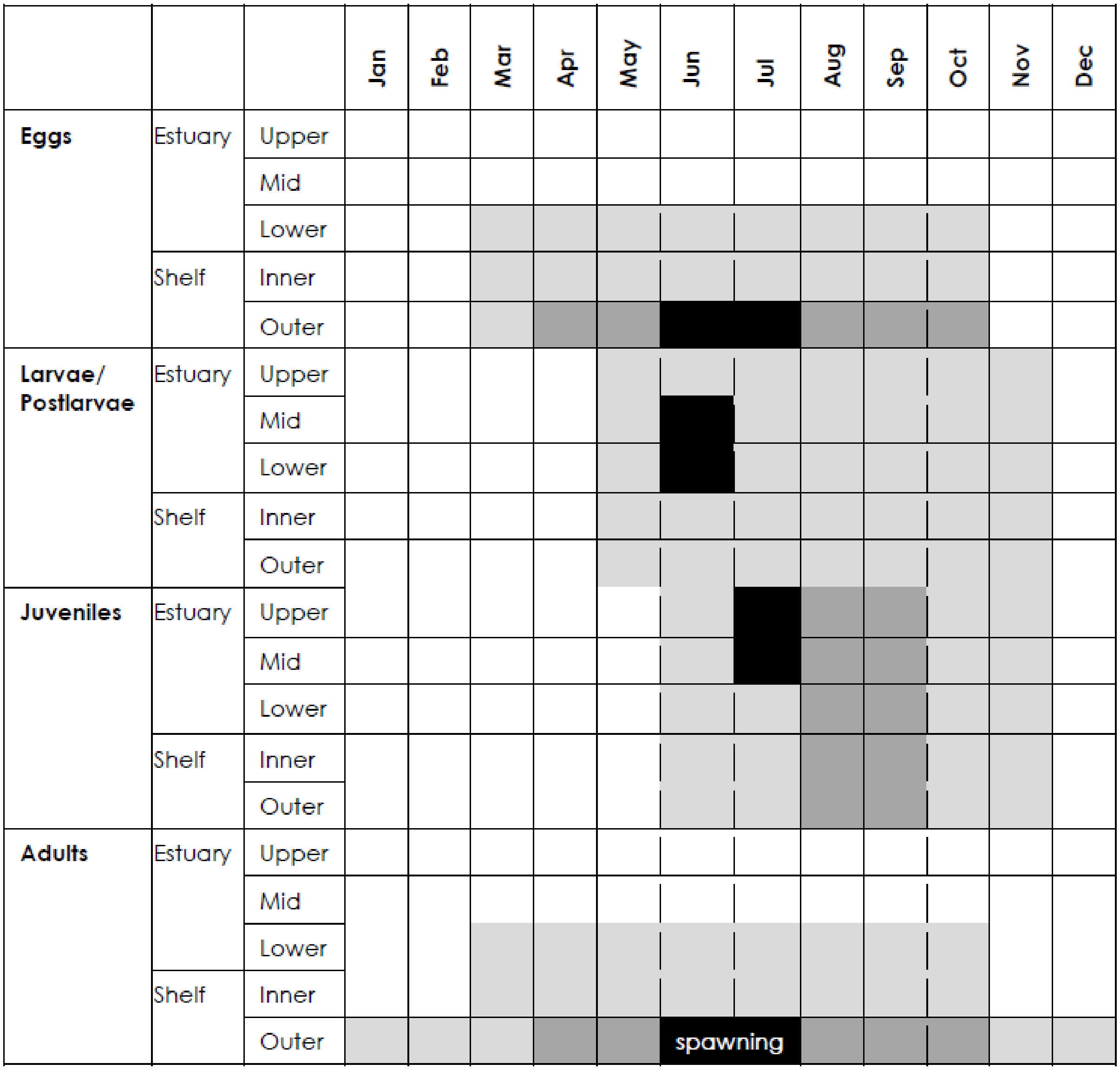

Figure 3.10: Spatial (upper, middle and lower estuary) and temporal (monthly) distribution of white shrimp by life stage. White cells indicate that the life stage is generally not present; light grey cells indicate low abundance; dark grey cells indicate high abundance (O'Connell et al. 2017a).

Table 3.8: Definition for the White Shrimp Habitat Suitability [WC2] performance measure.

White Shrimp Habitat Suitability [WC2]			
Indicator (and units)	Index (0-1) based on salinity (ppt) x temperature (°C)		
Management Objective	Maintain a balance of fresh and saltwater harvestable species populations		
+Driving physical variable(s)	(a) salinity; (b) temperature; (c) dissolved oxygen; (d) tidal movement		
Critical time period	J F M A M J J A S O N D	Critical periods for ensuring good nursery juvenile habitat conditions. Postlarvae migrate into inshore estuaries May – Nov, but with peaks in June and Sept.	
Key Locations	Postlarvae and juveniles prefer mud and peat bottoms with some decaying organic matter or vegetation.		
Physical models generating values at key locations & times	Real-time salinity gauges in Barataria and Pontchartrain Basins – May to November		
Daily / instantaneous suitability	Preferred / Good **e.g. HSI > 0.8**	Fair e.g. 0.4 < HSI < 0.8	Poor **e.g. HSI < 0.4**
Critical period / Annual suitability	Preferred / Good TBA	Fair TBA	Poor TBA
Desired annual recurrence frequency	TBA: ≥ 1 fair year every 2 years?		
Algorithm functional details & potential improvements	(1) The most sensitive indicator may target conditions for juvenile survival. (2) May need to separate into models – one for postlarvae / juveniles and one for adults. (3) Depending on feasibility, model could incorporate dissolved oxygen.		

	Positively correlated indicators	*Negatively correlated (antagonistic) indicators*
Potential trade-offs	• Improved salinity regime for *Spartina patens,* bottlenose dolphins and brown shrimp • Decreased flood risk for communities outside levees (e.g., Barataria Bay) • Navigable channel depth for commercial shipping in MR	• Reduced low-salinity regime for *Phragmites australis* • Increased flood risk for MR inside levees • Degraded habitat for manatees (in terms of temperature and salinity)
Foundational references / evidence / data Sources	Baker et al. (2014); Bourgeois et al. (2016); O'Connell et al. (2017a); Mace III and Rozas (2016); Rozas and Minello (2011)	

3.1.9 Brown Shrimp Habitat Suitability [WC3]

The Brown Shrimp Habitat Suitability [WC3] performance measure relates to the objective of maintaining a balance of fresh and saltwater harvestable species populations, to the extent that is practicable. This objective is of medium importance for the near and long-term. In practice, this objective will involve maintaining a suitable estuarine gradient (with seasonal variation) to support populations of both fresh and saltwater harvestable species. This estuarine gradient may be more representative of historic conditions rather than current ones, and therefore the current habitats (and associated fishing grounds) of the harvestable species may shift (Figure 3.12 and Figure 3.13). This potential shift in salinity regimes should be considered if TTO is included in the SDOT, since the abundance of (low commercial value) brown shrimp is partly due to saltwater intrusion resulting from current water management practices. The TTO-emphasis given the brown shrimp should be considered in relation to the needs of the commercially and historically more valuable white shrimp.

The Louisiana shrimp fishery accounts for 43% of all shrimp landings in the Gulf of Mexico. It is the second largest commercial fishery in Louisiana, as well as the most valuable for the state (Bourgeois et al. 2016). Brown shrimp (*Farfantepenaeus aztecus*) along with white and seabob shrimp, make up over 99% of the Louisiana commercial shrimp fishery by weight (Bourgeois et al. 2016). Brown shrimp are resilient to fishing pressure and populations can rebound from years of low abundance if the environmental conditions are suitable for growth and survival. Population modeling and other research suggests that suitable inshore estuary habitat conditions (e.g., salinity, water temperature, dissolved oxygen) for postlarvae and juvenile life stages are a critical factor in predicting brown shrimp population size and potential harvest for the following season (Leo et al. 2016). Brown shrimp growth rates and productivity may be adversely impacted if freshwater input from the diversion reduces estuarine salinities over large portions of the available postlarvae and juvenile habitat. Potential negative impacts could be alleviated by avoiding large freshwater releases from the diversions during peak recruitment periods. Some research suggests that limiting diversion operations to February and March – periods of low brown shrimp abundance in the estuaries – would minimize effects to the fishery (Adamack et al. 2012). Rozas and Minello (2011) also suggest that timing diversions operations to coincide with years when shrimp populations are already expected to be low (e.g., El Niño years) could help alleviate the adverse effects.

Simulating the spatial and temporal process of salinity is computationally intensive and complex, with many sources of uncertainty. Recognizing that different life stages have different habitat preferences, the approach adopted by the 2017 CMP (O'Connell et al. 2017b) incorporates salinity and temperature to develop a habitat suitability model for juveniles (Figure 3.11). The critical period for ensuring good inshore estuarine habitat conditions for juvenile brown shrimp is from February to April (Figure 3.14), with a minor peak in the fall as well (Bourgeois et al. 2016).

