

# LOWERMOST MISSISSIPPI RIVER MANAGEMENT PROGRAM

*Modeling of Alternative Management Strategies*

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## PREFACE

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This study was conducted by The Water Institute (the Institute) for the Coastal Protection and Restoration Authority of Louisiana (CPRA) as a part of the Lowermost Mississippi River Management Program (LMRMP). The report is a deliverable of the “Model Framework Adaptation and Implementation for Alternative Management Strategies” subtask, or Task Order 105. The study manager for CPRA is Jim Pahl, and the overall LMRMP project lead for the Institute is Mike Miner. Christopher Esposito led the subtask and the writing of the report for the Institute. This report describes the development and application of a 1-dimensional HEC-RAS numerical model-based decision analysis framework to evaluate management strategies for improving Lowermost Mississippi River management.





## EXECUTIVE SUMMARY

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The Mississippi River is the backbone of south Louisiana’s ecosystem, economy, and culture. It serves as an economical delivery mechanism by which sediment can reach areas that are critically in need of land building and is a key conduit for deep draft navigation to the largest port complex in the United States, serving more than 11,000 deep draft vessels and 450 million tons of cargo each year (Heath et al., 2018). But it also presents a potential flood risk to communities and infrastructure along its entire length and is occasionally vulnerable as a source of drinking water for the New Orleans Metropolitan Region and much of southeastern Louisiana. The Louisiana Coastal Protection and Restoration Authority (CPRA) has a mission to achieve comprehensive coastal protection and restoration for the state of Louisiana. In doing so, it must engage with the perspectives of a wide variety of stakeholders and decision makers with differing, and sometimes conflicting, interests regarding how the river should be managed and how risks inherent to life near the river should be mitigated. The goal of the Lowermost Mississippi River Management Program (LMRMP) is to evaluate approaches to water and sediment management that yield practical benefits across all interests.

This report describes implementation of the Lowermost Mississippi River Decision Analysis Framework (LMR-DAF) decision analysis and modeling framework for evaluating and adjusting river management strategies for ecosystem, navigation, and flood management in the Lowermost Mississippi River (LMR). The LMR-DAF was designed to analyze high-level management strategies that were defined through collaborative discussions with CPRA and stakeholders during earlier phases of LMRMP (Dalyander et al., 2022). The performance of each strategy was then modeled under a wide range of possible environmental forcings for the next 50 years to identify both vulnerabilities in the strategy and the tradeoffs that could be made to address those vulnerabilities. This report considers three potential strategies: a Business-as-Usual strategy that keeps decision making on the river similar to that of *Louisiana’s Master Plan for a Sustainable Coast* (CPRA, 2023); a set of Alternate Flow at Old River Control Structure strategies that consider alterations to the flow split between the Mississippi and Atchafalaya rivers; and a set of Alternate Navigation Channel Alignment strategies that consider changing the location at which ship traffic enters the Mississippi River Ship Channel.

The LMR-DAF builds on efforts during previous phases of LMRMP that engaged stakeholders and decision makers to identify potential river management strategies, specify desirable and undesirable outcomes, and itemize the environmental conditions to which each strategy should be subjected over the course of 50 years. The LMR-DAF consists of three components.

1. **HEC-RAS Model:** Hydraulic and sediment transport inputs for the decision analysis were produced with the U.S. Army Corp of Engineers’ (USACE) Hydrologic Engineering Center's River Analysis System (HEC-RAS). The HEC-RAS model used in this project, previously developed by Travis Dahl and others at the USACE Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory, was used because of its widespread application within USACE and to facilitate coordination with the Corps in their role as the primary decision-making authority on the river.



2. **Automation System:** The numerical model was implemented within an efficient automation system that was custom-designed for this project. The automation allowed for 7,290 individual realizations of the HEC-RAS model to be executed in a matter of days, and for selections from the very large output set to be processed and stored in fast data structures for use by the project team. Critically, this automation system can be adapted to other HEC-RAS models or other modeling platforms in future efforts.
  
3. **Decision Analysis:** The LMR-DAF then applies a systematic decision-analysis process to assess management strategies for vulnerability in the face of uncertain future environmental conditions, and then to identify the policy levers that decision makers have at their disposal to improve on the outcomes of those strategies. This process, based on the Robust Decision Making (RDM) methodology (Lempert et al., 2013), differs from traditional *a priori* decision support which evaluates a limited set of decision alternatives that are optimized for a specific projected future. Instead, RDM helps chart achievable paths through a wide range of plausible futures by querying a large set of numerical model output and assessing the performance.

These three components (Figure ES 1) provide the capability to efficiently explore a large parameter space of river management options under different future scenarios, identify vulnerabilities, and iteratively develop robust management strategies that perform well across a range of environmental conditions and a diverse set of program partners' priorities.

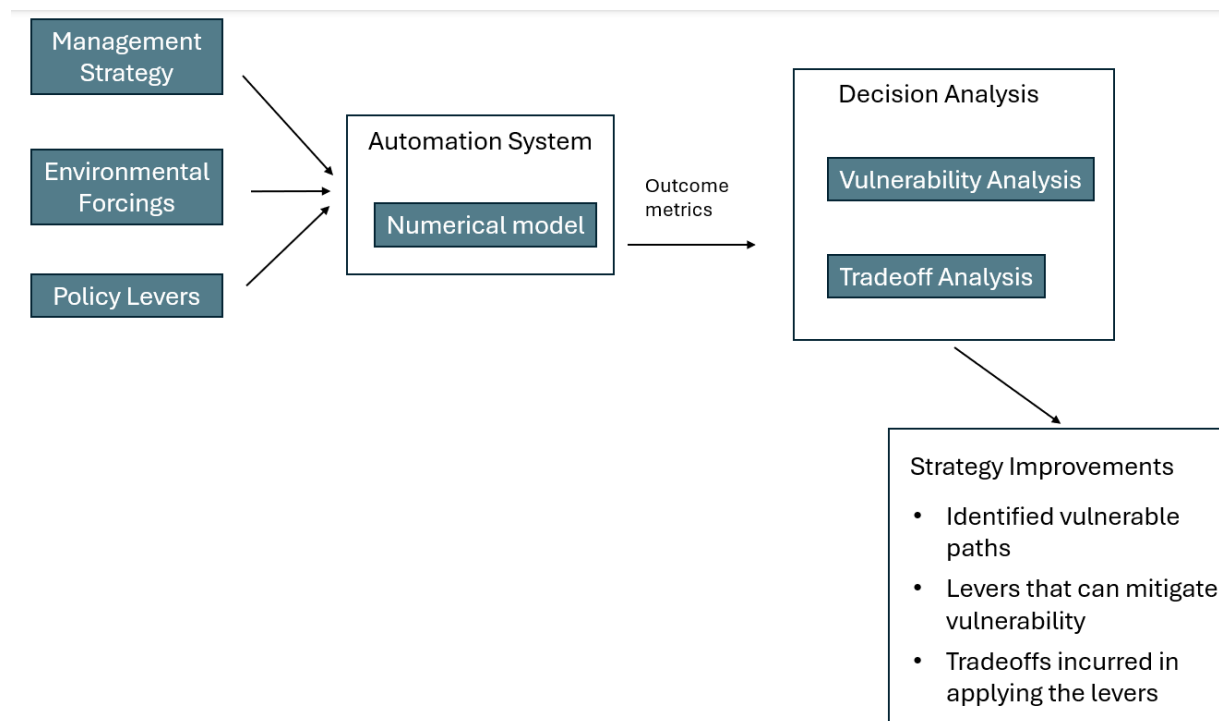


Figure ES 1. Components of the Lowermost Mississippi River Decision Analysis Framework (LMR-DAF)

This report describes the implementation of the LMR-DAF to test the performance of distinct river management strategies as they were represented by the underlying HEC-RAS model. This model was



used within the decision framework to provide the types of results that would be necessary to reach a real-world decision. Future use of the LMR-DAF could include subsequent analyses with other numerical models, or augmented versions of the current one, that have additional capabilities. Tackling real-world policy decisions with this tool will require broader stakeholder involvement and additional review of historical data and future predictions.



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## LIST OF ACRONYMS

Acronym	Term
BAU	Business-as-Usual
CART	Classification and regression tree
CMIP5	Coupled Model Intercomparison Project, Phase 5
CPRA	Coastal Protection and Restoration Authority
EMA	Exploratory Modeling and Analysis
ERDC	U.S. Army Engineer Research and Development Center
HEC-RAS	Hydrologic Engineering Center's River Analysis System
LMR	Lowermost Mississippi River
LMR-DAF	Lowermost Mississippi River Decision Analysis Framework
LMRMP	Lowermost Mississippi River Management Program
OMAR	Old River, Mississippi River, Atchafalaya River, and Red River
ORCS	Old River Control Structure
RCP	Representative Concentration Pathway
RDM	Robust Decision Making
RM	River Mile
SDM	Structured Decision Making
SLR	Sea level rise
SWP	Southwest Pass
USACE	U.S. Army Corps of Engineers
MVN	(USACE) New Orleans District
WRDA	Water Resources Development Act



# 1 INTRODUCTION

Decision-making authorities have traditionally managed the Mississippi River (the River) separately for the three objectives of navigation, flood protection, and ecosystem restoration, all of which are rooted in an attempt to manage water and sediment to meet decision-maker needs. The scope of the Lowermost Mississippi River Management Program (LMRMP) includes the identification of potential management strategies that could better balance the three objectives for the Lowermost Mississippi River (LMR) over timescales of 50 years.

The Water Institute (the Institute), through the previous LMRMP Task Order 69 funded by the Louisiana Coastal Protection and Restoration Authority (CPRA), has developed a unique decision analysis framework—the Lowermost Mississippi River Decision Analysis Framework (LMR-DAF)—to adjust and improve strategies so that they address all three objectives (Figure 1). CPRA had expressed the need for a flexible tool to produce organized and quantified model outputs that could be used while engaging with the wide variety of stakeholders on the LMR. These include federal agencies such as the U.S. Army Corps of Engineers (USACE), state agencies, and navigation interests. USACE is a key stakeholder and decision maker on the Mississippi River, and is responsible for maintaining navigation to serve approximately 11,000 deep draft vessel movements and 450 million tons of cargo each year (Heath et al., 2018). Based on available contract data from 1996 to 2019, USACE spends approximately \$100M annually on Mississippi River operational maintenance dredging within the USACE New Orleans’ District (MVN) boundaries, with nearly \$60M allocated to Southwest Pass (Miner et al., 2024).

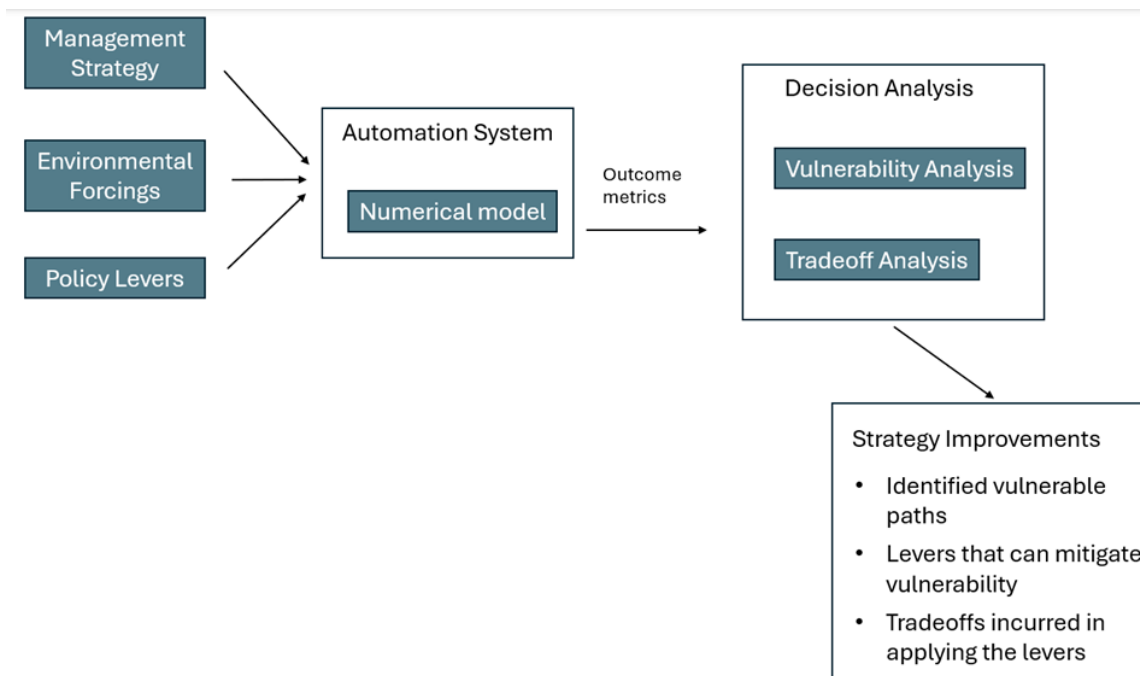


Figure 1. Components of the Lowermost Mississippi River Decision Analysis Framework (LMR-DAF)

Along with maintenance of the River for navigation purposes, USACE is also responsible for reducing flood risk along the River’s entire length, which has traditionally been managed with engineered earthen



levees and floodwalls, a series of spillways, and hardened channel bank and bed protection measures. Like CPRA, USACE has undertaken a series of studies to examine long-term decision making in the LMR (e.g., Lewis et al., 2022; Little et al., 2014). A key aim in this project was to facilitate productive interactions between CPRA and USACE during the ongoing Lower Mississippi River Comprehensive Management Study (hereafter the “Comprehensive Study”).

In response to the Water Resources Development Acts (WRDAs) of 2020 and 2022, USACE initiated the Comprehensive Study to be implemented by the Mississippi Valley Division and with MVN leading the analysis. The USACE Comprehensive Study covers the Mississippi River from Cape Girardeau, Missouri, to the Gulf of America and considers “a broad range of reasonable alternatives across the Lower Mississippi River Basin to comprehensively manage the basin and improve the maximum effective river resource use and control for the priority mission areas of hurricane and storm damage reduction, flood risk management, navigation, and ecosystem and environmental restoration.” (Pinkham, 2021) Through the USACE Comprehensive Study, USACE is required by WRDA to consider projects that are included in *Louisiana’s Comprehensive Master Plan for a Sustainable Coast* (CPRA, 2023) and to consider the use of natural and nature-based features as well as measures to improve the efficiency of operational and maintenance dredging.

CPRA intends for the outcomes of LMRMP investigations, including the work documented in this report, to inform the USACE Comprehensive Study and to facilitate future interagency collaborative efforts at river management.

## **1.1 THE LOWER MISSISSIPPI RIVER DECISION ANALYSIS FRAMEWORK (LMR-DAF)**

The LMR-DAF design starts with a defined high-level management strategy that has been identified through collaborative discussions with CPRA and stakeholders (Dalyander et al., 2022). The performance of the strategy is then modeled under a wide range of possible environmental forcings over multi-decadal timescales and with a variety of specific implementations (policy levers). The model outputs were then distilled into standardized outcome metrics, which are used as inputs for a decision analysis process that identifies vulnerabilities in each strategy, and identifies tradeoffs that would be incurred while addressing the vulnerabilities. The core of this effort is a systematic decision analysis process that produces robust decisions in conditions where deep uncertainty exists about the input conditions and the system’s response to them.

This process is based on Robust Decision Making (RDM; Lempert et al., 2006) and differs from traditional *a priori* decision support, which evaluates a limited set of decision alternatives optimized for a specific projected future—an approach that often proves to be inadequate when faced with deeply uncertain future conditions (e.g., Herman et al., 2015).

Instead, RDM offers decision support by querying a large set of numerical model outputs and empirical data. In running models numerous times to identify vulnerabilities, RDM can enhance the value of decision makers’ models and use them to identify plans that are robust over many combinations of assumptions (Lempert et al., 2013). This helps assess the performance of each strategy and allows the user to chart achievable paths through a wide range of plausible futures.



This report describes the implementation of the LMR-DAF to test the performance of distinct river management strategies projected by the underlying USACE Hydrologic Engineering Center's River Analysis System (HEC-RAS) model. As a step toward further analysis and conversation, this model was used within the decision framework to provide the types of results that would be necessary to reach a real-world decision. Subsequent analyses should be performed using other numerical models, or augmented versions of the current one, that have additional capabilities.

The LMR-DAF as implemented in this report depends on hydraulic and sediment transport inputs produced with HEC-RAS. The HEC-RAS model used here was previously developed by the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (Dahl et al., 2018) and was modified by the developer for this project. This model was chosen because the Comprehensive Study team also planned to use a version of it. Its use in this study lays the groundwork for further coordination with USACE in its role as the primary decision-making authority on the River.

This report describes the river management strategies that were investigated as well as the environmental forcings that each strategy was subjected to (Chapter 2), the decision analysis tools that were used to organize and make comparisons within this large body of output (Chapter 3), the environmental model that was used to execute each strategy (Chapter 4), and the results of two independent decision analyses that were performed (Chapter 5). The decision analyses include a vulnerability analysis to explore the combination of environmental futures and policy choices under which each management is vulnerable, and a tradeoff analysis that allows users to identify policy choices that prioritize one outcome over another.

Earlier phases of the LMRMP centered on the requirements for the numerical model and producing the tools, knowledge base, and conceptual framework to facilitate an in-depth assessment of the relevant river management outcomes. This included working with CPRA and stakeholders to determine the operational management practices in the River (Esposito et al., 2021, 2022; Miner et al., 2024) and the range of possible environmental conditions that would be faced by future decision makers (LaHatte et al., 2023). A set of strategies for managing water and sediment in the LMR was initially described by Dalyander et al. (2022a, 2022b) based on the input of an extensive and structured stakeholder outreach effort. From the same stakeholder consultations, a set of outcome metrics of interest was identified and then refined based on the availability of data for calculation and the relevance to the management strategies under consideration. The strategies, metrics, and environmental scenarios have been iteratively refined and are discussed in Chapter 2.





## 2 MANAGEMENT STRATEGIES AND ENVIRONMENTAL SCENARIOS

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Three high level strategies were tested for this report. Two of the strategies contain variants which in practice were investigated as independent strategies in their own right. Each management strategy that was investigated was initially developed in consultation with the Louisiana Coastal Protection and Restoration Authority (CPRA; Dalyander et al., 2022). The three strategies that were investigated are Business-as-Usual (BAU; Section 2.1.1), Alternative Navigation Channel Alignment (Section 2.1.2), and Adjusted Flow Ratio at Old River Control Structure (Section 2.1.3).

Each strategy was executed with a range of boundary conditions that represent environmental forcings that are outside of management control (Sections 2.2.1), and policy levers that managers can apply to improve outcomes (Section 2.2.2). The environmental forcings that are included in this report are variations in the rate of sea level rise, and in the input of sediment and water to the lower river from upstream. The policy levers that are applied in this report all represent changes to the discharge that is allowed through a set of 16 outlets in the lower river through which water and sediment exit the main channel through crevasses, diversions, and overbank flows. A single run within any strategy requires the selection of two environmental forcings and five policy levers, all possible combinations of which are shown in Table 1. For every strategy, there are 1,458 combinations of strategy and environmental forcing. In total, 7,290 runs were completed to represent the three strategies and two strategy variants analyzed in this report. Output from each run was used to compute outcome metrics that represent the performance for the three interests of ecosystem, navigation, and flood risk (Chapter 3). These metrics are then used as inputs for the two decision analyses (Chapter 5).

The modeled domain for this study is the Lowermost Mississippi River (LMR) from Tarbert Landing to its receiving basins (Figure 2). A full description of the HEC-RAS model is given by Dahl et al. (2018) and updated in Section 4.1 of this report. The upstream boundary is applied as a sediment and water input condition at Tarbert Landing, and the primary downstream boundary is a water level condition imposed at the end of Southwest Pass or an alternative navigation channel (see Section 2.1.2). Additional boundaries are imposed along the channel as lateral flow structures to represent outlets (i.e., distributary channels).



Table 1. A single run within any strategy requires the selection of two environmental forcings (dark blue columns), and five policy levers (light blue columns). Sea Level Rise is presented as the total amount of rise experienced over the 50-year model period. Each row contains the options for the forcing or policy lever indicated in the column header. Each strategy was implemented for every possible combination of policy lever and environmental forcing, for a total of  $2 \times 3^5 = 1,458$  possibilities per each of five strategies (7,290 runs total). Full descriptions of the environmental forcings and policy levers can be found in Sections 2.2.1 and 2.2.2, respectively.

Sea Level Rise over 50 years (feet)	Inlet hydrograph percentile (all years)	Discharge through Diversions	Discharge through Unmanaged Outlets	Discharge through Lower Outlets	Discharge through Bonne Carré	Discharge through Neptune
1.6	90 <sup>th</sup> (Wet)	High	High	High	High	High
2.5	50 <sup>th</sup> (Medium)	Medium	Medium	Medium	Medium	Medium
	10 <sup>th</sup> (Dry)	Low	Low	Low	Low	Low

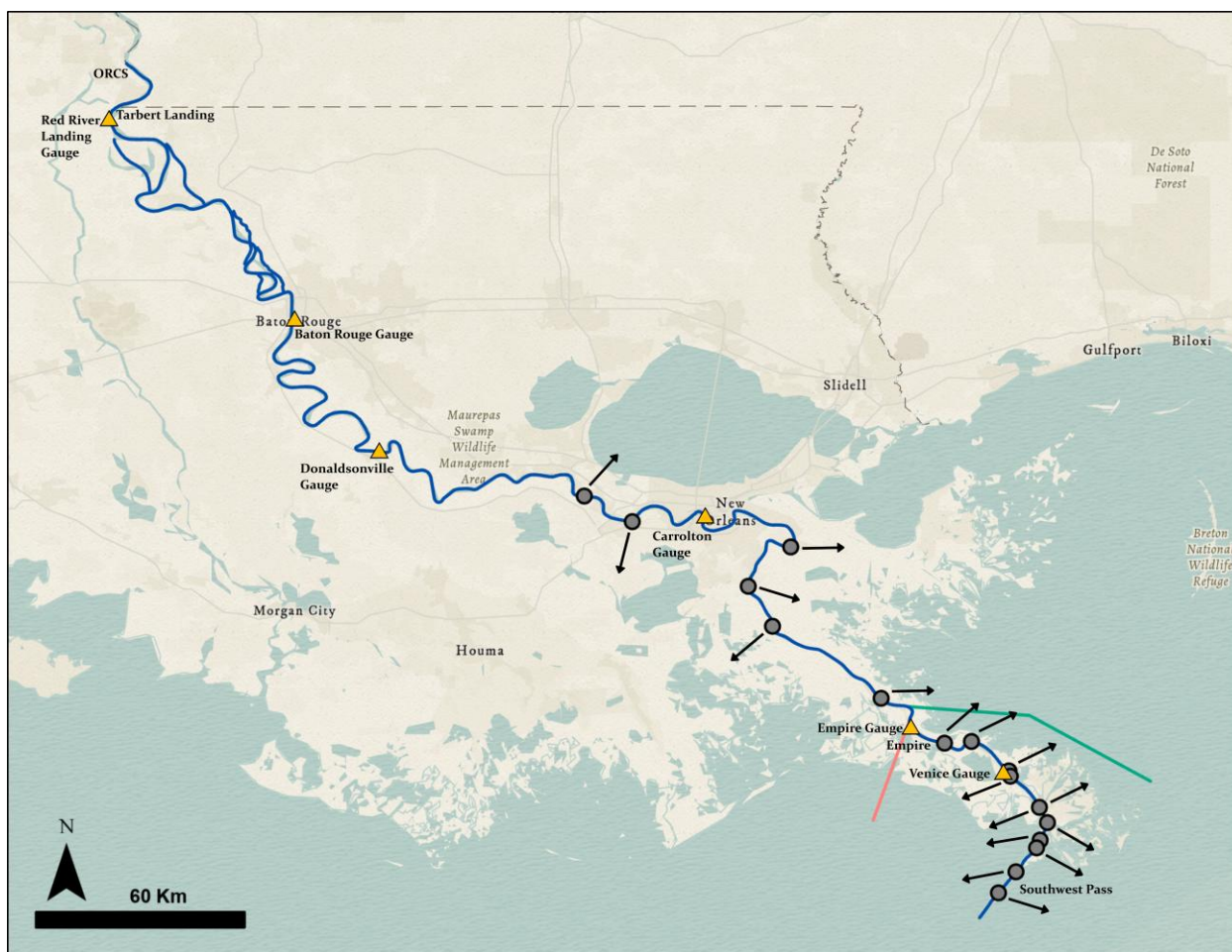


Figure 2. The HEC-RAS model domain runs from Tarbert Landing to the loss of flow confinement at the end of Southwest Pass. The channel path used for the BAU strategy is shown in blue, and the Turn Right and Turn Left paths are shown in orange and green, respectively. All outlets that were included in the study are indicated by a gray dot and an arrow showing their flow direction. Additional information about the outlets and their implementation can be found in Section 2.2.2 and Table 1. Gauges used in this report are indicated by yellow triangles.



## 2.1 STRATEGIES CONSIDERED

### 2.1.1 Business-as-Usual

The BAU strategy modeled a continuation of existing river management practices and navigation channel alignment. Outlets that are included in the Future Without Action scenario of the 2023 Coastal Master Plan (CPRA, 2023) were operated under assumptions consistent with the modeling approach used to inform the Coastal Master Plan. This includes sediment and water diversions, the Bonnet Carré Spillway, and other controlled features. Rating curves for all outlets included in the model operation are shown in Appendix C.

### 2.1.2 Alternative Navigation Channel Alignment (Turn Right, Turn Left)

This strategy establishes a different course for the deep draft navigation channel of the southernmost reach of the Mississippi River starting at Empire. Two variants of this strategy were modeled wherein the deep draft navigation channel exits to the West (“Turn Right”) or to the East (“Turn Left”) of the current main channel. Adjustments to the HEC-RAS model that were made to accommodate these two variants are described in Section 4.1.

### 2.1.3 Adjusted Flow Ratio at Old River Control Structure (Flatpeaks, Lowpeaks)

In the Adjusted Flow Ratio at Old River Control Structure (ORCS) strategy, the input hydrograph was altered so that the upstream boundary condition yields flows in the main stem that are consistent with flow ratios tested in USACE’s 2022 Old River, Mississippi River, Atchafalaya River, and Red River (OMAR) Study (see Table 4, Scenario 4 in Lewis et al., 2022). The two variants of this strategy included in this analysis are described below. Flow variants proposed in the OMAR Study that increased flows in the main stem of the Mississippi River were not able to be implemented for this study due to instabilities in the HEC-RAS model in the channel bed morphology at high flows (Travis Dahl, pers. comm.). These instabilities can be corrected for future efforts, but doing so was outside of the current project’s scope. The two variants that were modeled are described in brief below, and formal mathematical definitions for the input condition applied for each variant are given in Appendix A.

- **Lowpeaks:** During high flow, 60% of the flow was routed to the Mississippi River and 40% to the Atchafalaya. During low flow, 70% of the flow was routed to the Mississippi River and 30% to the Atchafalaya (the current Congressional authorization). Following the definition used in the OMAR Study (Lewis et al., 2022), the transition from low flow to high flow occurs when the discharge at Tarbert Landing exceeds 1 million cubic feet per second (Mcf/s).
- **Flatpeaks:** The hydrograph is kept as defined in BAU except a maximum discharge of 1.25 Mcfs is imposed. Above the maximum discharge, excess into the Atchafalaya River causing the flow ratio to be variable.

## 2.2 DEFINING RUNS WITHIN A STRATEGY

Each run is executed as a continuous 5-year HEC-RAS simulation with 1-D channel hydraulics and riverbed morphology active. The upstream and downstream boundary conditions were constructed so that the model experiences 50 years of change in environmental forcings. The choice to run 5-year simulations that experience 50 years of change was made to minimize computational time. The choice means that



modeled quantities are comparable between model runs, and they do represent relative variation resulting from differences in climate forcings, but they do not represent realistically- benchmarked projections for the next 50 years.

## 2.2.1 Environmental Forcings

The upstream boundary was forced by daily hydrographs that were produced by applying climate model precipitation predictions to a flow routing and land infiltration model throughout the LMR's entire drainage basin. LaHatte et al. (2023) produced flow duration curves and associated hydrographs for Tarbert Landing based on two climate scenarios. A dry/average/wet flow duration curve target was generated for each decade and climate scenario based on the 10<sup>th</sup>, 50<sup>th</sup>, and 90<sup>th</sup> percentiles of the corresponding hydrographs, and the representative hydrograph for that decade and condition was selected as the one with a flow duration curve that best-matched that target (Appendix B). The upstream boundary for any run is a series of five dry/moderate/wet hydrographs that were stitched together and smoothed over a +/- 2-week interval at the transitions between years (Figure 3). The boundary condition used in the BAU runs is shown in Figure 3, and additional details on seasonal corrections that were applied during the hydrograph selection process are described in Appendix B.

Eustatic sea-level rise (SLR) is accelerated so that each “effective year” experiences the range of sea-levels that would be present in the corresponding decade. During a simulation, increases in sea-level are cast as a linear function of time where 50 years of expected rise is accomplished by the end of a 5-year simulation (Figure 4). Spatially-variable subsidence is included in the HEC-RAS model (Dahl et al., 2018), though at an un-accelerated rate. The linear sea level curve was used to improve run times to accommodate the compressed project schedule, and to minimize the possibility of instabilities later in the model run which might have arisen later in the simulation from an accelerating SLR rate.

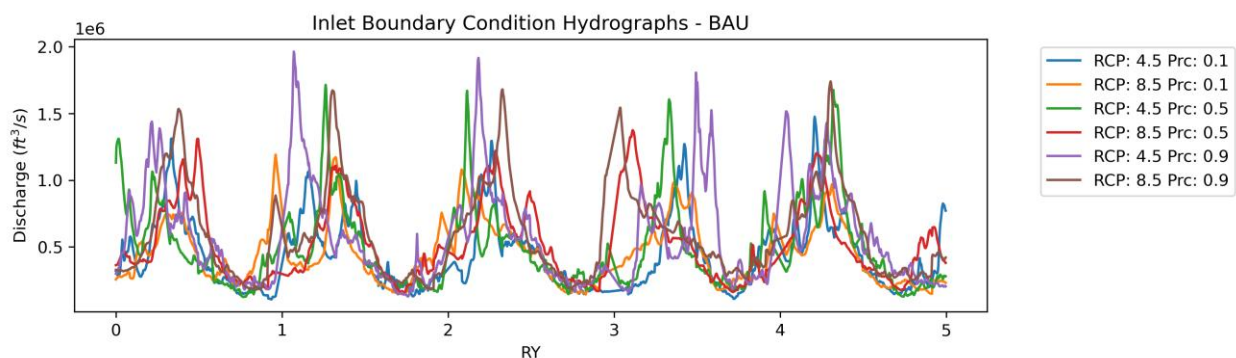


Figure 3. Example of concatenated representative hydrographs for the BAU scenario. Each line represents a combined of selection of a hydrograph percentile (Dry: 0.1, Moderate: 0.5, Wet: 0.9) and a climate representative concentration pathway (RCP 4.5, RCP 8.5).

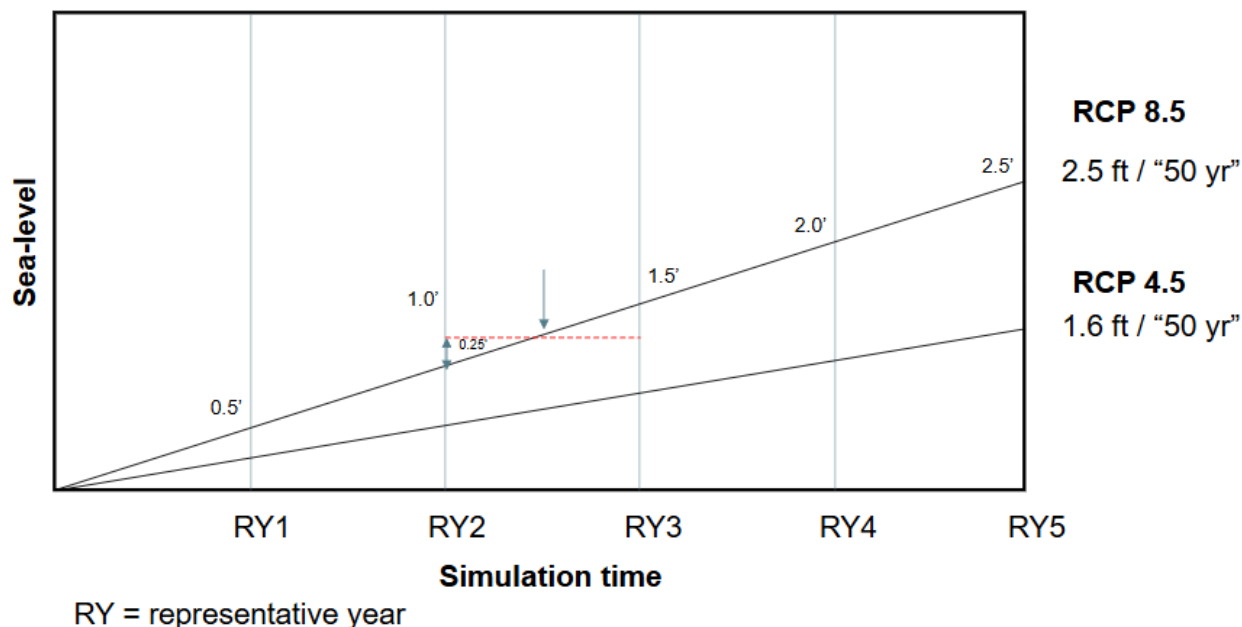


Figure 4. Sea level is imposed at the downstream boundary. The full rise that is expected over 50 years in each climate scenario is imposed linearly throughout the 5 years of simulation in the numerical model. The red dashed line and blue arrow indicate the average sea level during one representative year.

### 2.2.2 Policy Levers

Policy levers are model parameters considered to be under the control of decision makers. The distinction between policy levers and environmental uncertainties does not affect the implementation of the HEC-RAS model, but it is important to the analysis and interpretation of results in the decision analysis section.

The primary policy lever that is applied in all strategies is the control of 16 outlets for flow that leaves the main channel of the river beginning at the Bonnet Carré Spillway (River Mile 127). In all cases, the flow of water through each outlet is modeled according to a rating curve between Mississippi River discharge and outlet discharge (Q-Q), where discharge through the outlet ( $Q_{out}$ ) is a function of the local discharge in the river ( $Q_{riv}$ ) (Appendix C).

Each outlet is assigned both a *Type* and a *Management Group* (Table 2). The Type defines the style of rating curve used to relate  $Q_{out}$  to  $Q_{riv}$  and the treatment of uncertainty. The three types of outlets are described in Section 2.2.2.1 below. The Management Group defines how the outlets were applied as a policy lever. Rather than investigate each individual outlet as its own policy lever in order to constrain the total number of necessary model simulations for this project, the outlets were placed into five groups that are likely to be treated similarly by decision makers. These distinctions would be straightforward to change in future implementations. The Management Groups applied here (Figure 5) are:

- **Bonnet Carré Spillway**, which is operated with a control structure and a set management plan that is independent of the Diversions group.
- **Diversions**: Constructed or planned diversions that are operated with control structures, with the exception of the Bonnet Carré Spillway.



- **Unmanaged:** Outlets that are above Head of Passes and do not have a set flow target in any management plan. These outlets are not currently subject to significant management of their flow but are considered to be adjustable policy levers due to the potential for systematic crevasse management activities implemented by the U.S. Army Corps of Engineers (USACE) in the future. Outlets above Head of Passes are listed in Table 2 as “Unmanaged, Upper”, and those below Head of Passes are listed as “Unmanaged, Lower.”
- **Neptune Pass,** which is singled out as CPRA and the project team expect it to receive special treatment in the future.

Table 2. Outlets that are implemented in the numerical model. Outlet Type indicates the type of rating curve relationship that is imposed (Section 2.2.2.1), Management Group indicates the outlet’s grouping as it is imposed as a policy lever (See Table 1). River Mile above Head of Passes and Receiving Basin indicate the position of the outlet along the river, and the basin into which it discharges, respectively.

Outlet Name	Outlet Type	Management Group	River Mile above HOP	Receiving Basin
Bonnet Carré Spillway	2	Bonnet Carré	128	Pontchartrain
Davis Pond Diversion	2	Diversions	118	Barataria
Caernarvon Diversion	2	Diversions	81	Breton
Mid-Breton Diversion	2	Diversions	69	Breton
Mid-Barataria Diversion	2	Diversions	61	Barataria
Bohemia Spillway	2	Unmanaged, Upper	varies	Breton
Neptune Pass	3	Neptune Pass	24	Breton
Fort St. Philip Crevasse	2	Unmanaged, Upper	19.5	Breton
Baptiste Collette	1	Unmanaged, Upper	11.5	Breton
Grand Pass	1	Unmanaged, Upper	10.5	Barataria
West Bay Sediment Diversion	1	Unmanaged, Upper	4.7	Barataria
Cubits Gap	1	Unmanaged, Upper	3	Breton
South Pass and Pass a Loutre (combined)	1	Unmanaged, Upper	0	Lower
Southwest Pass Crevasse at Mile 3.0	2	Unmanaged, Lower	-3	Lower
Joseph Bayou	2	Unmanaged, Lower	-5	Lower
Outlet W-2	2	Unmanaged, Lower	-9	Lower
Burrwood Bayou	2	Unmanaged, Lower	-14	Lower

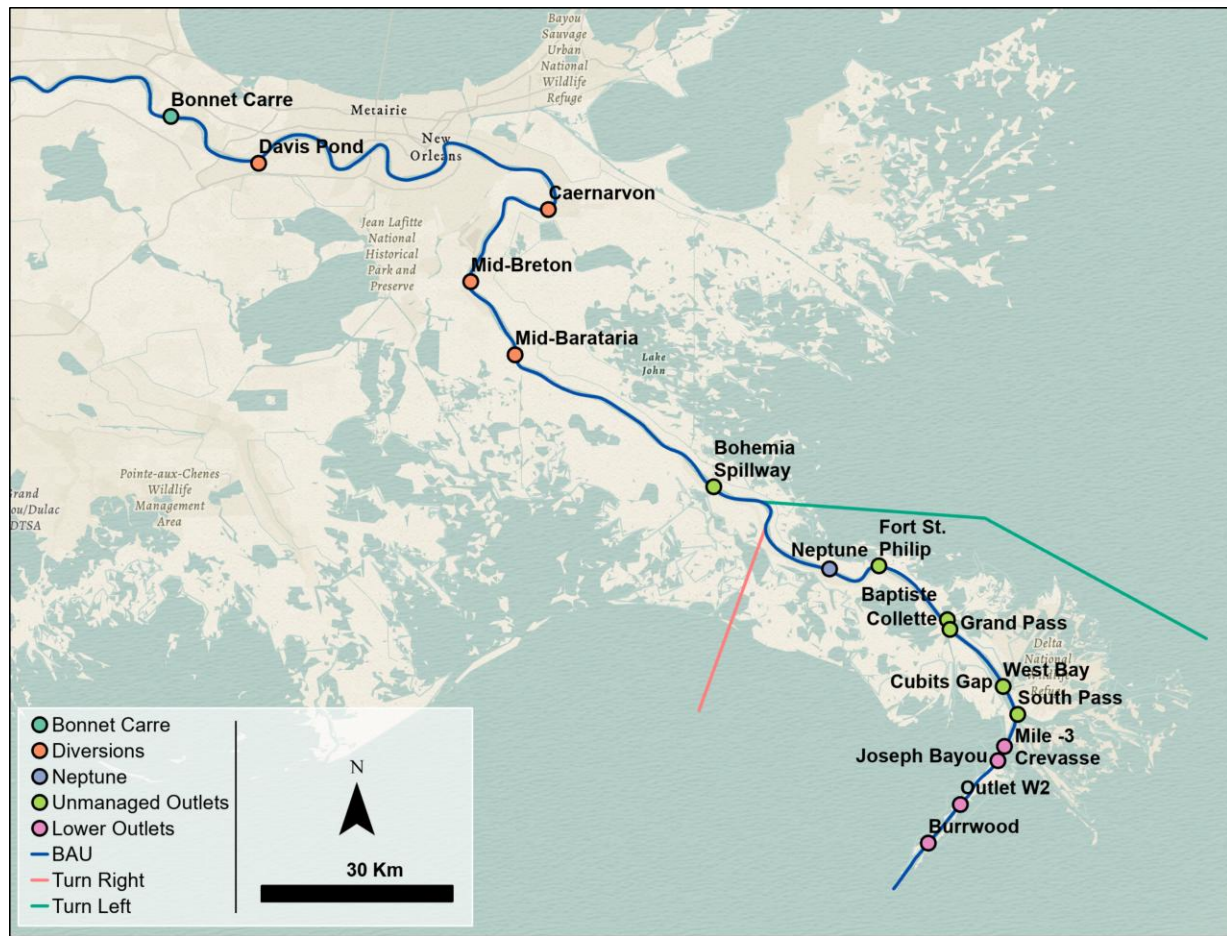


Figure 5. Outlets delineated by management group.

### 2.2.2.1 Outlet Types

Type 1 outlets are expected to remain stable throughout the entire study period. These outlets are free flowing and are not managed with a control structure. The rating curve for Type 1 outlets is imposed as a linear fit to the available data (see Figure 6). To account for the uncertainty in the rating curves, runs were implemented that varied the slope of the fit by +/- 10%.

Type 2 outlets are those with a tunable control structure and a well-defined management plan that is achieved in the real world through active management of the control structure. The Mid-Barataria Sediment Diversion is an example of this outlet type. Because these diversions are assumed to be under management control, their rating curves were set from planning documents (Esposito et al., 2017; Messina et al., 2019, 2021).

Type 3 outlets are free flowing outlets where major changes to the rating curve relationship are possible during the study period due either to geomorphic changes to the outlet itself or through major management activities. These outlets are subject to uncertainty in the same way that any other free flowing outlet is, but they are also subject to potentially large additional uncertainties.

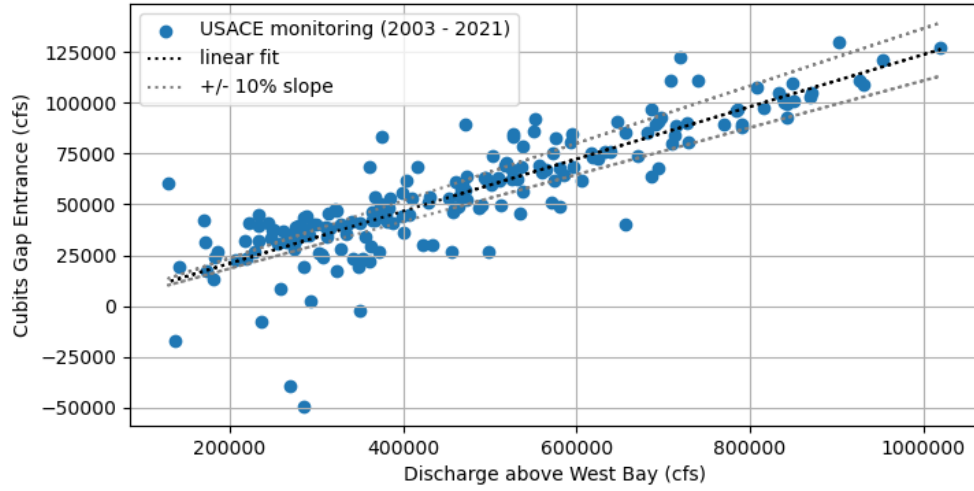


Figure 6. Cubit's Gap is an example of Outlet Type 1.



### 3 DECISION ANALYSIS

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The decision analysis process employed in the Lowermost Mississippi River-Decision Analysis Framework (LMR-DAF) is based on Robust Decision Making (RDM; Lempert et al., 2006), which is “a set of concepts, processes, and enabling tools that use computation, not to make better predictions, but to yield better decisions under conditions of deep uncertainty” (Marchau et al., 2019). Deep uncertainty happens “where the system model and the input parameters to the system model are not known or widely agreed on by the stakeholders to the decision” (Lempert, 2002). RDM “stress tests strategies over myriad plausible paths into the future and then to identify policy-relevant scenarios and robust adaptive strategies” (Marchau et al., 2019).

In traditional modeling approaches, model output is used to define the range of uncertainties in parameters that decision makers must react to. The decision makers then select a strategy based on the modeled distribution of uncertainty and their risk tolerance. In situations where there is deep uncertainty in the environmental system or in the predictive model or where there is no widely agreed-upon distribution for the uncertain parameters, the traditional approach may not be appropriate because it can lead to an unmanageably large set of decisions to make. When such deeply-uncertain conditions are present, RDM is used to improve on proposed strategies to identify those that are more robust to uncertainties in advancing desired outcomes. Through RDM, the strategies are iteratively examined for vulnerabilities (vulnerabilities are described in Section 5.1) and examined to determine what tradeoffs must be made in metrics of interest addressing any specific vulnerability. Vulnerability in this process is defined as the condition where outcome metrics fall above or below thresholds unacceptable to the decision makers or stakeholders.

In the Lowermost Mississippi River Management Program (LMRMP) decision analyses, model inputs are separated into two distinct categories: 1) uncertainties that are typically viewed as unknown and uncontrolled (e.g., what will the river hydrograph be in a given year?) and 2) policy levers that are viewed as under the control of a decision maker (e.g., when should diversions or floodways be opened?). Each strategy is simulated under all combinations of environmental forcings and policy levers identified in Table 1. Standardized metrics, described below, are then calculated from each run in the output dataset and aggregated to be used as the basis for vulnerability and tradeoff analyses. Each metric calculation is based on specified thresholds that describe system behavior (e.g., flood stage). Each metric description includes the specific thresholds used in this study, but threshold values are configurable inputs for each strategy.

Each simulation consists of a unique combination of environmental forcings and policy levers that were converted into appropriate inputs for the environmental model to conduct simulations. The environmental model then provides results for post-processing, where outcome metrics are calculated. Results were then aggregated across realizations for each scenario and analyzed using RDM to identify the future scenarios under which the strategy exceeds a benchmark reporting metric (and thus is deemed “vulnerable”), and the policy levers available to mitigate vulnerable outcomes. Used together, vulnerability and tradeoff analyses support identification of strategies that both maximize desired outcomes and are robust to uncertainties.



### 3.1.1 Ecosystem Metrics

Each outlet empties water and sediment into a defined basin or region (Figure 7). For each basin, two ecosystem metrics were applied. These metrics were defined during engagement efforts with CPRA and partners during Task Order 69 (Dalyander et al., 2022). First, river water entering the basin is summed over a monthly window (estimated from an instantaneous rate). If this ecosystem metric is less than that basin's threshold value, the month is listed as vulnerable. Next, the motion of water through each outlet conveys a sediment load to a basin. For each basin, the second ecosystem metric is computed as the monthly-summed mass of sediment entering the basin (in tons). If the monthly sum of sediment delivered to a basin is less than a threshold value (see Section 5.1), then the run is vulnerable.

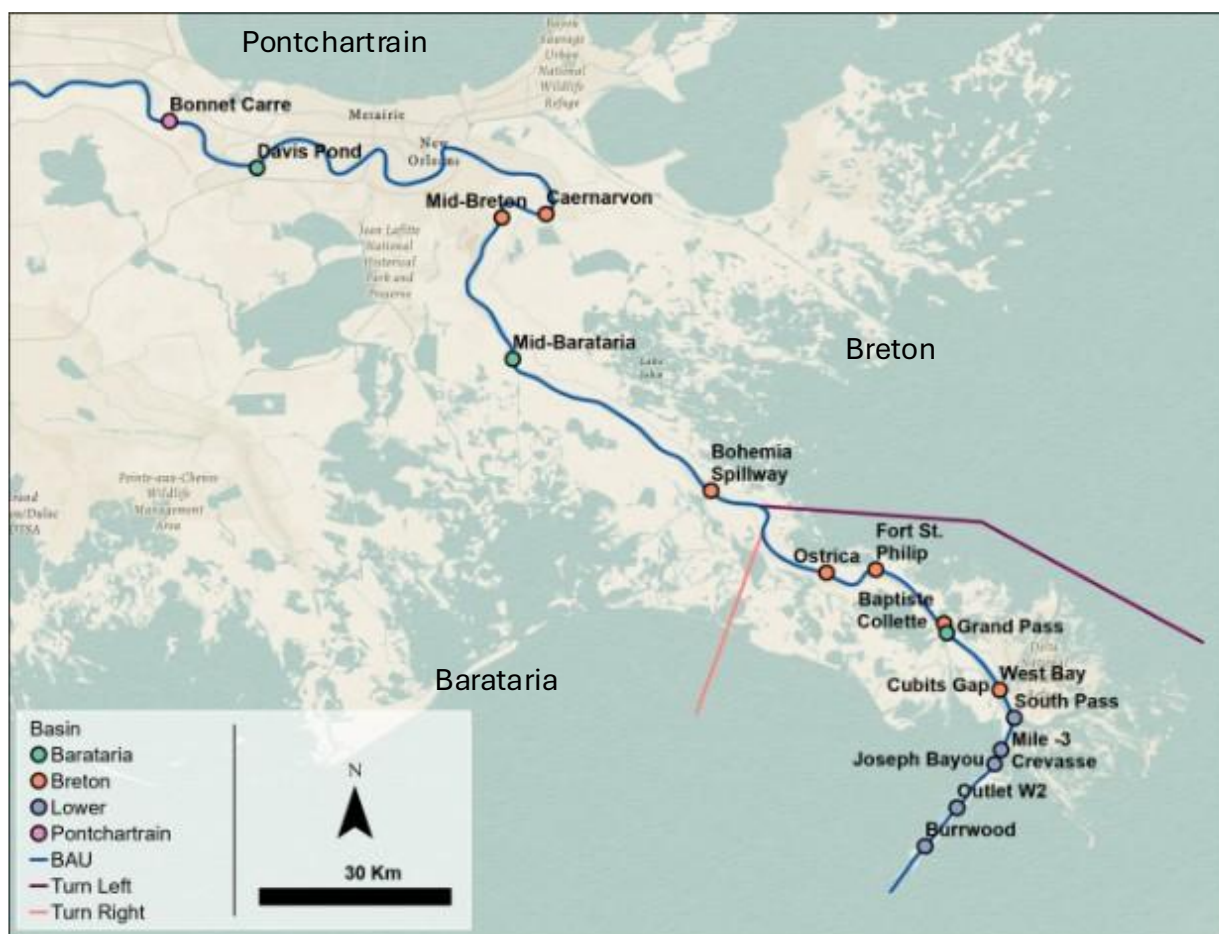


Figure 7. Outlets colored by receiving basin. The Barataria, Breton, and Pontchartrain basins are labeled. All discharges below Head of Passes are considered to discharge into the “Lower” basin.

### 3.1.2 Navigation Metrics

Metrics that impact navigation were computed along the mainstem of the simulated Mississippi River. These metrics are broadly categorized as (1) flow depth, (2) projected necessary dredging volume, and (3) hydrograph metrics.

1. Projected flow depth was computed across all the cross sections in defined reaches of the River. Each month, the minimum water column depth above the bed for each cross section in the



aggregate is computed, and if the result is less than a depth threshold of 50 ft. (per USACE channel depth requirement) then the month is marked as vulnerable. An entire run is marked as vulnerable when the ratio of vulnerable months to total months in the run is greater than a frequency threshold (Figure 8). The output of the flow depth metric is monthly maximum depth (ft.).

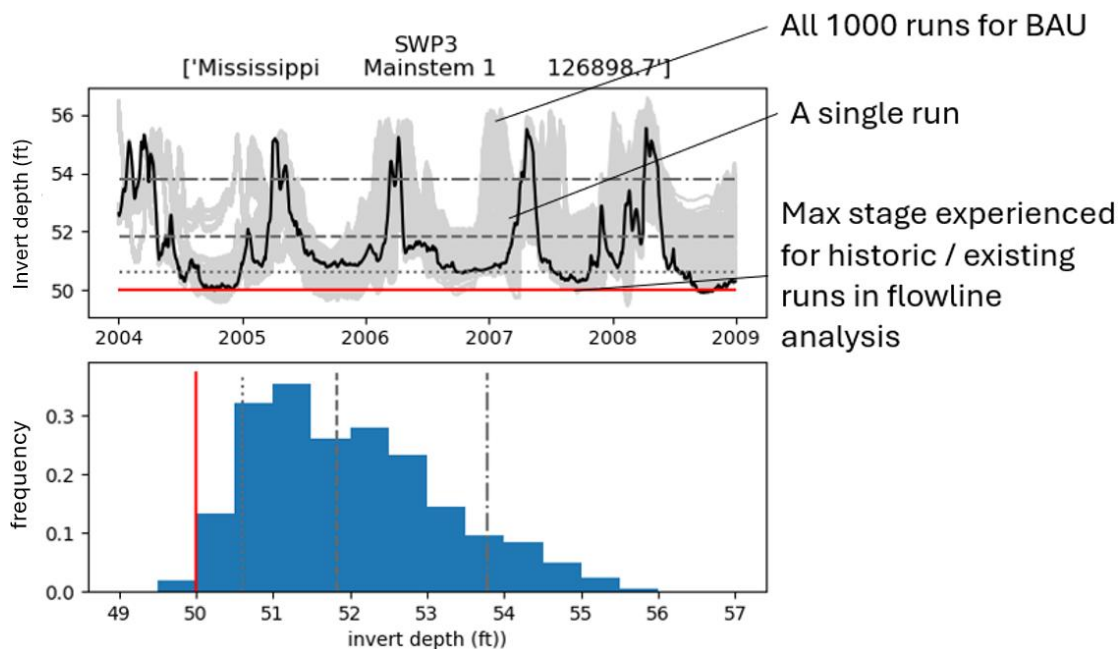


Figure 8. Depth threshold example showing time series of invert depth (top) and a histogram of invert depths used to identify thresholds (bottom).

2. Projected dredging volume was reported by the HEC-RAS model at all cross-sections of the main channel where dredging is performed as described by Dahl et al. (2018). The dredging metric is computed as the monthly sum of simulated dredged material (ft<sup>3</sup>). Because these dredging regions are spatially explicit, this metric does best to represent changes in dredging requirements within the specified dredging areas. The metric can only capture non-local effects from far field changes in outlet operation. A run is marked as vulnerable if the volume dredged in a reach (defined as a set of cross sections) across any 12-month interval exceeds a threshold volume.

The decisions that are made by the dredging operations staff are not fully formalized in a way that can be incorporated into inputs for the dredging module of the HEC-RAS model, so the dredged volume reported by the model may differ from realistic dredging output. Because there is a need to represent a variety of decision-making strategies by the dredgers, the operational dredging manager at USACE New Orleans District (MVN) was contacted to define certain situations that they regard as vulnerable, regardless of the volume that is dredged (*Jeff Corbino, personal comm. October 2023*). Based on this information, it was identified that operational dredging managers often interpret hydrograph “events” to anticipate dredging needs.

3. A pair of hydrograph metrics were created to describe (3a) sharp drops in river stage and (3b) pulses of increased stage during overall low water conditions. For sharp drops in stage (3a) at the



end of the flood season, the dredges must deepen the channel more rapidly than stage falls to maintain navigability in the Crossings. This can strain the capacity of the dredging fleet and represents a vulnerability that is not fully captured by the annual dredging volumes. To identify an instance of this vulnerability, a maxima and subsequent minima is identified within a rolling window of seven days. Vulnerability is detected if the difference between a local maxima and one of the subsequent local minima is greater than 10 ft. Each day (center of window) when this condition is met identifies a vulnerability. Daily vulnerabilities were aggregated monthly such that any month with a vulnerability is marked as vulnerable. The metric output of (3a) is the number of sharp drops in a month.

The second hydrograph metric (3b) describes a dredging issue that occurs at the Crossings during periods of prolonged low water. In the real world, when the river stage is low, the dredgers must cut the channel to accommodate an appropriate navigation depth. If a small flood pulse occurs it may temporarily increase flow depth, but when the pulse subsides, there is often deposition that has occurred in the channel that requires additional dredging to remove. This problem is not well captured by the absolute dredging volume, but it does cause operational difficulties because dredges are often elsewhere during prolonged low water periods. The pulsing hydrograph metric (3b) is computed in a similar fashion to the sharp drop metric (3a), but the average stage during the rolling window must be less than 10 ft. If a drop of more than 4 ft. occurs in such a window, the day is marked as vulnerable. The metric output is the number of pulses in a month.

### 3.1.3 Flood Risk Metrics

The flood stage metric reports vulnerability based on a single threshold at a single cross section that represents a stream gauge. Unlike flow depth, where multiple episodes of vulnerability are needed to render a run vulnerable if the stage at a gauged location exceeds the threshold value at any time during the run, then the entire run is marked as vulnerable. The flood risk metric is calculated at the six gauges indicated in Figure 2. For this report the threshold value is set by the 90<sup>th</sup> percentile of modeled stage values during the BAU run. The published flood thresholds from the gauges were not used because there are some systematic deviations in the flood stage predicted by the HEC-RAS model (see Figures 14 and 15 in Dahl et al. (2018)). In future applications a more intensive threshold-setting exercise could be used to determine appropriate thresholds.



## 4 ENVIRONMENTAL MODEL

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The environmental model consists of a numerical flow and sediment transport model that is controlled by a python module capable of modifying model files, running simulations, and post processing simulation information in batches using multiprocessing on a multicore Windows workstation. In the current project implementation, the underlying numerical model is an unsteady-state HEC-RAS hydraulic and sediment transport model developed by Dahl et al. (2018); however, the automation system as well as the overall Framework is adaptable to other HEC-RAS models or other modeling platforms.

### 4.1 HEC-RAS MODEL

Dahl et al. (2018) produced a HEC-RAS model that simulates the flow of water and sediment between Tarbert Landing and the mouth of the river at the end of Southwest Pass. The main stem of the Mississippi River is represented as a single channel, and flow losses through diversions, crevasses, and major passes are incorporated as discharges through lateral flow structures. Water and sediment input through a time series discharge boundary at the upstream end of the domain, and the downstream boundary is applied as a water level condition. Flow through individual outlet boundaries is modeled as a Q-Q condition where discharge through the outlet is a rating curve function of local flow in the channel. Sediment is removed at the outlet proportional to the outflow, but with a maximum grain size that varies depending on the outlet. Silts and clays are diverted at all outlets, but fine and very fine sands are only diverted at Mid-Breton, Mid-Barataria, West Bay, Cubits Gap, South Pass, and Pass a Loutre. Bonnet Carré diverts very fine, fine, and medium sands.

To prepare the model for each alternative strategy, ERDC made updates to the BAU model (4.1.1), and adapted the BAU model for use in the Turn Right (4.1.2) and Turn Left (4.1.3) models. No adjustments to the model were needed for the Alternative Flow Split at ORCS strategies, as only the input at the upstream boundary was changed.

#### 4.1.1 Business-as-Usual and Adjusted Flow Ratio Strategies

Only minor adjustments were made to the original (Dahl et al., 2018) BAU model, including:

- Updated Q-Q rating curves applied at the lateral flow structures for distributary outflows (Section 2.2.2.1).
- Added West Bay to the Cubit's Gap lateral flow structure on the East Bank of the river to improve numerical stability in sediment transport for that reach.
- Added a lateral flow structure to account for losses at Fort St. Philip on the East Bank.
- The revised model was tested in HEC-RAS 6.1 to ensure that the model was still calibrated.
- Added distributary outflows (lateral flow structures) for the Mid-Breton and Mid-Barataria diversions. Since these diversions were not in place during the calibration period (2004–2012), the model outputs were reviewed to ensure that the results were reasonable.
- Adjusted Flow Ratio at ORCS: The model is identical to the BAU model, but the upstream discharge is altered to represent a change to the 70/30 flow split at ORCS.



### 4.1.2 Turn Right Strategy

In this alternative, major modifications were made to the main navigation channel such that it diverges from its current path in the vicinity of the Empire Waterway, near River Mile (RM) 32 above Head of Passes. The new path exits the existing channel through the right descending bank and proceeds West to the Gulf along the most direct route. This is accomplished through a junction, so both the alternate flow route and the existing Southwest Pass reach are fully included in the model (Figure 9).

Bathymetry for the new route was obtained from the NOAA Bathymetric Data Viewer (NOAA, accessed 2024). A trapezoidal navigation channel with a bottom width of 800 ft. and bottom elevation of -50 ft. was stamped into the terrain model. This navigation channel was extended until it was at the same elevation as the surrounding bathymetry. A flow split (junction) was created in the model where the new navigation channel and existing channel centerline meet. Cross-sections, spaced 1–2 mi. apart, stretch between areas of high ground on either side of the new navigation channel. HEC-RAS calculates the distribution of flow between the existing and new channels based on assuming equal water surface elevations at the downstream boundary. Sediment is distributed between the two channels proportional to the flow.

The HEC-RAS model performs an annual dredging of material within the new navigation channel, ensuring that the full depth is available at the end of each March. While the actual practice might be to sidecast the material in this channel or otherwise use it for land creation, in this model, the material is removed from the model domain. Due to the large size of most of the cross-sections (up to 37 miles in length), this is unlikely to significantly affect the simulation results.

The revised model was run with the historical 2004–2012 flows to ensure that there were no numerical instabilities and that the distribution of flows, water surface elevations, and resulting effects on sedimentation in the Mississippi River were qualitatively similar to what would be expected from a conceptual analysis.

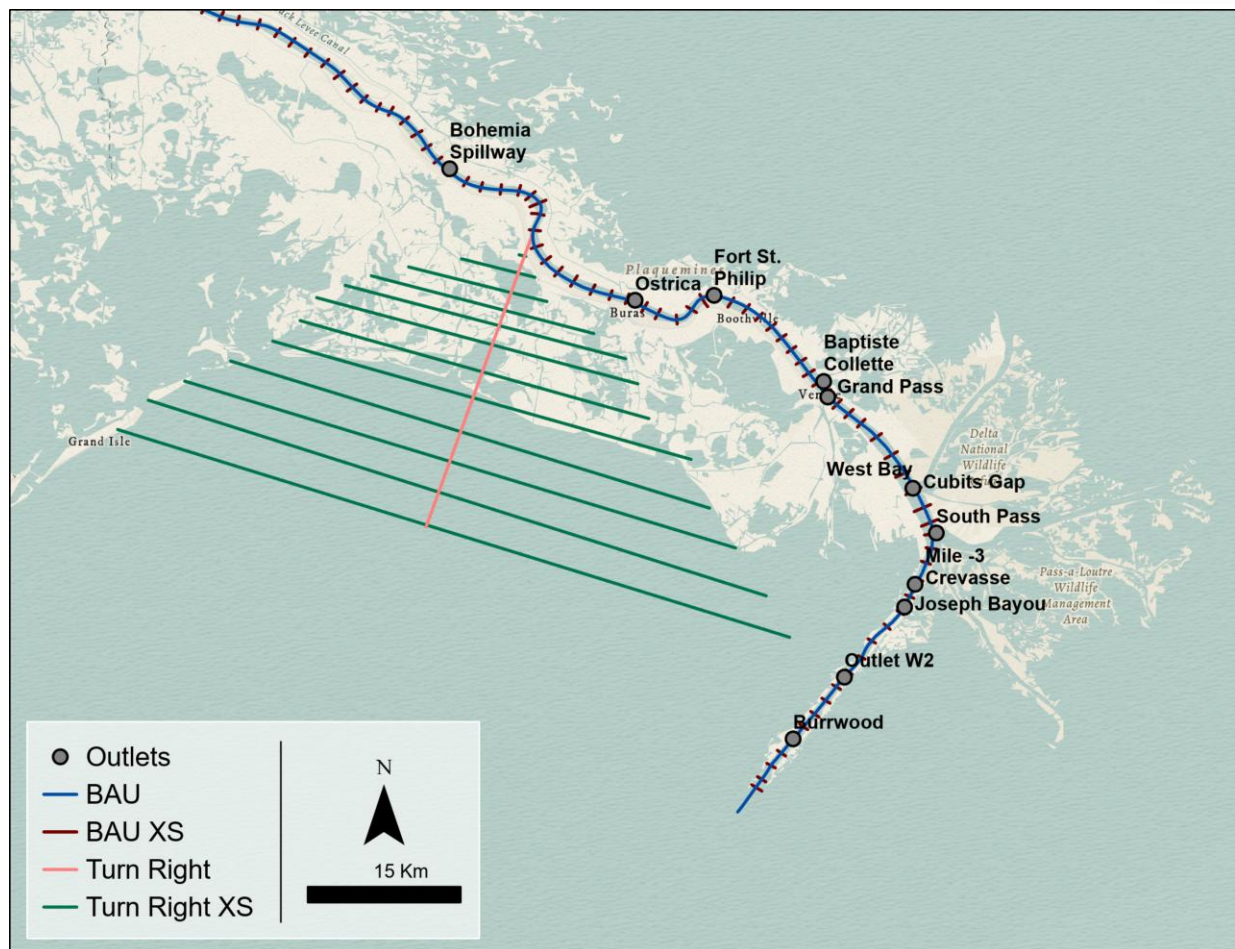


Figure 9. HEC-RAS model schematic showing the location of the model cross-sections (XS), including those for the Turn Right path.

#### 4.1.3 Turn Left Strategy

Major modifications were again made to the main navigation channel such that it diverges from its current path in the vicinity of Bayou Lamoque, near RM 35. However, in this alternative, the new channel exits the current channel through the left descending bank (Figure 10). The path proceeds East until it reaches deeper water and then follows the deeper water to the southeast. Bathymetry along this route was obtained from NOAA and a navigation channel with the same parameters used for the Turn Right alternative was stamped into terrain.

Similar to the modeling procedure for the Turn Right alternative, the Turn Left model uses a flow split (junction) that was created in the model where the new navigation channel and existing channel centerline meet. Cross sections, spaced 1–2 miles apart, stretch between areas of marsh on either side of the new navigation channel until the channel turns southward. From this point, cross sections extend approximately 16 miles to the left of the channel (northeastward) and to marsh edge on the right. HEC-RAS calculates the distribution of flow between the existing and new channels based on assuming equal water surface elevations at the downstream boundary. Sediment is distributed between the two channels proportional to the flow.



The HEC-RAS model performs an annual dredging of material within the new navigation channel, ensuring that the full depth is available at the end of each March. While the actual practice would likely be to sidecast the material or otherwise use it for land creation, it is removed from the model domain. Due to the large size of most of the cross sections (up to 37 miles), this is unlikely to significantly affect the simulation results.

The revised model was again run with the historical 2004–2012 flows and the results reviewed to ensure that they were reasonable.

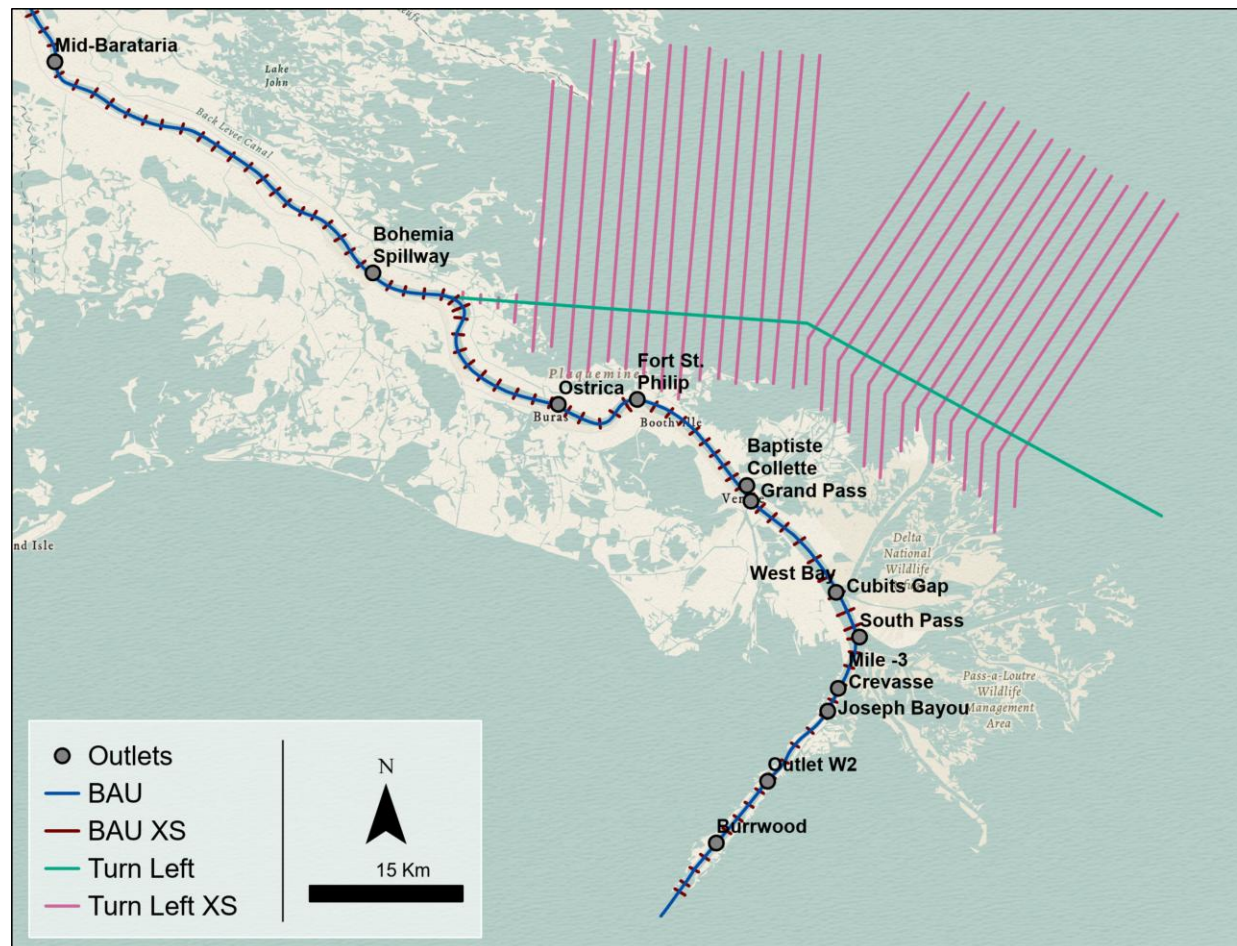


Figure 10. HEC-RAS model schematic showing the location of the model cross-sections (XS), including those for the Turn Left path.

## 4.2 AUTOMATION

A customized automation system was used to create and organize information to execute ensembles of HEC-RAS simulations with permutations of different model configurations. It is written in Python 3.9 and utilizes custom modules and open-source dependencies to load data, configure simulations, control HEC-RAS simulations, and gather HEC-RAS outputs into well-organized storage.

The automation system is structured around execution of a management strategy. A management scenario is defined by an RDM configuration and a 1D HEC-RAS model. The management strategy is specified



during initialization. The RDM configuration provides information to an Exploratory Modeling and Analysis (EMA) workbench, which is a research methodology that is implemented in Python, and which uses computational experiments to analyze complex and uncertain systems (EMA, 2024). It was used in this project to create a set of parameters and values that are packaged into a set of custom data containers (right portion of Figure 11). Each data container has information to programmatically change specified components of the HEC-RAS model.

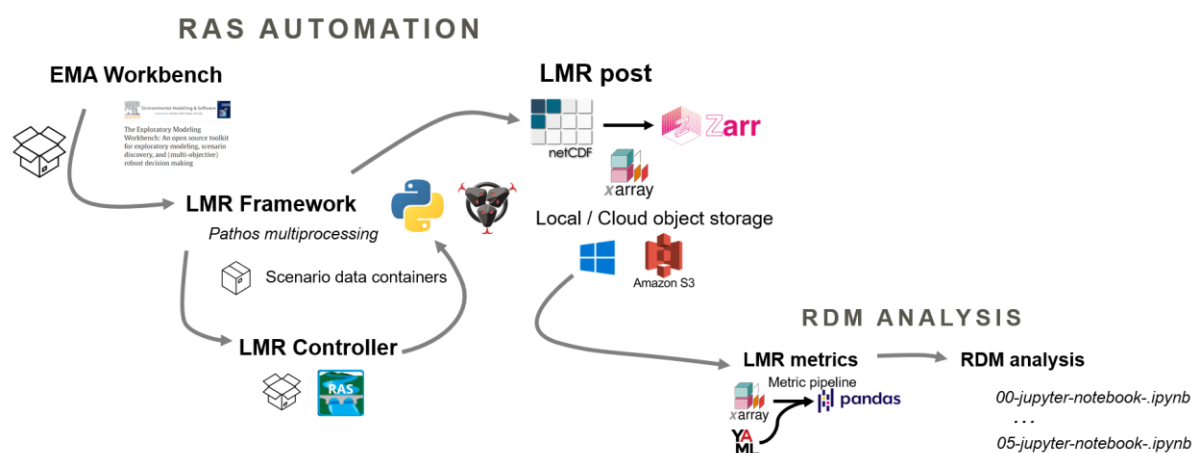


Figure 11. Flow chart of the automation system

The Pathos multiprocessing package is used to pair each data container with an instance of the LMR controller in batches that are executed simultaneously (batch size is specified in the LMR configuration; center portion of Figure 11). The LMR controller copies the specified HEC-RAS model to a temporary directory, modifies the HEC-RAS model as specified in the data container, and controls execution of the HEC-RAS program. After the simulation is complete, the LMR controller extracts specified output variables, writes the information as a NetCDF file, and deletes the temporary directory and associated HEC-RAS files. Instances of the LMR controller are created until all simulations of the management strategy have completed.

Once the automation system has completed execution of HEC-RAS simulations, the root directory of the simulation NetCDF files is given to LMR post. LMR post walks through simulation subdirectories and uses the xarray package to save the management scenario simulation data in Zarr format on local or cloud object storage (Figure 11). The Zarr data storage format is an open-source format designed to store large, compressed, multi-dimensional arrays efficiently, especially in cloud environments, by dividing data into smaller "chunks" which allow for fast, random access to specific subsets of the data.

Execution of the automation system was accomplished on a virtual machine running Microsoft Windows 10. The virtual machine was configured with 32 virtual cores (AMD EPYC 7763) and 64 gigabytes of memory. This configuration allowed 32 instances of HEC-RAS to run simultaneously. Although runtime was variable (due to overall server load) simulation of a single management strategy (1,458 HEC-RAS simulations) could be completed in approximately one day. The multiprocessing settings can be configured so the solution can be deployed on more robust HPCs or more modestly configured laptops.



To move toward an RDM analysis on a simulated management strategy, the LMR metrics module computes a set of custom metrics from HEC-RAS output variables (right portion of Figure 11). Each metric is specified in the management strategy configuration, which includes mathematical calculation and spatiotemporal aggregation. To compute metrics, HEC-RAS output data is read from the management scenario Zarr. After the required data is loaded into memory, each metric is calculated in serial and saved to local or cloud object storage as a comma separated values file (csv).

Mechanically, the RDM analysis is performed using a set of Python Jupyter Notebooks (right portion of Figure 11). Numbered 00 through 05, these notebooks contain the configuration used in the RDM analysis, import HEC-RAS data that is used to create RDM metrics, perform RDM computations, and generate RDM outputs in the form of tabular data and plots that are written to storage.



## 5 RESULTS

This section presents an example of how the Lowermost Mississippi River-Decision Analysis Framework (LMR-DAF) facilitates construction of innovative decision analyses that enable users to sort through a large and complex decision space for structured guidance. First, three vulnerability analyses are presented that show how to identify trends in the environmental forcings and management choices that lead to undesirable outcomes (Section 5.1). Then a Robust Decision Making (RDM) trade-off analysis is performed to guide users through the processes of addressing those vulnerabilities and identifying when improving one outcome is likely to lead to negative impacts on another (Section 5.2). These examples showcase the power that the Framework offers at scale. Codes that are used to identify specific environmental forcings and policy levers are identified in Table 3.

Table 3. Codes used to identify environmental forcings and policy levers and details on their implementation.

	Description	Code	Comment
Environmental Forcing	sea level scenario	hydro_rcp_8.5	True -> high sea level rise (SLR) rate, from RCP 8.5 False -> low SLR rate, from RCP 4.5
	River hydrograph	hydro_1_0.1	True ->Dry (10th percentile)
		hydro_1_0.5	True ->Average (50th percentile)
		hydro_1_0.9	True ->Wet (90th percentile)
Policy Lever	unmanaged outlets	grouped_out_unmanaged_0	True ->lower discharge
		grouped_out_unmanaged_1	True ->current discharge
		grouped_out_unmanaged_2	True ->higher discharge
	lower outlets	grouped_out_lower_0	True ->lower discharge
		grouped_out_lower_1	True ->current discharge
		grouped_out_lower_2	True ->higher discharge
	diversions outlets	grouped_out_diversions_0	True ->lower discharge
		grouped_out_diversions_1	True ->current discharge
		grouped_out_diversions_2	True ->higher discharge
	Neptune Pass	out_ostrica_0.5	True ->lower discharge
		out_ostrica_1.0	True ->current discharge
		out_ostrica_1.5	True ->higher discharge
	Bonnet Carré	out_bonnet_Carré_0.9	True ->lower discharge
		out_bonnet_Carré_1.0	True ->current discharge
		out_bonnet_Carré_1.1	True ->higher discharge

### 5.1 VULNERABILITY ANALYSIS

Vulnerability analysis was used to identify combinations of environmental forcings and policy choices that cause undesirable outcomes in one metric of interest at a time. Classification and Regression Tree



(CART) diagrams were used to understand the key drivers of vulnerability for each metric. CART creates a step-by-step process that applies questions or rules to separate data into specific categories—here, “vulnerable” and “not vulnerable” future conditions—and to pinpoint the most influential factors that affect vulnerability. The required input to this classification algorithm was a threshold that determines whether an outcome belongs to one of two classes. Ideally, for calibrated models and more clearly defined decision problems, this threshold can be informed by real-world experiences and concerns. In the absence of these ideal conditions, the threshold can instead be determined from the statistical distribution of metrics in the outputs. A meaningful threshold is one that results in a mix of vulnerable and non-vulnerable outcomes. Exploring model outputs to identify such thresholds can help decision makers better understand model performance and gain insights for model improvement and calibration. This section focuses on the key drivers of vulnerability, examining one metric at a time. Subsequent analyses could address questions such as: 1) how the key drivers of vulnerability differ across metrics, and 2) which metrics—and therefore which vulnerabilities decision makers prioritize. These follow-on iterations can build on this initial exploration, drawing additional insights from trade-off analysis (see Section 5.2).

In this vulnerability analysis, thresholds indicating a vulnerable outcome were set based on the statistical distribution of metrics in the outputs of the BAU strategy. Table 4 shows the thresholds used for the four metrics treated with vulnerability analyses. Because the HEC-RAS model is not calibrated to dredged volume, the flexibility and utility of this approach is shown by applying thresholds that are computed as data percentiles rather than derived from real world values. These thresholds are chosen to capture significant but not extreme conditions for that specific metric, leading to a meaningful classification of scenarios to “vulnerable” and “not vulnerable”. For each metric, the simulated Strategy/Scenario condition is classified as "vulnerable" if at any point it exceeds the vulnerability threshold for metrics that should be minimized or falls below the threshold for metrics that should be maximized. The same vulnerability thresholds are used across river management strategies to ensure meaningful comparisons.

*Table 4. Vulnerability analysis thresholds based on the statistical distribution of metrics in the outputs of the BAU strategy*

Metric	Threshold	Value	Desired direction
Southwest Pass dredged volume	99 <sup>th</sup> percentile	$7.80 \times 10^6 \text{ ft}^3$	Minimize
Barataria sediment delivery	5 <sup>th</sup> percentile	$7.09 \times 10^4 \text{ ft}^3$	Maximize
Breton sediment delivery	5 <sup>th</sup> percentile	$4.12 \times 10^4 \text{ ft}^3$	Maximize
Baton Rouge flood stage	90 <sup>th</sup> percentile	39.3 ft.	Minimize

There are two uncertain environmental factors: eustatic sea level rise (SLR) and Mississippi River hydrograph percentile (with three levers of dry, average, and wet). There are five levers in terms of outlet discharge: three outlet groups (diversions, Unmanaged-Upper, and Unmanaged-Lower) and two individual outlets (Bonne Carré and Neptune Pass; Table 1).

For each vulnerability metric, two CART vulnerability analyses were performed in Python to answer the following questions:



1. ***Which levers and uncertainties are the key drivers of vulnerability?***

To answer this, an analysis is performed using both environmental forcings and policy levers to identify which combinations of paths have vulnerable outcomes, thereby allowing the user to observe whether acceptable futures exist in the output data set with respect to the chosen metric and vulnerability threshold.

2. ***Under potentially vulnerable environmental conditions, which levers can mitigate vulnerability?***

A second analysis is then produced where environmental forcings and policy levers are strictly separated in the CART. This allows users to first identify combinations of environmental forcing where vulnerable paths exist, and then provides a simplified visual guide to identify the most impactful policy levers that can be applied to achieve less vulnerable outcomes.

An annotated explanatory key for the CART diagrams is given in Figure 12, showing how the vulnerability in the output space is quantified and displayed to present an organized picture of relevant environmental factors and policy levers. Each tree has three primary components: 1) *nodes* represent a split in the vulnerability space based upon the answer to a true/false question. 2) *branches*: When such a split is made, the CART shows two branches based on the possible answers. 3) *Leaves* are endpoints containing the final vulnerability classification. Each split is chosen to minimize the Gini impurity metric (Gini, 2005), which indicates whether one outcome (vulnerable vs. non-vulnerable) dominates (Gini = 0) or if there is a more even mix of outcomes (Gini = 1). Since the algorithm selects the best split at each step, earlier splits typically have a greater impact on predictive performance. While the top split is often highly influential, it is not the sole measure of a variable's overall contribution. A variable may not appear at the top of the tree but can be used multiple times across different branches, resulting in high overall importance. However, the algorithm's choice of splitting variables and their hierarchy provide a useful indicator for identifying key drivers of vulnerability.

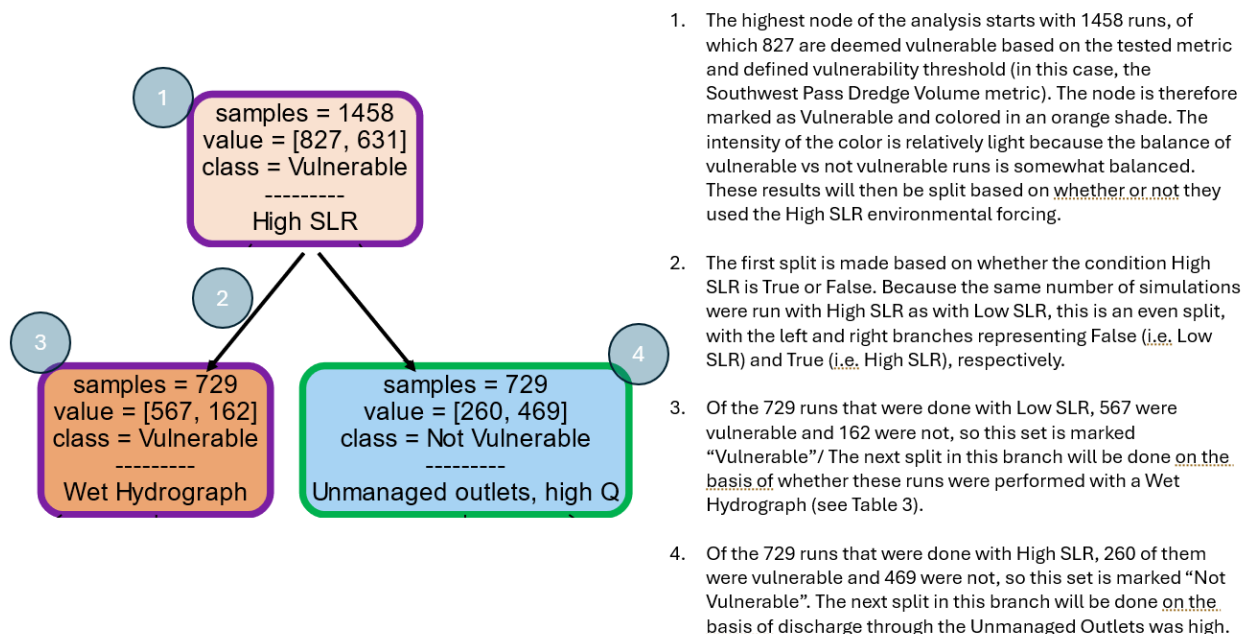


Figure 12. Analysis key for CART diagrams

### 5.1.1 Southwest Pass Dredge Volume

In this section, CART analyses are performed on the basis of the Southwest Pass Dredge Volume metric. Results are identical for the BAU, Flatpeaks, and Lowpeaks strategies.