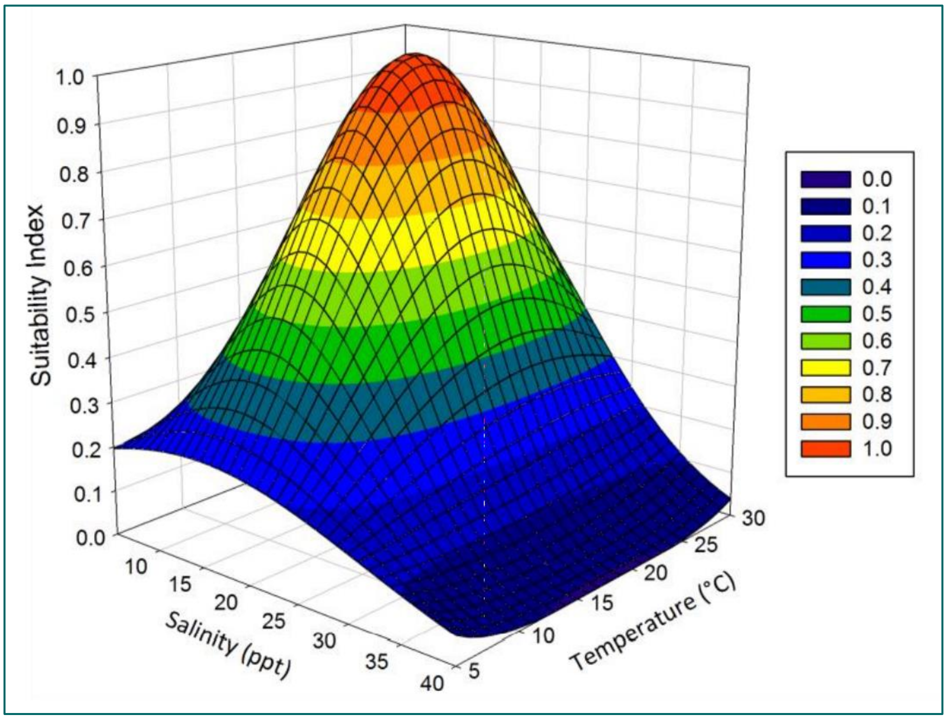

Figure 3.11: Brown shrimp juvenile habitat suitability model used by the 2017 CMP (O'Connell et al. 2017b).

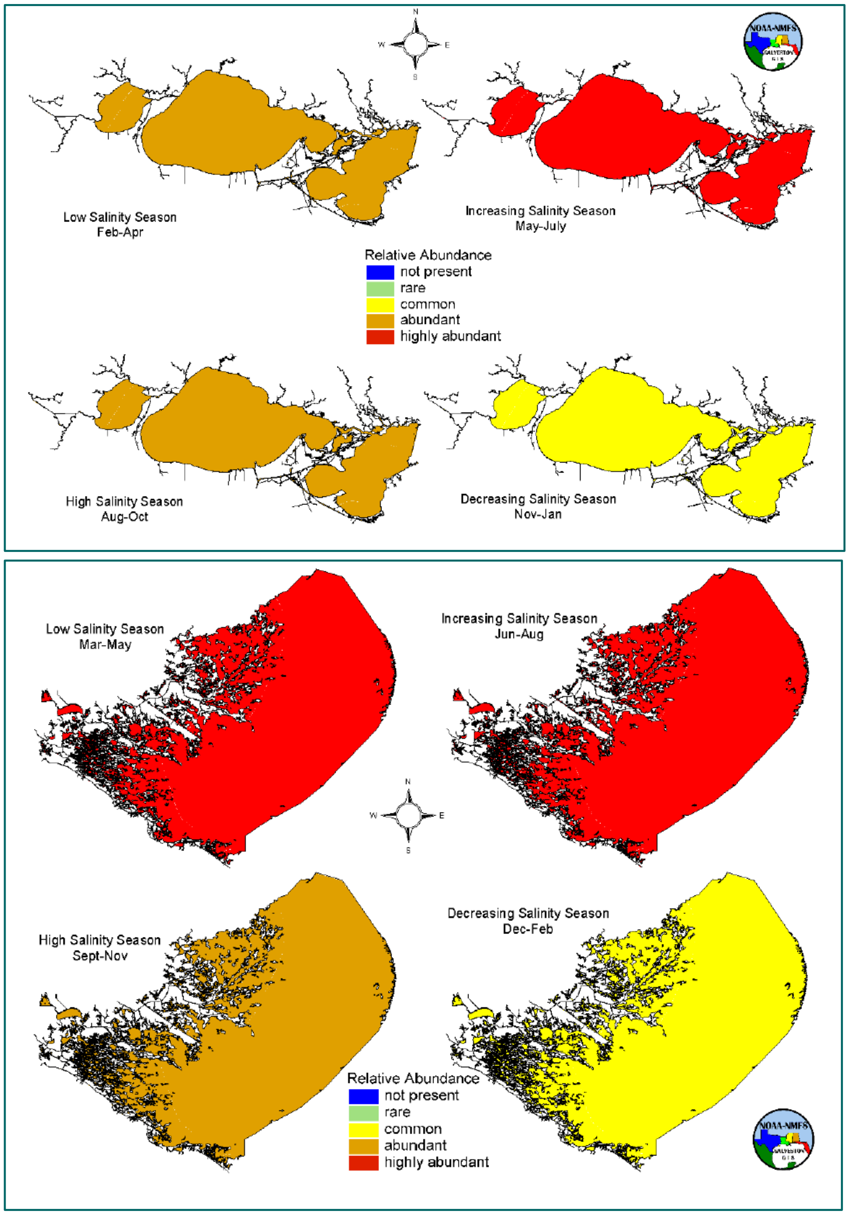

Figure 3.12: Juvenile brown shrimp abundance in Lake Pontchartrain (above) and Breton Sound (below) by season (NMFS 1998). Conditions have likely hanged due to the closure of the Mississippi River Gulf Outlet in 2009.

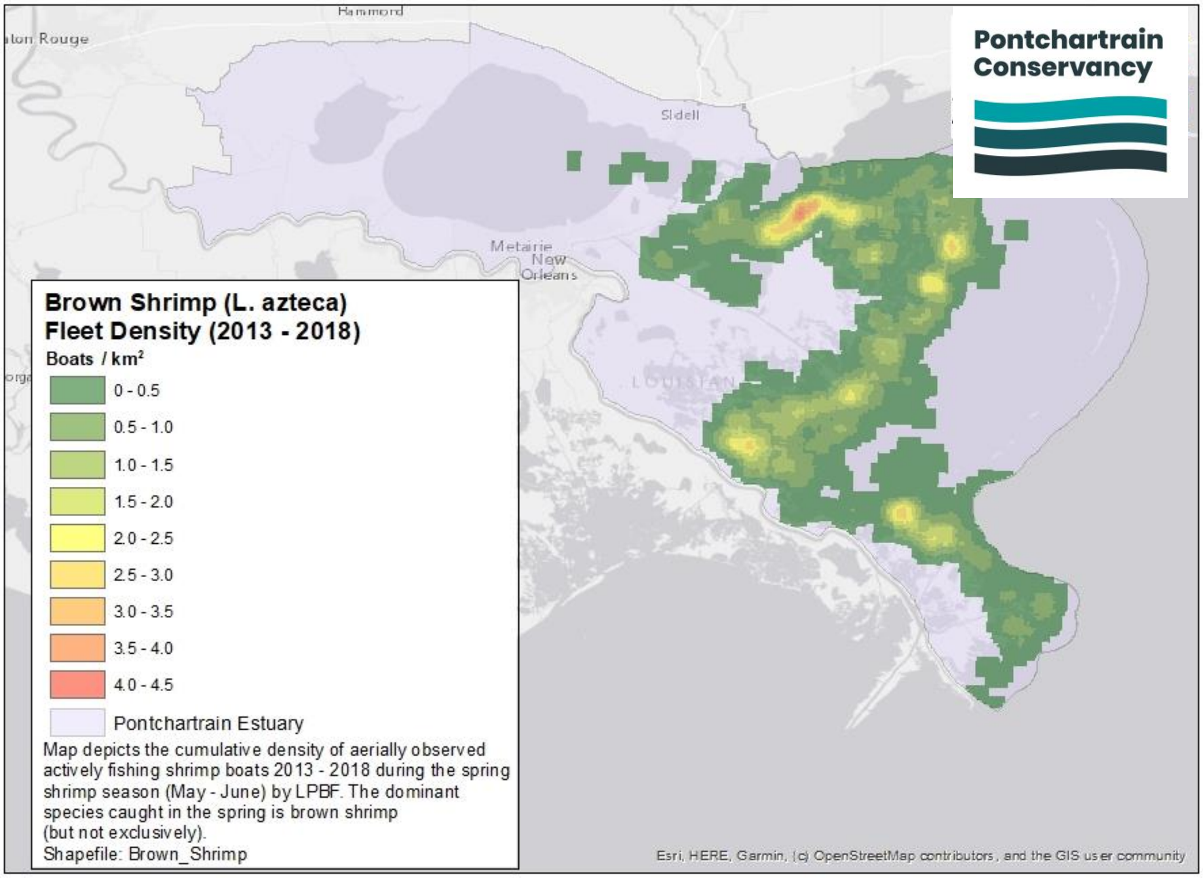

Figure 3.13: Brown shrimp fleet density (dark green = lowest density; red = highest density) in the Pontchartrain Basin (light purple) from 2013-2018 (post closure of the MRGO) (John Lopez, Pontchartrain Conservancy, personal communication, 2020).

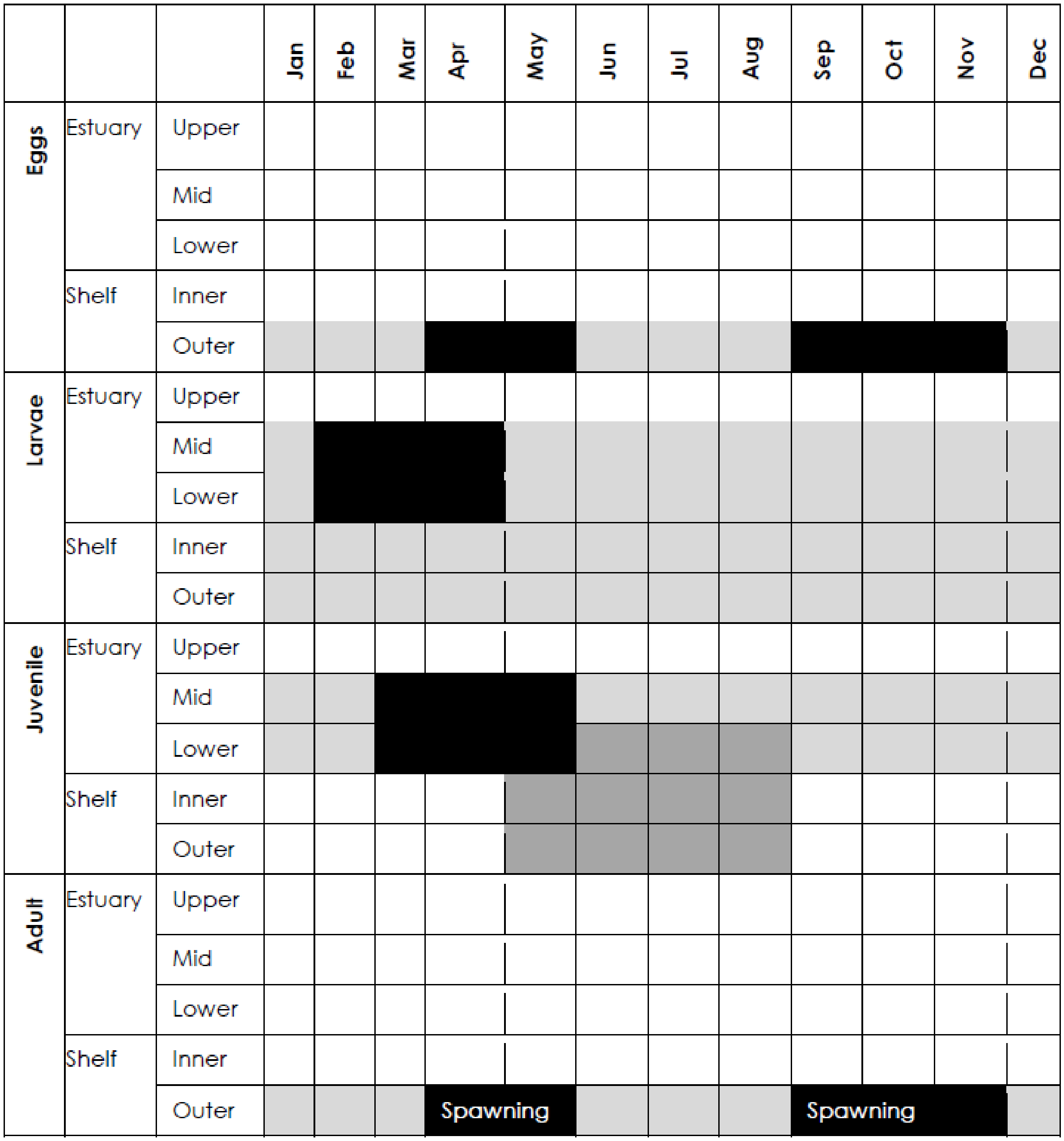

Figure 3.14: Spatial (upper, middle and lower estuary) and temporal (monthly) distribution of brown shrimp by life stage. White cells indicate that the life stage is generally not present; light grey cells indicate low abundance; dark grey cells indicate high abundance (O'Connell et al. 2017b).

Table 3.9: Definition for the Brown Shrimp Habitat Suitability [WC3] performance measure.

Brown Shrimp Habitat Suitabilty [WC3]			
Indicator (and units)	Index (0-1) based on salinity (ppt) x temperature (°C)		
Management Objective	Maintain a balance of fresh and saltwater harvestable species populations		
Driving physical variable(s)	(a) salinity; (b) temperature; (c) dissolved oxygen; (d) tidal movement		
Critical time period	J F M A M J J A S O N D		
Key Locations	Postlarvae and juveniles prefer shallow vegetated habitats, but also live on silty sand and non-vegetated mud bottoms.		
Physical models generating values at key locations & times	Real-time salinity gauges in Barataria and Pontchartrain Basins – May to November		
Daily / instantaneous suitability	Preferred / Good	Fair	Poor
	e.g. HSI > 0.8	e.g. 0.4 < HSI < 0.8	**e.g. HSI < 0.4**
Critical period / Annual suitability	Preferred / Good	Fair	Poor
	TBA	TBA	TBA
Desired annual recurrence frequency	TBA: ≥ 1 fair year every 2 years?		
Algorithm functional details & potential improvements	Literature indicates high variability in timing of postlarval recruitment to estuaries. Previous spatial modeling showed effects of tide height on productivity (because tide height impacts access to marshes). May need to separate into two PMs (postlarvae / juveniles and adults)		
Potential trade-offs	*Positively correlated indicators*	*Negatively correlated (antagonistic) indicators*	
	• Improved salinity regime for *Spartina patens,* bottlenose dolphins and white shrimp • Decreased flood risk for communities outside levees (e.g. Barataria Bay) • Navigable channel depth for commercial shipping in MR	• Reduced low-salinity regime for *Phragmites australis and Spartina patens* • Degraded habitat for manatees (in terms of temperature and salinity)	
Foundational references / evidence / data Sources	Adamack et al. (2012); Bourgeois et al. (2016); Leo et al. (2016); O'Connell et al. (2017b); Piazza et al. (2010); Rozas and Minello (2011)		

3.1.10 Alligator Habitat Suitability [WC4]

The Alligator Habitat Suitability [WC4] performance measure relates to the objective of maintaining a balance of fresh and saltwater harvestable species populations, to the extent that is practicable. This objective is of medium importance for the near and long-term. In practice, this objective will involve maintaining a suitable estuarine gradient (with seasonal variation) to support populations of both fresh and saltwater harvestable species. This estuarine gradient may be more representative of historic conditions rather than current ones, and therefore the current habitats (and associated fishing grounds) of the harvestable species may shift.

The American alligator (*Alligator mississippiensis*) is both culturally and economically important to the state of Louisiana (Nyman 2012). Once listed as a federally endangered species, the alligator has since increased in abundance in Louisiana and harvest has resumed with a managed hunt across all coastal parishes (Waddle 2017). Alligators rely on water for activities including foraging, thermal regulation, mating and refuge from predators (Waddle 2017). While primarily a freshwater species, alligators can tolerate saline conditions for short periods. However, extended time spent in saltwater reduces their growth rate and, without access to freshwater their ability to osmoregulate is lost (Waddle 2017). Water temperature is also an important consideration for alligator habitat because water can serve as a thermal refuge during more extreme changes in air temperature (e.g., caused by wind / sun) (Asa et al. 1998). Water depth is also known to be a determinant of habitat quality, with both extreme flooding and lack of flooding reducing the species' distribution. A simple performance measure relating to alligators would be a model of salinity and water temperature, however a more complex model that incorporates water depth may better capture alligators' high-quality habitats. A daily resolution may be needed to ensure that salinity and temperature conditions are maintained within the tolerance range of alligators. This index would need to be implemented year-round because alligators are permanent residents of the coastal marshes.

Table 3.10: Definition for the Alligator Habitat Suitability [WC4] performance measure.

<table>
<tr><th colspan="14">Alligator Habitat Suitability[WC4]</th></tr>
<tr><td>Indicator (and units)</td><td colspan="13">Index (0-1) based on salinity (ppt) x temperature (°C)</td></tr>
<tr><td>Management Objective</td><td colspan="13">Maintain a balance of fresh and saltwater harvestable species populations</td></tr>
<tr><td>Driving physical variable(s)</td><td colspan="13">(a) salinity; (b) temperature</td></tr>
<tr><td rowspan="2">Critical time period</td><td>J</td><td>F</td><td>M</td><td>A</td><td>M</td><td>J</td><td>J</td><td>A</td><td>S</td><td>O</td><td>N</td><td>D</td><td rowspan="2">Alligators are year-round residents</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

<table>
<tr><td>Key Locations</td><td colspan="3">Most abundant in coastal marshes, but also present in lakes, bayous, swamps, and canals.
Western Lake Pontchartrain, East Bank of the Mississippi River, Bayou Barataria, Pointe a la Hache. More distribution information is being sought.</td></tr>
<tr><td>Physical models generating values at key locations & time-frames</td><td colspan="3">Real-time salinity and temperature gauges in Barataria and Pontchartrain Basins</td></tr>
<tr><td rowspan="2">Daily / instantaneous suitability</td><td>Preferred / Good</td><td>Fair</td><td>Poor</td></tr>
<tr><td>29-31°C
0 ppt
tba</td><td>5-28°C
0-10 ppt
tba</td><td><5°C and >31°C
>10 ppt
tba</td></tr>
<tr><td rowspan="2">Critical period / Annual suitability</td><td>Preferred / Good</td><td>Fair</td><td>Poor</td></tr>
<tr><td>TBA</td><td>TBA</td><td>TBA</td></tr>
<tr><td>Desired annual recurrence frequency</td><td colspan="3">Fair conditions must be maintained yearly, preferred / good conditions might be acceptable every other year</td></tr>
<tr><td>Algorithm functional details & potential improvements</td><td colspan="3"></td></tr>
<tr><td rowspan="2">Potential trade-offs</td><td colspan="2">Positively correlated indicators</td><td>Negatively correlated (antagonistic) indicators</td></tr>
<tr><td colspan="2">• Improved low-salinity regime for Phragmites australis, manatees</td><td>• Potential for elevated water levels and inundation for communities outside levees (e.g., Barataria Bay)
• Potential for induced shoaling for commercial shipping in MR
• Degraded higher-salinity regime for Spartina patens, brown shrimp, white shrimp and bottlenose dolphin</td></tr>
<tr><td>Foundational references / evidence / data Sources</td><td colspan="3">Asa et al. (1998), Waddle (CMP Appendix) (2017), Nyman (CMP Appendix) (2012)</td></tr>
</table>