#### **Among both levers and uncertainties, which factors are the key drivers of vulnerability?**

The CART analysis shown in Figure 13 combines both the environmental forcings and policy levers as equivalents. Based on the pre-defined threshold (Table 4), CART classifies 827 of the 1,458 individual simulations modeled for the BAU strategy as vulnerable, and 631 as not vulnerable. The CART output identifies SLR forcing as the primary splitting factor.

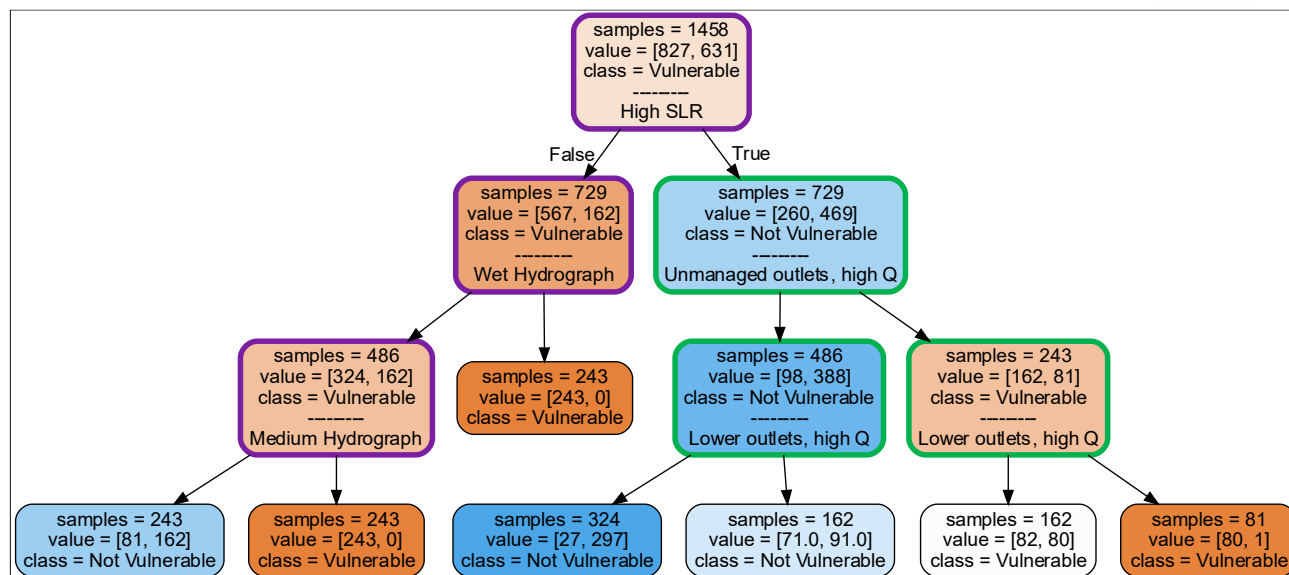


Figure 13. Combined uncertainty and lever CART for Southwest Pass metric in BAU strategy. The results are identical for Flatpeaks and Lowpeaks under adjusted flow river strategies. The boxes with purple borders are uncertain factors. The boxes with green borders are levers.

For Southwest Pass Dredged Volume, high SLR (RCP 8.5, right branch) was projected to require less dredging to maintain Southwest Pass navigability (i.e., fewer “Vulnerable” outcomes), particularly when discharge from unmanaged and lower outlets is not increased. However, if discharge from both outlet groupings increases under high SLR conditions, almost all outcomes become vulnerable.

The low SLR scenarios (left branch) appear to increase vulnerability. Under low SLR, dry conditions tend to result in less vulnerable outcomes, whereas average and wet conditions lead to entirely vulnerable outcomes.

It is likely that lower vulnerability in this metric is counterintuitively associated with high SLR because increased flow depths will result in decreased dredging.

### **Under potentially vulnerable environmental conditions, which levers can mitigate vulnerability?**

The Segmented CART (Figure 14), is performed in two iterations to first identify the key environmental drivers of vulnerability (top of the figure), and second, the policy levers that can mitigate vulnerability within one environmental scenario (bottom of the figure, outlined in red).

For the environmental drivers, the results are similar to those of the unsegmented analysis: the uncertainty-only CART shows that low SLR, followed by wet and average river hydrographs, leads to vulnerability in the Southwest Pass dredge volume metric.

The second segment examines a condition where SLR is high and the river hydrograph is average, leading to a nearly even mix of vulnerable and not vulnerable outcomes. The segmentation allows the user to investigate which levers can be used to reduce or might further exacerbate vulnerability under this environmental scenario. Two actionable guidance items arise from this analysis:



- Lower and/or constrained discharges through the Unmanaged Upper and Unmanaged Lower outlets were associated with reduced projected dredging needs in Southwest Pass.
- Allowing higher discharges from Neptune Pass was projected to reduce the need to dredge Southwest Pass when higher discharges from both unmanaged and diversion outlets were also allowed.

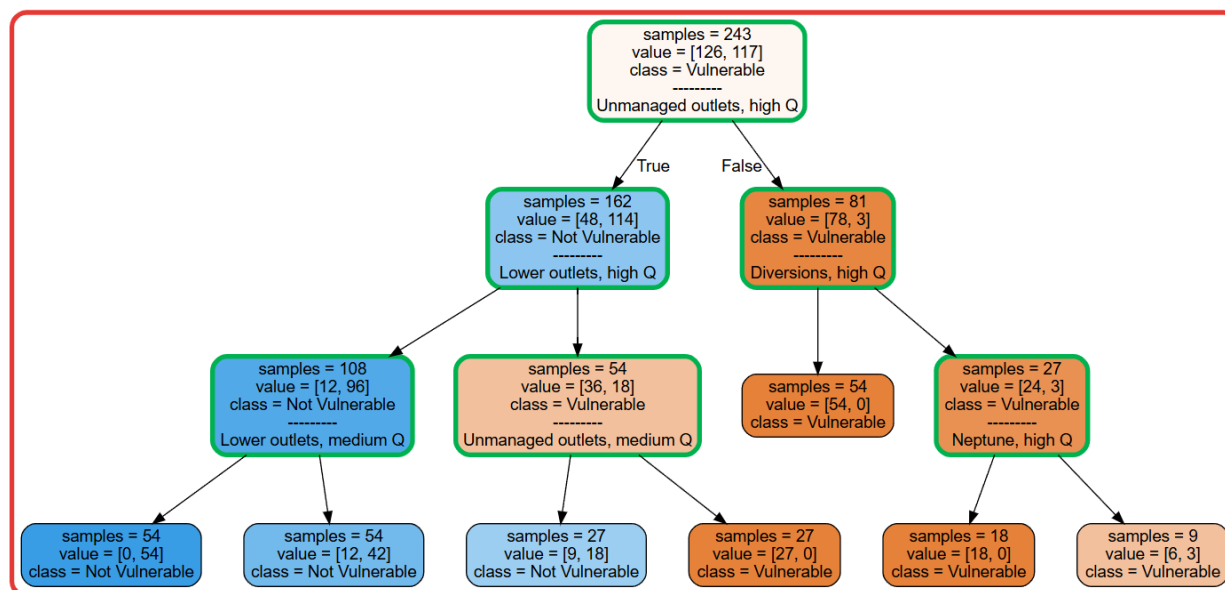
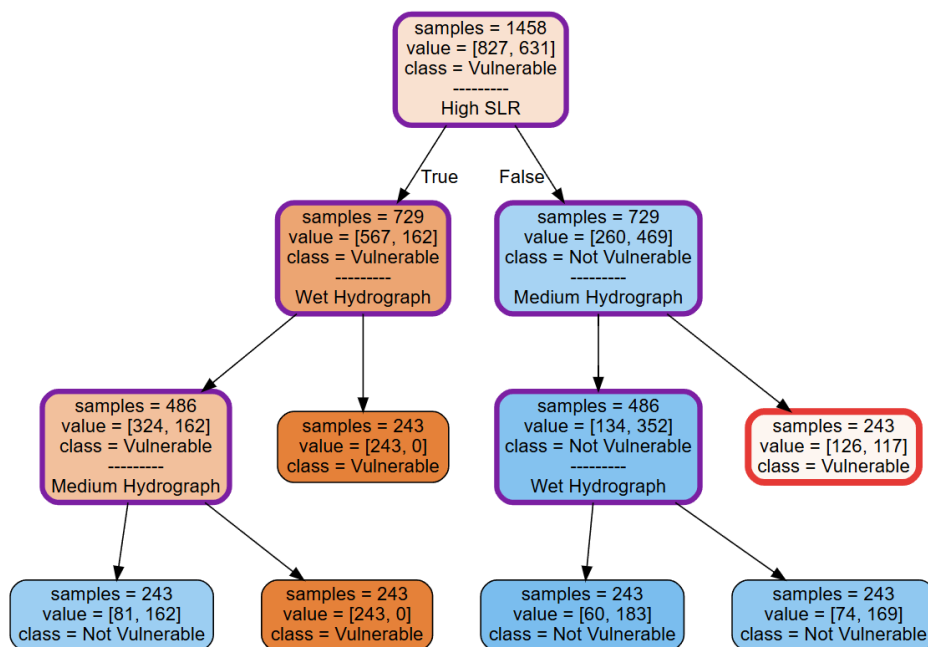


Figure 14. Segmented uncertainty and lever vulnerability analysis for Southwest Pass dredged volume metric in BAU strategy.



## 5.1.2 Sediment Delivery to the Basins

In this section, two vulnerability analyses are presented that investigate sediment delivery to the Breton and Barataria basins. The analyses are structured differently from one another to demonstrate flexibility in analysis methods. The first analysis (Section 5.1.2.1) addresses the combined sediment delivery to the two basins under the three strategies with the existing navigation channel, and the second (5.1.2.2) addresses Breton and Barataria separately.

### 5.1.2.1 BAU and Adjusted Flow Strategies, Combined Sediment Delivery

#### Among both levers and uncertainties, which factors are the key drivers of vulnerability?

The CART analysis shown in Figure 15 combines both the environmental forcings and policy levers as equivalents. The metric of interest is the total sediment delivery to both Breton and Barataria basins. As with the Southwest Path (SWP) Dredge Volume, the CARTs for the BAU and the two adjusted flow path strategies were identical (Appendix E), so only the BAU is shown here. This strategy has 1,215 vulnerable and 243 not-vulnerable cases based on the threshold defined for this metric.

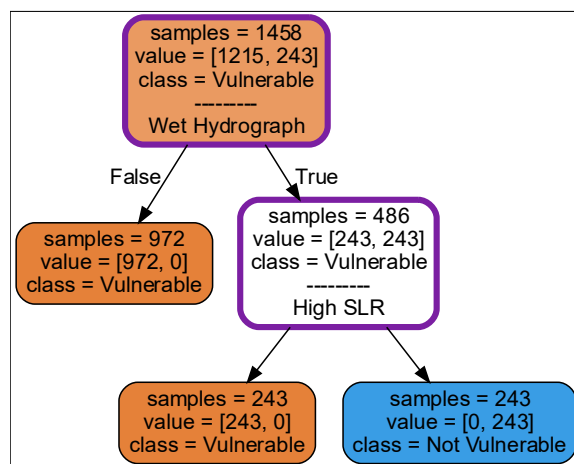


Figure 15. Combined uncertainty and lever CART for Barataria and Breton sediment metric in BAU and adjusted flow (Flatpeaks and Lowpeaks) strategies.

For projected total sediment delivery, under BAU operation conditions, variations in the sea level rise and Mississippi River hydrograph entirely drive the vulnerability distinctions. Environmental forcings that have dry hydrographs (left branch) only resulted in reductions in projected sediment delivery to Barataria and Breton basins (i.e., entirely vulnerable scenarios). When the hydrograph is wet (right branch in Figure 17), low SLR results in completely vulnerable outcomes (less than desired sediment delivered) and high SLR in completely non-vulnerable outcomes (desired sediment delivered). The presence of wet river hydrographs is the top tier driver of outcomes, and within the space of dry and average hydrographs, SLR is critical in determining vulnerability.

There is no need to do a segmented analysis in this case, because the environmental scenarios on their own produce perfect leaves with Gini = 0 (i.e., either all vulnerable or all not vulnerable). Note, however, that changes to the vulnerability threshold may alter the combined tree, potentially incorporating levers and thus necessitating a segmented analysis. That said, in the example provided here, uncertainties are the



absolute drivers of vulnerability for both Barataria and Breton under both BAU and adjusted flow management strategies.

### 5.1.2.2 Alternative Channel Management Strategies (Turn Right)

#### Among both levers and uncertainties, which factors are the key drivers of vulnerability?

Figure 16 shows the combined uncertainty and lever CARTs for the Barataria sediment delivery and the Breton sediment delivery metrics in the Turn Right strategy.

In Barataria, the initial Turn Right runs had 1,437 vulnerable and 21 not-vulnerable scenarios. While the initial state is mostly vulnerable, a route to less vulnerable outcomes (right branch) consists of high discharge allowed from unmanaged outlets, wet hydrograph, and high SLR.

- The magnitude of flow through unmanaged outlets emerge as the first (top-level) driver.
- Given higher discharges from unmanaged outputs, vulnerability is associated with wet hydrograph conditions and high SLR.

In Breton, the initial Turn Right runs had 1,296 vulnerable and 162 not-vulnerable scenarios based on vulnerability criterion defined in the introduction. As with Barataria, the initial state is mostly vulnerable but a route to less vulnerable outcomes (right branch) consists of wet hydrograph, high SLR, and high discharge allowed from Neptune Pass. Breton is less vulnerable than Barataria on the basis of this metric overall, and the presence of Neptune Pass allows for significant policy influence over this lever.

- River hydrograph levels are the first (top-level) driver.
- SLR emerges as the second (top-level) driver.
- Under wet hydrograph conditions and high SLR, higher discharge from Neptune Pass can play a role in providing more sediment to basins.

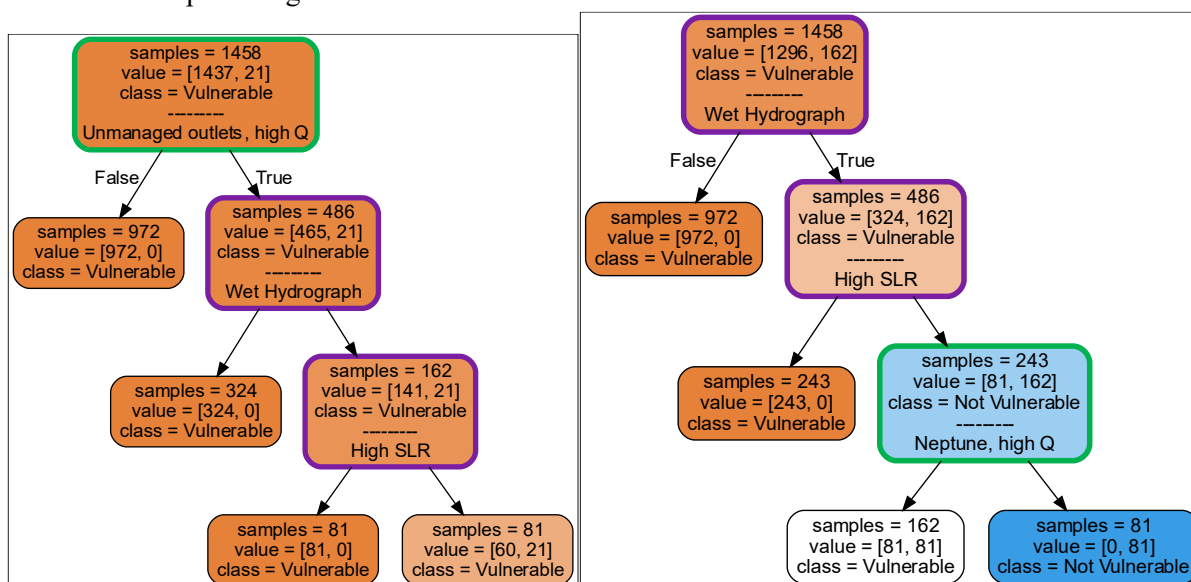


Figure 16. Barataria sediment discharge (left) and Breton sediment discharge (right) CART.



**Which policy levers can be applied to mitigate vulnerability that is associated with specific environmental forcings?**

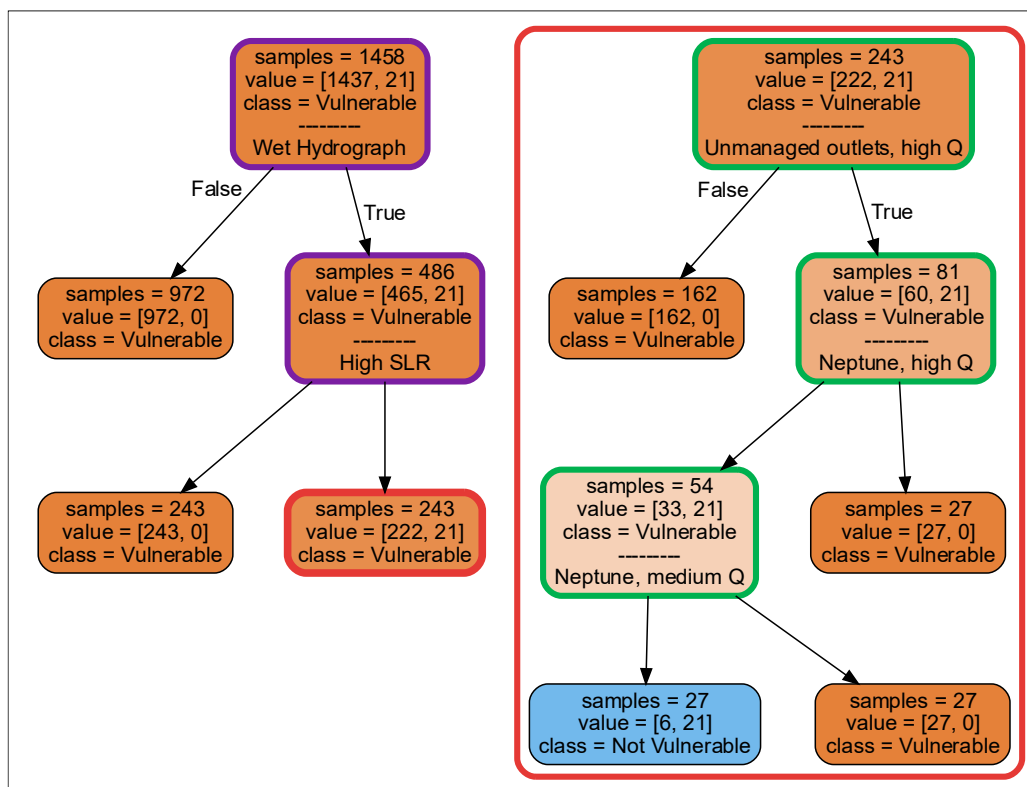


Figure 17. Barataria sediment discharge initial uncertainty CART (left) and Leaf lever CART (right). The initial node of the lever CART is highlighted with a red border in uncertainty CART.

In the first segment of the Barataria segmented analysis (Figure 17), the CART shows that wet hydrograph and higher SLR result in scenarios with sediment delivered above the set threshold (i.e., less vulnerable scenarios). The second segment examines a condition where the river hydrograph is wet and SLR is high, to investigate the levers that can help reduce or might further exacerbate vulnerability in this environmental scenario. It shows that high discharge from unmanaged outlets and low discharge from Neptune Pass can keep the sediment delivered above the set threshold (i.e., reduce vulnerability). Low or current discharge levels from unmanaged outlets result in entirely vulnerable scenarios. Even if there is high discharge from unmanaged outlets, if discharge from Neptune Pass remains at current levels or increases, the outcomes will still be entirely vulnerable as well (sediment delivered above the set threshold).

In Barataria, keeping unmanaged outlets at higher discharge while maintaining low Neptune discharge tends to increase sediment transport to the basin (i.e., reduce overall vulnerability). This suggests that high discharges from Neptune Pass are capturing flows that would otherwise enter Barataria. This interaction results from Grand Pass being included as an input the Barataria basin, a choice that would likely be adjusted in future implementations.



Similar to Barataria, the Breton uncertainty-only CART shows that a wet hydrograph and higher SLR result in less vulnerable scenarios. The second segment examines a condition where the river hydrograph is wet and SLR is high. By focusing on levers, it investigates the impact of outlet discharge policies on reducing or exacerbating vulnerability in this environmental condition. Here, the model projected that Neptune Pass was the dominant lever, and the pattern was opposite to the delivery of sediment to Barataria. Only low discharge from Neptune Pass leads to reduced sediment transport into Breton. If the discharge from Neptune Pass remains at current levels or increases, the outcomes will still be entirely not vulnerable.

It is notable that the model projected that Neptune Pass was a key driver in both Barataria and Breton basins, but with different effects. This type of result is ideal for further consideration via tradeoff analysis that is performed in Section 5.2.

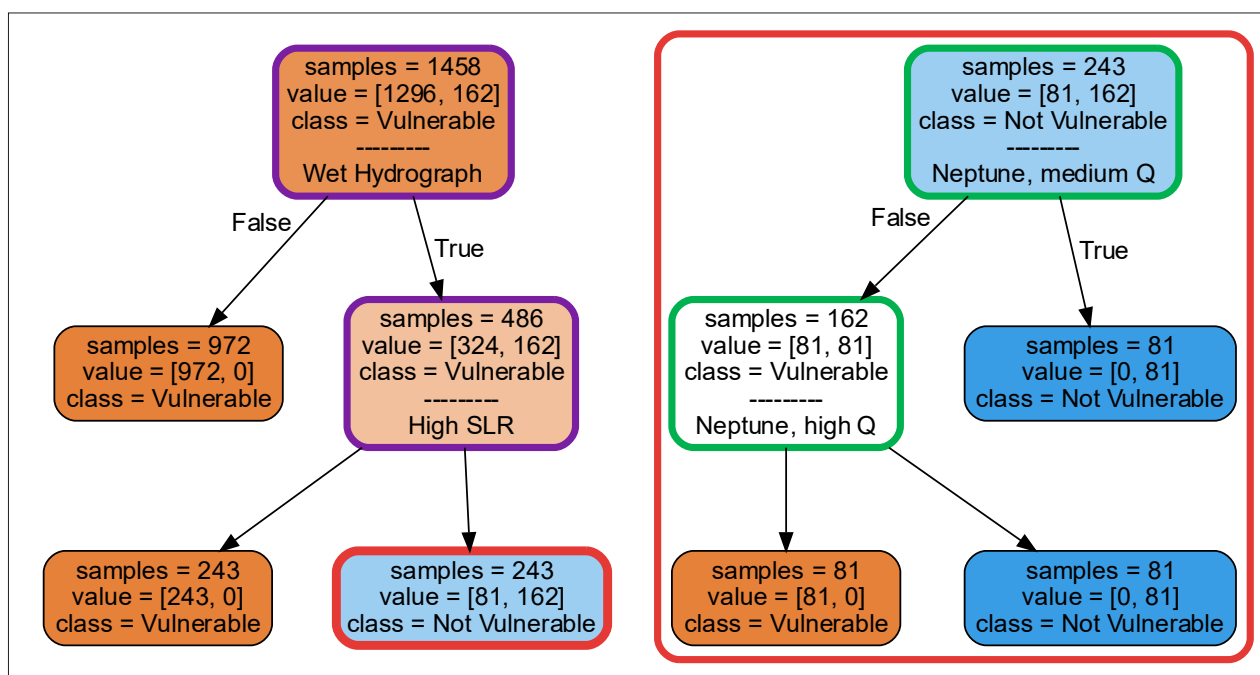


Figure 18. Breton sediment discharge initial uncertainty CART (left) and Leaf lever CART (right). The initial node of the lever CART is highlighted with a red border in uncertainty CART.

### 5.1.3 Baton Rouge Flood Metric

A comparison between the unsegmented CARTs for the Baton Rouge flood metric across all strategies showed equivalent vulnerability in this metric, except for Lowpeaks.

#### 5.1.3.1 All Management Strategies Versus Lowpeaks

The unsegmented CART analysis for Baton Rouge flood metric provides identical results in BAU, Flatpeaks, and both alternative channel strategies (Figure 19). The graph shows that the two climate uncertainties entirely drive vulnerability/invulnerability in both metrics.



Low SLR (left branch) results in entirely vulnerable scenarios (flood stage above the set threshold), but in high SLR scenarios (right branch), there are some non-vulnerable outcomes to be found in the drier hydrographs. Since the combined CART analysis results in a tree with only uncertain factors and perfect leaves with zero impurity (Gini = 0), the first part of the segmented analysis produces identical results to the combined analysis, and no further lever CART is generated.

However, the hydrograph properties are also the subject of the Lowpeaks strategy (Figure 20). The CART analysis for the Lowpeaks provides very similar results to that of the others, except that in a high SLR scenario, both dry and average hydrographs can lead to not-vulnerable outcomes instead of only dry conditions in other river management strategies.

Note again that changing the vulnerability threshold may alter the combined tree, potentially incorporating levers, meaning the trees are sensitive to vulnerability thresholds.

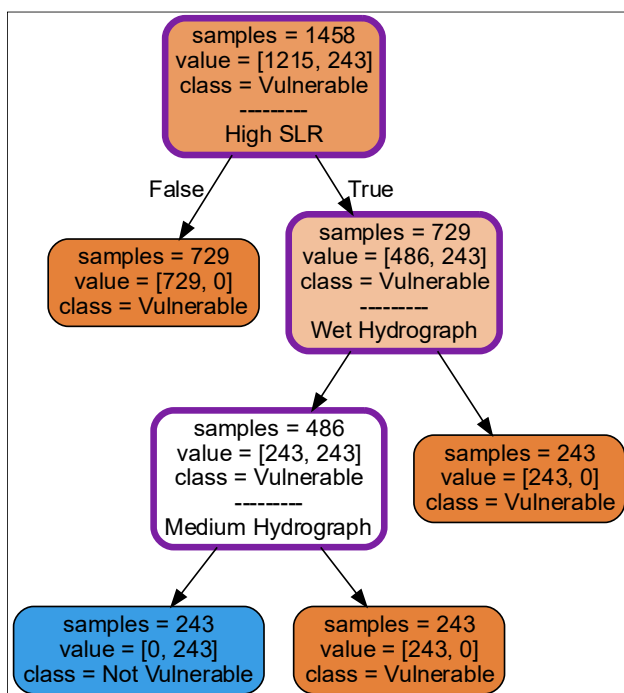


Figure 19. Unsegmented CART for Baton Rouge flood stage BAU, Flatpeaks, and alternative channel strategies. The boxes with purple borders are uncertain factors.

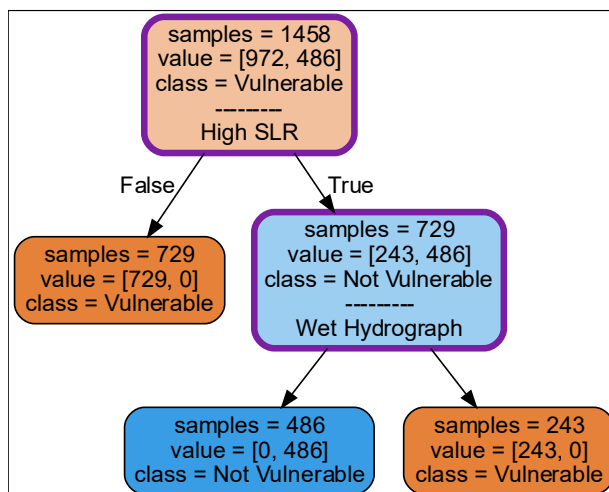


Figure 20. Baton Rouge flood stage in Lowpeaks strategy. The boxes with purple borders are uncertain factors.

## 5.2 TRADEOFF ANALYSIS

In the tradeoff analysis, the river management strategies described in Chapter 2 are investigated to understand how to use available policy levers for improving the performance of the multiple metrics under consideration. Each strategy was subject to two environmental forcings (SLR and river hydrograph) that are out of management control and five policy levers related to outlet discharge rates (grouped lower outlets, grouped diversions, grouped unmanaged outlets, Bonnet Carré outlet, and Neptune outlet). This experimental design provides 1,458 runs within each river management strategy.

However, unlike the vulnerability analysis, the tradeoff analysis focuses entirely on the impact of policy levers that are under decision-maker control (in this case, outlet discharges). Each environmental scenario is a combination of levels of the two uncertain environmental forcings. The first is SLR rise, which has two levels (1.6 ft. over 50 years, and 2.5 ft. over 50 years), while the second is river hydrograph, which has three levels—dry (10th percentile), average (50th percentile), and wet (90th percentile). This gives six environmental scenarios, each consisting of 243 runs.

The results of 1,458 runs of interest are displayed in Figure 21, color coded by the 243 runs done for each environmental scenario. This figure—a parallel axis plot—is the basis of the tradeoff analyses. It allows relationships between multiple metrics of interest to be displayed in a single figure and compared efficiently. Note that the direction of each axis is oriented such that metric values considered by CPRA as “desirable” (i.e., lower dredging needs in the Crossings and Southwest Pass and higher discharges of sediment into Barataria and Breton Sound Basins) is up, regardless of whether that direction is increasing or decreasing, and that the axes can show fundamentally different quantities and units while still allowing metric performance to be meaningfully compared in this way. In Figure 21 there is one set of runs (RCP 4.5, hydro = 0.5) that stands out from the others in the Crossings-dredged volume metric. The stark difference is due to the timing of the flood in the hydrograph that was selected for input in these runs (see the description of hydrograph selection in Section 2.2.1). It is a physically plausible result, so it is left in the analysis, but it points to a need for further efforts to standardize inputs in future uses of the LMR-DAF.

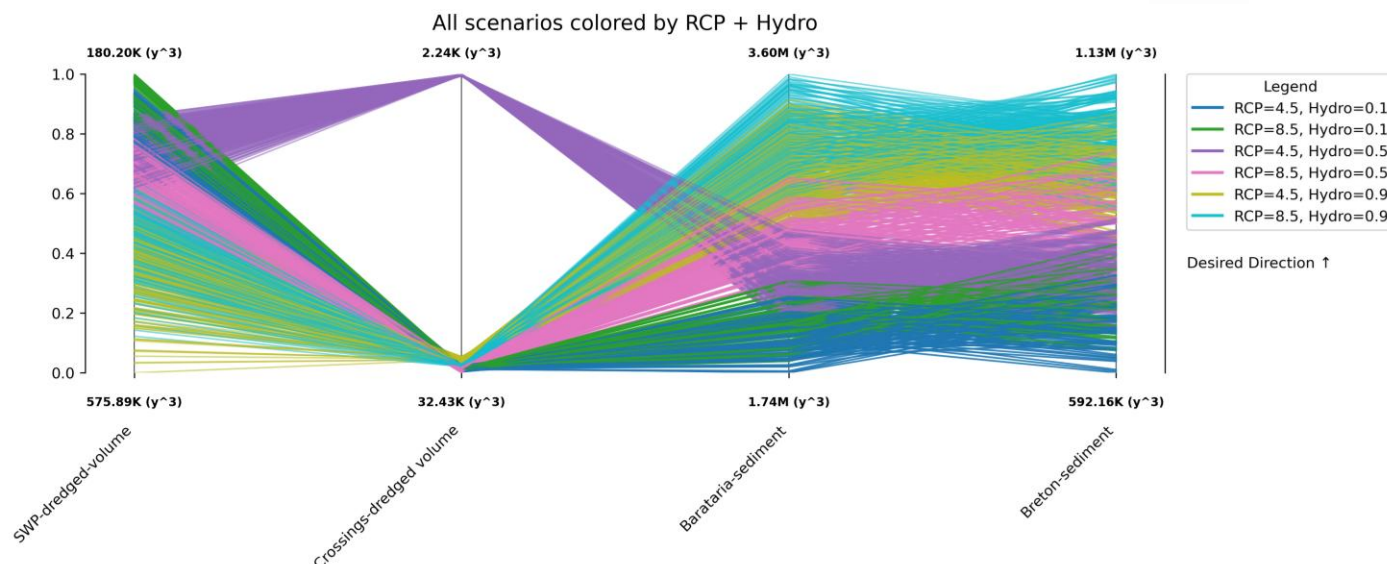


Figure 21. Performance of all 1,458 runs in BAU, color-coded by the environmental scenarios, displayed as a parallel axis plot. Each environmental scenario contains 243 runs. The direction of each axis is oriented such that the desirable direction for that metric is up, regardless of whether that direction is increasing or decreasing. The leftmost y-axis is presented as normalized units, while the native units for each metric are given in their respective axis. The y axis shows a normalized unit.

### 5.2.1 Tradeoffs within BAU

The tradeoff analysis within the BAU strategy is organized around five questions posed by CPRA. The first three assess how improved performance in one metric affects performance in the others, while the final two are framed to focus on identifying influential policy levers.

1. When examining simulations that minimize Southwest Pass dredging, what are the tradeoffs with other management metrics?
2. When examining simulations that minimize dredging at the Crossings, what are the tradeoffs with other management metrics?
3. When examining simulations that maximize sediment delivery to the Delta Plain (Barataria + Breton), what are the tradeoffs with other management metrics?
4. What outlet discharge levers achieve better projected sediment delivery to Breton Sound and Barataria basins and reduce maintenance needs at Southwest Pass?
5. Do the scenarios that perform best across Southwest Pass dredge volume and basin sediment delivery metrics have anything in common regarding outlet discharge levels?

#### 5.2.1.1 When examining simulations that minimize Southwest Pass dredging, what are the tradeoffs with other management metrics?

Figure 22 displays 243 scenarios within the selected environmental conditions (low SLR and average hydrograph) under the BAU strategy in a parallel axis plot. Among these, the top 10% or best-performing scenarios in the Southwest Pass dredging volume metric are highlighted in blue. The best-performing scenarios are those that, depending on the described direction of the metric (e.g., maximize or minimize),



fall below the 10th percentile (for metrics to be minimized) or above the 90th percentile (for metrics to be maximized). Here, the dredge volume metric is to be minimized. Thus, the top-performing scenarios are those with a dredge volume at or below the 10th percentile. The Figure 23 shows how the selected 243 scenarios and the top performers within that group compare with the full output space of this strategy.

The results indicate that scenarios with the best performance in terms of dredged volume at Southwest Pass also perform relatively well in Breton sediment discharge and crossings dredged volume metrics but exhibit lower performance in the Barataria sediment metric.

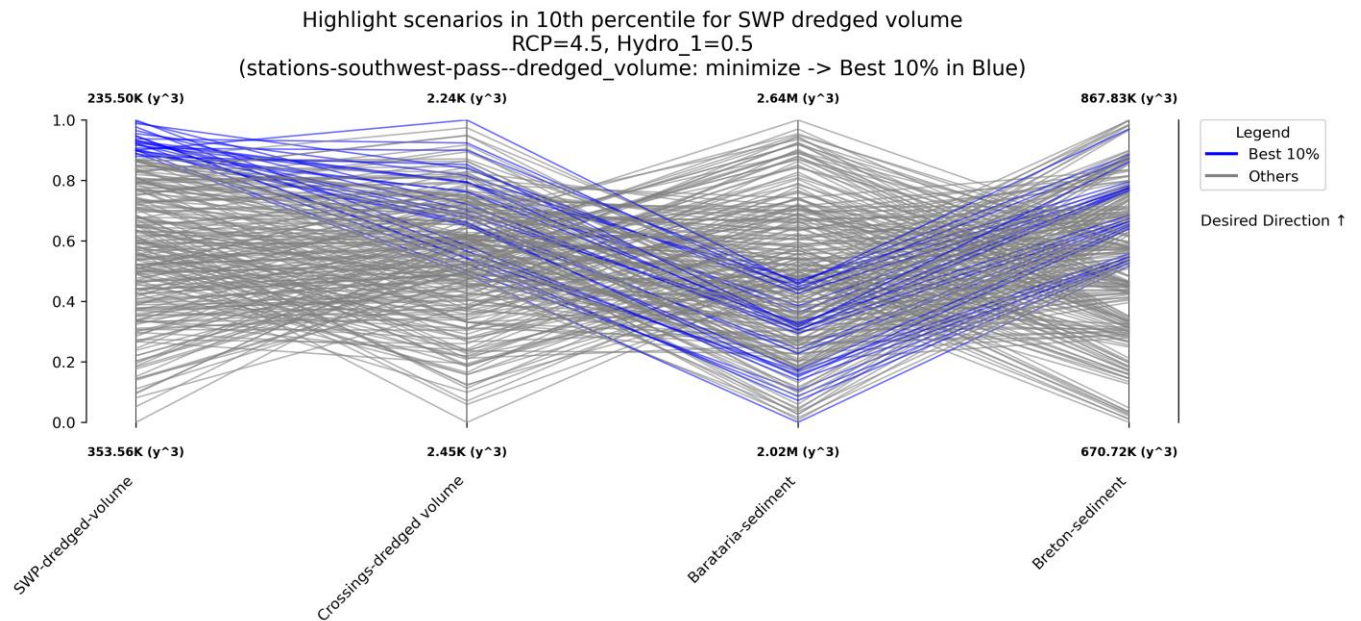


Figure 22. Tradeoff analysis focused on high-performing scenarios in Southwest Pass dredge volume.

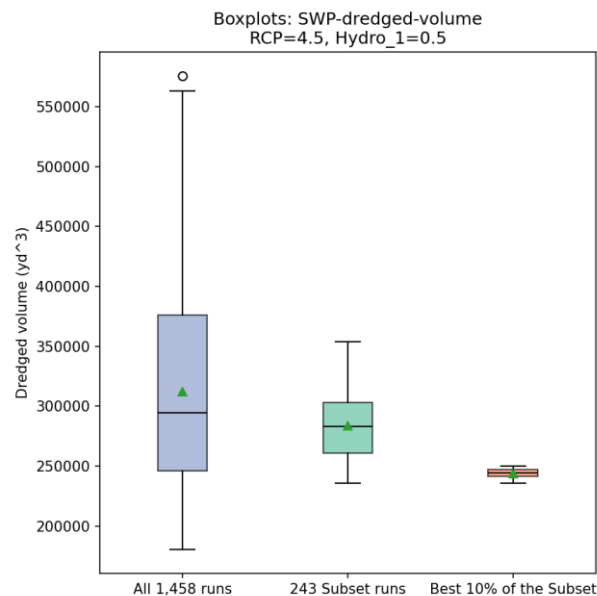


Figure 23. Distribution of Southwest Pass (SWP) dredge volume metric values. The boxplot illustrates the distribution of metric values, including the minimum, maximum, median (horizontal line), and mean (green triangle) for three



different scenario sets. Outliers are represented by circles. From left to right, the boxplots show the distribution for all 1,458 runs in the BAU scenario, 243 runs in a specific environmental subset with Low SLR (RCP 4.5) and an average hydrograph (hydro\_1 = 0.5), and the top 10% of scenarios, which were highlighted in blue in the previous figure.

### 5.2.1.2 When examining simulations that minimize dredging at the Crossings, what are the tradeoffs with other management metrics?

Figure 24 displays 243 scenarios within the selected environmental conditions (low SLR and average hydrograph) under the BAU strategy in a parallel axis plot. Among these, the best-performing scenarios in the Crossings dredging volume metric are highlighted in blue. Figure 25 shows how the selected 243 scenarios and the top performers within that group compare with the full output space of this strategy.

The graph indicates that scenarios with the best performance in terms of dredged volume at Crossings also perform relatively well in Breton sediment discharge and Southwest Pass dredged volume metrics but exhibit reduced sediment transport to the Barataria Basin.

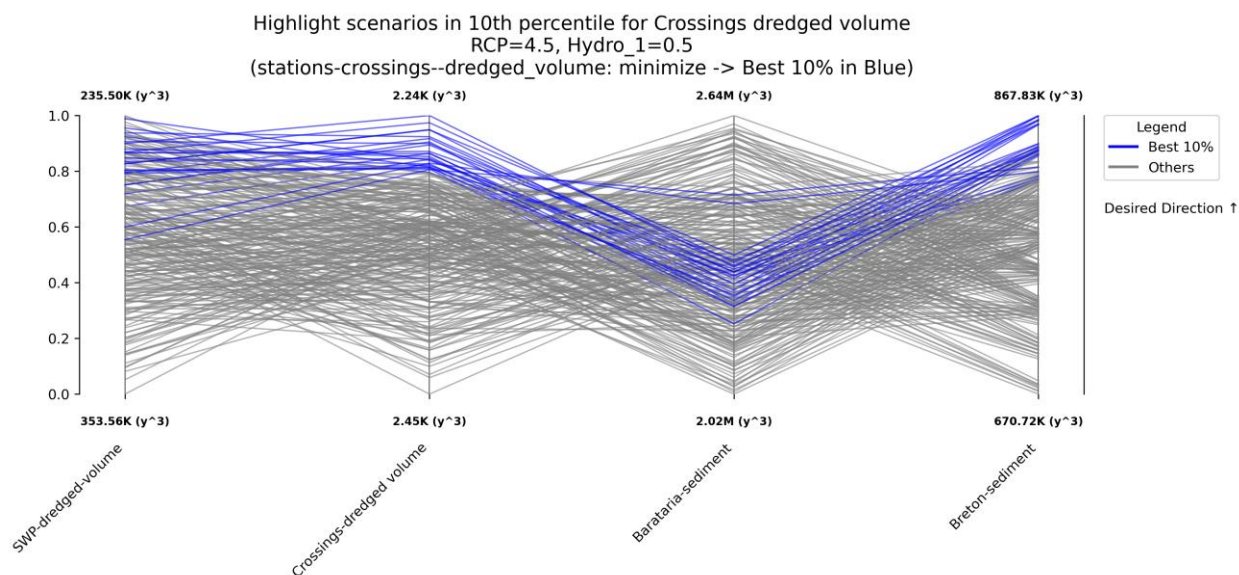


Figure 24. Tradeoff analysis focused on high-performing scenarios in Crossings dredge volume.