3.2 Recommended Physical Sub-Models to Drive Performance Measures

Given the important role of natural hydrodynamics (river, estuary, and ocean), water diversions and entrainment in affecting so many processes in the Delta, it is critical that PMs be linked to physical driving variables at the appropriate temporal and spatial scale. A high-level view of the processes and linkages envisioned for the SDOT is shown in Figure 3.15

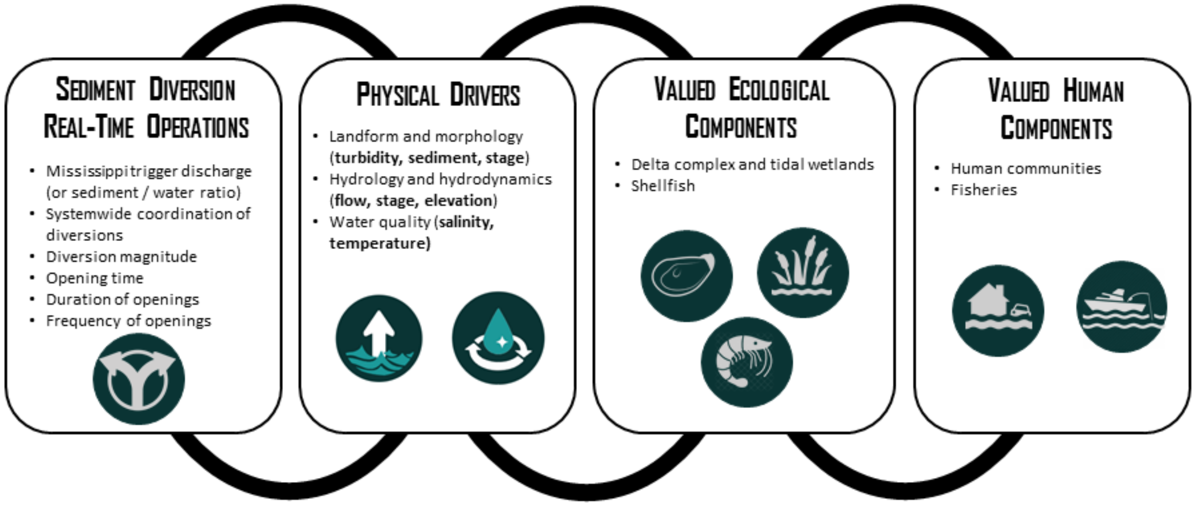

Figure 3.15: Potential management actions and physical processes that could affect valued ecological and human components within the MRD.

For comparison, Figure 3.16 shows the candidate components that were included in the 2012 Coastal Master Plan. Using the same high-level approach, many of the physical models used in 2012 were subsequently more fully integrated in the 2017 CMP, which merged many independent models into a single computational framework (Figure 3.18), the Integrated Compartment Model (ICM) (CPRA 2017). Although framed slightly differently in the three figures, there is clearly overlap between the physical drivers and linkages envisioned in the SDOT, the ecohydrology processes encapsulated in Figure 3.16 and the many components and linkages shown more explicitly in Figure 3.18. Key differences between the ICM and the SDOT approaches are (A) potential differences in temporal and spatial resolution and extent, (B) the SDOT emphasis on short-term forecasting for a suite of representative indicators (e.g., 1-2 weeks), and (C) the incorporation of continuous updated data from real-time gauges in the SDOT, which is not clear from the CPRA (2017) documentation. This last feature would require enhancements to the 2017 model so that monitoring data was incorporated into simulations in near real-time.

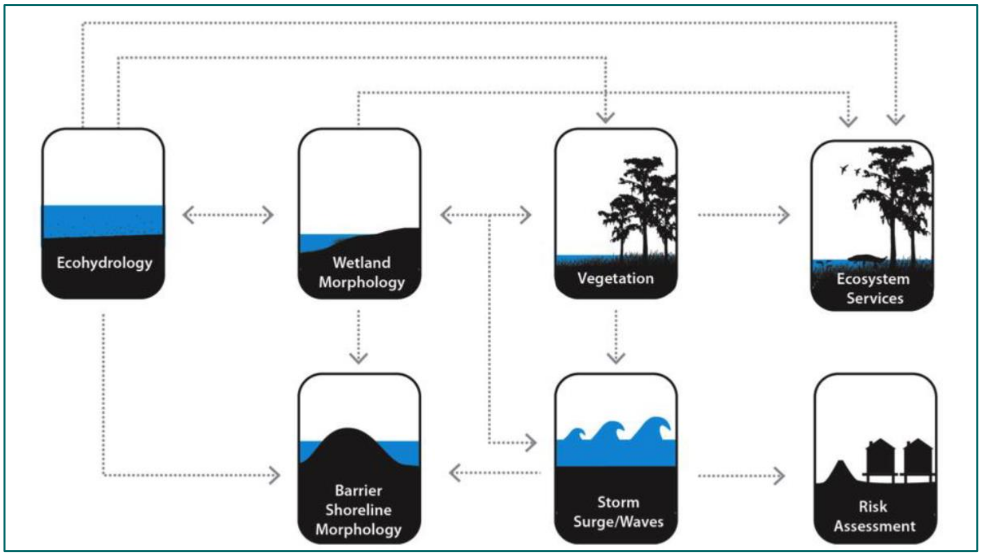

Figure 3.16: Major physical processes and linkages contributing to MRD simulations conducted as part of the 2012 Coastal Master Plan (Figure 1, Meselhe et al. 2017).

To make location-specific predictions for each Performance Measure, the SDOT will need to forecast physical conditions (e.g., stage/elevation, salinity, temperature) using live linkages to available real-time data sources (e.g., see Figure 2.3, Figure 2.4, and Figure 2.5), coupled with a hydrodynamic simulation projection of the area. The Delta's real-time monitoring network will enable the inference of current conditions at many locations; and is complemented by the network of in-river and in-basin gauges. But the simplicity or complexity necessary to forecast those physical variables (or their proxies) into the future will greatly affect the level of effort required to make the SDOT a reality. We have reviewed previous modeling exercises carried out in the MRD using these sources:

- 2010 inventory of models for the Louisiana coastal zone (Dragos and Wisneski 2010)
- 2012 Coastal Master Plan Appendices [URL]
- 2013 inventory of models for the Louisiana coastal zone (Leadon and Byrd 2013)
- 2017 Coastal Master Plan Appendices (and appendices) [URL]

Although some of the references are dated, together they provide an inventory of the hundreds of models that have been developed over the last decade, many of which are now integrated into the most recent ICM system used for the 2017 Coastal Master Plan. The ICM integrates six spatially explicit sub-models (Hydro, BIMODE, LAVegMod, Morph, HSI, EwE), each of which is coded in either Fortran or Python. Python is used extensively by the ICM, including geoprocessing through linkages to ArcGIS. It is because of the level of integration that has been achieved with the ICM that we believe it is the best candidate modeling system to support the forecasting needs of the SDOT. As noted above, the ICM would need to be enhanced to meet the needs of the SDOT by incorporating near real-time inputs from the network of sensors.

In the world of complex hydrodynamic simulation requiring 2D or 3D models, **water elevation** and **flow** are considered easier to forecast, followed by **salinity**, then **turbidity / sediments**. While obviously critical to supporting aquatic life, **dissolved oxygen** is considered difficult to predict and more uncertain because of its linkage to photosynthesis and nutrients, processes which carry their own burden of complexity (Ehab Meselhe, Tulane University, *personal communication*, 2020). The SDOT would track each of these key physical variables based on needs of other valued components / objectives alongside real-time data for representing the **current state** of the system combined with **advance multi-week forecasts** forward of the current decision date. The further forecasts go into the future the larger the uncertainty (error bounds) in forecasting river flows and other physical variables noted. However, one of the goals of SDOT development would be to try to “*push the envelope*” of how far into the future the forecasts could be generated (ideally at least 4-6 weeks into the future).

The further into the future forecasts can be made, the more anticipation and better influence operators will have to balance objectives. Also, it is important to understand that SDOT diversion operators would be continually reviewing conditions and continuously re-running predictions on *weekly or sub-weekly intervals*. This differs from a situation where the operator looks at a 4-week advance forecast, runs several SDOT simulations, makes a decision, and then returns 4 or 5 weeks later to review “what happened”. By continuously considering emergent conditions in real-time every few days or week, diversion operators will be able to make adjustments to forecasts that may turn out to be too high or too low. That said, the better the accuracy and distance into the future of forecasts, the greater the practical utility of the SDOT.

Based on our survey of the hundreds of models described in the bullet-list above, we believe that the ICM is the model which is most likely and able (with some modification) to support the SDOT, and that with some enhancement its simulations and forecasts will likely be able to incorporate data from real-time gauges. The previous 2012 coastal modeling exercise made use of several stand-alone models, which made it impossible to update the complete landscape annually and introduced laborious and error-prone manual steps to synchronize the sub-models. These difficulties were overcome through the development of the ICM, which integrates and automates linkages among the six main sub-models. Our current understanding of the key features of the ICM are summarized in Table 3.11, Figure 3.17, and Figure 3.18. Table 3.12 provides a high-level summary of the candidate VCs for the SDOT and the driving variables required by each PM, all of which can be forecast by the ICM.

Table 3.11: Key features of the ICM (CPRA 2017, Ehab Meselhe, Tulane University, personal communication).

Category	Notes
Key processes	*River flow, precipitation*, evapotranspiration *Air temperature* *Water temperature, salinity, stage, elevation* *Tidal dynamics, wind*, *wave* and *storm-wave* action, *gulf water level* Suspended *sediments*, sedimentation Marsh dynamics: elevation change, edge erosion Barrier island dynamics, long-shore transport, accretion, erosion
Spatial resolution	Variable mesh grid, (30m, 500m, 1km, 10km) depending on configuration and process
Spatial extent	Can include all or parts of MRD, depending on need
Temporal resolution	As short as 1m for some processes, depends on configuration and process
Temporal extent	Sub-daily to as long as 50 years, depends on need
Key inputs	Gauge data for ***italicized*** processes above, bathymetry and elevation
Key outputs	See ***italicized*** processes above, temporal and spatial aggregation depend on need
Owner	ESRI mapping software is licensed commercial software, some component sub-models are USACE or open source; substantial IP investment with multiple academic contributors

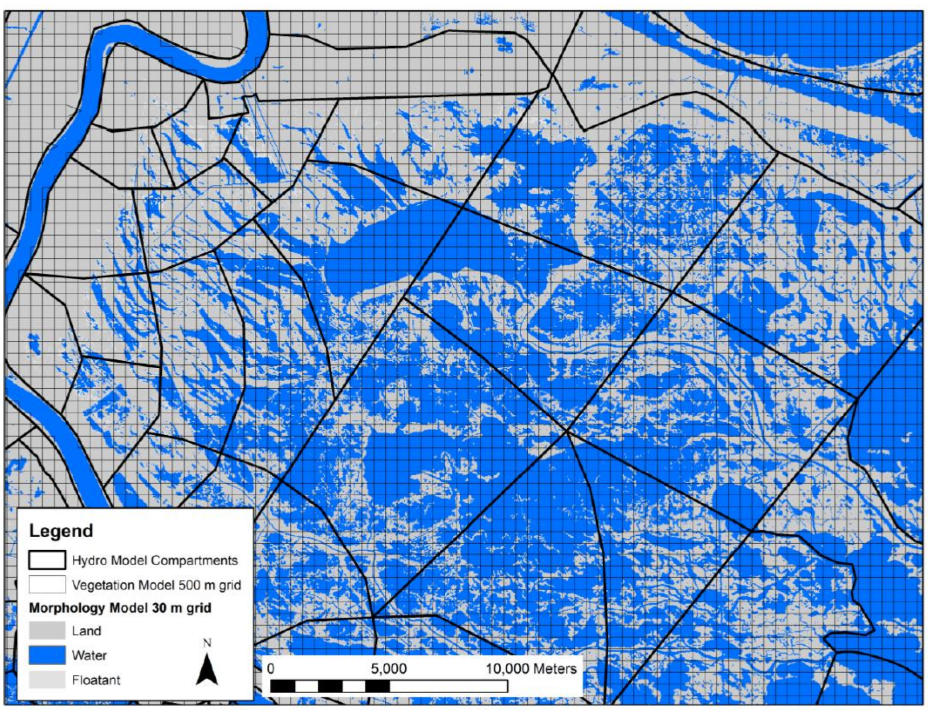

Figure 3.17: The ICM uses a variety of regular and irregular polygons, depending on the process (Figure 5, CPRA 2017).

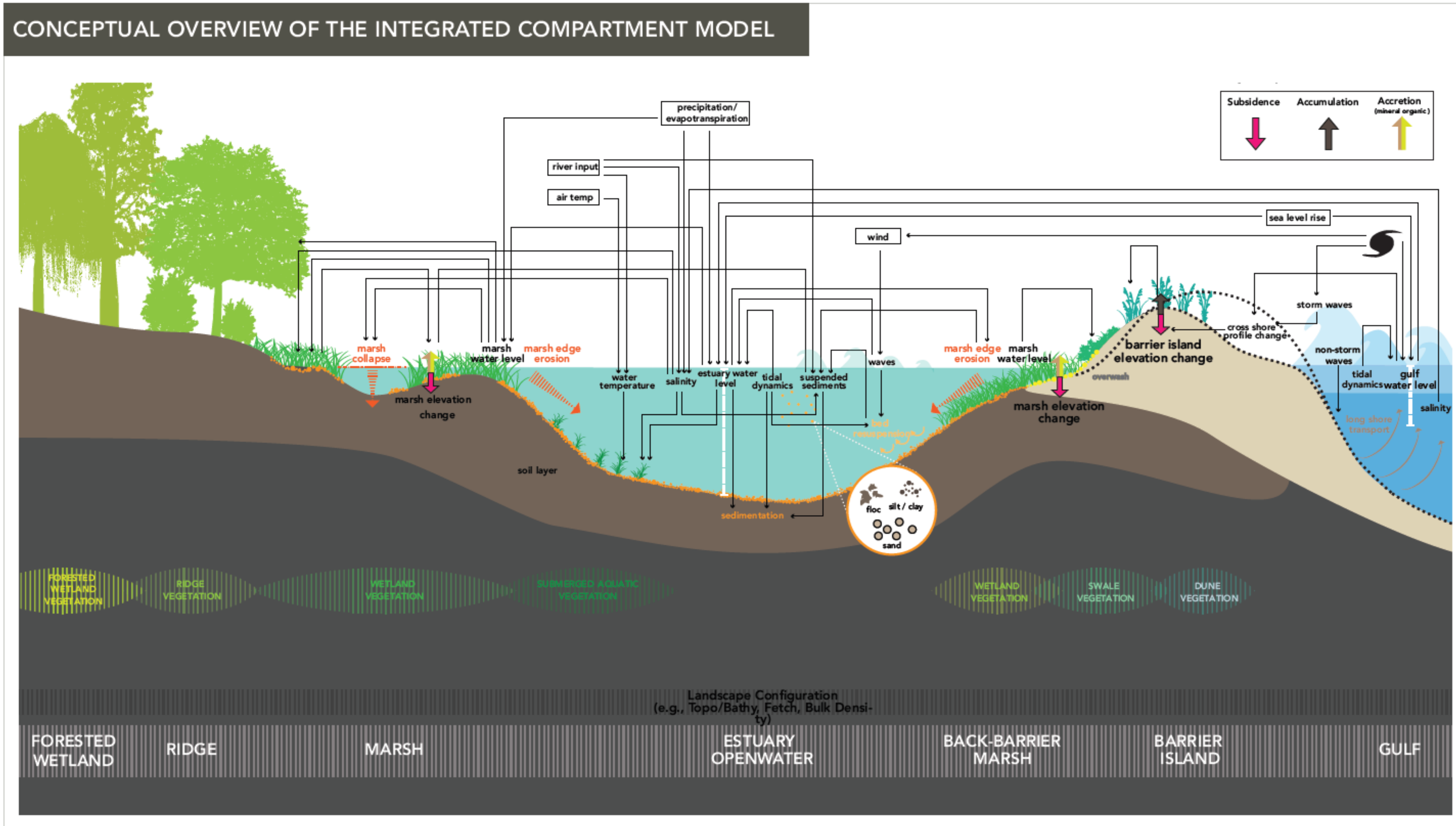

Figure 3.18: Major physical processes and linkages contributing to MRD simulations conducted as part of the 2017 Coastal Master Plan (Figure 3.5, CPRA 2017).

Table 3.12: A simplified list of the environmental requirements for each proposed performance measure. Environmental requirements in gray are not explicitly needed for the performance measure but are a necessary part of the driving hydrologic system, needed to simulate the primary requirements.

Performance Measure (PM)	PM Code	Flow	Stage, Elevation	Tide, Weather	Salinity	Tempera-ture	Turbidity	Time Step	Spatial Resolution	Notes
Sediment capture	DP1	✓					✓	day	–	Bed load and sediment load depend on turbidity
Sediment distribution	DP2	✓					✓	hour	2D or 3D	Sediment size categories
Stagnant water	DP3	✓		✓				hour	2D or 3D	Like particle tracking
Floodplain inundation	DP4	✓	✓	✓				hour	2D	DEM required
Flood risk to basin communities	RR1	✓	✓	✓				hour	2D	Risk to Lafitte
Oyster habitat suitability	WC1	✓		✓	✓	✓	?	hour	2D	May require two indicators for life-stages
White shrimp habitat suitability	WC2	✓		✓	✓	✓		hour	2D	
Brown shrimp habitat suitability	WC3	✓		✓	✓	✓		hour	2D	
Alligator habitat suitability	WC4	✓		✓	✓	✓		day	2D	

3.2.1 Flow

In rivers, flow is a measure of the rate at which the river discharges water. It is usually computed indirectly based on stage using a rating-curve relationship empirically calibrated at gauge locations. The main way that flow is used is to guide management of river operations, such as through the use of flow (or stage) rules to manage the opening or closing of control structures. Sediment diversions may also be operated using flow-based criteria (among other considerations) for opening or closing the diversion.