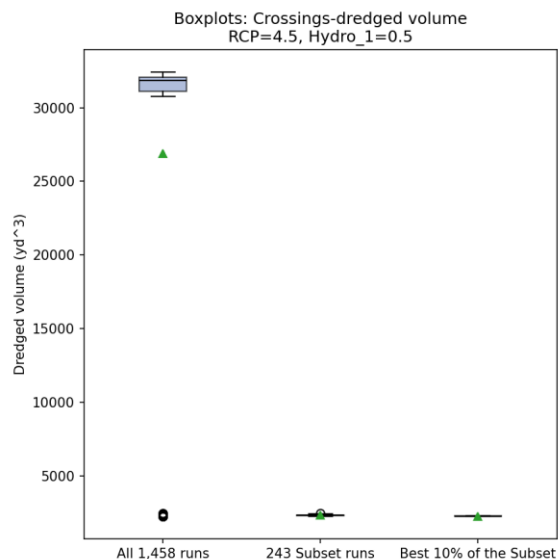


Figure 25. Distribution of Crossings dredge volume metric values. The boxplot illustrates the distribution of metric values, including the minimum, maximum, median (horizontal line), and mean (green triangle) for three different scenario sets. Outliers are represented by circles. From left to right, the boxplots show the distribution for all 1,458 runs in the BAU scenario, 243 runs in a specific environmental subset with Low SLR (RCP 4.5) and an average hydrograph (hydro\_1 = 0.5), and the top 10% of scenarios, which were highlighted in blue in the previous figure.

### 5.2.1.3 3. When examining simulations that maximize sediment delivery to the Delta Plain (Barataria + Breton), what are the tradeoffs with other management metrics?

Figure 26 displays 243 scenarios within the selected environmental conditions (low SLR and average hydrograph) under the BAU strategy in a parallel axis plot. Among these, the best performing scenarios in the delta plain sediment delivery metric are highlighted in blue. Figure 27 shows how the selected 243 scenarios and the top performers within that group compare with the full output space of this strategy.

The graph shows a general tradeoff between delta plain sediment delivery and Southwest Pass dredged volume, in which the highest performing scenarios in Delta sediment delivery show relatively low to average performance in SWP dredged volume. The same scenarios show mostly average performance in Crossings dredged volume.

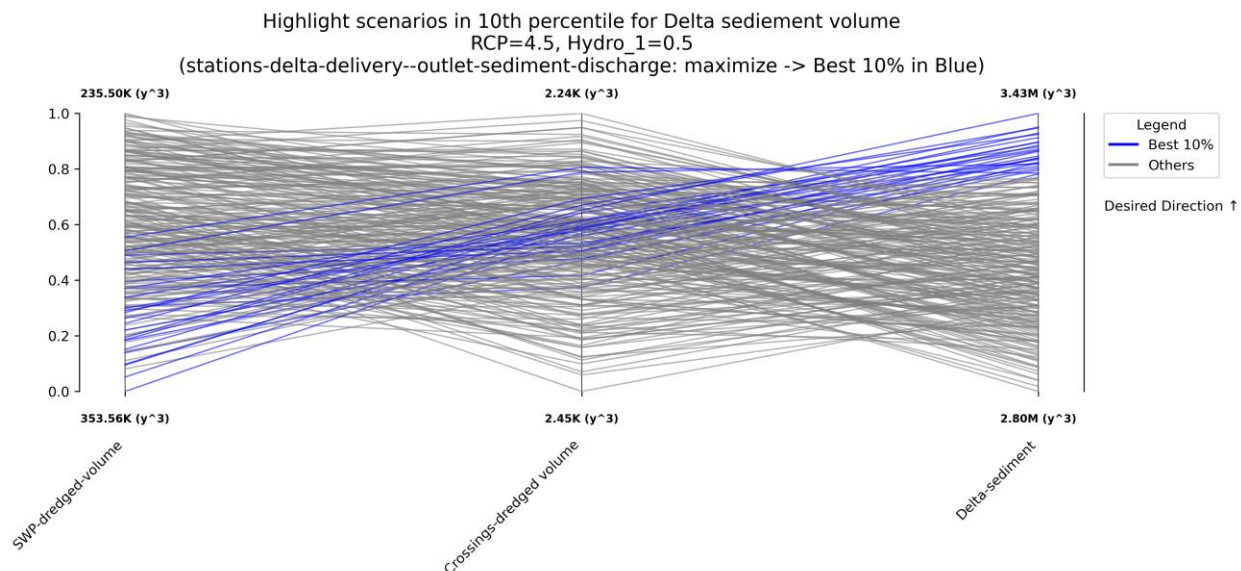


Figure 26. Tradeoff analysis focused on high-performing scenarios in the Delta Plain Sediment delivery metric.

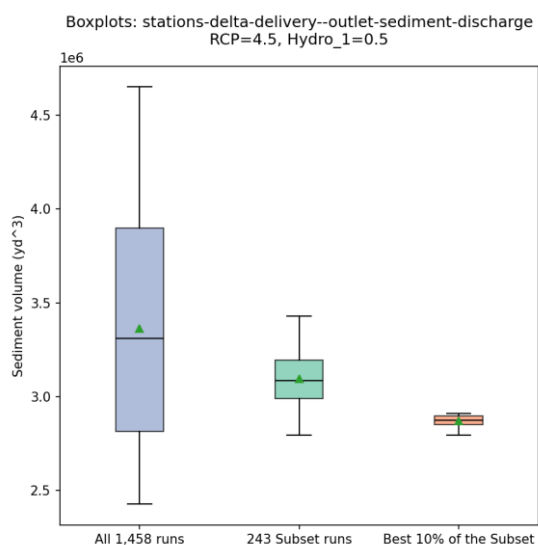


Figure 27. Distribution of Delta plain sediment delivery metric values. The boxplot illustrates the distribution of metric values, including the minimum, maximum, median (horizontal line), and mean (green triangle) for three different scenario sets. Outliers are represented by circles. From left to right, the boxplots show the distribution for all 1,458 runs in the BAU scenario, 243 runs in a specific environmental subset with Low SLR (RCP 4.5) and an average hydrograph (hydro\_1 = 0.5), and the top 10% of scenarios, which were highlighted in blue in the previous figure.



#### 5.2.1.4 What outlet discharge levers achieve better projected sediment delivery to Breton Sound and Barataria basins and reduce maintenance needs at Southwest Pass?

To answer this question, the same set of metrics was plotted but individual runs were highlighted based on the outlet discharge policy levers. This analysis revealed that the group of unmanaged outlets (Figure 28) and Neptune Pass (Figure 29) have a more direct impact on the performance of these metrics. Specifically, the high and non-high levels of these two outlet groupings show distinct differences in performance across some key metrics. Other outlet groupings that were considered did not exhibit a similar pattern.

The results show that high levels of discharge from unmanaged outlets are associated with relatively good performance in sediment metrics and Crossings dredged volume but were not associated with improved performance of the SWP dredge volume metric. By contrast, high levels of discharge from Neptune resulted in a relatively good performance in Breton sediment and SWP and Crossings dredged volume metrics but poor to average performance in Barataria sediment metric.

In summary:

- High discharge from Neptune can help both Breton sediment discharge and SWP navigation ease but understandably does not help Barataria sediment delivery.
- High discharge from the unmanaged outlets helps deliver more sediment to basins but does not improve SWP navigation maintenance.

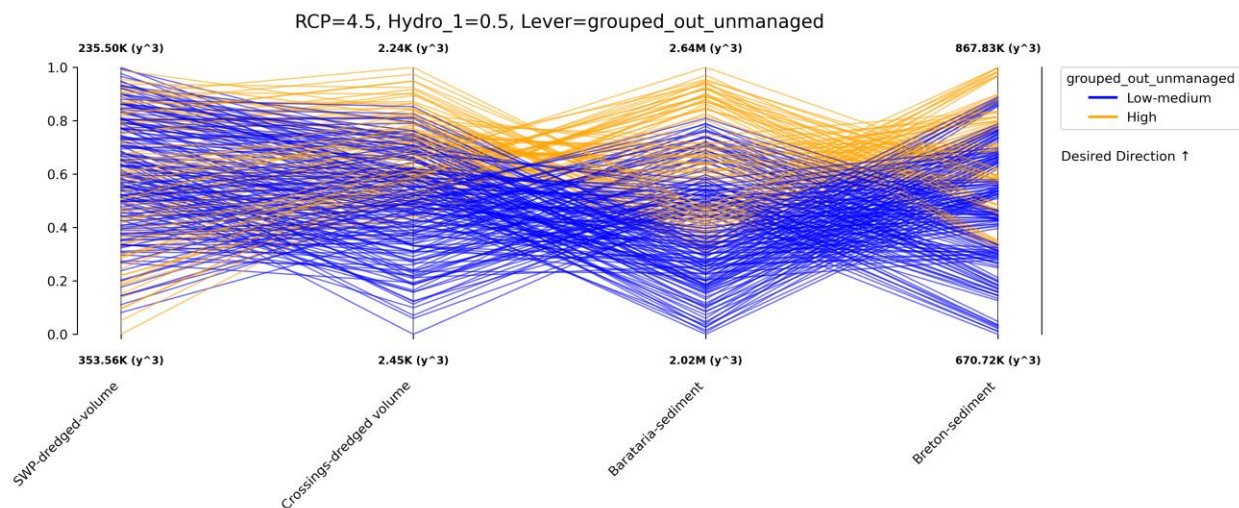


Figure 28. Policies within the environmental scenario are highlighted by the level of discharge allowed from the unmanaged outlets (high: orange, low-medium: blue).

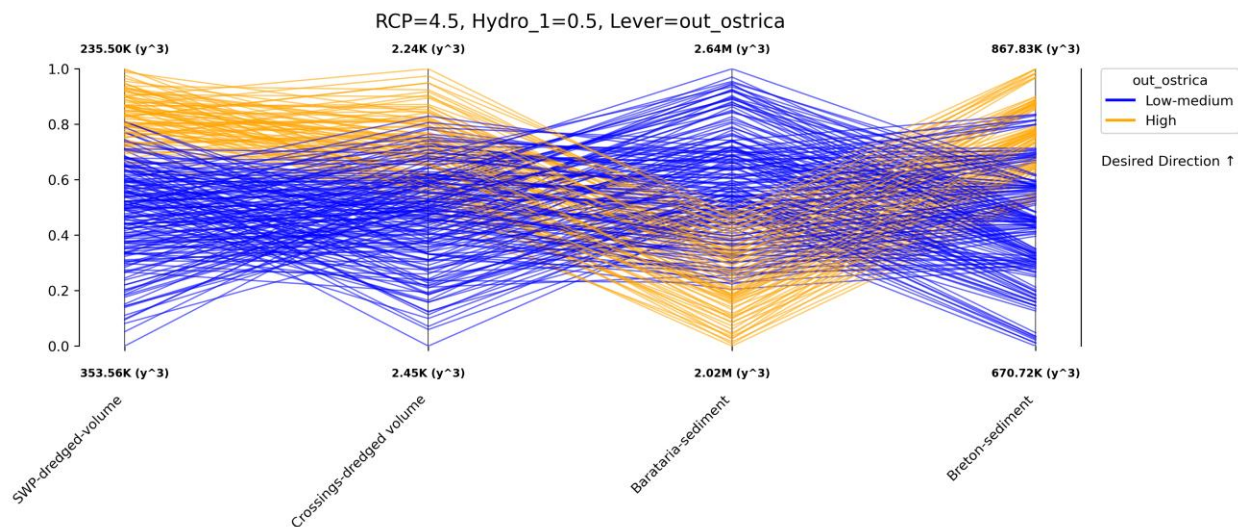


Figure 29. Policies within the environmental scenario are highlighted by the level of discharge allowed from the Neptune (high: orange, low-medium: blue).

#### 5.2.1.5 Do the scenarios that perform best across Southwest Pass dredge volume and basin sediment delivery metrics have anything in common regarding outlet discharge levels?

To address this question, the results under each of the three metrics were investigated to understand what combinations of outlet discharge levers the top-performing scenarios have in common. This was accomplished with a two-step process to screen the top scenarios: 1) Scenarios were ranked using the composite score to find the top ones, and 2) Within those top solutions, the “Pareto” set was identified where no other case is strictly better on all metrics.

For calculating the composite score, each metric was converted to a 0–1 scale based on whether the desired state is for the metric to be maximized or minimized, and the results are summed into a single “composite score.” Fifteen scenarios with the highest composite scores are then selected, and within those top solutions, the calculation for non-dominated scenarios resulted in 9 solutions (Pareto set). A solution is dominated if another is at least as good in every metric and strictly better in at least one. Note that these scenarios are top performers across metrics and differ from the best 10% of scenarios highlighted in Sections 5.2.1.1–5.2.1.3, which were selected based on the top 10% for individual metrics.

Figure 30 shows the 15 top performers based on the composite score in 243 scenarios representing low SLR and average hydrograph under the BAU strategy. The colored lines represent the ‘best possible’ (Pareto) scenarios within the highest composite scores. All of the ‘best possible’ scenarios have high levels of outlet discharge from unmanaged outlets and Neptune Pass, consistent with the findings in the previous section.

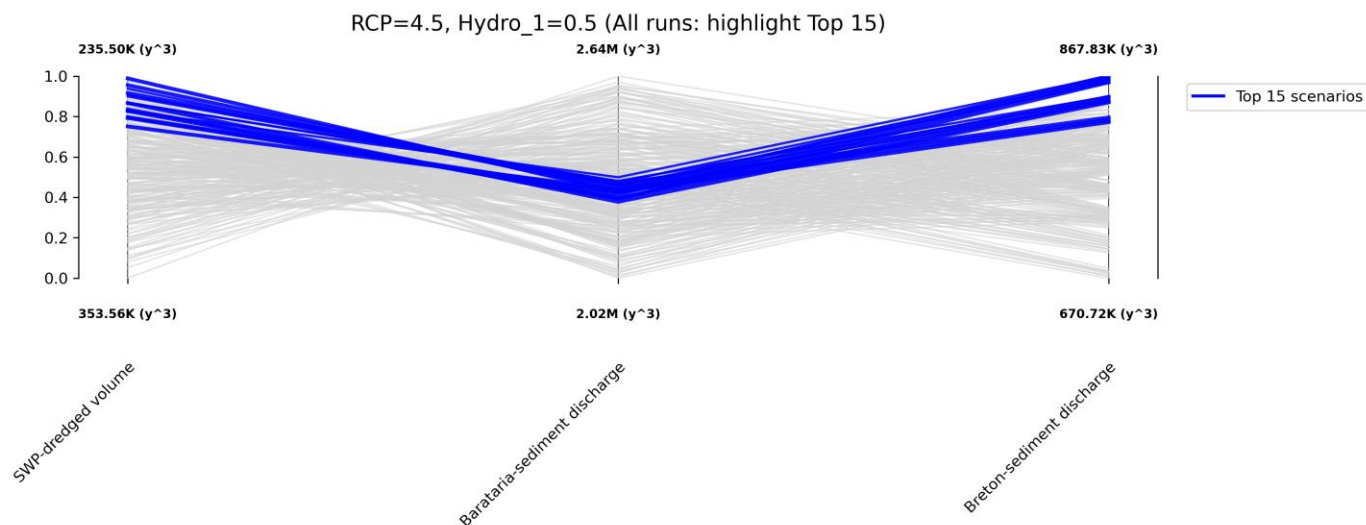


Figure 30. Top 15 scenarios based on the composite score.

Table 5. Combinations of the outlet discharge levels allowed in 9 Pareto scenarios in the top 15 BAU scenarios based on the composite score.

Diversion outlets	Lower outlets	Unmanaged outlets	Bonnet Carré	Neptune Pass
1	2	2	1	1.5
1	2	2	1.1	1.5
1	2	2	0.9	1.5
2	0	2	1.1	1.5
2	0	2	1	1.5
2	0	2	0.9	1.5
1	1	2	0.9	1.5
1	1	2	1.1	1.5
1	1	2	1	1.5

As can be seen from Table 5, all Pareto scenarios share the highest level of discharge allowed from unmanaged outlets and Neptune. The levels are mixed in all other outlets, showing their less direct impact on the overall performance of these three metrics.

### 5.2.2 Tradeoffs Between Strategies

The same style of tradeoff analysis that was used to compare the impact of policy levers within a strategy can also be used to compare performance between strategies.

Figure 31 shows the average performance of 243 scenarios under the selected environmental conditions (low SLR and average hydrograph) for each river management strategy. The BAU and adjusted flow strategies (Flatpeaks and Lowpeaks) generally perform better on sediment delivery metrics at Barataria and Breton but worse on the SWP dredging volume metric compared to alternative navigation strategies



(Turn Left and Turn Right). While the range of the Crossing metric is small, Turn Right appears to perform worse on this metric than the other management strategies.

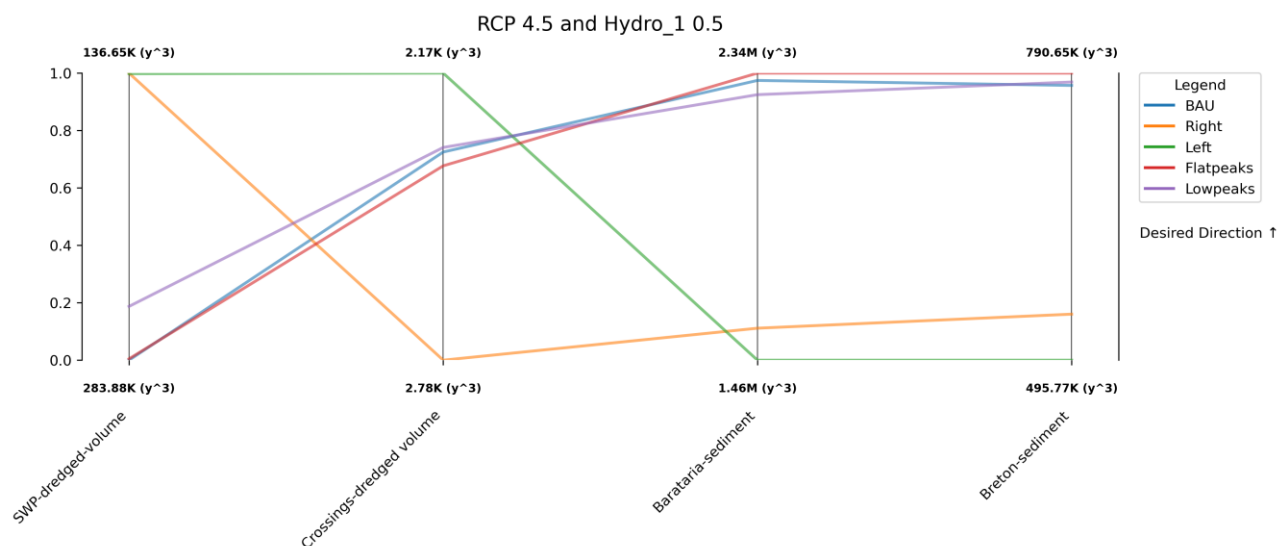


Figure 31. Tradeoffs between management strategies considering average performance in the environmental scenario.

Figure 32 to Figure 35 show the range of performance for each management strategy in the selected environmental scenario. A similar pattern emerges, where alternative navigation channel strategies reduce dredging needs at the no longer needed SWP but also decrease sediment delivery to the basin at both Barataria and Breton. The low values for dredging in the Crossings that are evident in Figure 33 and Figure 35 result from the hydrograph selection that was described in the introduction to Section 5.2.

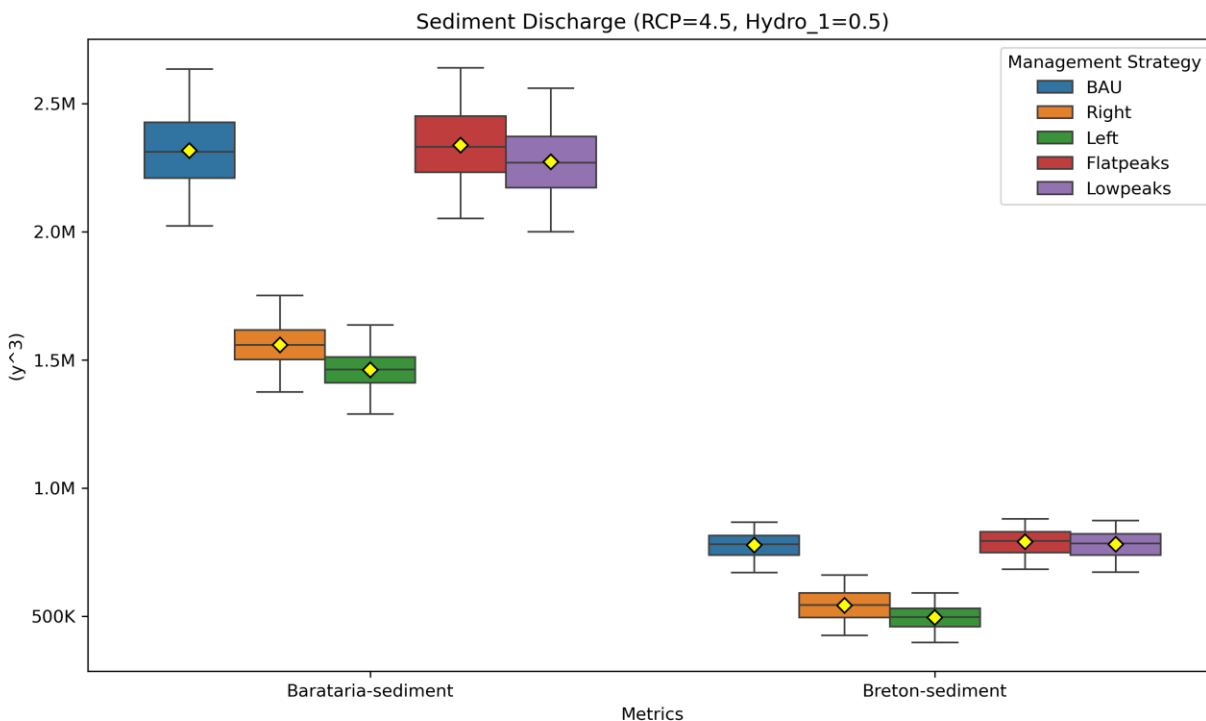


Figure 32. The performance of river management strategies in Barataria and Breton sediment delivery across in the selected environmental scenario.

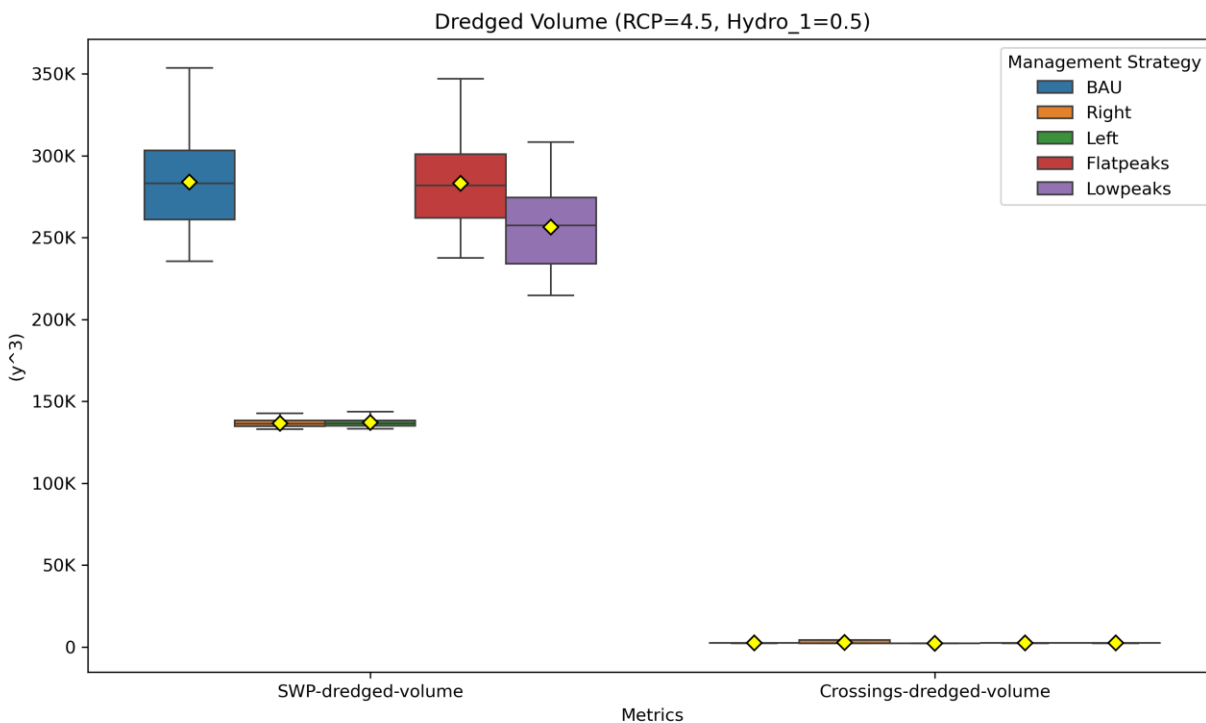


Figure 33. The performance of river management strategies in SWP and Crossings dredged volume metrics in the selected environmental scenario.



The range of performance for each management strategy across all environmental scenarios shows a similar pattern as well.

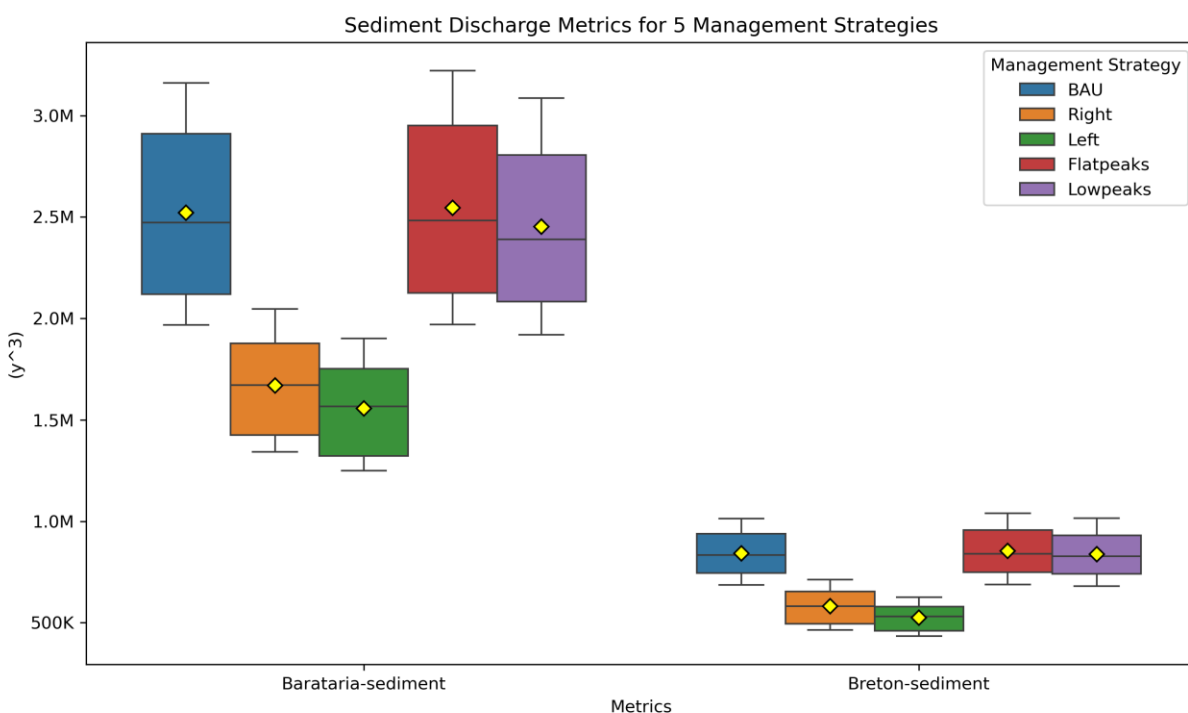


Figure 34. The performance of river management strategies in Barataria and Breton sediment delivery across all environmental scenarios.

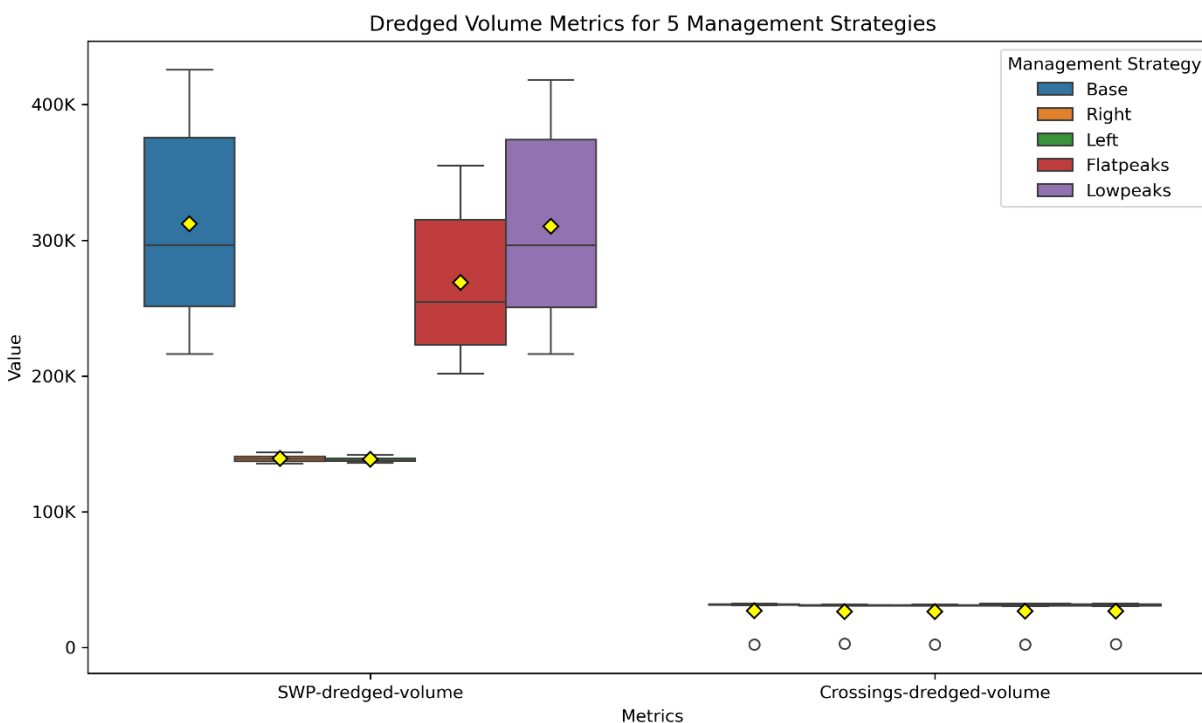


Figure 35. The performance of river management strategies in SWP and Crossings dredged volume metrics across all environmental scenarios

### 5.3 STUDY LIMITATIONS

This report describes the implementation of the LMR-DAF to project the performance of distinct river management strategies as they were represented by the underlying HEC-RAS model. Tackling real-world policy decisions with this tool will require broader stakeholder involvement (Dalyander et al., 2022), a rigorous review of historical data and future predictions, and a comprehensive analysis with an exhaustive examination of strategies, forcings, and levers. As well, the choice of thresholds and vulnerability criteria and the weighting of their importance can significantly change the outcomes of the analysis and the rankings of the “best” solutions. Moreover, the judgment of performance (better or worse) in each metric is based on its relative range within the model outputs.

The interpretation of the numerical results must also be tempered with the simplicity of the way in which outlet configurations were modified, boundary conditions were configured, the chosen model domain, and the single bathymetric initial condition that was used. These results do well to demonstrate the capability of the automation system to modify, execute, and analyze model results. However, these results are best viewed as a firm foothold from which further progress can be made rapidly through refinement of the way management strategies, boundary conditions, and other model information are collected and implemented.

The results of this work provide a novel decision-support framework for evaluating large-scale management strategies under environmental scenarios that come with large uncertainty over the long term (e.g., 50 years). However, it is beyond the scope of the present effort to investigate the physical basis for



every result, to improve or recalibrate the numerical model on the basis of those investigations, or to iteratively improve upon the decisions to identify an optimal implementation of any given strategy.





## 6 CONCLUSIONS AND NEXT STEPS

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A key takeaway from the vulnerability analysis is that the influence of uncertain environmental factors versus policy decision levers depends on the metric of interest. Environmental uncertainties (such as eustatic sea level rise (SLR) and Mississippi River discharge) may dominate some metrics' vulnerability, while others allow more room for policy levers (such as outlet discharge rates) to mitigate it. For example, in the sample results, outlet discharge levers have a greater influence on the Southwest Pass (SWP) dredge metric, while environmental uncertainties are solely responsible for driving vulnerability in the Baton Rouge flood metric. While these findings should be interpreted with caution due to the limitations discussed in Section 5.3, they offer valuable guidance on when and how to use decision levers.

Tradeoff analyses further provide valuable insights into how different outlet discharge configurations affect specific metrics performance. For example, the demonstration results show that, for dredging metrics and sediment delivery, Neptune and the unmanaged outlets play a more direct role in management strategy performance. However, these dynamics may shift depending on the metrics analyzed. Understanding these tradeoffs helps decision-makers design policy levers that align with management goals while minimizing inefficiencies.

Tradeoff analyses also highlight how different river management strategies perform across various metrics. For instance, the sample results indicate that sediment delivery to basins is significantly higher under the Business-as-Usual (BAU) and adjusted flow strategies compared to alternative channel configurations. While this outcome may be expected based on the fundamental characteristics of the management strategies, applying the same approach to other metrics can reveal more nuanced tradeoffs into how policy levers interact with environmental scenarios. For example, the most effective outlets for intervention may differ between a high SLR scenario with wet river hydrographs and a low SLR scenario with dry conditions.

In both the tradeoff and vulnerability analyses, the treatment of outlets is an important lever to influence outcomes in the river. The specific groupings that were used in this project can be investigated for future studies, but their importance in driving this analysis underscores the need to consider the entire network of outlets in the lower river as an important component of any river management strategy.

Finally, this project represents a significant advance in the technical capacity connecting numerical modeling with decision support. To connect a deterministic numerical model with a decision analysis framework, a custom model simulation framework was developed using Python 3.9 and configured for each management scenario. The custom model automation system translates a management scenario configuration into run-specific model simulation information. As shown in this study, it is tractable to create a multiprocessing controller that copies a HEC-RAS model, modifies files for run-specific conditions, controls HEC-RAS simulation, and samples HEC-RAS outputs in batches. This functionality is novel, as the selected simulation model (HEC-RAS) does not include utilities of its own to perform these tasks. Furthermore, execution of thousands of HEC-RAS simulations can be performed on relatively modest computational hardware in relatively reasonable runtimes.



In this example, a high-performance desktop equivalent virtual machine was able to complete simulation of a management scenario (1,458 runs) in approximately 1.5 days. This performance allows for iteration and refinement of simulation configuration without significant delays. Once complete, the LMR-DAF includes a set of Robust Decision Making (RDM) analysis notebooks which can reproduce the demonstration analysis contained in this report, but also offers a template for the creation of new RDM analyses from future simulations.

## 6.1 NEXT STEPS

To extend this work, it is recommended that CPRA consider the following:

- Extend the runs to full 50-year morphological simulations. This was not possible within the current project both because of the time necessary to run longer morphology models, and because of the time required for validation, but it is a natural and achievable next step now that a prototype LMR-DAF has been successfully implemented.
- Continued interaction with stakeholders to identify and refine management strategies, review output, identify thresholds, and specify where the choice of modeled strategies, scenarios, and levers does and does not reflect real-world decision making.
- Incorporate data driven hindcasts into the workflow. This would show the performance of outcome metrics for time periods that decision makers and CPRA are familiar with and help build connections for stakeholders to interact with the results.
- Develop a suite of visualizations and interactive user tools to enable efficient and in-depth inspection of results during stakeholder engagements.
- Adjust the dredging routines in the HEC-RAS model so that they are more in sync with real-world operational dredging decisions. This will require both model improvements and continuing sustained interaction with USACE dredging operations managers.
- Apply the automation system to one or several other HEC-RAS models, or link the framework to other automated models. There is no one numerical model that can capture all of the behavior necessary to guide decision making on the river. The automation capability developed for this project can play a major role in addressing that common limitation.



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## APPENDIX A. ALTERNATIVE FLOW SPLIT DEFINITIONS

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In the Adjusted Flow Ratio at the Old River Control Structure (ORCS) strategy, the input hydrograph was altered so that the upstream boundary condition yields flows in the main stem that are consistent with the flow ratios used Scenarios 4 – 8A in the Old River, Mississippi River, Atchafalaya River, and Red River (OMAR) Study (see Table 4 in Lewis et al., 2022).

The upstream boundary that is implemented in the Business-as-Usual scenarios is assumed to represent 70% of the combined flow of the Mississippi and Red Rivers, consistent with the existing policy for operating the Old River Control Structure. Below are descriptions of how each alternative is implemented for the Alternative Flow Split at ORCS scenarios, with  $Q_{bau}(t)$  representing the water discharge at the upstream boundary as it is implemented in the BAU case.

Note that variants that increased flow in the main stem of the river were not stable in the HEC-RAS model (Section 2.1.3), so HIGHPEAKS and LOWDIVERT were not analyzed, but are included here because they are available in the coded framework..

**LOWPEAKS:** 60/40 during high flow, with 70/30 on long-term basis through water volume tracking. High flow is defined in the OMAR Study as when the discharge at Tarbert Landing exceeds 1Mcfs.

$$Q_{alt}(t) = \begin{cases} \frac{6}{7} Q_{bau}(t), & \text{for } Q_{bau}(t) > 1,000,000 \text{ cfs} \\ Q_{bau}(t), & \text{for } Q_{bau}(t) \leq 1,000,000 \text{ cfs} \end{cases}$$

**HIGHPEAKS.** 80/20 during high flow, with 70/30 on long term basis through water volume tracking.

$$Q_{alt}(t) = \begin{cases} \frac{8}{7} Q_{bau}(t), & \text{for } Q_{bau}(t) > 1,000,000 \text{ cfs} \\ Q_{bau}(t), & \text{for } Q_{bau}(t) \leq 1,000,000 \text{ cfs} \end{cases}$$

**FLATPEAKS.** Keep the hydrograph as defined except impose a maximum discharge of 1.25 Mcfs.

$$Q_{alt}(t) = \begin{cases} 1,250,000, & \text{for } Q_{bau}(t) > 1,250,000 \text{ cfs} \\ Q_{bau}(t), & \text{for } Q_{bau}(t) \leq 1,250,000 \text{ cfs} \end{cases}$$

**LOWDIVERT.** Adjust the split to be 80/20 at all times.

$$Q_{alt}(t) = \frac{8}{7} Q_{bau}(t)$$



## APPENDIX B. SEASONAL CORRECTIONS TO HYDROGRAPHS

Prior to generating the representative hydrographs, the predictions at Tarbert Landing were assessed by comparing the hindcast period to observational flow data from the same period. This comparison identified a persistent bias in the model predictions that varied by month (Figure B-1).

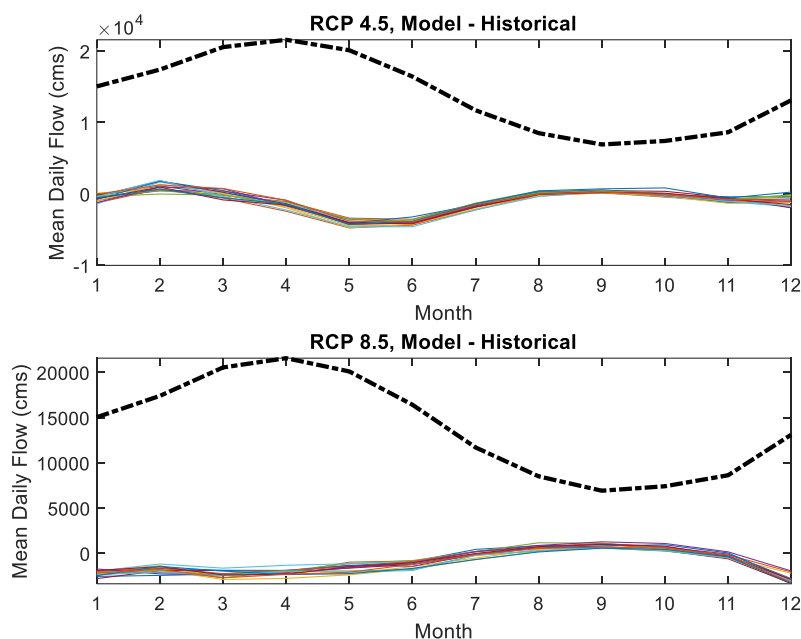


Figure B-1. Comparison of monthly mean daily flow values at Tarbert Landing for 1950-2005 from gauge data (black dashed line) to 16 model predictions for RCP 4.5 (top) and 8.5 (bottom) climate scenarios. Note that here flows are given in cubic meters per second (cms).

This bias was calculated for each model, RCP scenario, and month, then corrected for in the model predictions (i.e., the correction for each month was applied to that month for all years), which removed the bias (Figure B-2) while preserving the peaks and variability in the flow (Figure B-3 and Figure B-4).