River and estuary gauges are maintained by the NWS, USACE, and USGS and near real-time flow is customarily computed along with the measurement of stage. We anticipate using flow computed at the same gauges as the stage measurements, tentatively identifying Reserve and Port Eads as the furthest upstream and downstream gauges of interest (see Figure 2.4), although the final geographic boundary has not yet been confirmed. Between these locations, there are about 15 stage gauges in the River.

We do not propose to develop an internal model describing and projecting watershed hydrology. Instead, we propose to use real-time queries of the NWS data system, whose Advanced Hydrologic Prediction Service (AHPS) provides tools for river-forecasting, described below for Stage in Section 3.2.2. Because river forecasts predict stage and not flow, we will likely need to interpolate stage-flow relationships based on historical measurements if estimated flow is not provided by NWS. An example of a stage-flow rating curve is shown in Figure 3.19 (taken from the Old River Control Structure). Real-time queries of the USGS data system will be used when appropriate.

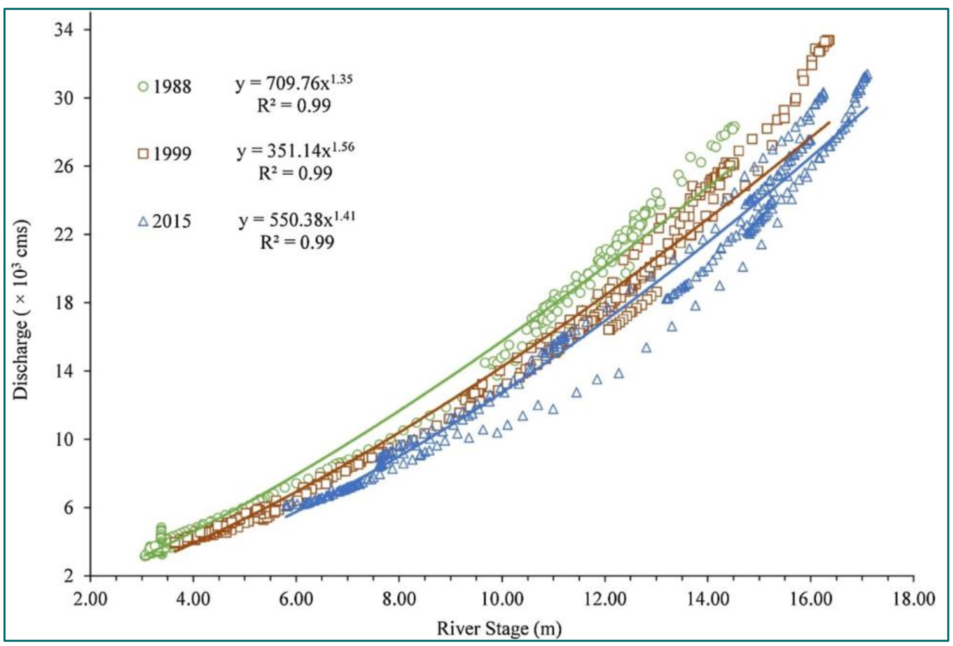

Figure 3.19: Example of Stage-Discharge rating curve (Wang and Xu 2016).

In near-shore environments movement of water is influenced by many forces, including discharge from rivers, tides, currents, and weather. Prediction of flow in these environments is made using hydrodynamic simulation models that are fundamentally based on equations of motion and mass conservation (e.g., for water movement and salinity prediction), driven by a variety of external forces. We propose to make use of the suite of ICM modeling tools for the simulation of all near-shore physical variables, including those related to water movement.

3.2.2 Stage & Elevation

Stage is a measure of river elevation, or in open water the elevation of a lake, bayou, or bay, relative to a standard such as sea level. The main way that stage and elevation are used is in the measurement of flood risk or marsh inundation. With the levee system, at each gauge location different levels of flood-risk are provided based on historical flooding events. For example, at New Orleans (NWS gauge NORL1) minor, moderate, and major flooding thresholds are established at 17, 19, and 20 feet.

None of the high priority PMs make use of river stage but RR1 (Flood risk to Basin communities) depends on the estimation of water elevation in the basin to quantify flooding risk in communities like Lafitte, Myrtle Grove and Grand Bayou. The forecasting of water elevation in Barataria Basin will require linkage to hydrodynamic models that incorporate real-time gauge data. We propose to incorporate real-time internet services which allow queries of the USGS (and other) gauges to provide current elevation at a 15-minute resolution. Because of the spatial and temporal complexity of the River and Gulf hydrodynamics, we do not envision developing an internal quantitative model describing and projecting sediment transport. Instead, we propose incorporating the suite of ICM simulation tools for projection spatially transport, to the extent that this is possible. We anticipate that the simulation of water elevation will require 2D simulations but not 3D detail.

In addition to real-time gauges in the near-shore environment, we see the need to incorporate river stage forecasts (and therefore flow inputs) from the NWS AHPS, which provides two forecasting tools. The first of these forecasts weather for the next 24 hours and projects stage every 6 hours for the next 30 days with no additional precipitation at four gauges (Baton Rouge, Donaldsonville, Reserve, New Orleans). At two gauges (Reserve and New Orleans) NWS offers a second experimental tool which provides 28-day stage projections based on either 2-day or 16-day forecasts of rainfall.[13] Figure 3.20 provides an example of stage forecasts available from NWS. We will attempt to incorporate the second of these projections to meet the need to forecast river stage.

We will explore incorporating ways in which the various projections may be used together and interpolated as needed, and how those may be integrated with the ICM tools. We propose to use site-specific internal rating curves based on historical flow-stage to infer flow based on stage.

[13] https://www.weather.gov/lmrfc/experimental_28day_mississippi_plot; Forecasts are made for 28 days but include weather projections for only 16 days.

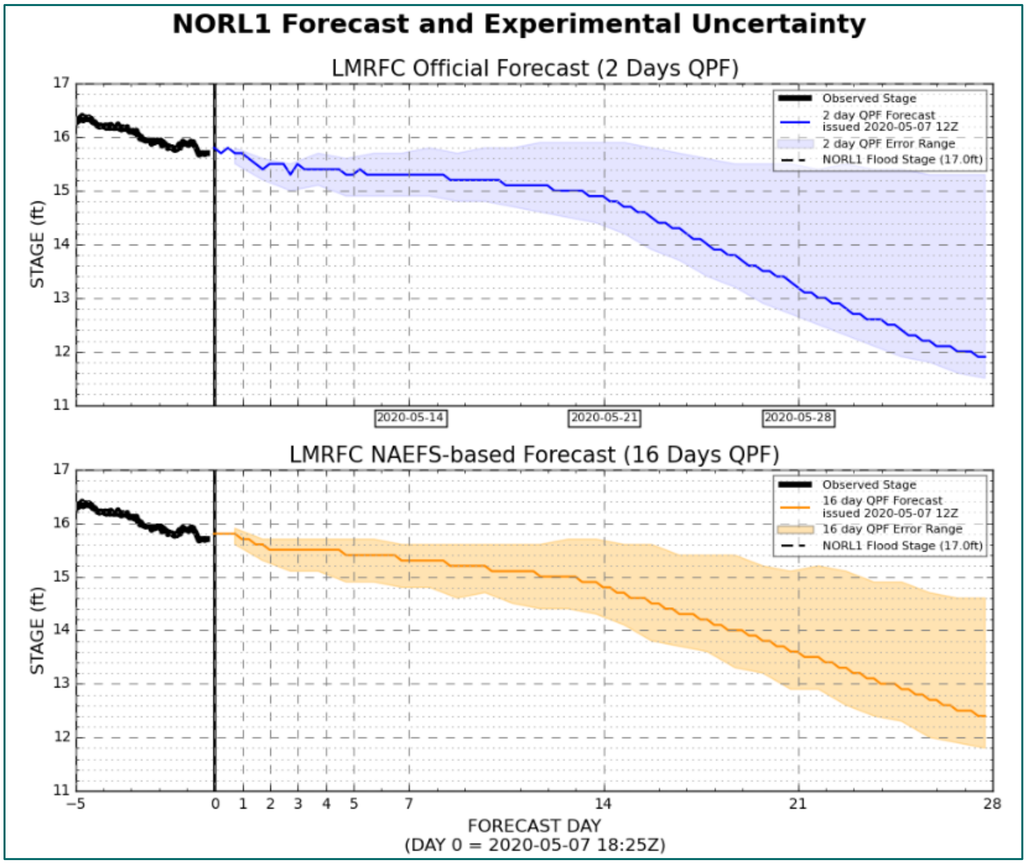

Figure 3.20: Example of NWS 2- and 16-day stage forecasts at New Orleans provided through the AHPS.

3.2.3 Salinity

Salinity measures the concentration of salt in the estuary and bays opening into the Gulf, and in tidally influenced river reaches. Depending on methodology, salinity may be expressed in units of parts per thousand (ppt), PSU, or as conductivity in units of micro-siemens per centimeter (mS/cm). Salinity is an attribute of the physical habitat known to affect the distribution and viability of a wide variety of plant and animal species and communities, including differential sensitivities at different life history stages.