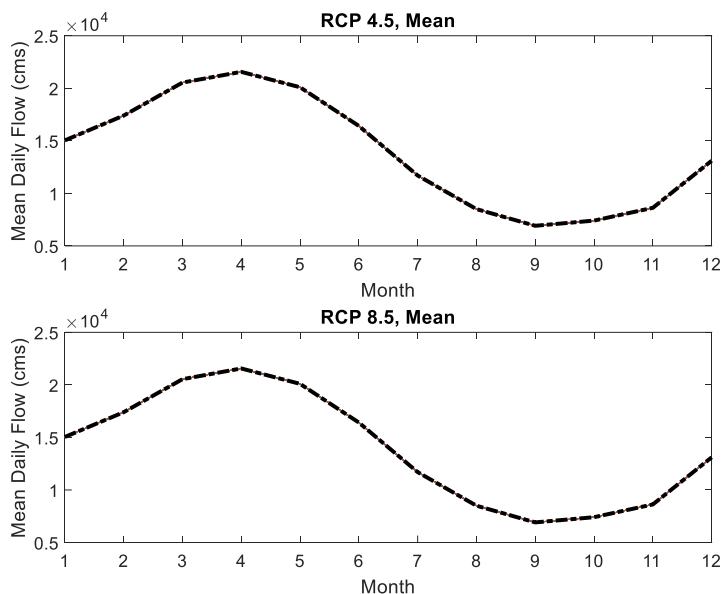


Figure B-2. Model predictions for 1950-2005 corrected based on calculated monthly bias for the RCP 4.5 (top) and RCP 8.5 (bottom) climate scenario. The observational data (black dashed line) falls on top of the model predictions (colored lines). Flows are given in cubic meters per second (cms).

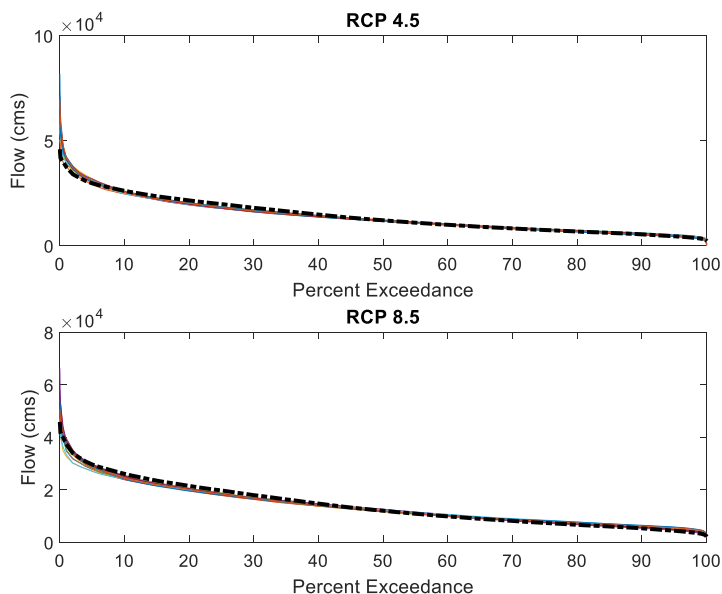


Figure B-3. Percent exceedance for corrected model predictions of flow (colored lines) compared to observed (black dashed line) for the RCP 4.5 (top) and RCP 8.5 (bottom) climate scenario. Flows are given in cubic meters per second (cms).

After correcting for bias, the process of generating the representative hydrographs consisted of the following:

1. Identify a target flow duration curve for each climate scenario, weather condition (wet, dry, and average), and future decade through statistical analysis of the 16 model predictions (50<sup>th</sup>



percentile for average scenario, 10<sup>th</sup> percentile for dry scenario, and 90<sup>th</sup> percentile for wet scenario);

2. Identify the model prediction that most closely matches the target flow duration curve for that weather condition, scenario, and decade by minimizing the sum of squared differences between the flow duration curve for each prediction and the target;
3. Apply the best match scenario for each decade as the representative hydrograph (boundary condition) for the Lowermost Mississippi River Management Program (LMRMP) model for that weather condition and climate scenario.

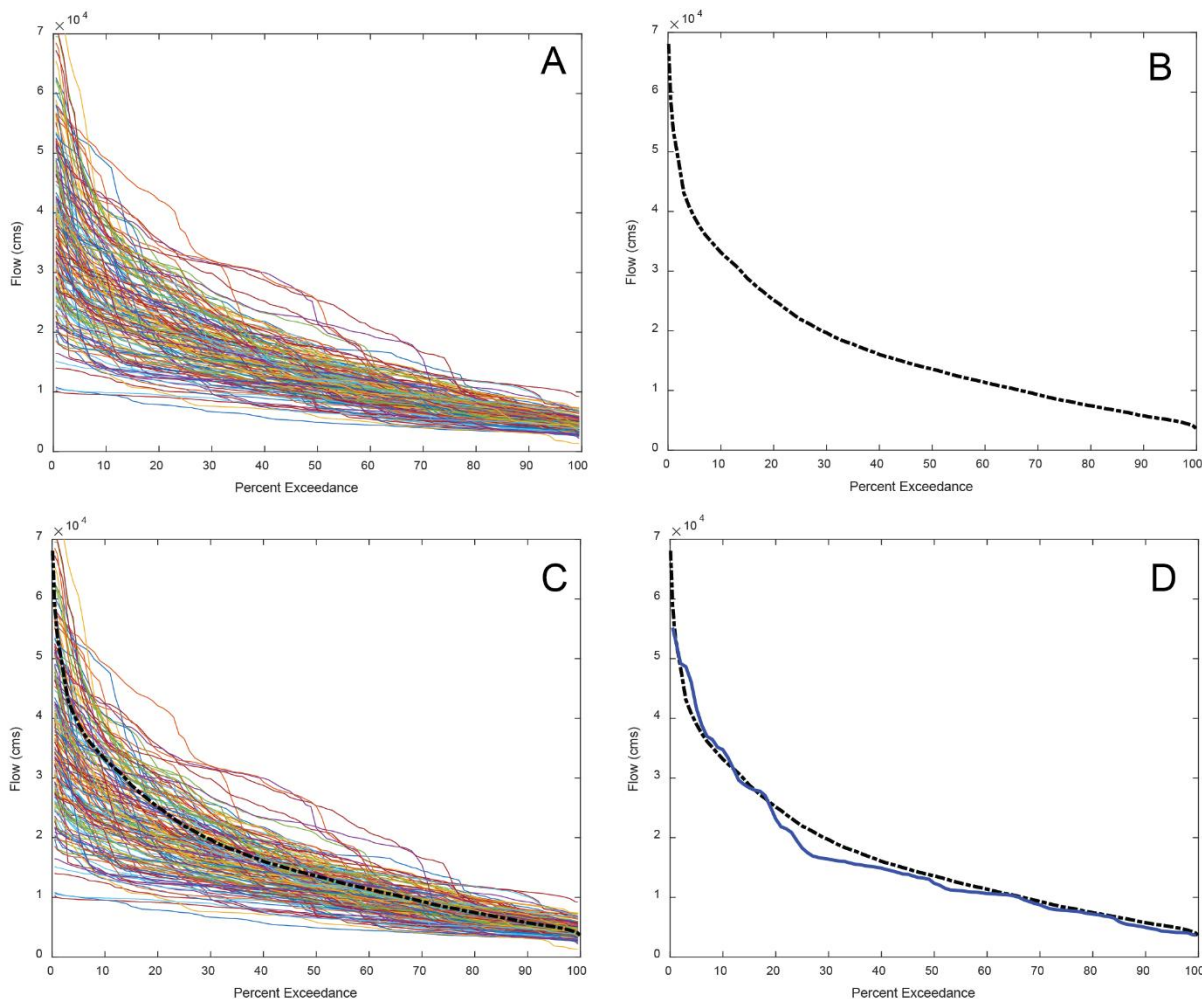


Figure B-4. Illustration of selection of best-match hydrograph for each climate and weather scenario. The suite of yearly model predictions for a particular climate scenario and decade (A; shown is RCP4.5 for the 2040s) is compared to a target flow exceedance curve calculated as a percentile across predictions for that decade for all years and model predictions (B; shown is the 50<sup>th</sup> percentile). The year and model prediction for that climate scenario and decade that best matches the target (i.e., lowest least-square difference) (C; colors are the model predictions, black dashed line is the target) is selected as the hydrograph for that climate scenario, weather condition, and decade (D; compares chosen hydrograph, in blue, to target, black-dashed line). Flows are given in cubic meters per second (cms).



## APPENDIX C. OUTLET RATING CURVES

Base case rating curve for every outlet included in the HEC-RAS model.

Lateral Weir - Bonnet Carre - Diversion RC (Dummy Weir)

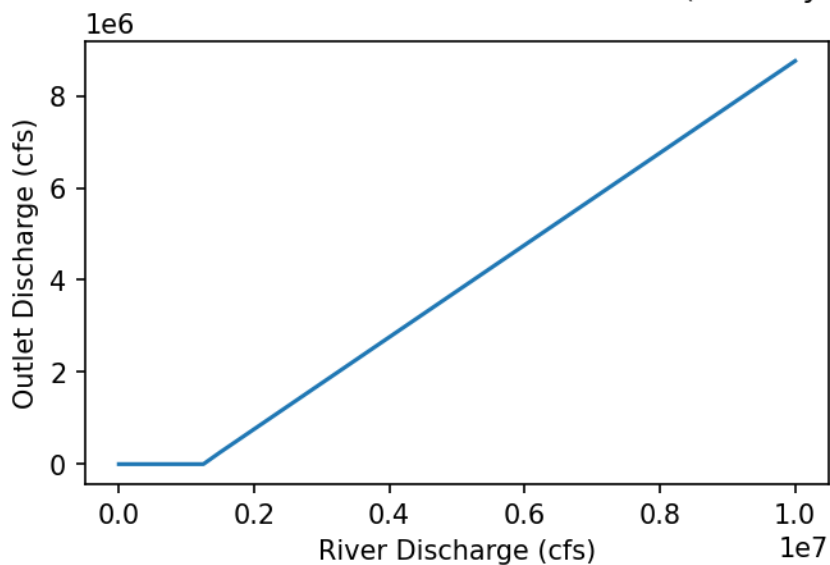


Figure C-1. Bonnet Carré outlet rating curve.

Lateral Weir - Davis Pond Diversion - Diversion RC (Dummy Weir)

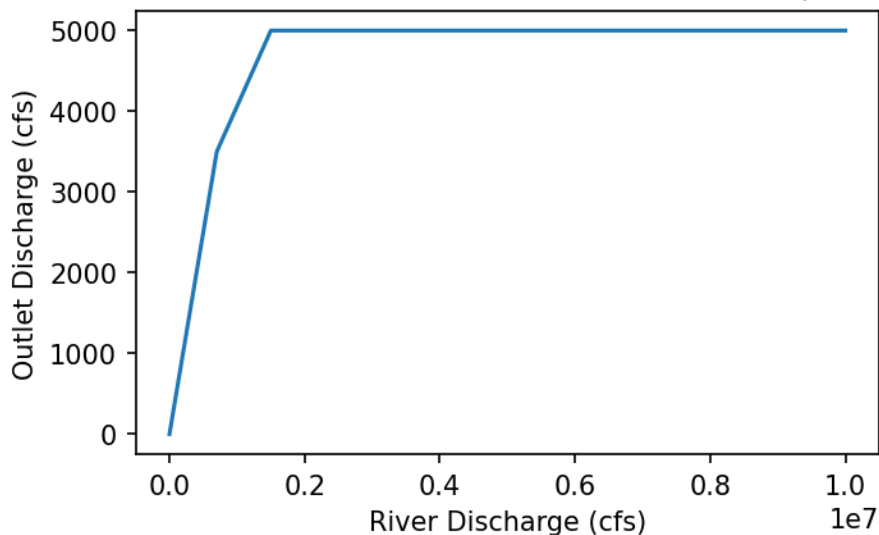


Figure C-2. Davis Pond outlet rating curve

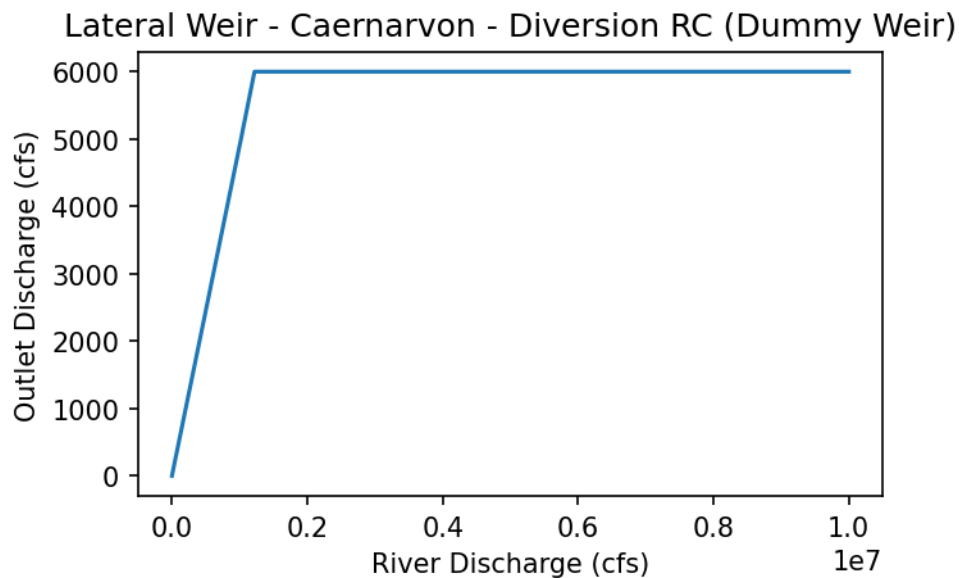


Figure C-3. Caernarvon outlet rating curve

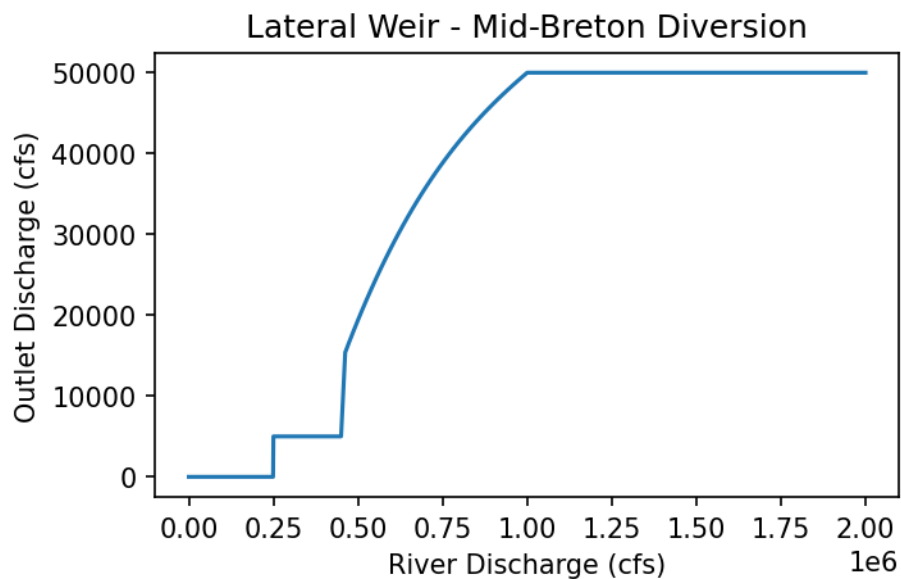


Figure C-4. Mid-Breton outlet rating curve

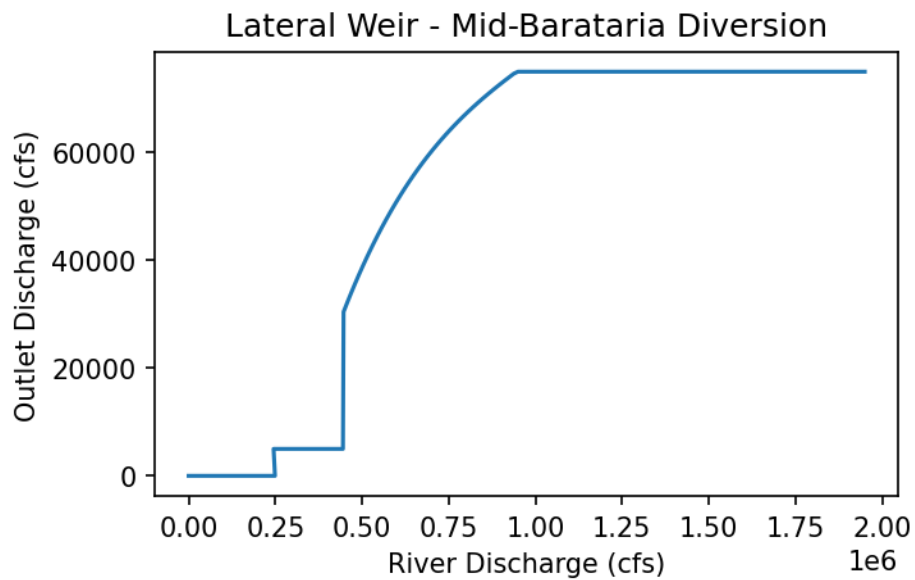


Figure C-5. Mid-Barataria outlet rating curve

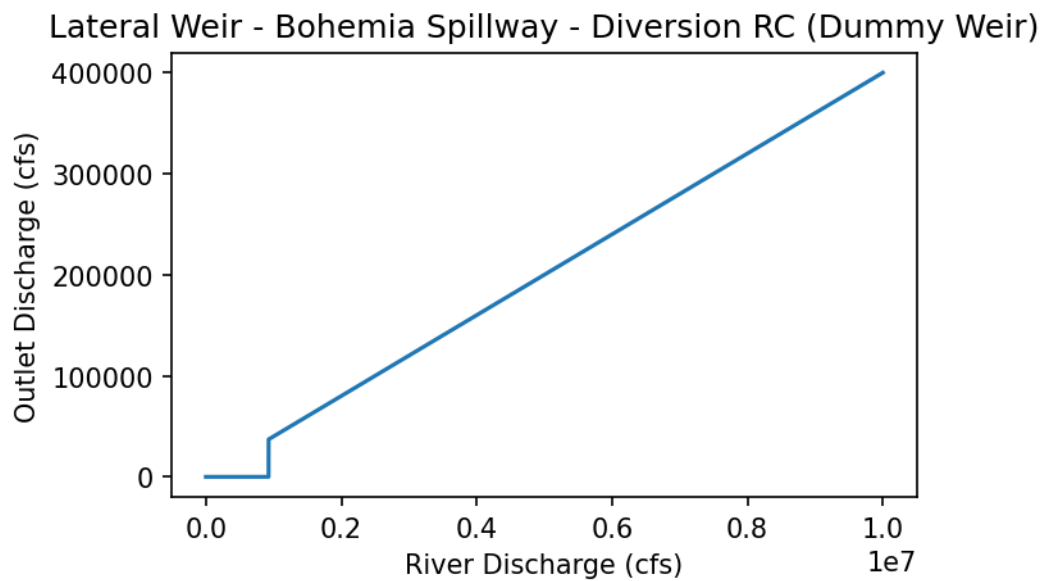


Figure C-6. Bohemia outlet rating curve

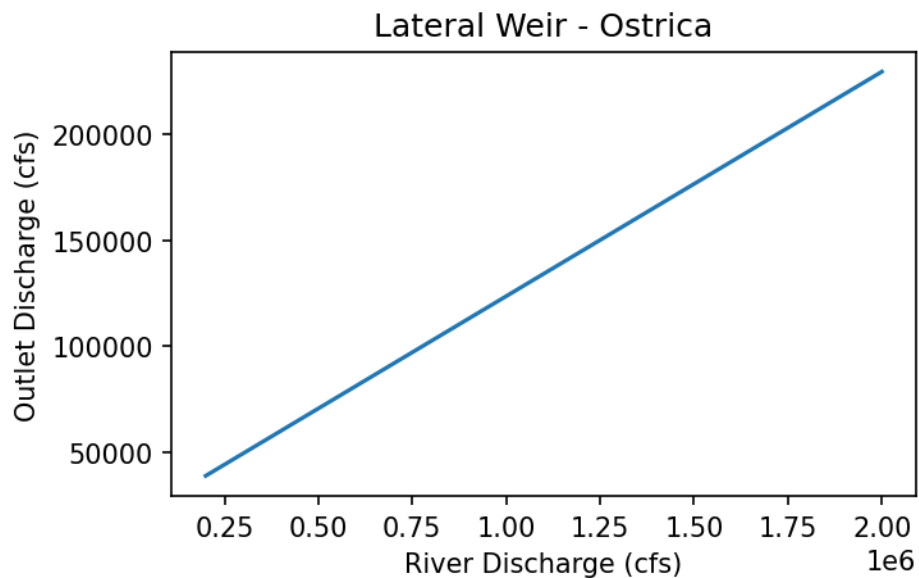


Figure C-7. Neptune Pass outlet rating curve

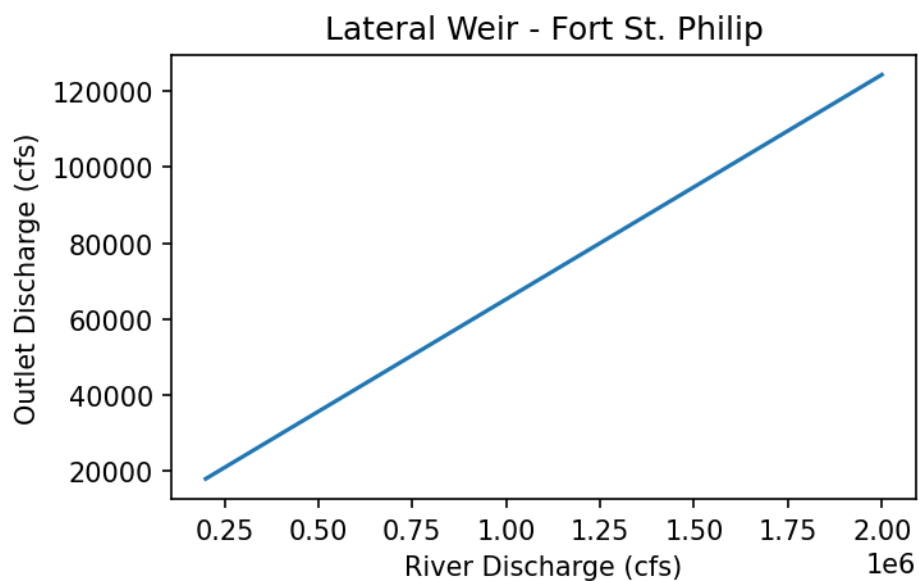


Figure C-8. Fort St. Philip outlet rating curve



### Lateral Weir - Baptiste Collette - Diversion RC (Dummy Weir)

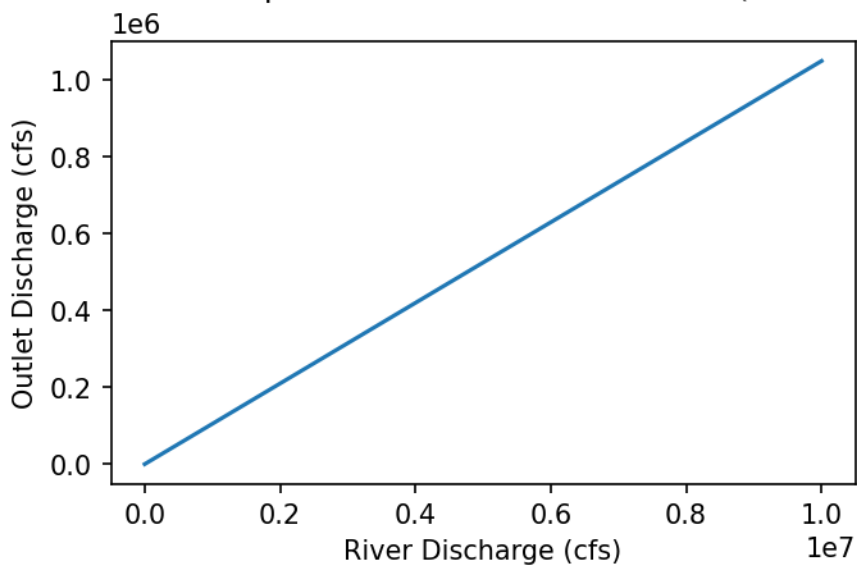


Figure C-9. Baptiste Collette outlet rating curve

### Lateral Weir - Grand Pass - Diversion RC (Dummy Weir)

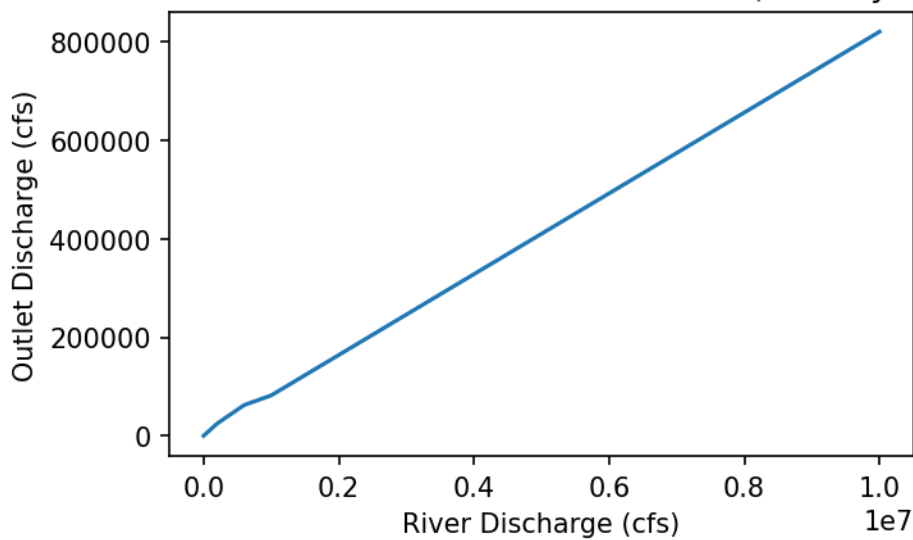


Figure C-10. Grand Pass outlet rating curve



### Lateral Weir - West Bay + Cubits Gap and Overbank Flows - Diversion RC (Dummy Weir)

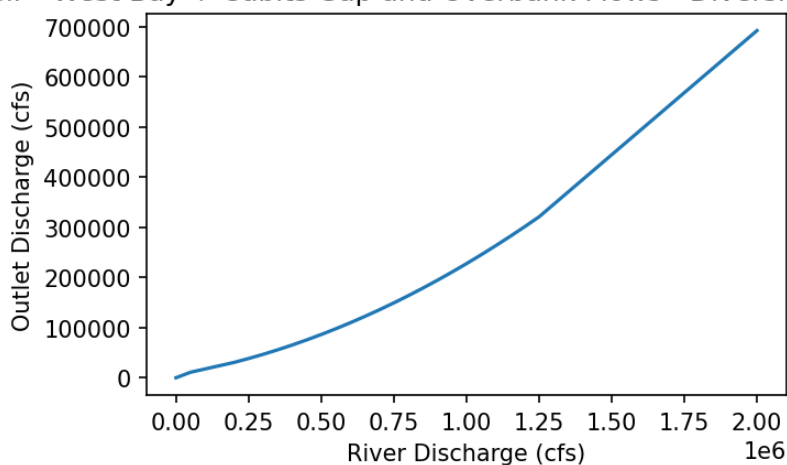


Figure C-11. Rating curve for the combined West Bay + Cubit's Gap outlet

### Lateral Weir - South Pass and Pass a Loutre - Diversion RC (Dummy Weir)

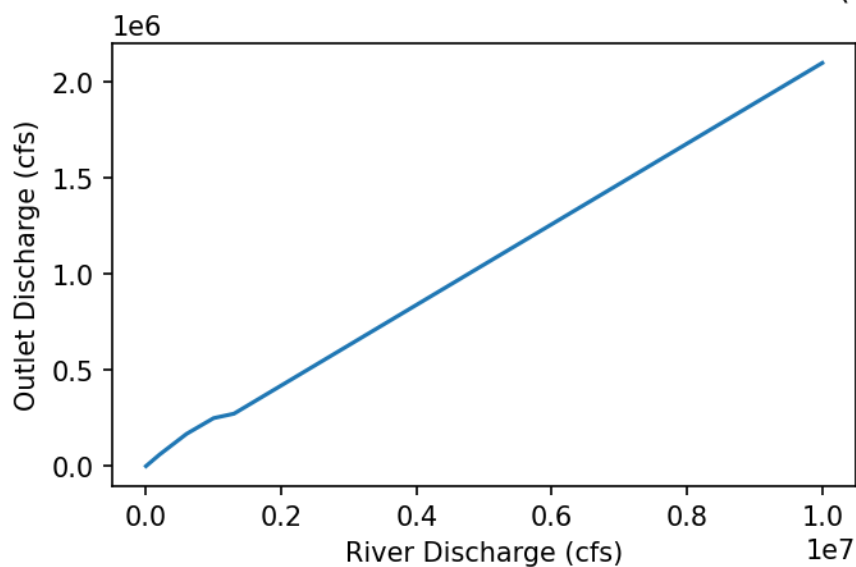


Figure C-12. Combined rating curve for the South Pass + Pass a Loutre rating curve



### Lateral Weir - Southwest Pass at Mile 3.0 West - Diversion RC (Dummy Weir)

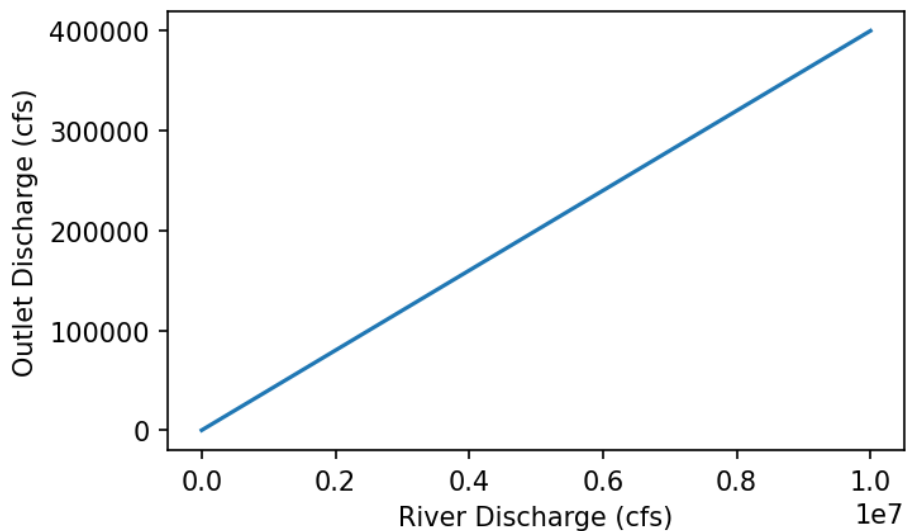


Figure C-13. Rating curve for the SWP Mile 3 crevasse outlet

### Lateral Weir - Joseph Bayou - Diversion RC (Dummy Weir)

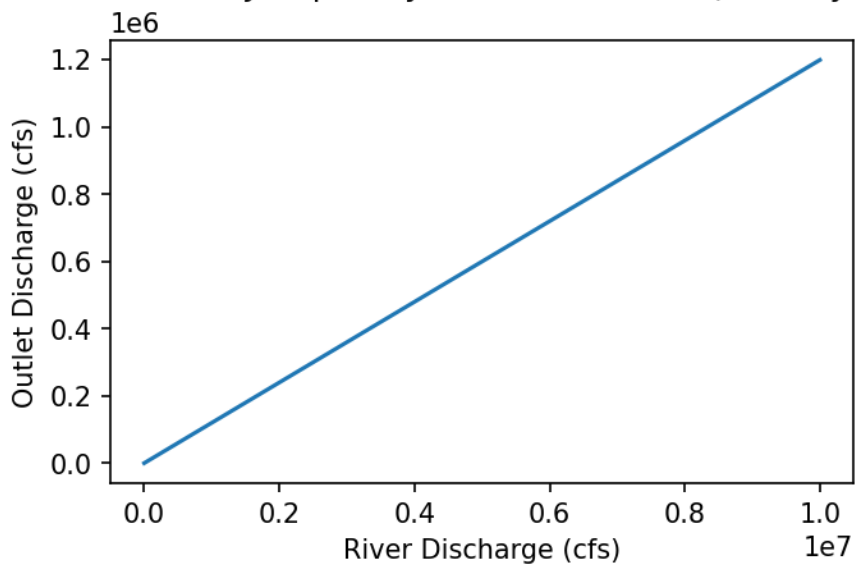


Figure C-14. Joseph Bayou outlet rating curve



### Lateral Weir - Outlet W-2 and Overbank Flows - Diversion RC (Dummy Weir)

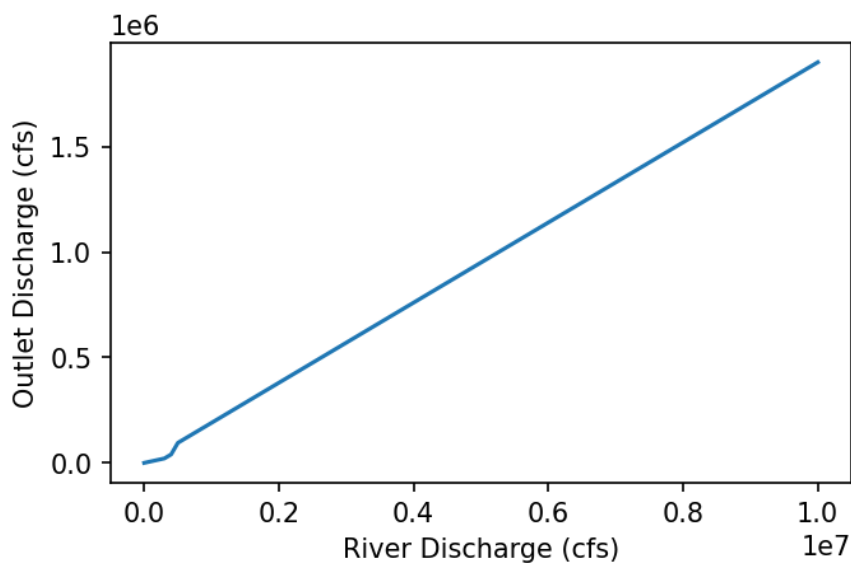


Figure C-15. Outlet for crevasses and overbank flows in SWP.

### Lateral Weir - Burrwood Bayou - Diversion RC (Dummy Weir)

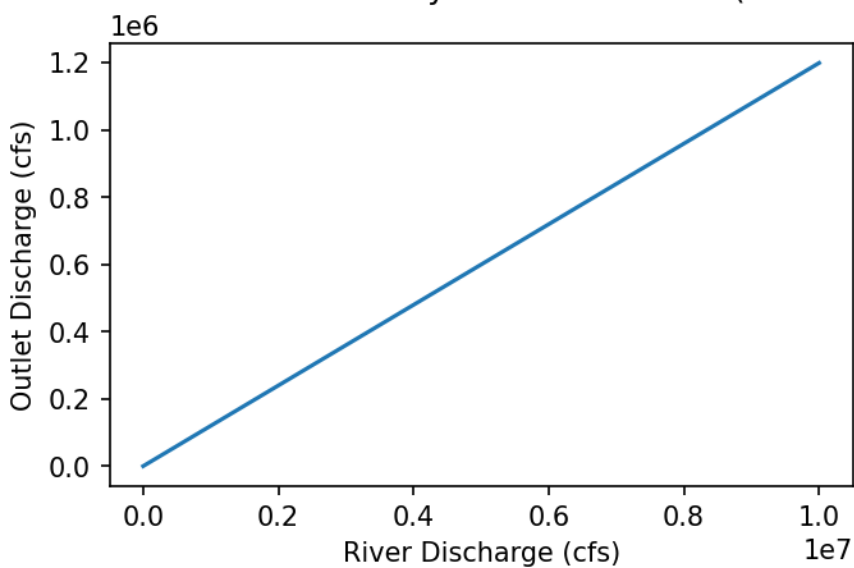


Figure C-16. Burrwood Bayou rating curve.



## APPENDIX D. COST TO RUN THE RIVER

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### Standardized Cost Compilation for Mississippi River Maintenance and Infrastructure

This analysis compiles and standardizes historical federal investment data related to the maintenance and infrastructure of the Lower Mississippi River (LMR), focusing on dredging and civil works activities. The objective is to provide a consistent financial baseline—expressed in constant 2022 dollars—to support future planning, economic evaluation, and strategy development for river operations and sediment management. Standardizing costs in this way eliminates the effects of inflation, allowing for meaningful comparisons of expenditures across different fiscal years.

It is important to note that the available data used in this cost analysis have varying levels of resolution. Many civil works expenditures sourced from work plans are reported at a U.S. Army Corps of Engineers (USACE) Division level, rather than a District or project level, making it difficult to isolate costs specific to the LMR or to any single state such as Louisiana. The clarity and granularity of project descriptions also vary significantly across fiscal years, with some line items referencing basin-wide activities (e.g., Atchafalaya Basin) not directly tied to Mississippi River navigation or infrastructure. In addition, dredging costs are sometimes captured in both project-level records and Division-level work plans, creating the potential for partial double-counting when expenditures are combined. These limitations should be kept in mind when interpreting the standardized cost summaries presented in this appendix. Accordingly, when evaluating dredging costs for the Lowermost Mississippi River, the project-level records compiled from the USACE New Orleans District (MVN) should be considered the most reliable and preferred dataset (Section D.1).

All cost data were adjusted using the USACE Civil Works Construction Cost Index System (CWCCIS), in accordance with guidance set forth in Engineer Manual EM 1110-2-1304 (USACE, 2021). Sections D.1 and D.2 used the following formula to adjust cost to 2022 dollars:

$$\frac{\text{Avg. Cost Index of Subset of Feature Codes: Year 2022}}{\text{Avg. Cost Index of Subset of Feature Codes: Year A}} \times \text{Cost in Year A (Known)} = \text{Cost in Year 2022 (Unknown)}$$

#### Supplemental Files:

The following files include excel spreadsheets that detail cost calculations for this analysis, along with supporting data.

#### Mississippi River Ship Channel Navigation Maintenance Dredging Costs:

Filename: Dredging Report Master Sheet (96-21) Prices Converted to Present.11.10.22

Supporting Data: Multiple .pdf records (FY 1996-2021) of dredging records sourced from USACE MVN.

#### Mississippi River and Tributaries Program Costs:

Filename: MR&T\_Cost\_FY2011to2022



Supporting Data: Multiple .pdf records (FY 2011-2022) of Mississippi River and Tributaries Work Plans detailing program costs.

**Cost Summary:**

Filename: LMRMP\_annual\_costs

Supporting Data:

- Dredging Report Master Sheet (96-21) Prices Converted to Present.11.10.22
- MR&T\_Cost\_FY2011to2022

## **D.1 MISSISSIPPI RIVER SHIP CHANNEL NAVIGATION MAINTENANCE DREDGING COSTS**

Dredging cost data were compiled for the Lowermost Mississippi River using records from the USACE New Orleans District (MVN) spanning federal fiscal years 1996 through 2019 and are included in this appendix. Some of this effort was carried out jointly by Royal Engineering and The Water Institute (Miner et al., 2024). Relevant feature codes derived from CWCCIS (Navigation Ports & Harbors, Channels and Canals, and Beach Replenishment) were averaged, then a multiplier was calculated to adjust cost by fiscal year based on the average of those feature codes' cost indices from fiscal year 2022.

Data from federal fiscal years 2020 and 2021 were not included in this analysis due to incomplete records; while dredged volumes were available, contract cost information was missing for those years, which precluded the calculation of meaningful unit costs. The dataset was organized by fiscal year and dredging reach—for example, Redeye Crossing—with each record capturing both the total volume dredged and the associated contract expenditure. These records were then used to calculate average unit costs on a per-cubic-yard basis for each location and year. An Excel workbook containing the detailed results and calculation methodology is included as an attachment to this appendix. The referenced workbook is Dredging Report Master Sheet (96-21) Prices Converted to Present.11.10.22, with dedicated tabs and calculations by fiscal year, 2022 dollars per cubic yard on tab 'All Reaches Summary', and overall Mississippi River dredging costs (2022 dollars) on tab 'Summary (Converted Prices)'. A summary of Mississippi River annual dredging costs is shown in Figure D-1.