The forecasting of salinity in either (or both) Pontchartrain and Barataria Basins will require linkage to hydrodynamic models that incorporate real-time gauge data. We propose using real-time internet services which allow queries of the USGS (and other) gauges, to provide current salinity at 15-minute resolution where possible, to enable the enhanced ICM to update its simulations based on near real-time data. Because of the spatial and temporal complexity of the River and Gulf hydrodynamics, we do not envision developing an internal quantitative model describing and projecting salinity. Instead, we propose incorporating the suite of ICM simulation tools for projection of spatially explicit salinity. It is not yet clear whether the simulations will require 2D or 3D detail.

3.2.4 Temperature

Temperature is an attribute of the physical habitat known to affect the distribution and viability of a wide variety of plant and animal species and communities. Sensitivity to temperature can also vary with the life history stage of particular species.

The forecasting of temperature in either (or both) Pontchartrain and Barataria Basins will require linkage to hydrodynamic models that incorporate real-time gauge data. As noted above, we propose to incorporate real-time internet services which allow queries of the USGS (and other) gauges, to provide current temperature at a 15-minute resolution. Because of the spatial and temporal complexity of the River and Gulf hydrodynamics, we do not envision developing an internal quantitative model describing and projecting water temperature. Instead we propose incorporating the suite of ICM simulation tools for projection spatially explicit temperature. It is not yet clear whether the simulations will require 2D or 3D detail.

3.2.5 Turbidity & Sediment

Turbidity is a measure of water clarity that can be related to concentration of suspended solids (silt and clay) in the river and estuarine waters. Turbidity is known to affect the distribution and viability of a wide variety of plant and animal species and communities, in addition to its role in the accretion of wetland. It is typically expressed in units of formazin nephelometric units (FNU). We expect that we will not be able to estimate the separate contribution of clay and silt to turbidity, and that we must find ways to develop (or discover) plausible relationships between turbidity and transport of coarser sediments, including bed load sediments. We anticipate the potential need to simulate the transport and fate of a range of sediment size classes (potentially calibrated with data from Acoustic Doppler Current Profilers), since these will probably differ in their contribution to Sediment Distribution [DP2].

The forecasting of turbidity and sediment transport in either (or both) Pontchartrain and Barataria Basins will require linkage to hydrodynamic models that incorporate real-time gauge data. We propose to incorporate real-time internet services which allow queries of the USGS (and other) gauges, to provide current turbidity at a 15-minute resolution. Because of the spatial and temporal complexity of the River and Gulf hydrodynamics, we do not envision developing an internal quantitative model describing and projecting sediment transport. Instead, we propose incorporating the suite of ICM simulation tools for projecting spatial transport, to the extent that this is possible. It is not yet clear whether the simulations will require 2D or 3D detail.

4 Recommended Next Steps

4.1 Major Development Steps

Developing and building cross-disciplinary tools of this kind are best conducted through an iterative process. As described in the sections that follow, there are 5 stages for delivering a fully operational SDOT.

4.1.1 Stage 1: Scoping & Conceptual Design

This step has been completed and is embodied in this document, although additional objectives and/or performance metrics may need to be added based on the needs of decision-makers.

4.1.2 Stage 2: Sub-Model Vetting & Fully Specifying Performance Measures

The next major step is to thoroughly vet the suggested physical modeling framework discussed in Section 3.2 that would serve as the core foundation for generating forecasts of physical variables needed by the performance measures described in Section 3.1. This would be combined with verifying the real-time gauging stations that would be used to report actual physical conditions. Further, substantial spatial gaps in areal coverage needed by PMs, whether model mesh or real gauging stations may require additional modeling and / or deployment of select additional stations.

Chosen physical models also have to be reviewed for performance optimizations and calibration stability to ensure that model run times are consistent with unattended deployment. Meaning, the models can be run in a cloud computing setting over the needed spatial horizon, resolution, and time-period over reasonable run times (preferably several minutes or at worst, no longer than a few hours). This also means the models are sufficiently robust and stable that expert modeling teams are not required to "*patch and baby sit*" the models. This requirement often leads to additional model configuration simplifications, development of new APIs, work arounds and / or optimization efforts.

During this step, the PMs should be carefully reviewed and identify gaps in specificity requirements are identified. PMs that cannot meet specificity requirements are typically dropped from scope / replaced. After this work is completed, there will be full confidence in the underlying physical models, real-time gauging stations, supplementary information sources and PMs that will be included in the prototype system. While unrelated to the technical integration matters, another key activity during Stage 2 is to clearly identify who the long-term system owner / host entity would be. Failure to clarify tool ownership and long-term maintenance responsibilities from the outset is one of the leading causes of failure in Decision Support Tool projects (Moran et al. 2020).

4.1.3 Stage 3: Final Feature Prioritization & Initial Proof-of-Concept Development

During Stage 3, work shifts from aligning physical models and specific PMs to elaborating upon the system design. This involves a deeper dive into user stories / scenarios (or use cases) and functional requirements that then allows user experience designers and developers to prioritize user interface design and functionality packages.

From here, a prototype system is built and trialed with a small group of system operators, ending with identifying deficiencies and needed refinements. **This represents a significant unit of work (1-2 years effort) that requires commensurate funding.**

4.1.4 Stage 4: Acceptance Testing, Refinement & Feature Enhancement

Once a functioning prototype system exists and deficiencies have been identified through user acceptance tests, the development team gets to work on bug fixes and refinements. Often, it is only after “seeing” the functional software system that users are truly able to articulate their needs completely.

The suggested refinements must again be prioritized, and additional software development cycles are completed iteratively alongside additional rounds of acceptance testing to bring the system to a completed state. This may take a couple of real-world operational cycles to complete.

Likewise, this represents another significant unit of work typically over 2-3 years (to allow for acceptance testing cycles) and requires commensurate funding.

Due to the anticipated trade-off challenges amongst performance measures, the SDOT could be designed to capitalize on the power of Turn-Taking Optimization (See Box 1) to track prior year results and use this prior year outcome information to inform weighting factors that could be applied to objectives in the current decision-year and relay occurrence of other trigger events to tool users. This has been shown to be a highly effective method for optimizing available operational flexibility (Alexander et al. 2018; Morton et al. 2019).

Because the MRD landscape demands consideration of a broad range of ecosystem and socio-economic benefits provided by the Mississippi River, it is also necessary and prudent to break down silos across the various models and indicators in support of more integrated multi-objective decision-making. This is precisely the aim of the TTO approach (Alexander et al. 2018) which permits exploration of many thousands of possible scenarios while transparently revealing trade-offs across the many values the MRD provides.

4.1.5 Stage 5: As-Built Documentation, Training, & Long-term Operational Deployment

Once the system functions are well specified and implemented, work shifts to memorializing the (significant) investment. This includes additional roll out presentations, providing as-built system documentation, training videos, and deploying the software to a long-term hosting environment with related system administration essentials described. These documentation and training products are needed to help overcome inevitable turnover in staff through time and accelerate learning of new operators to avoid "*re-discovering the wheel.*"

It is also typical at this stage to draft terms of reference or memorandum of understanding that secure needed long-term funding commitments for annual operating and (potentially) licensing costs of the software, including as-needed advanced technical support.

Minimum routine costs for decision support tools of this nature are typically $15,000-$20,000 annually in perpetuity (not including costs associated with specialized licenses for components of specialized models, maintaining real-time networks or functionality upgrades, technology modernization efforts, etc.). Therefore, given need to dedicate ongoing funds for hosting in perpetuity, the decision of who the system owner will be is of paramount importance and should be one of the critical components to clarify *early* in the development process (i.e., in Stage 2, as noted previously).

4.2 Opportunities for Collaboration & Synergy with Related Efforts

Beyond the above development steps, supporting progress towards the SDOT also represents an opportunity to catalyze further synthesis of existing knowledge, multi-disciplinary coordination, and clarity around critical knowledge gaps that can ultimately improve decision-making around diversions, as well as clarify research and monitoring needs along the Louisiana coast. To be successful, it will be important that the SDOT be aligned with related efforts to avoid duplication and take advantage of potential synergies so it has maximum relevance and utility. There are four broadly defined and related efforts that have potential linkages to this work and provide opportunities for collaboration going forward.

Planned Sediment Diversions

The Coastal Master Plan identifies sediment diversions as one type of project to help build land and restore the Louisiana coast (CPRA 2017). In particular, the Coastal Protection and Restoration Authority (CPRA) of Louisiana is proposing to construct, operate, and maintain the Mid-Barataria and Mid-Breton Sediment Diversions to convey sediment, freshwater, and nutrients from the Mississippi River into the MRD. The nature and magnitude of these projects require a review and approval following preparation of an environmental impact statement (EIS) as part of the National Environmental Policy Act (NEPA). These projects are at different stages in the NEPA review process (e.g., GEC Inc 2018).

Despite a substantial level of detailed modeling and analysis of these projects, some uncertainties remain as to how they can best be operated to maximize land building and restore MRD ecosystems (e.g., Peyronnin et al. 2016; 2017). This conceptual design lays out a framework for decision-making that could further leverage content from these regulatory processes and provide a way of improving effectiveness of decision-making if some uncertainties remain once these regulatory processes have concluded.

Existing Diversions and Spillways

In addition to the planned sediment diversions mentioned above, there are a series of legacy diversions and spillways that have been in operation for some time (e.g., Caernarvon and Davis Pond Diversions). These projects were constructed by the US Army Corps of Engineers and are operated by CPRA with the support of advisory committees and operational control plans that focus on influencing salinities to enhance the delta ecosystem in their respective influence areas.[14] Although they are sited to minimize sediment capture from the Mississippi River, their operations do result in sediment diversion, land building, and wetland creation (Lopez et al. 2014). Hence, operational decisions that relate to the discharge triggers, magnitude, timing, duration, and frequency of both freshwater and sediment diversions are indirectly coupled and have a shared influence on Mississippi River inflows, as well as the physical conditions and ecological responses of the delta.