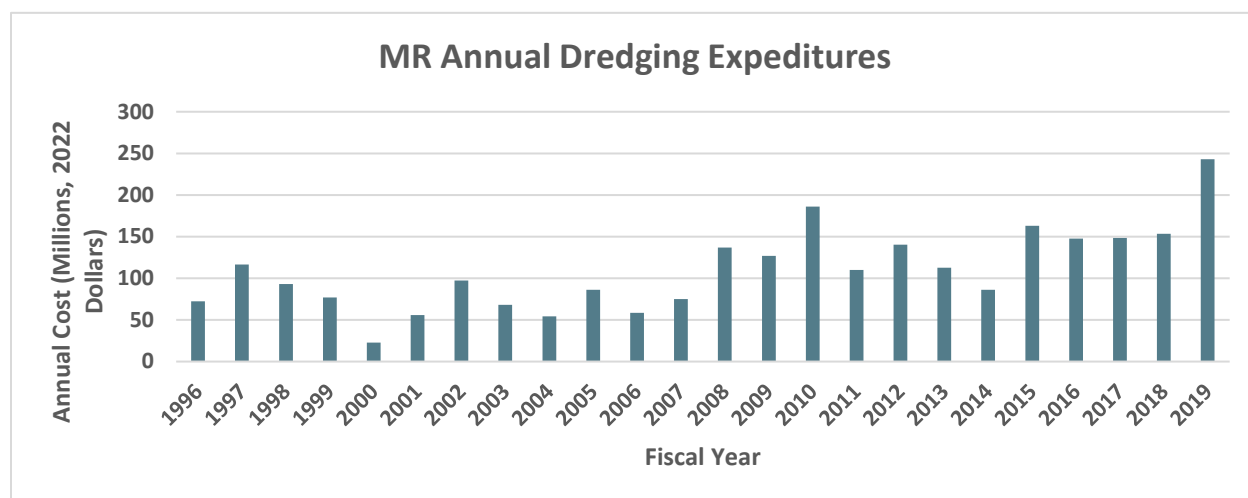
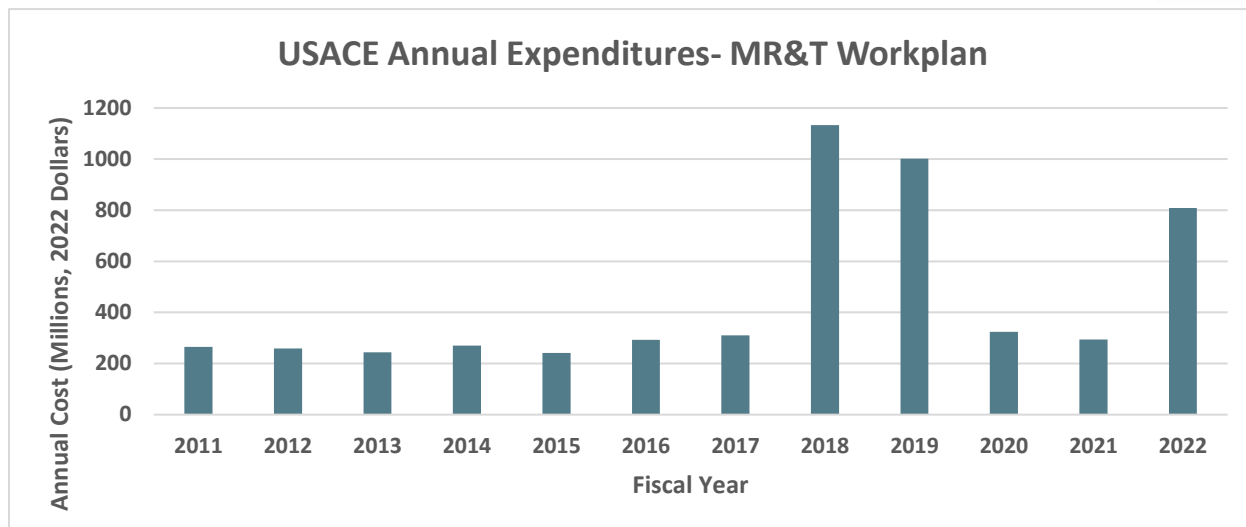


Figure D-1. Annual expenditures derived from USACE dredging data. Costs include dredging operations from multiple locations (Shallow Draft Crossings, Deep Draft Crossings, Southwest Pass, etc.). For a detailed breakdown of locations, refer to attachment on dredging costs and calculations.

## D.2 MISSISSIPPI RIVER AND TRIBUTARIES PROGRAM COSTS

In addition to dredging, cost data were compiled for items such as levees, revetments, and structural improvements as part of the Mississippi River and Tributaries (MR&T) civil works program. This information was sourced from publicly available USACE Civil Works budgets. Publicly available records include both budget justification sheets and annual work plans. Justification sheets are pre-appropriations documents submitted as part of the President’s Budget, whereas work plans reflect final post-appropriations funding allocations. Work plans are only available on record starting for fiscal year 2011. This analysis cataloged work plans that span fiscal years 2011-2022 and have been standardized in 2022 dollars, consistent with the reporting for the dredging data. Relevant feature codes derived from CWCCIS (Navigation Ports & Harbors, Channels and Canals, Levees and Floodwalls, Floodway Control and Diversion Structure, and Bank Stabilization) were used to compile cost data, which was then, adjusted based on the average cost associated with each feature codes’ cost indices from fiscal year 2022.

A major challenge in interpreting the civil works data lies in the limited resolution of project-level detail. Many line items within the work plans, particularly those associated with levee and bank stabilization work, are reported at the Division level—specifically the Mississippi Valley Division (MVD)—which includes multiple states and river segments. This reporting limits the ability to isolate expenditures for the Lowermost Mississippi River. Project descriptions vary in detail across fiscal years, with some referencing basin-wide activities such as the Atchafalaya Basin. Also, disaster supplemental funds have been included in this analysis and represent a significant portion of spending in given fiscal years. For the period of analysis (2011-2022), disaster supplemental funds were received in fiscal years 2018, 2019, and 2022. An Excel workbook (MR&T\_Cost\_FY2011to2022) containing the detailed results and calculation methodology is included as an attachment in this report. A summary of annual costs is shown in Figure D-2.



*Figure D-2. Annual expenditures derived from MR&T work plans by fiscal year. Costs include both construction and operations and maintenance. Costs are reported in 2022 dollars. Disaster supplemental funds are included.*

Despite these limitations, this dataset provides a valuable starting point for understanding the magnitude and variability of federal investments in the LMR system. It establishes a normalized baseline for comparing costs across time and among river management activities, even where fine-grained attribution to specific locations or asset types remains constrained by the resolution of available documentation.

# APPENDIX E. ADDITIONAL VULNERABILITY ANALYSES

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## E.1 INTRODUCTION

While tradeoff analysis is focused on metrics and levers, vulnerability analysis extends the focus to uncertain factors. This document presents a demonstration of vulnerability analysis on three metrics that were at the center of the tradeoff analysis demonstration: Southwest Pass dredge volume, Barataria sediment delivery, and Breton sediment delivery as well as Baton Rouge flood stage metric. In particular, the project team uses vulnerability analysis to answer the following questions:

1. Among both levers and uncertainties, which factors are the key drivers of vulnerability for each metric?
2. Under potentially vulnerable environmental conditions, which levers can mitigate vulnerability?

Classification and Regression Tree (CART) analysis is used to understand the key drivers of vulnerability for each metric. CART creates a step-by-step process that uses questions or rules to separate data into specific categories—here, “Vulnerable” and “Not Vulnerable” future conditions—to pinpoint the most influential uncertain factors that affect vulnerability. Trees have three main components; 1) Nodes which represent a split where a question is asked, 2) Branches which show possible answers (True/False), and 3) Leaves which are the endpoints that have the final classification. In CART, each split is chosen to minimize the Gini impurity metric. In the vulnerability analysis, the Gini metric indicates whether vulnerable scenarios dominate ( $Gini = 0$ ) or non-vulnerable scenarios prevail ( $Gini = 0$ ). Since the algorithm greedily selects the best split at each step, earlier splits typically have a greater impact on predictive performance. While the top split is often highly influential, it is not the sole measure of a variable’s overall contribution. A variable may not appear at the top of the tree but can be used multiple times across different branches, resulting in high overall importance. However, the choice of splitting variables and their hierarchy provides a useful indicator for identifying key drivers of vulnerability.

For each metric, the project team performed two types of CART analysis: 1) with both uncertain factors and levers and, 2) with uncertain factors first and perform a second CART on the leaves only with levers. The first analysis corresponding to the first question can be informative to see between the uncertain factors and levers which might be key for the vulnerability of the metric. The second analysis corresponding to the second question shows future scenarios where the metric might be vulnerable and how the levers can be used to prevent vulnerability.

Vulnerability thresholds for these metrics are set based on their statistical distribution in the business-as-usual (BAU) strategy. Table E-1 below shows the thresholds used for the four metrics of interest.



Table E-1. Thresholds used in vulnerability analysis

Metric	Threshold	Value
Southwest Pass dredged volume (yd <sup>3</sup> )	99th percentile in BAU	7.802433e+06
Barataria sediment delivery (yd <sup>3</sup> )	5 <sup>th</sup> percentile in BAU	7.098586e+04
Breton sediment delivery (yd <sup>3</sup> )	5 <sup>th</sup> percentile in BAU	4.127000e+04
Baton Rouge flood stage (ft.)	90 <sup>th</sup> percentile in BAU	39.3

These thresholds are chosen to capture significant but not extreme conditions for that specific metric, leading to a meaningful classification of scenarios. For each metric, a scenario is classified as "vulnerable" if, at any point, it exceeds the vulnerability threshold for metrics that should be minimized or falls below the threshold for metrics that should be maximized. The same BAU vulnerability thresholds were used across river management strategies to ensure meaningful comparisons.

Two analyses were conducted for three metrics and the details of these are provided in the following sections. However, the same approach can be taken to describe and understand any other metric trees.

## E.2 SOUTHWEST PASS DREDGE VOLUME

### E.2.1 Turn Right

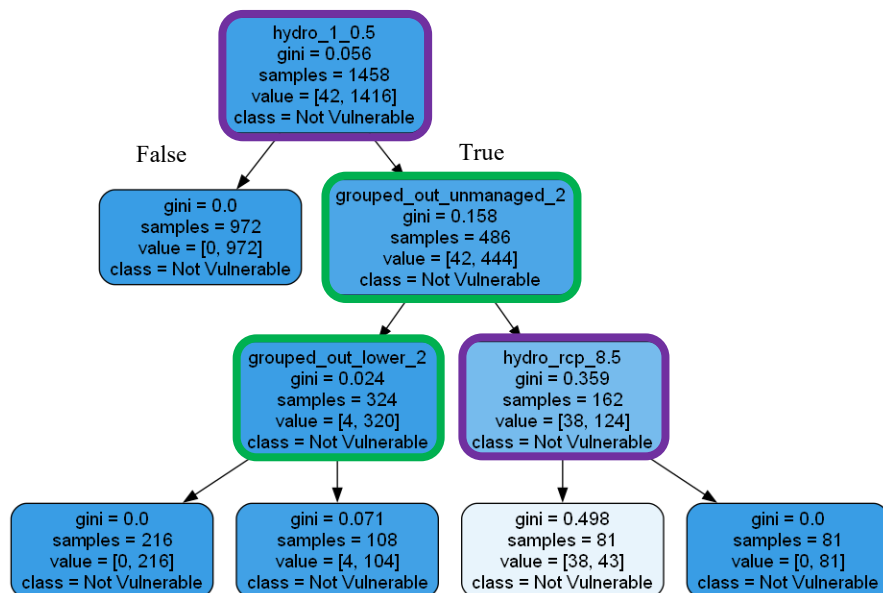


Figure E-1. Combined uncertainty and lever CART for Southwest Pass metric in the Turn Right strategy

Keeping the same vulnerability criterion across management strategies (Figure E-1), the alternative channel strategies are generally less vulnerable in the Southwest Pass dredge volume metric.

Here, the initial Turn Right strategy runs had only 42 Vulnerable and 1416 not-vulnerable scenarios based on the vulnerability criterion defined in the introduction. From the tree, the following can be seen:



- Left branch
  - When the hydrograph is not average, vulnerability is further reduced (left branch).
- Right branch
  - When the hydrograph is average, high discharge from the unmanaged outlet and lower discharge from lower outlets can increase vulnerability.
  - Under conditions with an average hydrograph and high discharge from the unmanaged outlet, high SLR can reduce vulnerability.

CART can be used to identify the key drivers of vulnerability for each metric among both levers and uncertainties. The analysis reveals the following patterns:

- River hydrograph emerges as the first (top-level) driver
- Under average hydrograph, discharge management from unmanaged and lower outlets is crucial
- High SLR can help reduce vulnerability

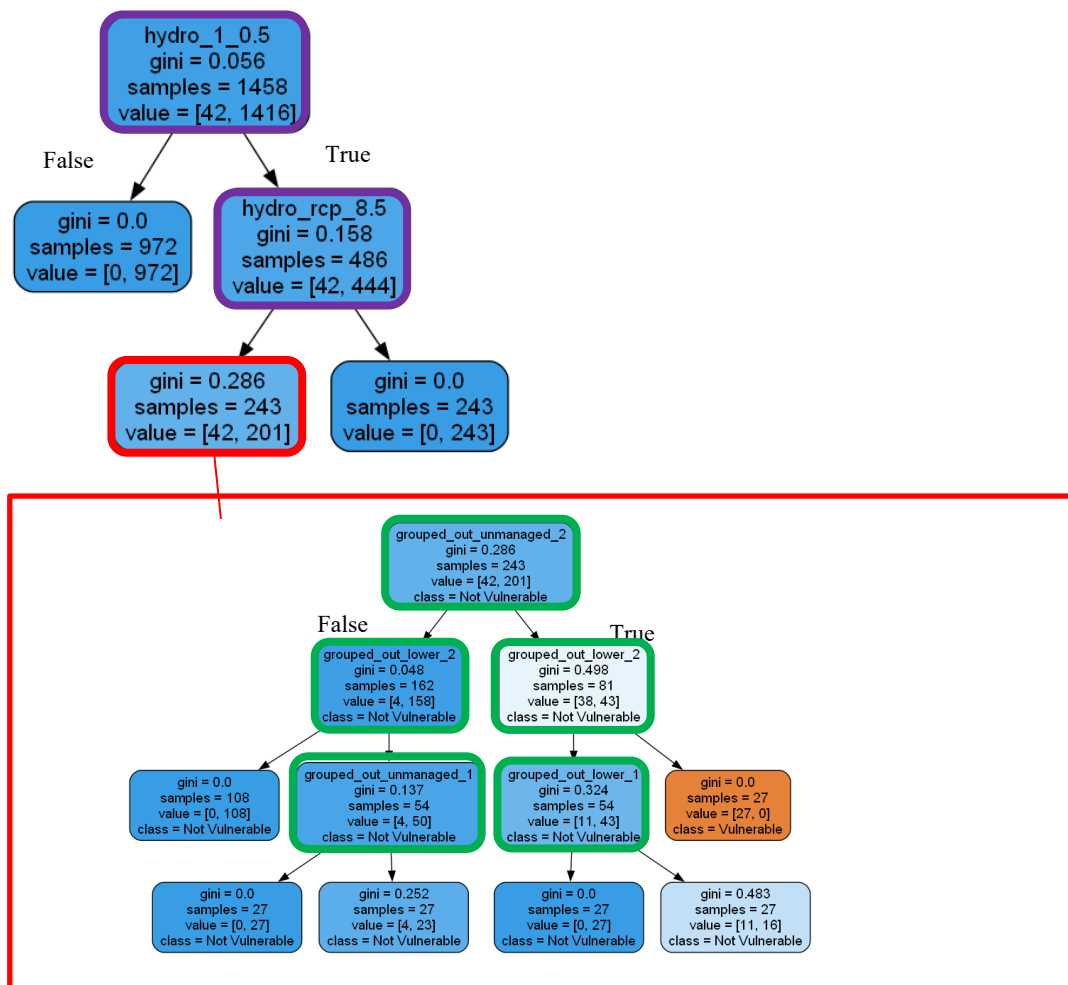


Figure E-2. Segmented uncertainty and lever vulnerability analysis for Southwest Pass dredged volume metric in the Turn Right strategy.



The first segment, the uncertainty-only CART shows that average hydrograph and low sea level rise, lead to more vulnerability in the Southwest Pass dredge volume metric (Figure E-2).

The second segment examines a condition where the river hydrograph is average and SLR is low, investigating which levers can be used to reduce or might further exacerbate vulnerability. This shows that:

- High discharge from the unmanaged and lower outlets **can increase vulnerability significantly** and the opposite can help reduce vulnerability.

Under potentially vulnerable conditions, certain management levers can help mitigate vulnerability:

- **Maintaining lower discharge from the unmanaged and lower outlets**—this significantly reduces the likelihood of vulnerability.

## E.2.2 Turn Left

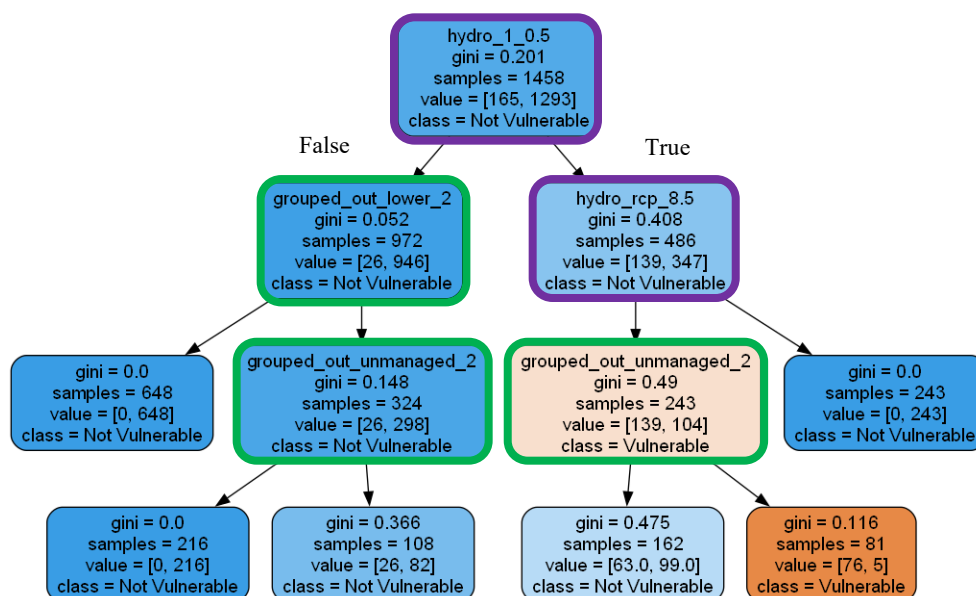


Figure E-3. Combined uncertainty and lever CART for Southwest Pass metric in Turn Left strategy

Keeping the same vulnerability criterion across management strategies, it is shown that alternative navigation strategies are generally less vulnerable in the Southwest Pass dredge volume metric.

Here, the initial Turn Left strategy runs had only 165 Vulnerable and 1293 not-vulnerable scenarios based on the vulnerability criterion defined in the introduction (Figure E-3).

- Left branch
  - When the hydrograph is not average and the discharge from unmanaged and lower outlets is not high, vulnerability is further reduced.
- Right branch



- When the hydrograph is average and SLR is low, high discharge from the unmanaged outlet can increase vulnerability.
- Under conditions with an average hydrograph, a high SLR can reduce vulnerability.

CART can be used to identify the key drivers of vulnerability for each metric among both levers and uncertainties. The analysis reveals the following patterns:

- River hydrograph emerges as the first (top-level) driver
- Under not average hydrograph, discharge management from unmanaged and lower outlets is crucial
- Under not average hydrograph, discharge management from unmanaged and SLR is important

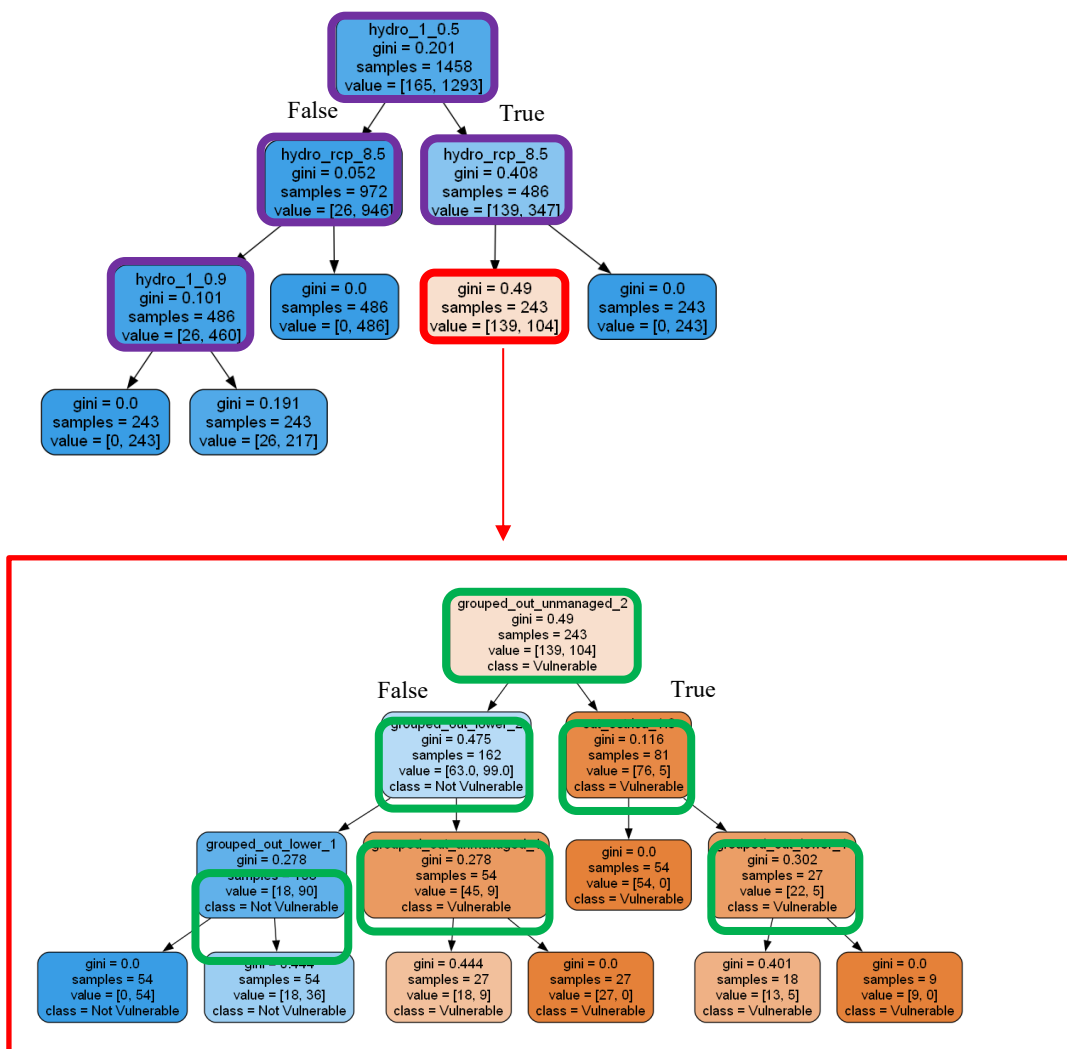


Figure E-4. Segmented uncertainty and lever vulnerability analysis for Southwest Pass dredged volume metric in the Turn Left strategy



Similar to Turn Right, the first segment, the uncertainty-only CART shows that average hydrograph and low sea level rise, lead to more vulnerability in the Southwest Pass dredge volume metric (Figure E-4). The second segment examines a condition where the river hydrograph is average and SLR is low, investigating which levers can be used to reduce or might further exacerbate vulnerability.

- Left branch
  - Low discharge from the unmanaged and lower outlets can reduce vulnerability.
- Right branch
  - Under high discharge from unmanaged outlets, non-current (lower/higher) discharge from Neptune Pass and lower outlets can increase vulnerability.

Under potentially vulnerable conditions, certain management levers can help mitigate vulnerability:

- Maintaining lower discharge from the unmanaged and lower outlets — this significantly reduces the likelihood of vulnerability.
- Under high discharge from unmanaged outlets, management of Neptune Pass is crucial.

## **E.3 BARATARIA AND BRETON SEDIMENT DELIVERY METRICS**

### **E.3.1 Alternative channel management strategies**

Keeping the same vulnerability criterion across management strategies, the alternative channel strategies exhibit a different pattern in vulnerability analysis for Barataria and Breton sediment delivery metrics.

#### *Turn Left*

##### **Barataria sediment delivery**

Under the Turn Left strategy and keeping the vulnerability threshold, all scenarios are marked as vulnerable so no combined or separated CART can be developed.

##### **Breton sediment delivery**

The Breton combined and segmented analysis is identical to the Turn Right strategy.

# APPENDIX F. ADDITIONAL TRADEOFF ANALYSES

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## F.1 INTRODUCTION

For tradeoff analysis, the project team looked at the five river management strategies. An experimental design was created that provides a full factorial combination of the two uncertain environmental factors (sea level rise and river hydrograph) and five policy levers related to outlet discharge rates (grouped lower outlets, grouped diversions, grouped unmanaged outlets, Bonnet Carré outlet, and Neptune Pass). This full factorial experimental design provides 1,458 runs within each river management strategy, for a total of 7,290 model runs (See Table 1 in main document).

Since the tradeoff analysis focuses on the impact of policy levers, this appendix focuses on a subset of the runs within a specific environmental scenario. Each environmental scenario is a combination of levels of the two uncertain environmental factors. The experimental design consists of two environmental factors: 1) sea level rise, which has two RCP levels (4.5 and 8.5), and 2) river hydrograph, with three levels—dry (10th percentile), average (50th percentile), and wet (90th percentile). This provides six environmental scenarios:

- Low sea level rise and dry hydrograph (RCP 4.5 and 10<sup>th</sup> percentile hydrograph)
- Low sea level rise and average hydrograph (RCP 4.5 and 50<sup>th</sup> percentile hydrograph)
- Low sea level rise and wet hydrograph (RCP 4.5 and 90<sup>th</sup> percentile hydrograph)
- High sea level rise and dry hydrograph (RCP 8.5 and 10<sup>th</sup> percentile hydrograph)
- High sea level rise and average hydrograph (RCP 8.5 and 50<sup>th</sup> percentile hydrograph)
- High sea level rise and wet hydrograph (RCP 8.5 and 90<sup>th</sup> percentile hydrograph)

Each of these environmental scenarios consists of 243 runs from the full experimental design (1,458 runs total). For this demonstration, the low sea level rise and average hydrograph scenario as the base environmental scenario was selected by the project team to showcase the tradeoff analysis. Note that the code produces the same graphs for all six environmental scenarios, and future work can compare how the impact of levers might differ or be similar across these scenarios.

This demonstration is organized around example questions that can be addressed using tradeoff analysis. These questions focus on the tradeoffs between navigation (dredging volume) and ecosystem (sediment delivery) goals. Particular attention is given to the following metrics:

- Southwest Pass (SWP) dredging volume
- Crossings dredging volume
- Barataria sediment delivery
- Breton sediment delivery

The example questions are:



6. How does improved performance in one metric affect performance in the others? For example:
  - When minimizing crossings dredging needs, what are the trade-offs with other management metrics?
  - When minimizing SWP dredging needs, what are the trade-offs with other management metrics?
  - When maximizing sediment delivery to the Barataria Basin, what are the trade-offs with other management metrics?
  - When maximizing sediment delivery to the Breton Sound Basin, what are the trade-offs with other management metrics?
  - When maximizing sediment delivery to the Deltaic Plain (BA + BS), what are the trade-offs with other management metrics?
7. What are the most influential levers (outlet discharges) for achieving better performance in sediment delivery to the Breton and Barataria basins and for reducing maintenance challenges at SWP for navigation?
8. What do the scenarios that perform best across SWP dredge volume and basin sediment delivery metrics have in common regarding outlet discharge levels?

## F.2 WITHIN STRATEGY

### F.2.1 Flatpeaks Strategy

*How does improved performance in one metric affect performance in the others?*

This section details the performance tradeoff between the metrics of interest.

**When minimizing SWP dredging needs, what are the trade-offs with other management metrics?**

Figure F-1 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Flatpeaks strategy. Among these, the scenarios in the lowest 10th percentile for SWP dredging volume are highlighted in blue (Best 10%). The graph indicates that scenarios with the best performance in terms of dredged volume at SWP (25 scenarios) also perform



relatively well in Breton sediment discharge and crossings dredged volume metrics but exhibit lower performance in the Barataria sediment metric.

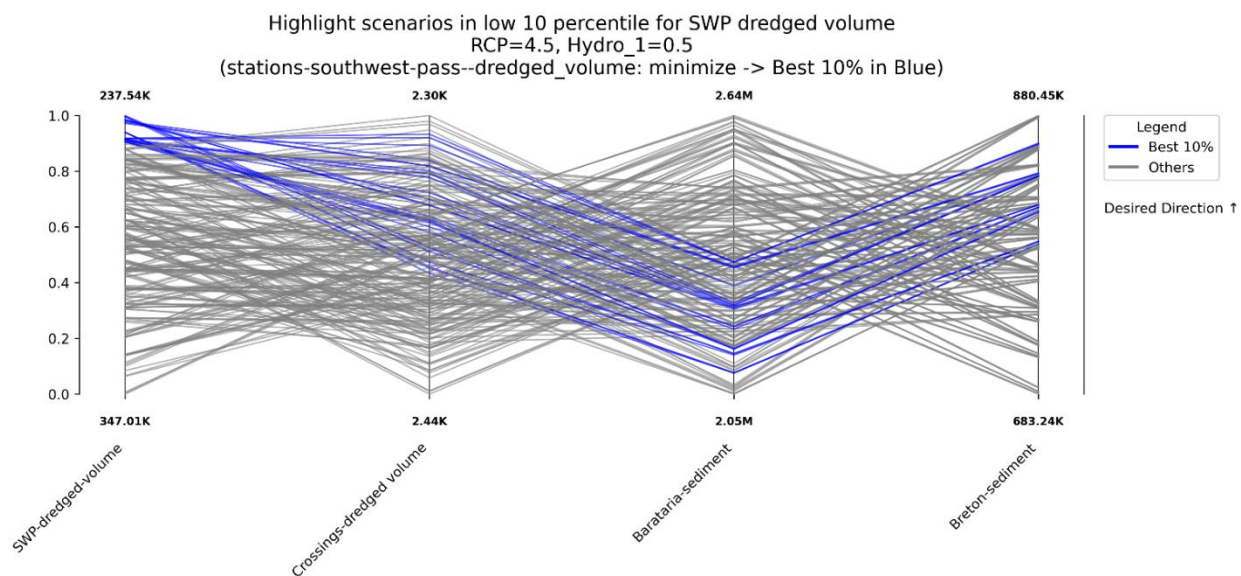


Figure F-1. Tradeoff analysis focused on high-performing scenarios in SWP (SWP) dredge volume

Figure F-2 is a summary statistic and distribution plot of the metric of focus for reference.

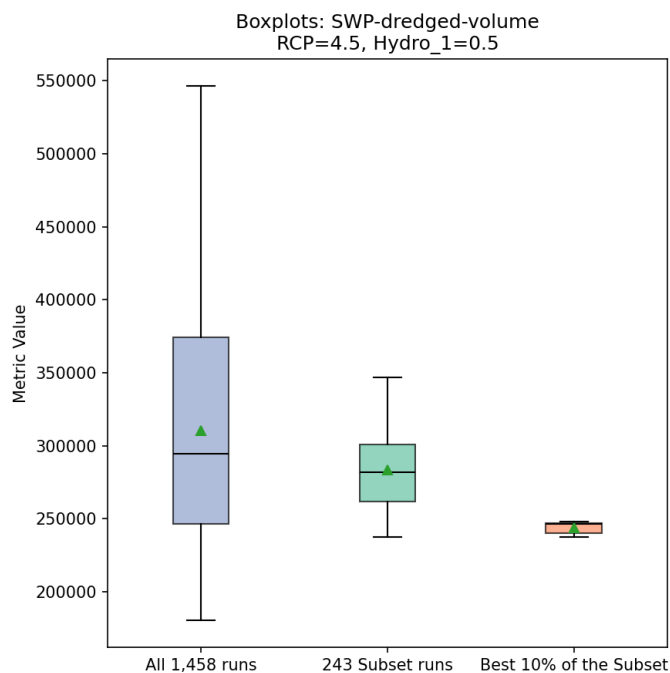


Figure F-2. Distribution of SWP dredge volume metric values



This figure shows the distribution of southwest pass dredge volume values under the Flatpeaks strategy, for 1) all runs, 2) the environmental scenario subset, and 3) the 10 best percentile scenarios within the subset (Table F-1).

Table F-1. Distribution of Southwest Pass Dredge volume results.

Metric	Group	Mean (yd <sup>3</sup> )	StdDev (yd <sup>3</sup> )	N
SWP-dredged-volume	All Global	310,366.37	81,723.45	1458
	Subset	283,198.18	2,6650.41	243
	Subset Best 10%	243,835.89	3,826.486	25

### When minimizing Crossings dredging needs, what are the trade-offs with other management metrics?

Figure F-3 displays the data from 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Flatpeaks strategy. Among these, the scenarios in the lowest 10th percentile for Crossings dredging volume are highlighted in blue (Best 10%). The graph indicates that scenarios with the best performance in terms of dredged volume at Crossings (25 scenarios) also perform relatively well in Breton sediment discharge and SWP dredged volume metrics but exhibit lower performance in the Barataria sediment metric.

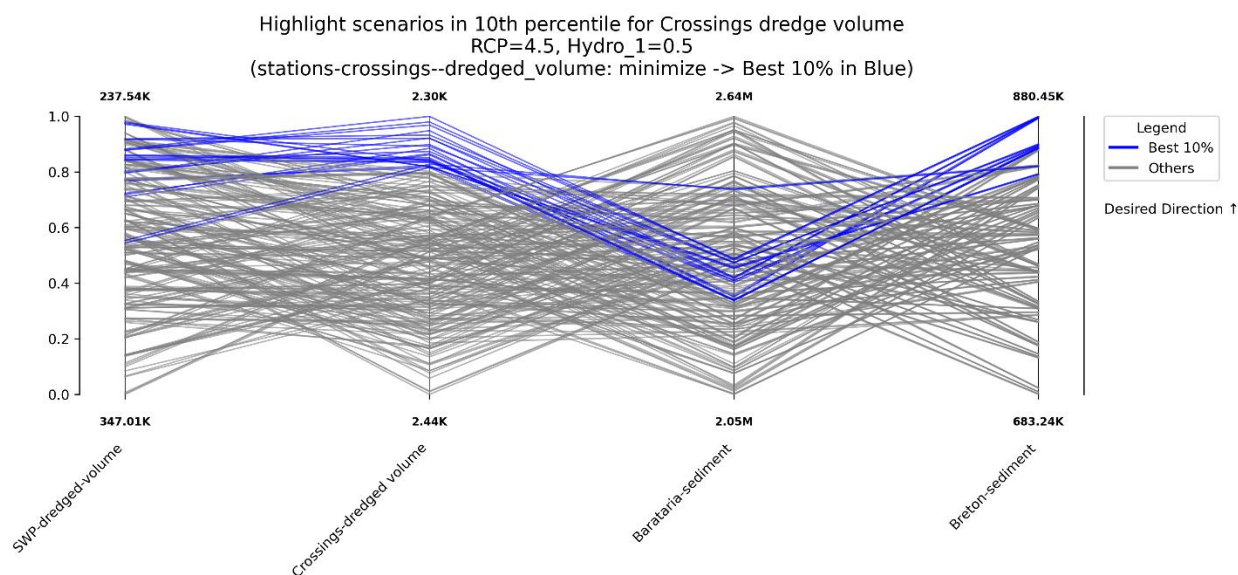


Figure F-3. Tradeoff analysis focused on high-performing scenarios in Crossings dredge volume

Figure F-4 is a summary statistic and distribution plot of the metric of focus for reference, and shows the distribution of Crossings dredge volume values under the Flatpeaks strategy, for 1) all runs, 2) the environmental scenario subset, and 3) the 10 best percentile scenarios within the subset. As shown, the



environmental scenario shows relatively very low Crossings dredged volume (Table F-2). Future work is needed to investigate the underlying reason.

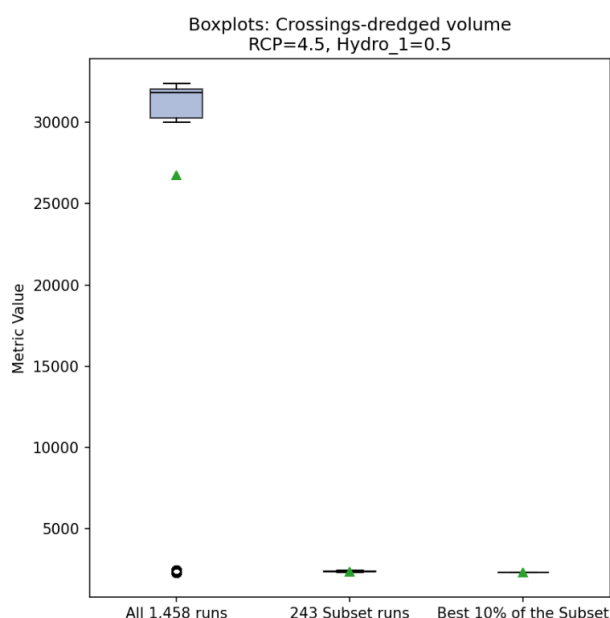


Figure F-4. Distribution of Crossings dredge volume metric values

Table F-2. Distribution of Crossings Dredge volume results.

Metric	Group	Mean (yd <sup>3</sup> )	StdDev (yd <sup>3</sup> )	N
Crossings-dredged volume	All runs	26,747.495	10,925.97	1458
	Subset	2,367.198	32.154	243
	Subset Best 10%	2,313.536	8.038	25

**When maximizing sediment delivery to the Barataria Basin, what are the trade-offs with other management metrics?**

Figure F-5 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Flatpeaks strategy. Among these, the scenarios in the highest 10th percentile for Barataria sediment delivery are highlighted in blue (Best 10%). The graph indicates that scenarios with the best performance in terms of Barataria sediment delivery (25 scenarios) perform average in Breton sediment discharge and crossings dredged volume metrics but exhibit lower performance in the SWP dredged volume metric.

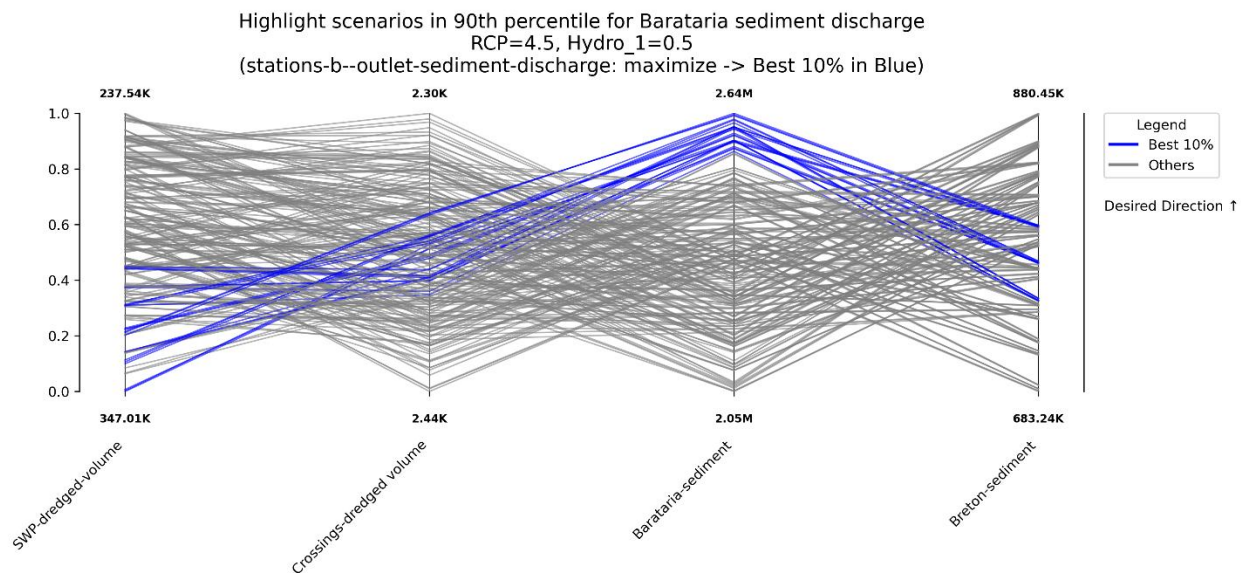


Figure F-5. Tradeoff analysis focused on high-performing scenarios in Barataria Sediment delivery

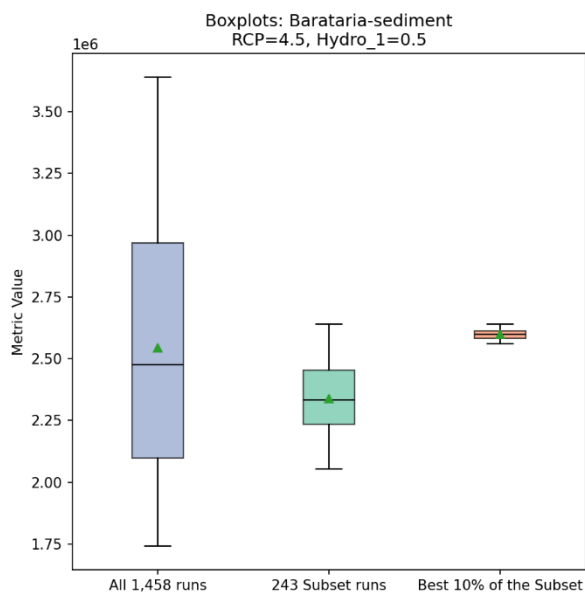


Figure F-6. Distribution of Barataria sediment delivery metric values

Figure F-6 shows the distribution of Barataria sediment delivery values under the Flatpeaks strategy, for 1) all runs, 2) the environmental scenario subset, and 3) the 10 best percentile scenarios within the subset (Table F-3).



Table F-3. Distribution of Barataria Sediment delivery results.

Metric	Group	Mean (yd <sup>3</sup> )	StdDev (yd <sup>3</sup> )	N
Barataria-sediment	All Global	2,544,820.1	500,733.4	1458
	Subset	2,339,077.6	147,185.1	243
	Subset Best 10%	2,599,700.6	23,763.97	25

**When maximizing sediment delivery to the Breton Sound Basin, what are the trade-offs with other management metrics?**

Figure F-7 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Flatpeaks strategy. Among these, the scenarios in the highest 10th percentile for Breton sediment delivery are highlighted in blue (Best 10%). The graph indicates that scenarios with the best performance in terms of Breton sediment delivery (25 scenarios) perform very well in SWP and Crossings dredged volume metrics but exhibit average performance in the Breton sediment discharge metric.

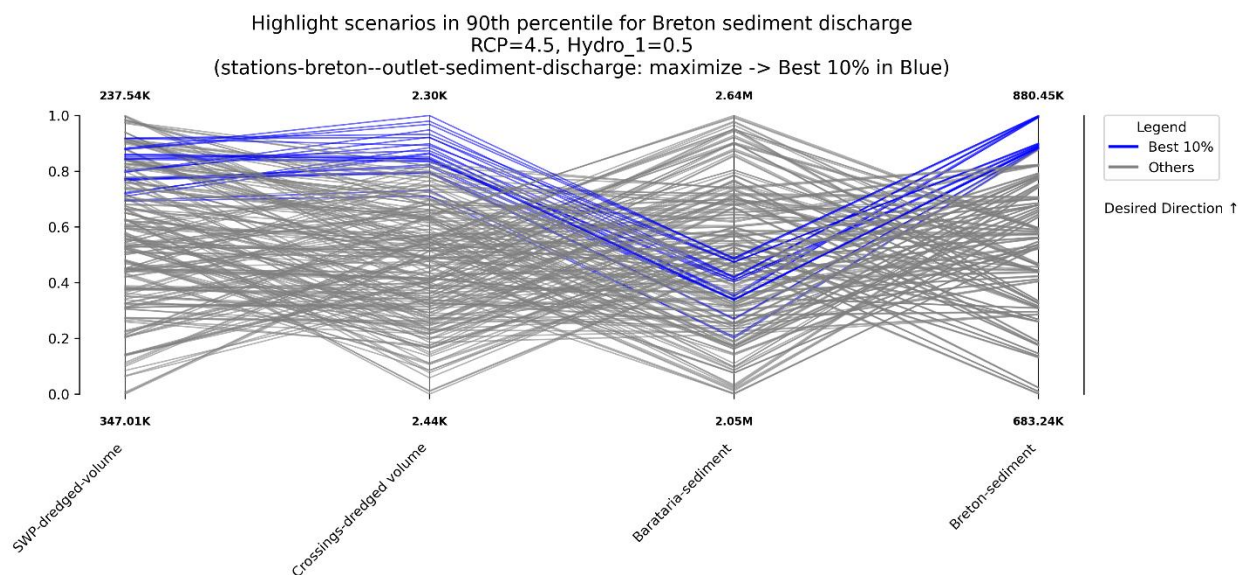


Figure F-7. Tradeoff analysis focused on high-performing scenarios in Breton Sediment delivery

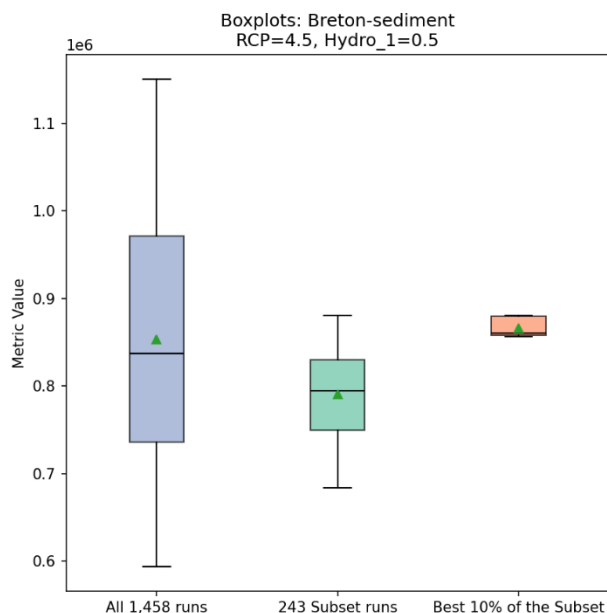


Figure F-8. Distribution of Breton sediment delivery metric values

This figure shows the distribution of Breton sediment delivery values under the Flatpeaks strategy, for 1) all runs, 2) the environmental scenario subset, and 3) the 10 best percentile scenarios within the subset (Table F-4).

Table F-4. Distribution of Breton Sediment delivery results

Metric	Group	Mean (yd <sup>3</sup> )	StdDev (yd <sup>3</sup> )	N
Breton-sediment	All Global	853,425.9	137,096.4	1458
	Subset	790,654.7	48,319.76	243
	Subset Best 10%	866,212.8	10,428.71	25

**When maximizing sediment delivery to the Deltaic Plain (BA + BS), what are the trade-offs with other management metrics?**

The project team also looked at the same tradeoff but with combined Barataria and Breton Sediment as Delta Plain sediment delivery. Figure F-9 displays the results from 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Flatpeaks strategy. Among these, the scenarios in the highest 10th percentile for Delta Plain sediment delivery are highlighted in blue (Best 10%). The graph shows a general tradeoff between Delta Plain sediment delivery and SWP dredged volume, in which the highest performing scenarios in Delta Plain sediment delivery show relatively low to average performance in SWP dredged volume. The same scenarios show mostly average performance in Crossings dredged volume.

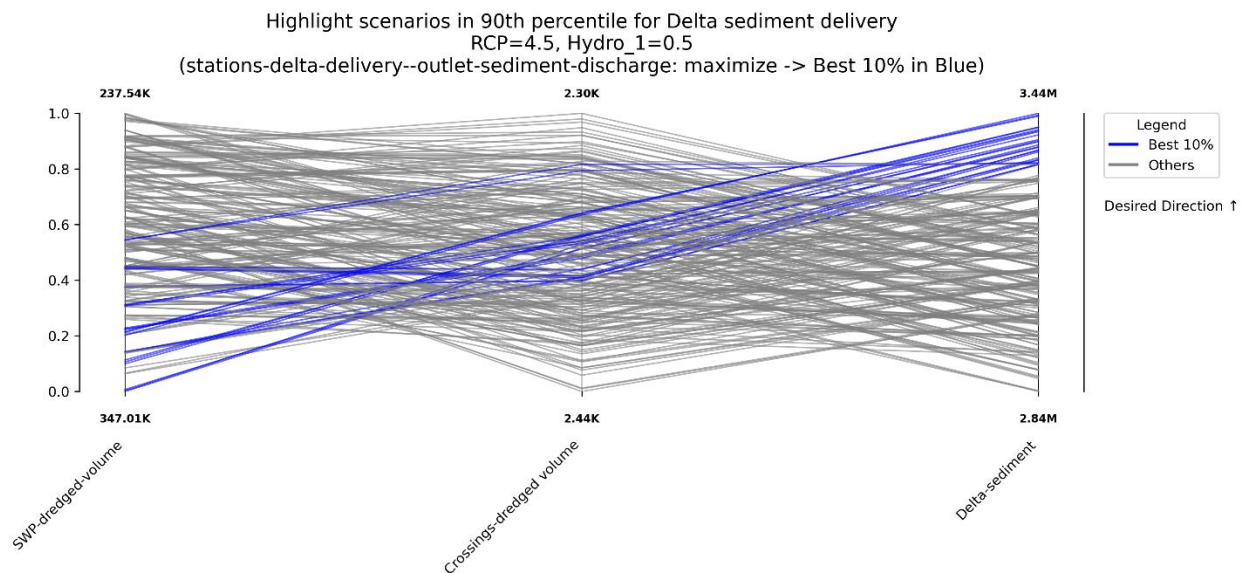


Figure F-9. Tradeoff analysis focused on high-performing scenarios in Delta Plain Sediment delivery

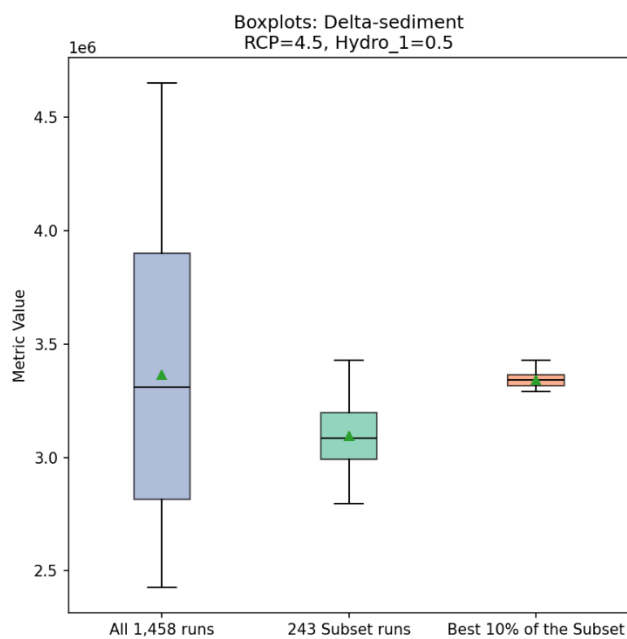


Figure F-10. Distribution of Delta plain sediment delivery metric values

Figure F-10 shows the distribution of Delta plain sediment delivery values under the Flatpeaks strategy, for 1) all runs, 2) the environmental scenario subset, and 3) the 10 best percentile scenarios within the subset (Table F-5).



Table F-5. Distribution of Delta plain sediment delivery values under the Flatpeaks strategy

Metric	Group	Mean (yd <sup>3</sup> )	StdDev (yd <sup>3</sup> )	N
Delta-sediment	All Global	3,398,246	620,219	1458
	Subset	3,129,732	140,326.6	243
	Subset Best 10%	3,377,450	34,572.42	25

*What are the most influential levers (outlet discharges) for better performance in sediment delivery to Breton and Barataria basins, and for ease of maintenance at SWP for navigation?*

To answer this question, the project team plotted the same set of metrics but highlighted them based on the levels of the outlet discharge policy levers. This analysis revealed that the group of unmanaged outlets and Neptune Pass have a more direct impact on the performance of these metrics. Specifically, the high and non-high levels of these two outlet groupings show distinct differences in performance across some key metrics.

Figure F-11 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Flatpeaks strategy. Among these, the scenarios with high discharge allowed from the unmanaged outlets are highlighted in orange and not high levels (low-medium) are highlighted in blue. The graph shows that high levels of discharge from unmanaged outlets resulted in a relatively good performance in sediment metrics and Crossings dredged volume but did not improve the SWP dredge volume metric.

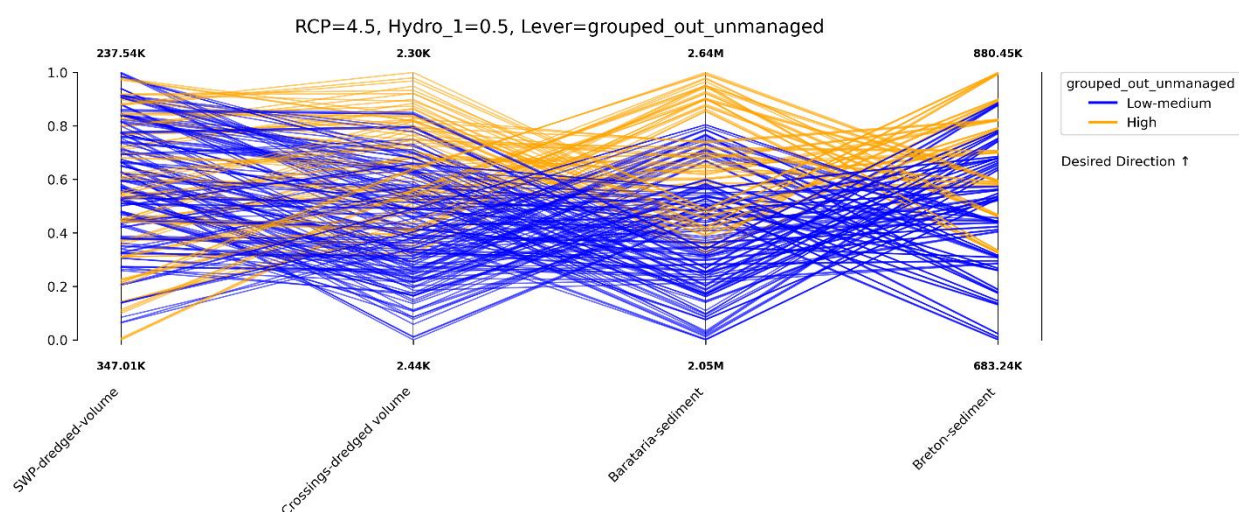


Figure F-11. Policies within the environmental scenario are highlighted by the level of discharge allowed from the unmanaged outlets (high: orange, not high: blue)

Figure F-12 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Flatpeaks strategy. Among these, the scenarios with high discharge



allowed from the Neptune Pass are highlighted in orange and not high levels (low-medium) are highlighted in blue. The graph shows that high levels of discharge from Neptune Pass resulted in a relatively good performance in Breton sediment and SWP and Crossings dredged volume metrics and poor to average performance in Barataria sediment metric.

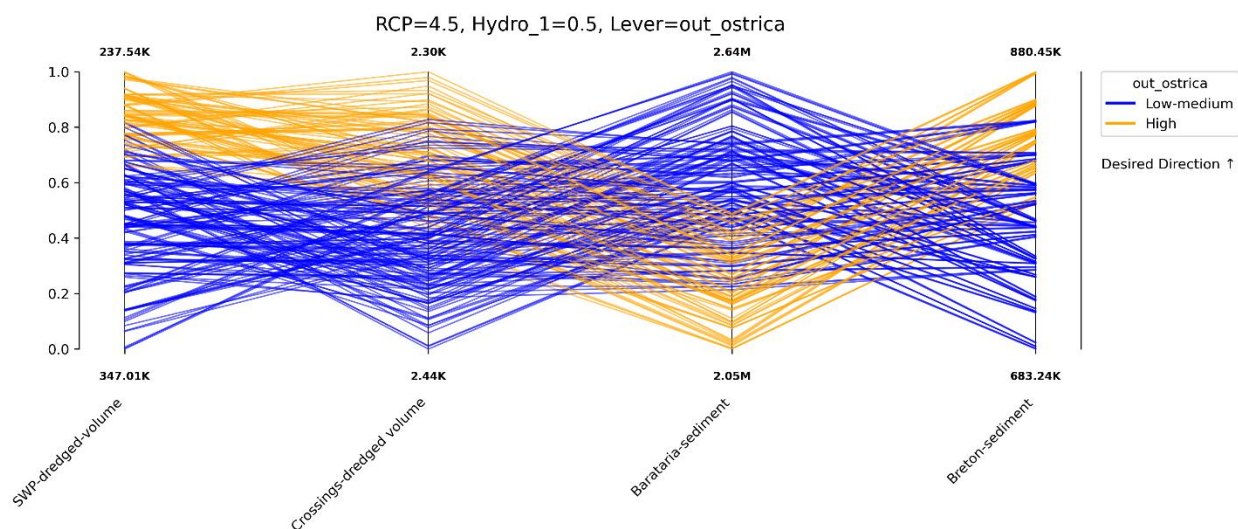


Figure F-12. Policies within the environmental scenario are highlighted by the level of discharge allowed from the Neptune Pass (high: orange, not high: blue)

In summary:

- High discharge from Neptune Pass can help both Breton sediment discharge and SWP navigation ease, but does not help Barataria sediment delivery.
- High discharge from unmanaged outlets helps more sediment delivery to basins but does not improve SWP navigation maintenance.

***What do the scenarios that perform best across SWP dredge volume and basin sediment delivery metrics have in common regarding the level of outlet discharge?***

To address this question, the project team looked at these three metrics to understand what combinations of outlet discharge levers the top-performing scenarios have in common. This is done by using a two-step process to screen the top scenarios; 1) the scenarios are ranked using the composite score to find the top ones, and 2) within those top solutions, the “Pareto” set is identified.

For calculating the composite score, each metric is converted to a 0–1 scale based on whether the metric desired state is to be maximized or minimized then add them up into a single “composite score.” Then the project team picks N scenarios with the highest composite score and within those top solutions, the project team finds non-dominated or Pareto scenarios where no other scenario is strictly better on all metrics. A solution is dominated if another is at least as good in every metric and strictly better in at least one.



Figure F-13 shows the 15 top performers based on the composite score in 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph). The colored lines represent the ‘best possible’ (Pareto) scenarios within the highest composite scores. All of those scenarios have high levels of outlet discharge from unmanaged outlets and Neptune Pass, consistent with the findings in the previous section .

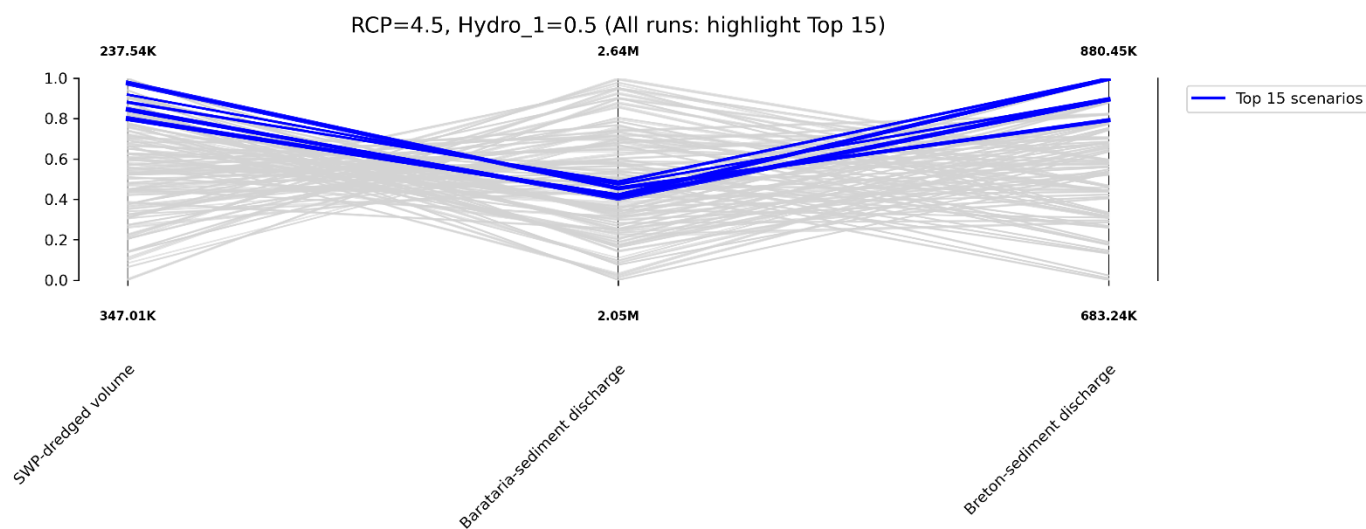


Figure F-13. Top 15 scenarios based on the composite score

Table F-6. Outlet discharge levels used in Pareto analysis

Diversion outlets	Lower outlets	Unmanaged outlets	Bonnet Carré	Neptune Pass
2	0	2	1.1	1.5
2	0	2	0.9	1.5
1	2	2	1	1.5
1	2	2	0.9	1.5
1	2	2	1.1	1.5
1	1	2	0.9	1.5
1	1	2	1.1	1.5
1	1	2	1	1.5
2	0	2	1.1	1.5

Table F-6 shows the combination of the outlet discharge levels allowed in 9 Pareto scenarios in the Top 15 scenarios based on the composite score. As can be seen, all of these scenarios share the highest level of discharge allowed from unmanaged outlets and Neptune Pass. The levels are mixed in all other outlets, showing their less direct impact on the overall performance of these three metrics.



## F.2.2 Lowpeaks Strategy

*How does improved performance in one metric affect performance in the others?*

Here, the project team looked at the performance tradeoff between the metrics of interest. Lowpeaks strategy shares very similar tradeoffs with Flatpeaks and BAU.

**When minimizing SWP dredging needs, what are the trade-offs with other management metrics?**

Figure F-14 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Lowpeaks strategy. Among these, the scenarios in the lowest 10th percentile for SWP dredging volume are highlighted in blue (Best 10%). The graph indicates that scenarios with the best performance in terms of dredged volume at SWP (25 scenarios) also perform relatively well in Breton sediment discharge and crossings dredged volume metrics but exhibit lower performance in the Barataria sediment metric.

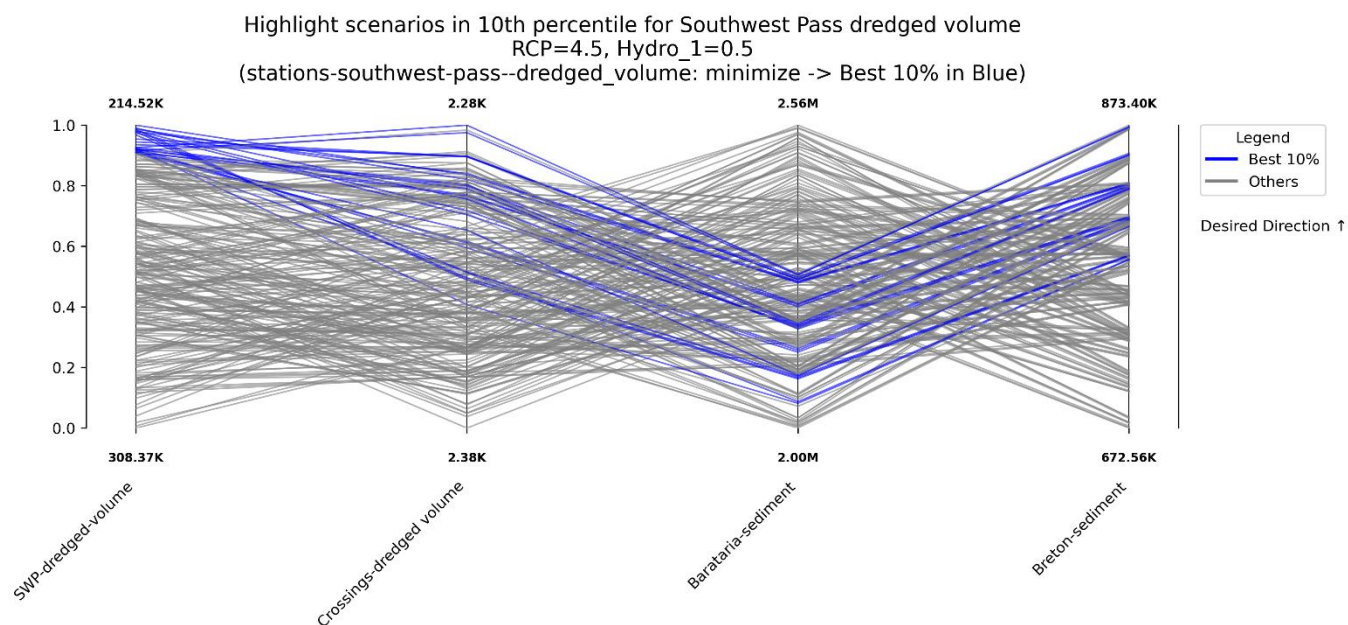


Figure F-14. Tradeoff analysis focused on high-performing scenarios in SWP dredge volume



Figure F-15 is a summary statistic and distribution plot of the metric of focus for reference.

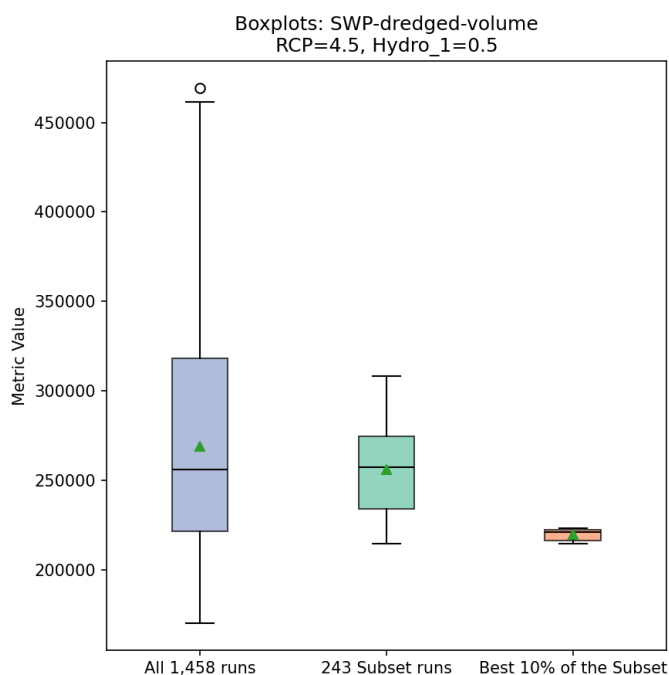


Figure F-15. Distribution of SWP dredge volume metric values

This figure shows the distribution of southwest pass dredge volume values under the Lowpeaks strategy, for 1) all runs, 2) the environmental scenario subset, and 3) the 10 best percentile scenarios within the subset (Table F-7).

Table F-7. Distribution of southwest pass dredge volume values under the Lowpeaks strategy

Metric	Group	Mean	StdDev	N
SWP-dredged-volume	All Global	268,940.3	63,754.98	1458
	Subset	256,315.3	24,211.49	243
	Subset Best 10%	219,759.1	2,980.069	25

**When minimizing Crossings dredging needs, what are the trade-offs with other management metrics?**

Figure F-16 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Lowpeaks strategy. Among these, the scenarios in the lowest 10th percentile for Crossings dredging volume are highlighted in blue (Best 10%). The graph indicates that scenarios with the best performance in terms of dredged volume at Crossings (25 scenarios) also perform



relatively well in Breton sediment discharge and SWP dredged volume metrics but exhibit lower performance in the Barataria sediment metric.

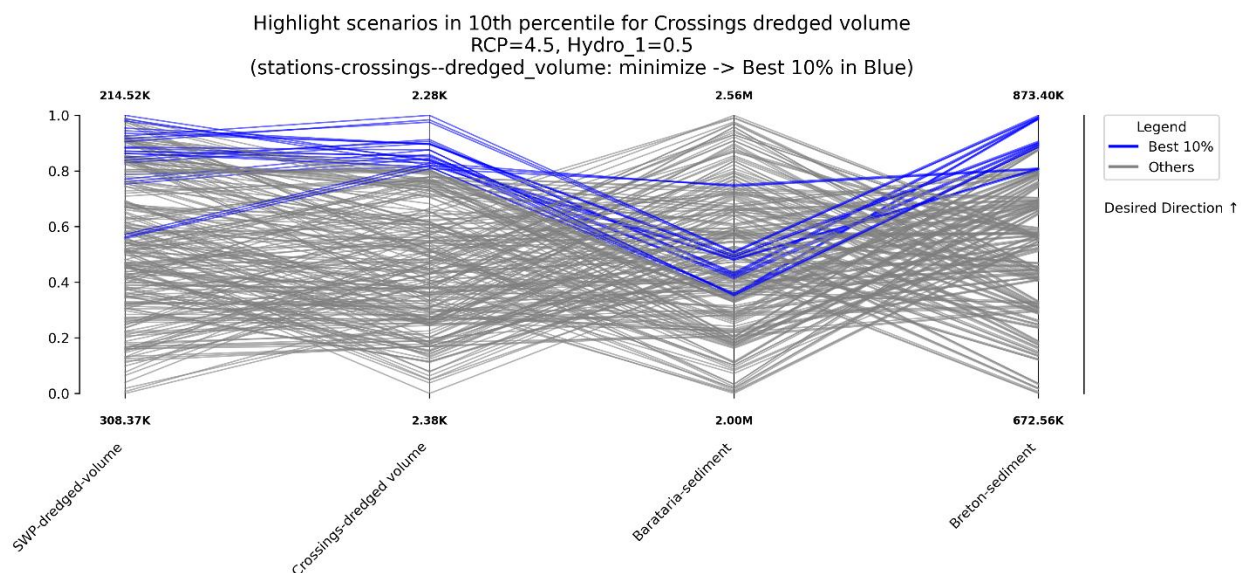


Figure F-16. Tradeoff analysis focused on high-performing scenarios in Crossings dredge volume

Figure F-17 is a summary statistic and distribution plot of the metric of focus for reference.

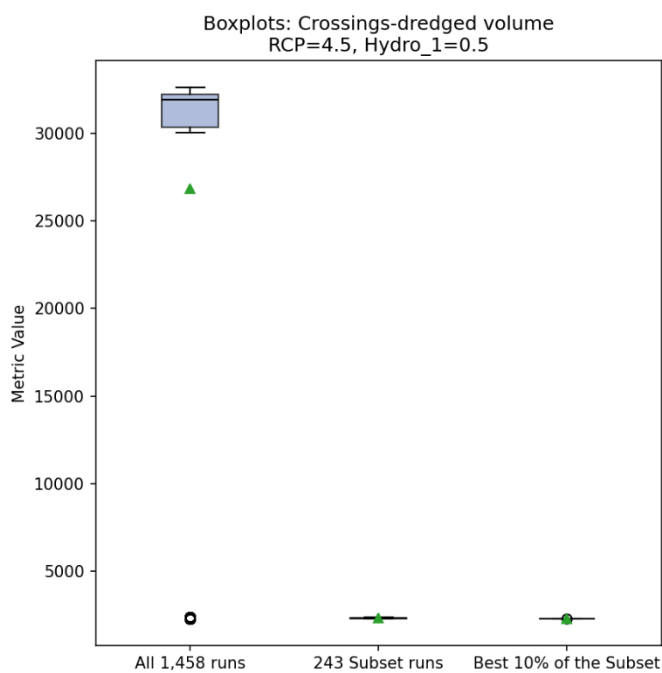


Figure F-17. Distribution of Crossings dredge volume metric values



This figure shows the distribution of Crossings dredge volume values under the Lowpeaks strategy, for 1) all runs, 2) the environmental scenario subset, and 3) the 10 best percentile scenarios within the subset. As it can be seen the environmental scenario shows relatively very low Crossings dredged volume. Future work is needed to investigate the underlying reason (Table F-8).

Table F-8. Distribution of Crossings dredge volume values under the Lowpeaks strategy

Metric	Group	Mean	StdDev	N
Crossings-dredged volume	All runs	26,847.92	10,990.89	1458
	Subset	2,327.98	23.376	243
	Subset Best 10%	2,290.326	5.32	25

### When maximizing sediment delivery to the Barataria Basin, what are the trade-offs with other management metrics?

Figure F-18 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Lowpeaks strategy. Among these, the scenarios in the highest 10th percentile for Barataria sediment delivery are highlighted in blue (Best 10%). The graph indicates that scenarios with the best performance in terms of Barataria sediment delivery (25 scenarios) perform average in Breton sediment discharge and crossings dredged volume metrics but exhibit lower performance in the SWP dredged volume metric.

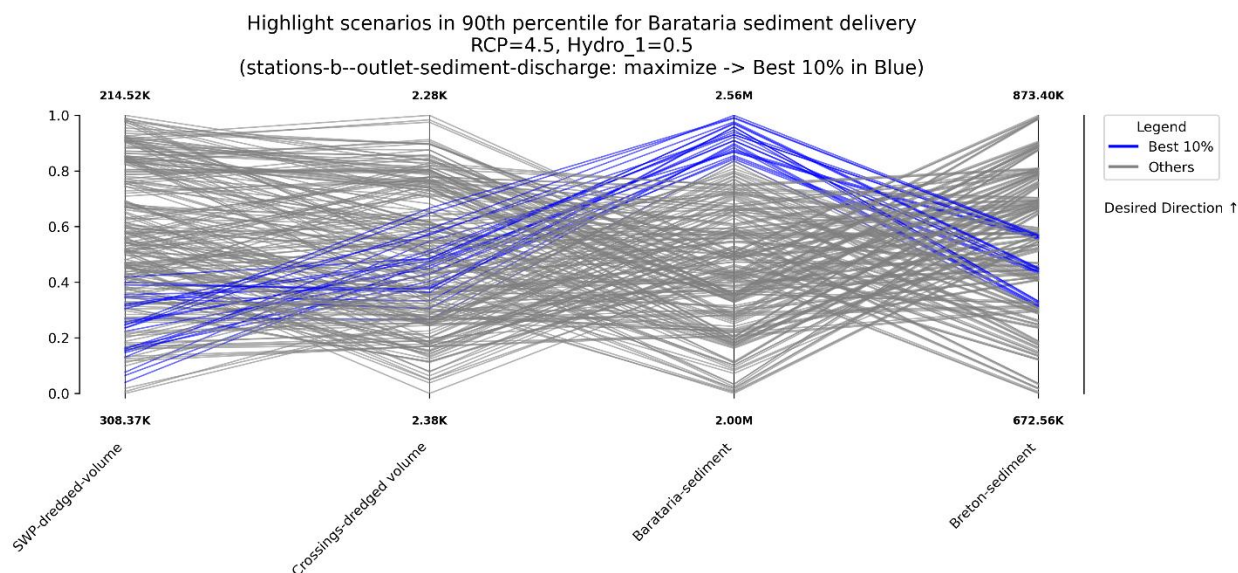


Figure F-18. Tradeoff analysis focused on high-performing scenarios in Barataria Sediment delivery

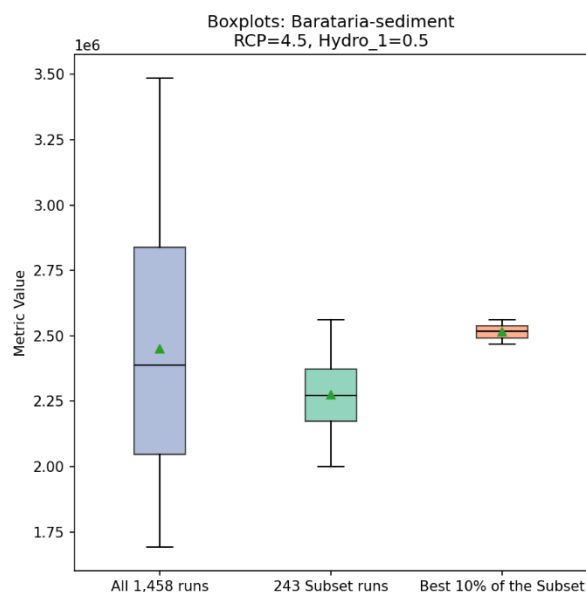


Figure F-19. Distribution of Barataria sediment delivery metric values

Figure F-19 shows the distribution of Barataria sediment delivery values under the Lowpeaks strategy, for 1) all runs, 2) the environmental scenario subset, and 3) the 10 best percentile scenarios within the subset (Table F-9).

Table F-9. Distribution of Barataria sediment delivery values under the Lowpeaks strategy

Metric	Group	Mean (yd <sup>3</sup> )	StdDev (yd <sup>3</sup> )	N
Barataria-sediment	All Global	2,451,462	457,066.1	1458
	Subset	2,273,178	137,119.3	243
	Subset Best 10%	2,515,068	28,238.07	25

**When maximizing sediment delivery to the Breton Sound Basin, what are the trade-offs with other management metrics?**

Figure F-20 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Lowpeaks strategy. Among these, the scenarios in the highest 10th percentile for Breton sediment delivery are highlighted in blue (Best 10%). The graph indicates that scenarios with the best performance in terms of Breton sediment delivery (25 scenarios) perform very well in SWP and Crossings dredged volume metrics but exhibit average performance in the Breton sediment discharge metric.

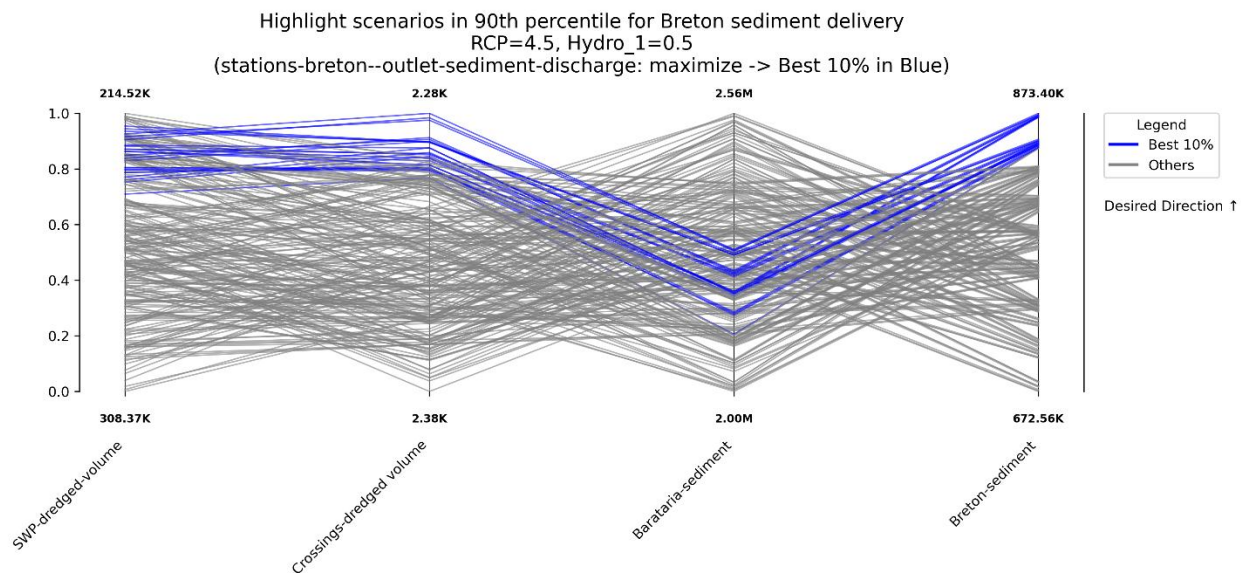


Figure F-20. Tradeoff analysis focused on high-performing scenarios in Breton Sediment delivery

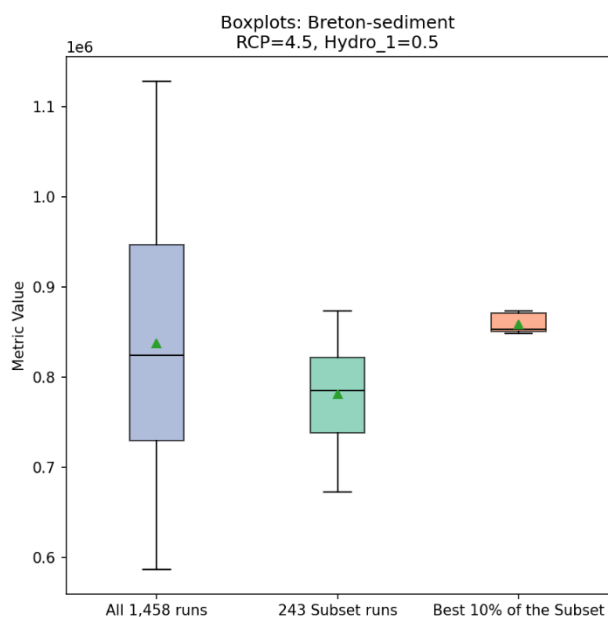


Figure F-21. Distribution of Breton sediment delivery metric values

Figure F-21 shows the distribution of Breton sediment delivery values under the Lowpeaks strategy, for 1) all runs, 2) the environmental scenario subset, and 3) the 10 best percentile scenarios within the subset (Table F-10).



Table F-10. Distribution of Breton sediment delivery values under the Lowpeaks strategy

Metric	Group	Mean (yd <sup>3</sup> )	StdDev (yd <sup>3</sup> )	N
Breton-sediment	All Global	837,994	129,827.2	1458
	Subset	781,499.8	49,479.27	243
	Subset Best 10%	858,750.2	9,975.511	25

**When maximizing sediment delivery to the Deltaic Plain (BA + BS), what are the trade-offs with other management metrics?**

The project team also looked at the same tradeoff but with combined Barataria and Breton Sediment as Delta Plain sediment delivery. Figure F-22 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Lowpeaks strategy. Among these, the scenarios in the highest 10th percentile for Delta Plain sediment delivery are highlighted in blue (Best 10%). The graph shows a general tradeoff between Delta plain sediment delivery and SWP dredged volume, in which the highest performing scenarios in Delta sediment delivery show relatively low to average performance in SWP dredged volume. The same scenarios show mostly average performance in Crossings dredged volume.

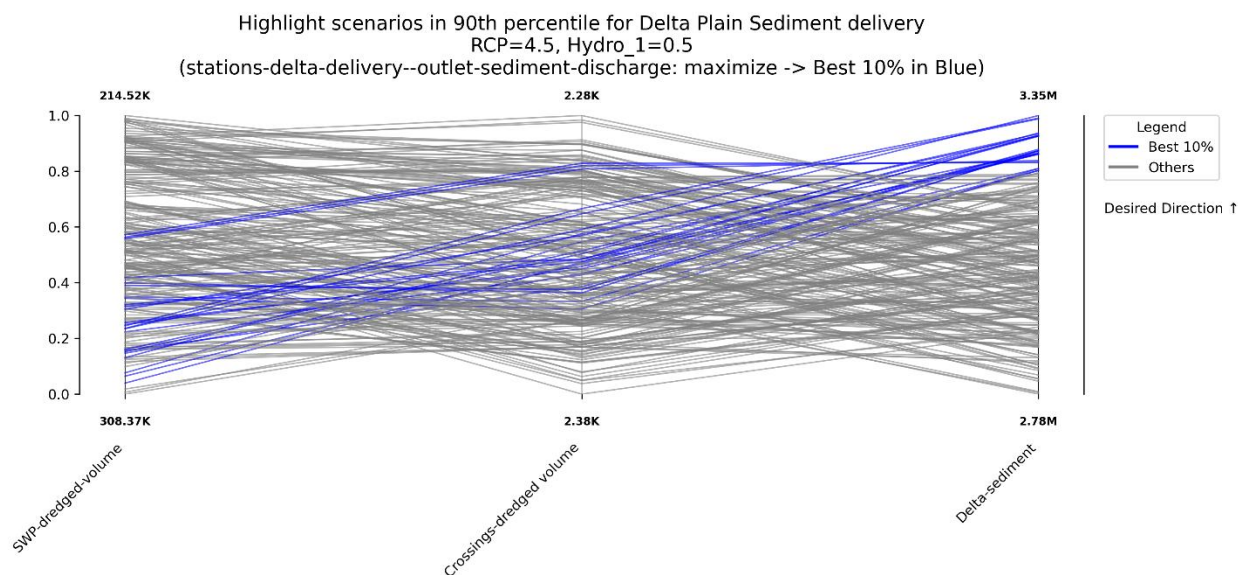


Figure F-22. Tradeoff analysis focused on high-performing scenarios in Delta Plain Sediment delivery

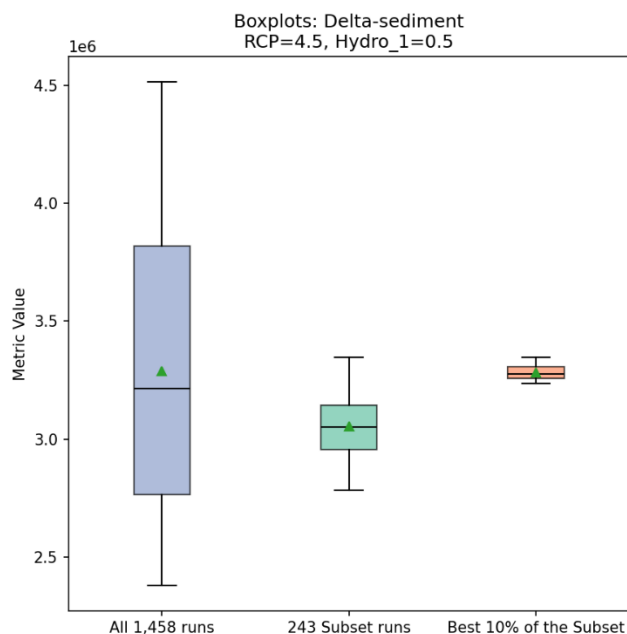


Figure F-23. Distribution of Delta Plain Sediment delivery metric values

Figure F-23 shows the distribution of Delta plain sediment delivery values under the Lowpeaks strategy, for 1) all runs, 2) the environmental scenario subset, and 3) the 10 best percentile scenarios within the subset (Table F-11).