These shared influences mean that meeting the objectives at one diversion has the potential to influence the ability of decision-makers to meet objectives at another diversion in a different location. In other words, balancing tradeoffs across multiple objectives at one sediment diversion will be further complicated by the need to balance tradeoffs across objectives across the entire social-ecological system represented by the lower Mississippi River and its delta. The SDOT provides an opportunity to establish a formalized accounting tool that can track progress towards meeting and balancing objectives across diversions at different locations and for different purposes across this entire area.

Model Development and Application

Substantial investments have been made to support development of quantitative and conceptual models that support planning, assessment, and related decision-making activities across the Louisiana Coast (Dragos and Wisneski 2010; Leadon and Byrd 2013). An extensive set of hydrodynamic and ecosystem models has been developed by a variety of organizations including federal agencies (e.g., USGS, USEPA, USACE, US Navy), state agencies (e.g., Louisiana Department of Environmental Quality, Louisiana Department of Natural Resources), and academia (e.g., Louisiana State University, University of Notre Dame, University of New Orleans, University of Louisiana at Lafayette, University of Texas, Texas A&M). The purposes, levels of sophistication, and applications of these models vary, but include efforts to support planning processes associated with the ongoing evolution and development of the Coastal Master Plan (CPRA 2017), NEPA processes (Deepwater Horizon Natural Resource Damage Assessment Trustees 2016), as well as efforts to support the analysis and engineering design

[14] Caernarvon and Davis Pond Diversions: http://coastal.la.gov/diversion-operations/

of specific restoration projects, including the diversions discussed above (GEC Inc., 2018). In general, these models have been useful for helping resolve the scientific and technical uncertainties associated with implementing adaptive management and Louisiana's coastal restoration program.

Existing modeling capabilities represent the current scope for integrating quantitative performance measures that reflect the management objectives of decision-makers into the SDOT. As reflected in Section 3.2, the intent with developing this tool would not be to duplicate any of these modeling efforts, but rather to leverage and link existing capabilities into a common and useful framework for decision-making. As such, this work provides a broad framework for clarifying potential modeling gaps and priorities for future model development that would best serve the real-time operational needs of diversions.

Adaptive Management and Monitoring

Given the inherent scientific uncertainties of coastal restoration across the Louisiana coast, adaptive management has been proposed as a cornerstone to the Coastal Master Plan (TWIG 2013; Hijuelos and Reed 2017). At a conceptual level, this approach involves programmatic and project level applications which involve iterative planning, monitoring, and assessment. To date, adaptive management has been practiced as an informal approach of accumulating wisdom and lessons learned amongst restoration practitioners. As such, there has been a recent recognition of the need to formalize and unify around a more common adaptive management process for coastal restoration as the governance of coastal restoration has increased in complexity (TWIG 2020; Carruthers et al. 2020).

Development of the SDOT provides an opportunity to operationalize the principles of adaptive management and pilot a rigorous template at a project or multi-project scale. In particular, the SDOT provides an opportunity for explicitly integrating forecasting models, management objectives, and management uncertainties alongside real-time monitoring and evaluation into an integrated framework for decision-making. It also provides an opportunity for strengthening the linkages between the shorter time scale of operational decisions with the longer time horizons of ecosystem response and long-term monitoring (Hijuelos and Hemmerling 2016; TWIG 2019). Such a framework would strengthen the ability of real-time operators to improve their decisions and ensure they are appropriately being adjusted within the broader and longer-term context of ecosystem responses.

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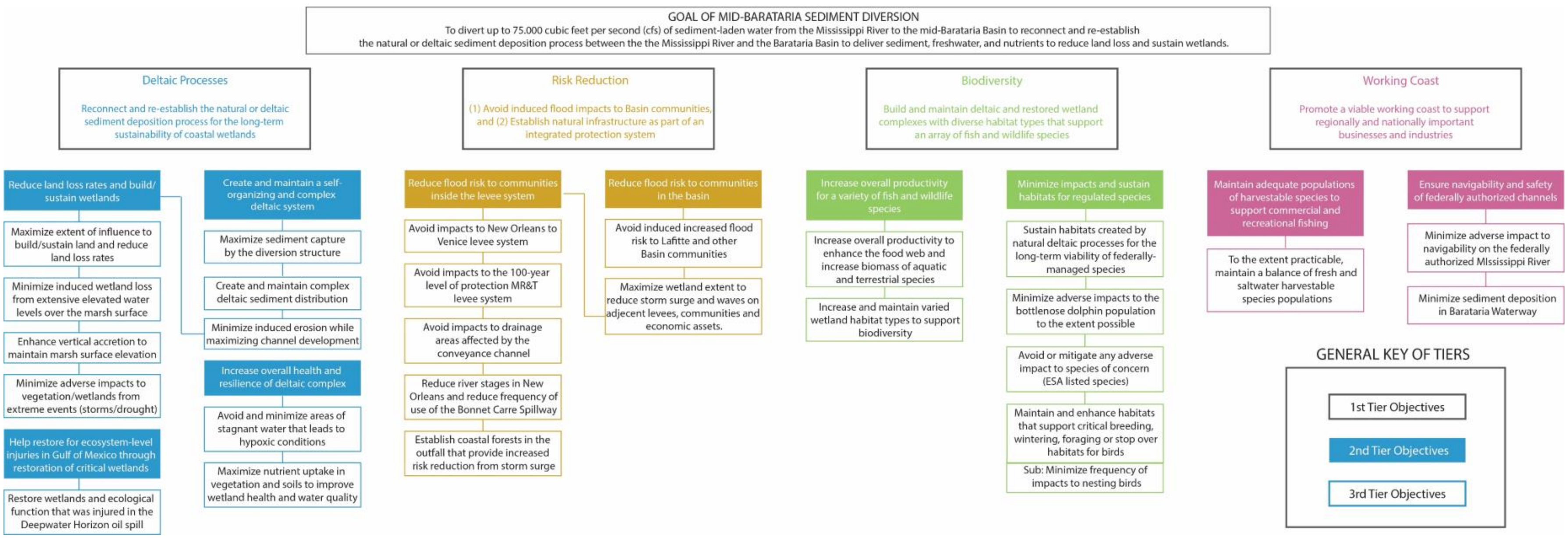
Appendix A: An objectives hierarchy for the Mid-Barataria Sediment Diversion



Appendix B: Importance and timeframe of potential management objectives for the Mid-Barataria Sediment Diversion

List of potential management objectives and their rated importance during three phases of operation of the Mid-Barataria Sediment Diversion (EW=Early Warning (0-3 years), NR=Near-Term (4-10 years), and LT=Long-Term (10+ years)). Objectives are sorted by earliest phase of relevance and highest rating of importance.

Objective	EW	NR	LT
Avoid induced increased flood risk to Lafitte and other Basin communities.	High	High	Medium
Avoid impacts to the New Orleans to Venice levee system.	High	Medium	Medium
Avoid impacts to the 100-year level of protection on the MR&T levee system.	High	Medium	Medium
Avoid impacts to drainage in areas affected by the conveyance channel.	High	Low	Low
Minimize induced wetland loss from extensive elevated water levels over the marsh surface.	High	High	
Minimize induced erosion while maximizing channel development.	High		
Minimize adverse impact to navigability on the federally authorized Mississippi River.	Medium	Low	Low
Minimize adverse impacts to bottlenose dolphin populations to the extent practicable and consistent with the purpose of the project.	Medium	Low	
Avoid or mitigate any adverse impacts to species of concern.	Medium	Low	
Avoid or minimize areas of stagnant water that could lead to hypoxic conditions.	Low	Low	Low
Create and maintain complex deltaic sediment distribution.		High	High
Maximize sediment capture by the diversion structure.		High	High
Enhance vertical accretion to maintain marsh surface elevation.		High	High
Maximize extent of influence to build/sustain land and reduce land loss rates.		High	High
Restore wetlands and ecological function that was injured in the Deepwater Horizon oil spill.		High	High

Objective	EW	NR	LT
Increase overall wetland health and resilience by inputs of freshwater, sediment and nutrients.		High	High
To the extent practicable, maintain a balance of fresh and saltwater harvestable species populations.		Medium	Medium
Maximize nutrient uptake in vegetation and soils to improve wetland health and water quality.		Medium	Medium
Minimize the frequency of impacts to nesting birds.		Low	
Minimize sediment deposition in the federally authorized Barataria Waterway.		Low	Low
Maximize wetland extent to reduce storm surge and waves on adjacent protection systems, communities and economic assets.			High
Minimize adverse impacts to vegetation/wetlands from extreme events, including storms and droughts.			Medium
Increase and maintain varied wetland habitats to support biodiversity.			Medium
Sustain habitats created by natural deltaic processes for the long-term viability of federally managed species.			Medium
Increase primary productivity to enhance the food web and increase biomass of aquatic and terrestrial species.			Medium
Maintain and enhance the habitats that support critical breeding, wintering, foraging and stop-over habitats for birds.			Low
Reduce river stages in New Orleans (and the frequency of use of the Bonnet Carré spillway to benefit Lake Pontchartrain).			Low
Provide conditions that support the establishment of coastal forests in the outfall area to increase protection from storm surge.			Low