Table F-11. Distribution of Delta plain sediment delivery values under the Lowpeaks strategy

Metric	Group	Mean (yd <sup>3</sup> )	StdDev (yd <sup>3</sup> )	N
Delta-sediment	All Global	3,289,456.241	567,663.26	1458
	Subset	3,054,677.653	130,415.941	243
	Subset Best 10%	3,282,130.172	33,164.91	25

**What are the most influential levers (outlet discharges) for better performance in sediment delivery to Breton and Barataria basins, and for ease of maintenance at SWP for navigation?**

To answer this question, the project team plotted the same set of metrics but highlighted them based on the levels of the outlet discharge policy levers. Similar to Flatpeaks strategy, this analysis revealed that the group of unmanaged outlets and Neptune Pass have a more direct impact on the performance of these metrics. Specifically, the high and non-high levels of these two outlet groupings show distinct differences in performance across some key metrics.

Figure F-24 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Lowpeaks strategy. Among these, the scenarios with high discharge allowed from the unmanaged outlets are highlighted in orange and not high levels (low-medium) are highlighted in blue. The graph shows that high levels of discharge from unmanaged outlets resulted in a



relatively good performance in sediment metrics and Crossings dredged volume but did not improve the SWP dredge volume metric.

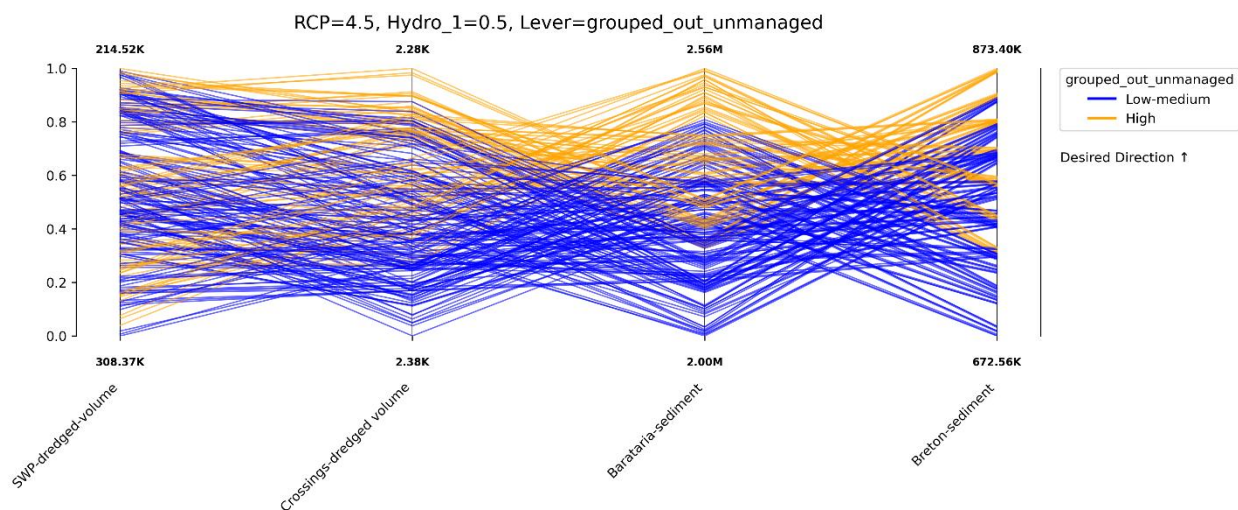


Figure F-24. Policies within the environmental scenario are highlighted by the level of discharge allowed from the unmanaged outlets (high: orange, not high: blue)

Figure F-25 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Lowpeaks strategy. Among these, the scenarios with high discharge allowed from the Neptune Pass are highlighted in orange and not high levels (low-medium) are highlighted in blue. The graph shows that high levels of discharge from Neptune Pass resulted in a relatively good performance in Breton sediment and SWP and Crossings dredged volume metrics and poor to average performance in Barataria sediment metric.

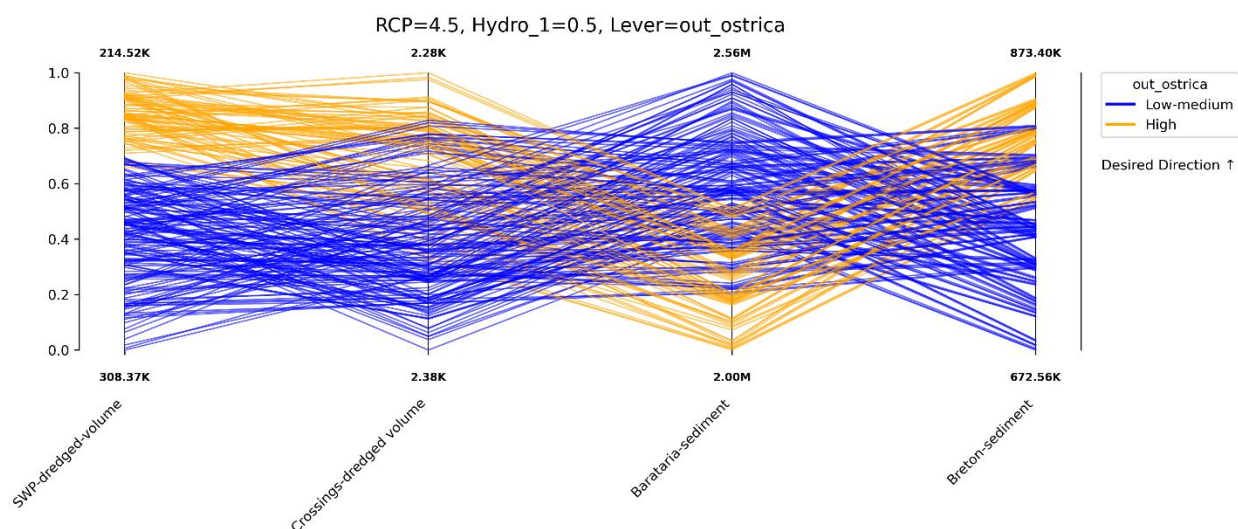


Figure F-25. Policies within the environmental scenario are highlighted by the level of discharge allowed from the Neptune Pass (high: orange, not high: blue)

In summary similar to BAU and Flatpeaks:



- High discharge from Neptune Pass can help both Breton sediment discharge and SWP navigation ease, but does not help Barataria sediment delivery.
- High discharge from unmanaged outlets helps more sediment delivery to basins but does not improve SWP navigation maintenance.

*What do the scenarios that perform best across SWP dredge volume and basin sediment delivery metrics have in common regarding the level of outlet discharge?*

To address this question, the project team looked at these three metrics to understand what combinations of outlet discharge levers the top-performing scenarios have in common. This is done using a two-step process to screen the top scenarios; 1) The scenarios are ranked using the composite score to find the top ones, and 2) Within those top solutions, the “Pareto” set is identified.

For calculating the composite score, each metric is converted to a 0–1 scale based on whether the metric desired state is to be maximized or minimized then add them up into a single “composite score.” Then the project team picks N scenarios with the highest composite score and within those top solutions, the project team finds non-dominated or Pareto scenarios where no other scenario is strictly better on all metrics. A solution is dominated if another is at least as good in every metric and strictly better in at least one.

Figure F-26 shows the 15 top performers based on the composite score in 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph. The colored lines represent the ‘best possible’ (Pareto) scenarios within the highest composite scores. We see that all those scenarios have high levels of outlet discharge from unmanaged outlets and Neptune Pass, consistent with the findings in the previous section.

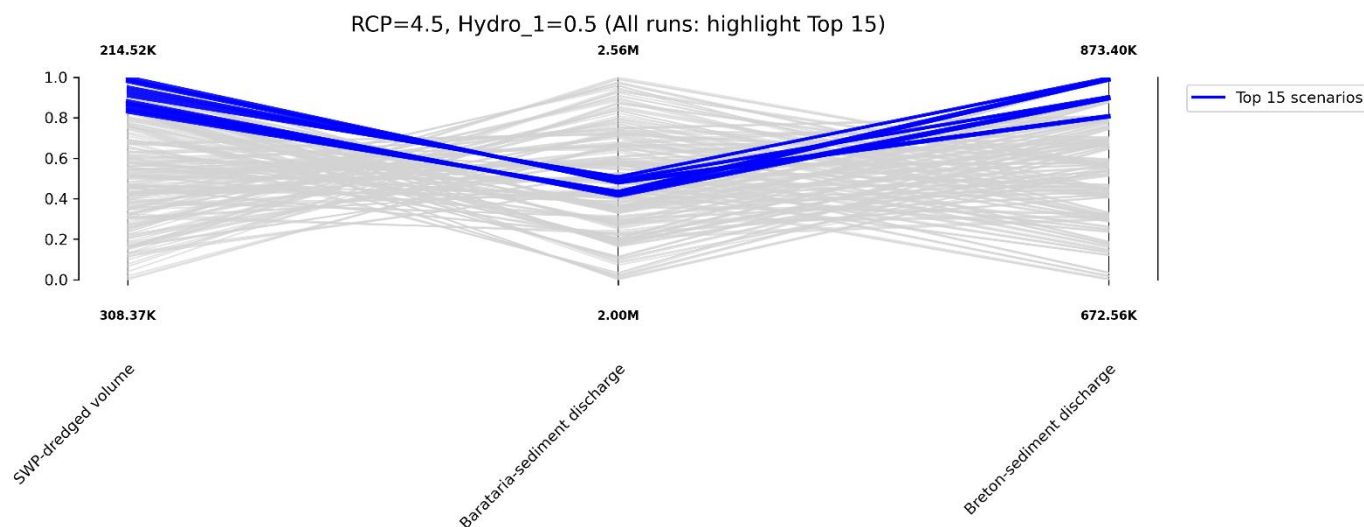


Figure F-26. Top 15 scenarios based on the composite score

Table F-12 shows the combination of the outlet discharge levels allowed in 9 Pareto scenarios in the Top 15 scenarios based on the composite score. As can be seen, all of these scenarios share the highest level of



discharge allowed from unmanaged outlets and Neptune Pass. The levels are mixed in all other outlets, showing their less direct impact on the overall performance of these three metrics.

Table F-12. Outlet discharge levels used in Pareto scenarios.

Diversion outlets	Lower outlets	Unmanaged outlets	Bonnet Carré	Neptune Pass
2	0	2	1.1	1.5
2	0	2	1	1.5
2	0	2	0.9	1.5
1	2	2	1.1	1.5
1	2	2	1	1.5
1	2	2	0.9	1.5
1	1	2	1.1	1.5
1	1	2	1	1.5
1	1	2	0.9	1.5

### F.2.3 Turn Right Strategy

*How does improved performance in one metric affect performance in the others?*

Here, the project team looked at the performance tradeoff between the metrics of interest.

**When minimizing SWP dredging needs, what are the trade-offs with other management metrics?**

Figure F-27 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Turn Right strategy. Among these, the scenarios in the lowest 10th percentile for SWP dredging volume are highlighted in blue (Best 10%). The graph indicates that scenarios with the best performance in terms of dredged volume at SWP (25 scenarios) perform low to



average in sediment delivery metrics at both Barataria and Breton and are divided into both higher and lower performance at Crossings dredged volume metric.

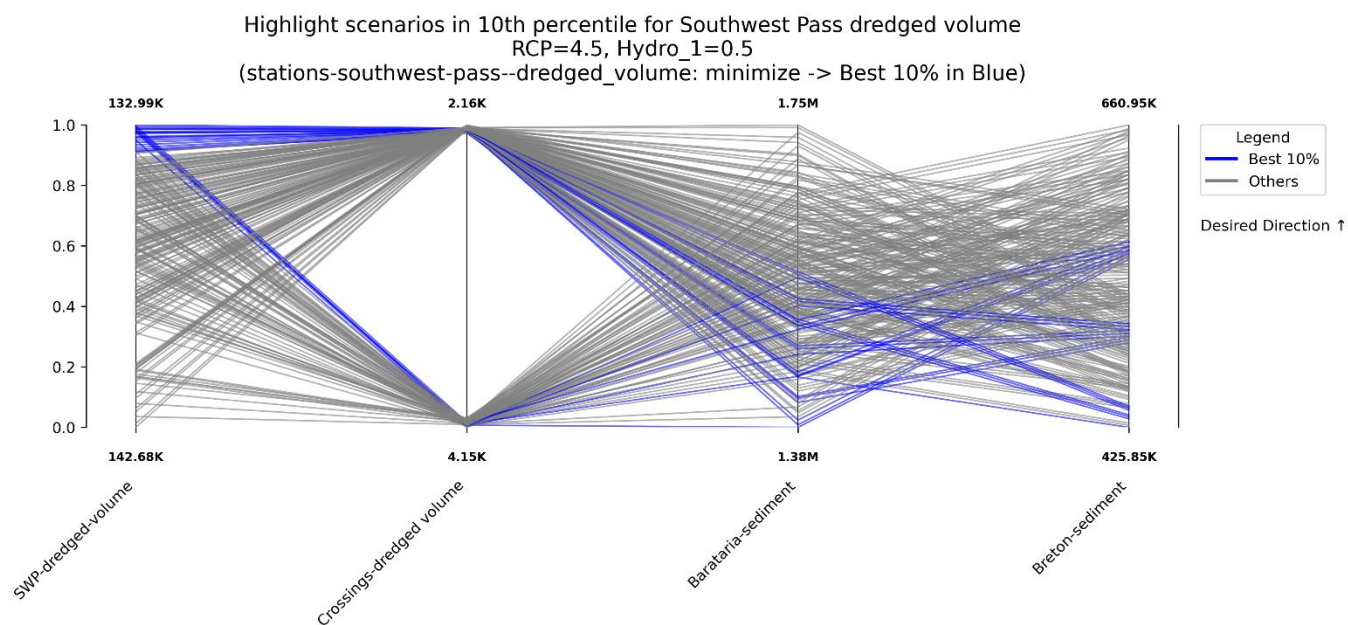


Figure F-27. Tradeoff analysis focused on high-performing scenarios in SWP dredge volume

Figure F-28 is a summary statistic and distribution plot of the metric of focus for reference.

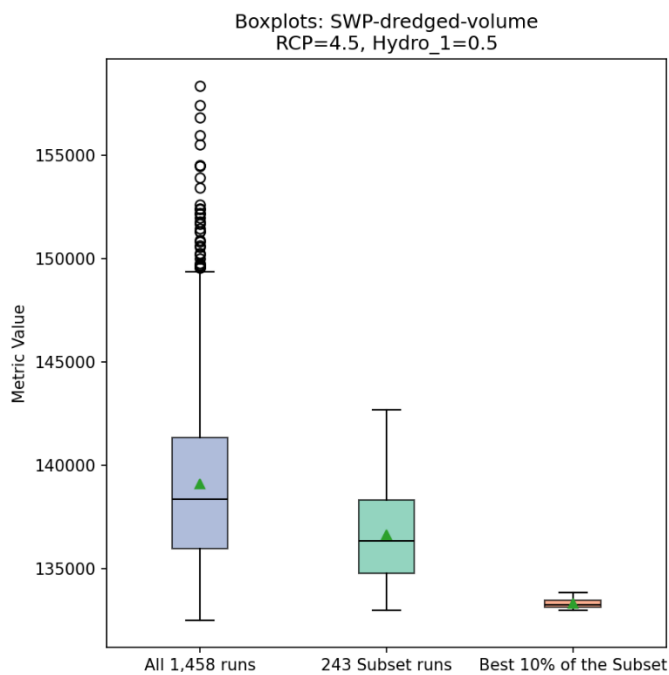


Figure F-28. Distribution of SWP dredge volume metric values



This figure shows the distribution of southwest pass dredge volume values under the Turn Right strategy, for 1) all runs, 2) the environmental scenario subset, and 3) the 10 best percentile scenarios within the subset (Table F-13).

Table F-13. Distribution of Southwest Pass dredge volume values under the turn right strategy

Metric	Group	Mean	StdDev	N
SWP-dredged-volume	All Global	139,095.9	4,240.678	1458
	Subset	136,648.7	2,366.186	243
	Subset Best 10%	133,335.6	262.298	25

### When minimizing Crossings dredging needs, what are the trade-offs with other management metrics?

Figure F-29 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Turn Right strategy. Among these, the scenarios in the lowest 10th percentile for Crossings dredging volume are highlighted in blue (Best 10%). The graph indicates that the 25 scenarios with the best performance in terms of dredged volume at Crossings also perform relatively well in Breton and achieve average to good performance in Barataria sediment metrics. However, their performance in SWP dredged volume is more variable, spanning the entire range.

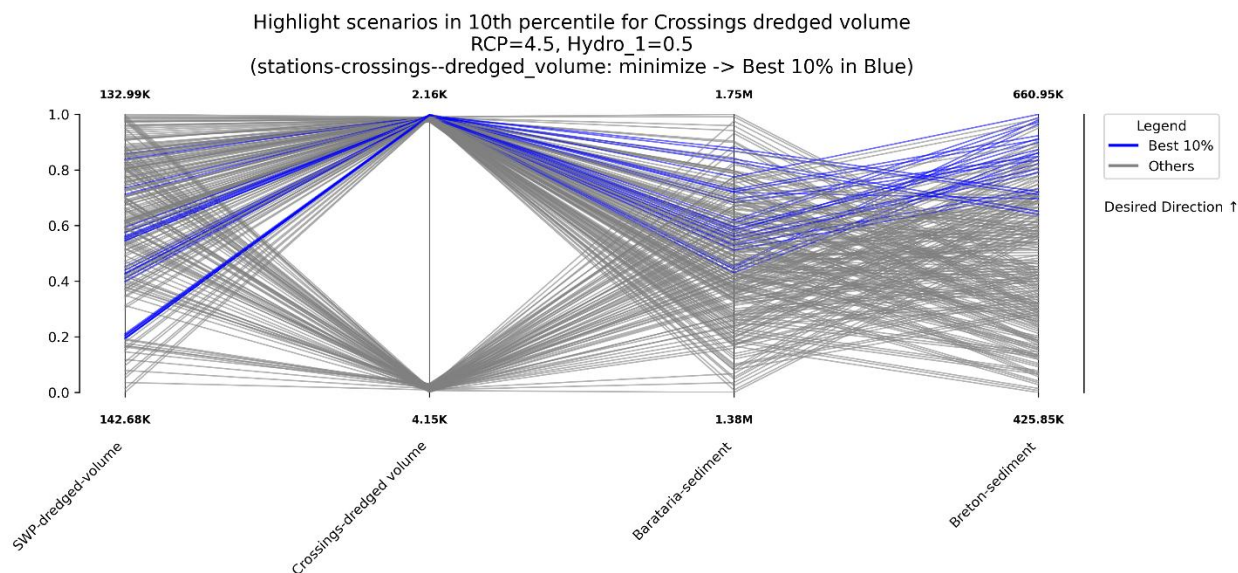


Figure F-29. Tradeoff analysis focused on high-performing scenarios in Crossings dredge volume

Figure F-30 is a summary statistic and distribution plot of the metric of focus for reference.

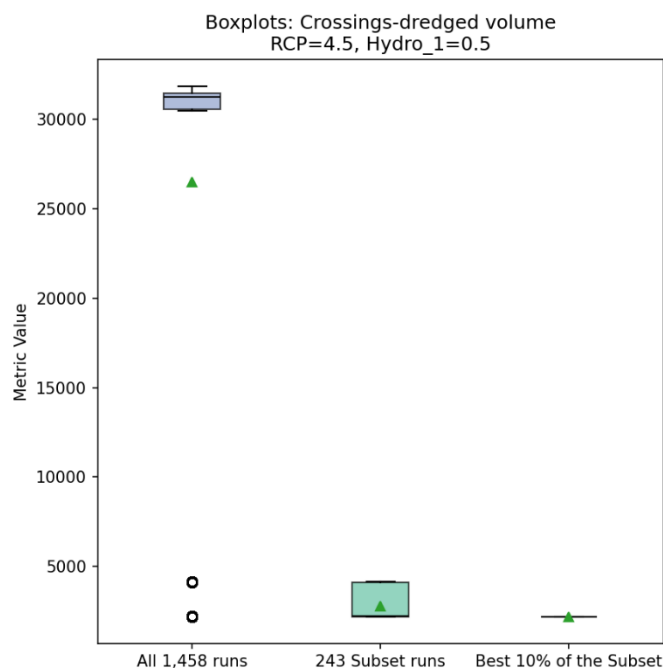


Figure F-30. Distribution of Crossings dredge volume metric values

This figure shows the distribution of Crossings dredge volume values under the Turn Right strategy, for 1) all runs, 2) the environmental scenario subset, and 3) the 10 best percentile scenarios within the subset. As can be seen, the environmental scenario shows relatively very low Crossings dredged volume. Future work is needed to investigate the underlying reason Table F-14.

Table F-14. Distribution of Crossings dredge volume values under the Turn Right strategy

Metric	Group	Mean (yd <sup>3</sup> )	StdDev (yd <sup>3</sup> )	N
Crossings-dredged volume	All runs	26,524.2	10,633.47	1458
	Subset	2,782.603	897.587	243
	Subset Best 10%	2,167.121	4.275	25

### When maximizing sediment delivery to the Barataria Basin, what are the trade-offs with other management metrics?

Figure F-31 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Turn Right strategy. Among these, the scenarios in the highest 10th percentile for Barataria sediment delivery are highlighted in blue (Best 10%). The graph indicates that scenarios with the best performance in terms of Barataria sediment delivery (25 scenarios) perform average in Breton sediment discharge their performance in dredged volume metrics at SWP and Crossings is more variable, spanning the entire range.

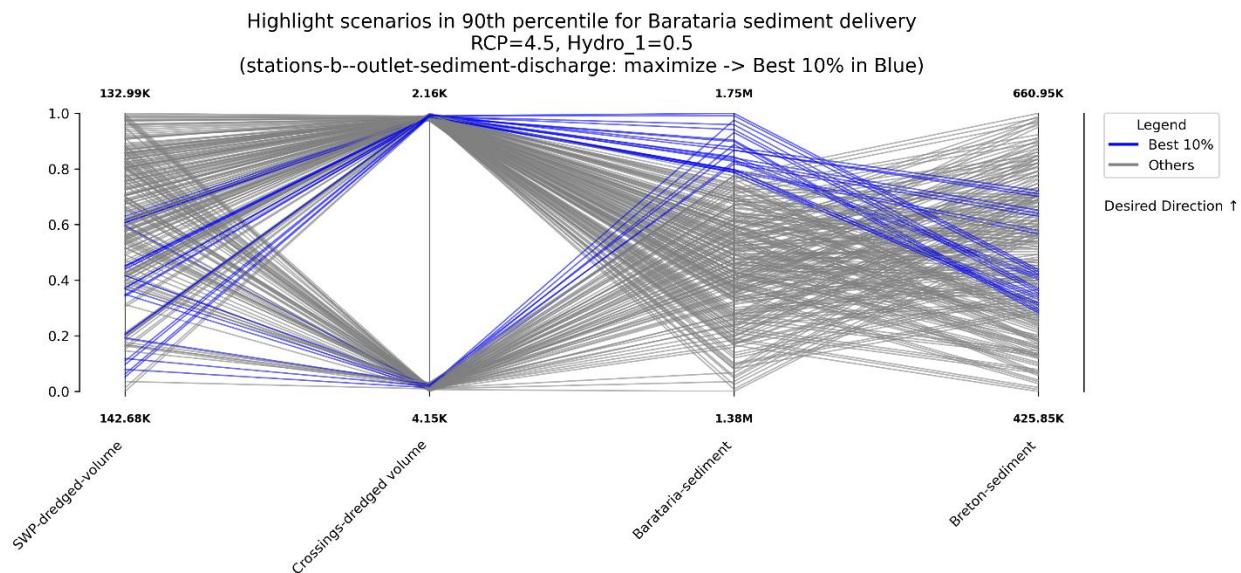


Figure F-31. Tradeoff analysis focused on high-performing scenarios in Barataria Sediment delivery

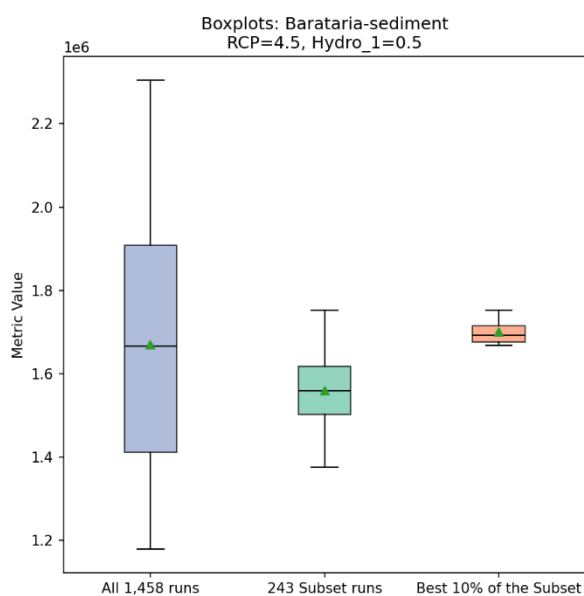


Figure F-32. Distribution of Barataria sediment delivery metric values

Figure F-32 shows the distribution of Barataria sediment delivery values under the Turn Right strategy, for 1) all runs, 2) the environmental scenario subset, and 3) the 10 best percentile scenarios within the subset (Table F-15).



Table F-15. Distribution of Barataria sediment delivery values under the Turn Right strategy

Metric	Group	Mean (yd <sup>3</sup> )	StdDev (yd <sup>3</sup> )	N
Barataria-sediment	All Global	1,669,914	278,726.3	1458
	Subset	1,558,927	83,149.35	243
	Subset Best 10%	1,701,203	26,029.22	25

**When maximizing sediment delivery to the Breton Sound Basin, what are the trade-offs with other management metrics?**

Figure F-33 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Turn Right strategy. Among these, the scenarios in the highest 10th percentile for Breton sediment delivery are highlighted in blue (Best 10%). The graph indicates that scenarios with the best performance in terms of Breton sediment delivery (25 scenarios) perform average in the Barataria sediment delivery metric and perform low to average in the Southwest pass dredged volume metric. However, their performance in dredged volume metrics at Crossings is more variable, spanning the entire range.

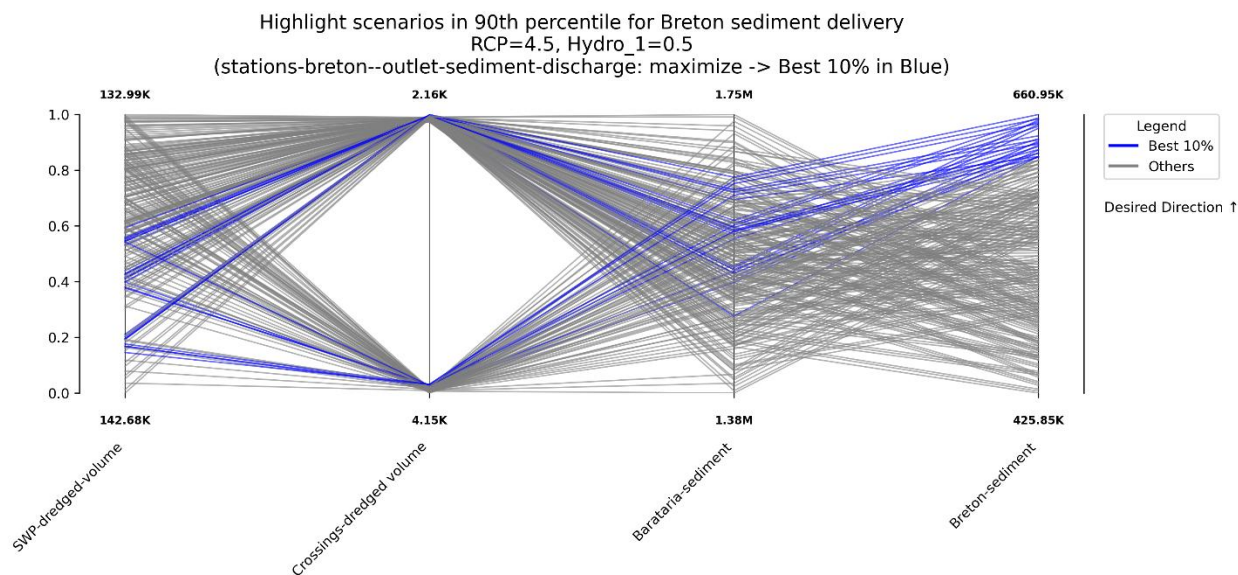


Figure F-33. Tradeoff analysis focused on high-performing scenarios in Breton Sediment delivery

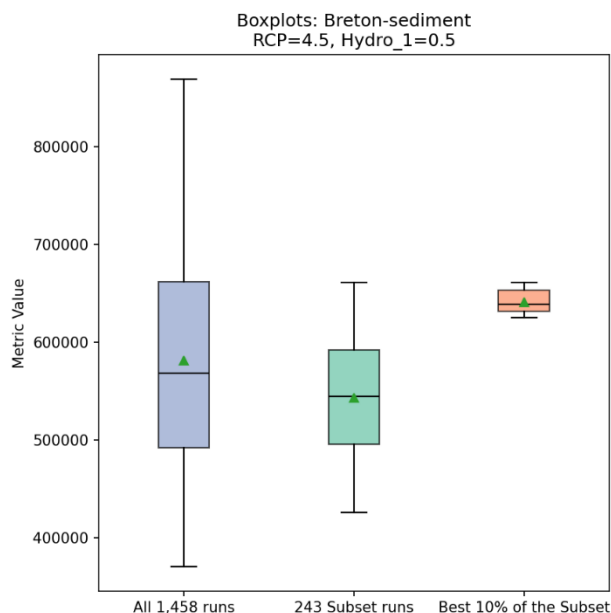


Figure F-34. Distribution of Breton sediment delivery metric values

Figure F-34 shows the distribution of Breton sediment delivery values under the Turn Right strategy, for 1) all runs, 2) the environmental scenario subset, and 3) the 10 best percentile scenarios within the subset (Table F-16).

Table F-16. Distribution of Breton sediment delivery values under the Turn Right strategy

Metric	Group	Mean (yd <sup>3</sup> )	StdDev (yd <sup>3</sup> )	N
Breton-sediment	All Global	580,714.5	113,096.1	1458
	Subset	543,038.4	60,171.96	243
	Subset Best 10%	640,735.6	12,008.13	25

**When maximizing sediment delivery to the Deltaic Plain (BA + BS), what are the trade-offs with other management metrics?**

The project team also looked at the same tradeoff but with combined Barataria and Breton Sediment as Delta Plain sediment delivery. Figure F-35 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Turn Right strategy. Among these, the scenarios in the highest 10th percentile for Delta Plain sediment delivery are highlighted in blue (Best 10%). The graph shows a general tradeoff between Delta Plain sediment delivery and SWP dredged volume, in which the highest performing scenarios in Delta Plain sediment delivery show relatively low to average performance in SWP dredged volume. The scenarios show mostly good performance in Crossings dredged volume but the range for this metric is too small to be meaningful.

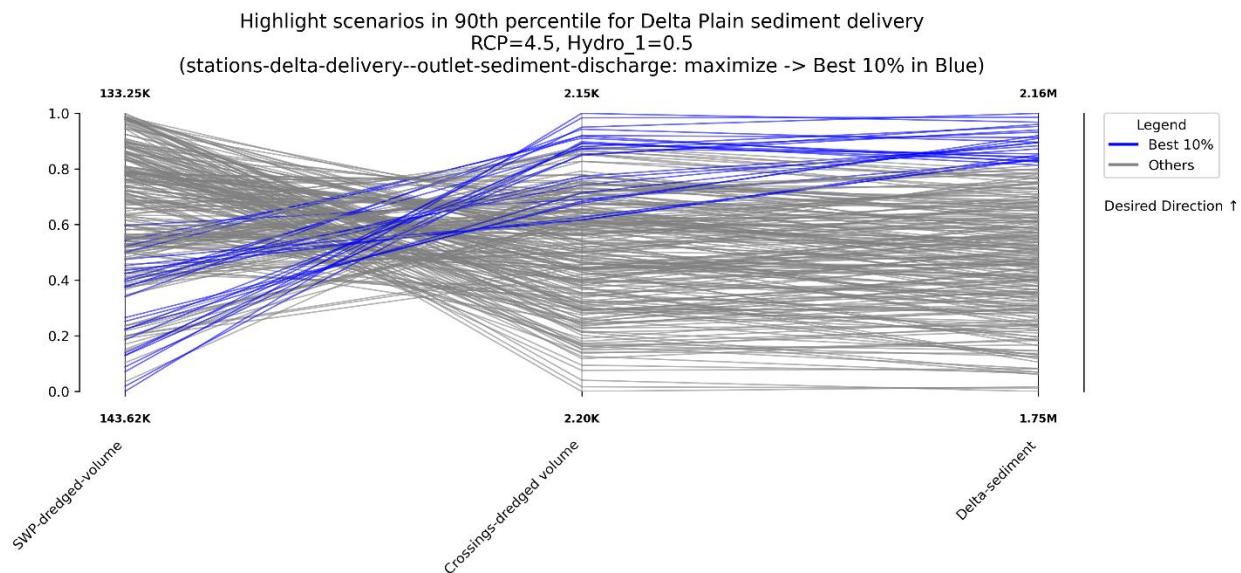


Figure F-35. Tradeoff analysis focused on high-performing scenarios in Delta Plain Sediment delivery

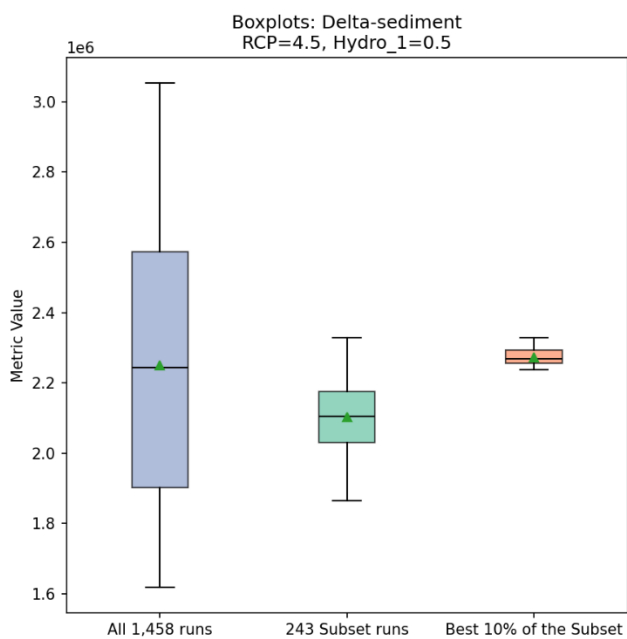


Figure F-36. Distribution of Delta plain sediment delivery metric values

Figure F-36 shows the distribution of Delta plain sediment delivery values under the Turn Right strategy, for 1) all runs, 2) the environmental scenario subset, and 3) the 10 best percentile scenarios within the subset (Table F-17).



Table F-17. Distribution of Delta plain sediment delivery values under the Turn Right strategy

Metric	Group	Mean (yd <sup>3</sup> )	StdDev (yd <sup>3</sup> )	N
Delta-sediment	All Global	2,250,629	373,246.7	1458
	Subset	2,101,966	103,480.8	243
	Subset Best 10%	2,273,644	25,126.78	25

*What are the most influential levers (outlet discharges) for better performance in sediment delivery to Breton and Barataria basins, and for ease of maintenance at SWP for navigation?*

To answer this question, the project team plotted the same set of metrics but highlighted them based on the levels of the outlet discharge policy levers. This analysis for the alternative channel strategies did not result in distinct differences in performance across some key metrics for high levels of specific outlet groupings as much as BAU and adjusted flow strategies. However, the plots do provide some insights.

Figure F-37 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Turn Right strategy. Among these, the scenarios with high discharge allowed from the diversion outlets are highlighted in orange and not high levels (low-medium) are highlighted in blue. The graph shows that high levels of discharge from diversion outlets resulted in a relatively good performance in the Barataria sediment metric but led to variable results in other metrics.

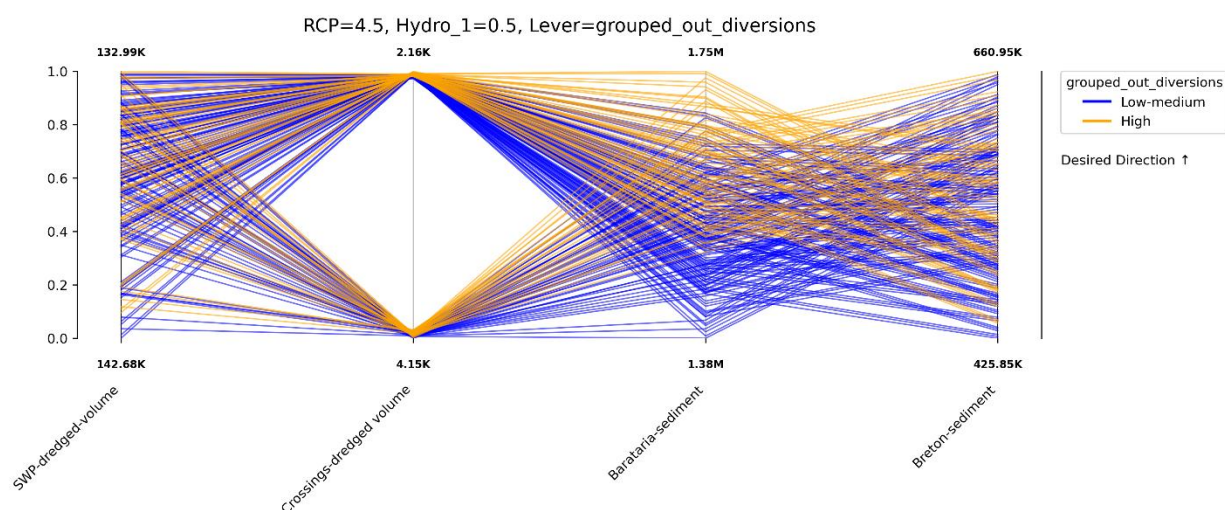


Figure F-37. Policies within the environmental scenario are highlighted by the level of discharge allowed from the diversion outlets (high: orange, not high: blue)

Figure F-38 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Turn Right strategy. Among these scenarios, those with high discharge allowed from Bonnet Carré are highlighted in orange, while those with low to medium discharge levels are highlighted in blue. The graph shows that high discharge levels from Bonnet Carré largely determine



the division in performance for the Crossings dredged volume metric, where scenarios with lower discharge levels tend to perform better.

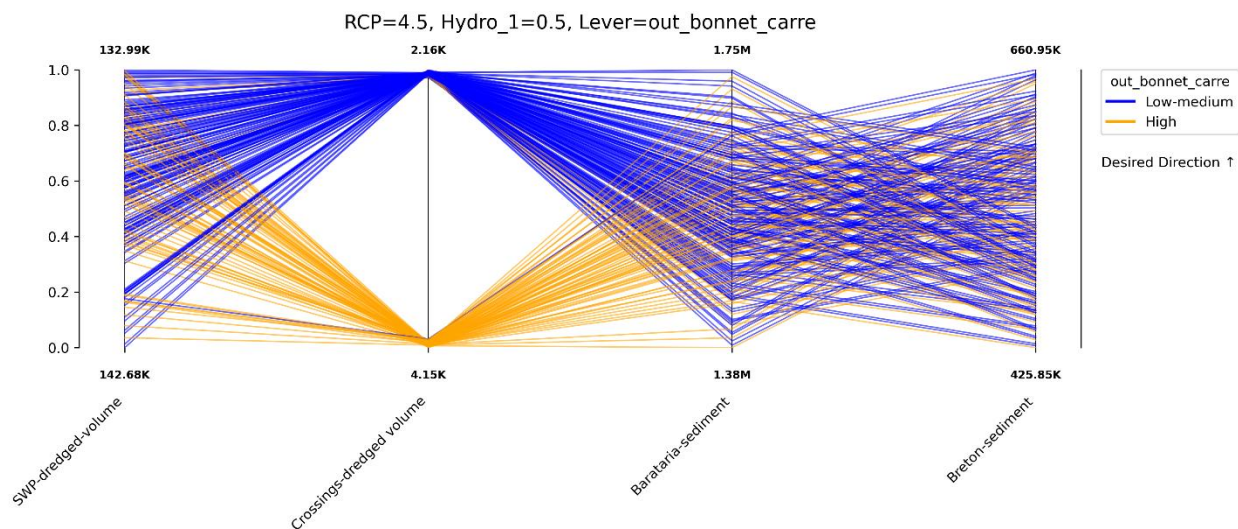


Figure F-38. Policies within the environmental scenario are highlighted by the level of discharge allowed from the Bonnet Carré (high: orange, not high: blue)

Figure F-39 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Turn Right strategy. Among these, the scenarios with high discharge allowed from Neptune Pass are highlighted in orange and not high levels (low-medium) are highlighted in blue. The graph shows that high levels of discharge from Neptune Pass resulted in a relatively good performance in the Breton sediment metric but led to variable results in other metrics.

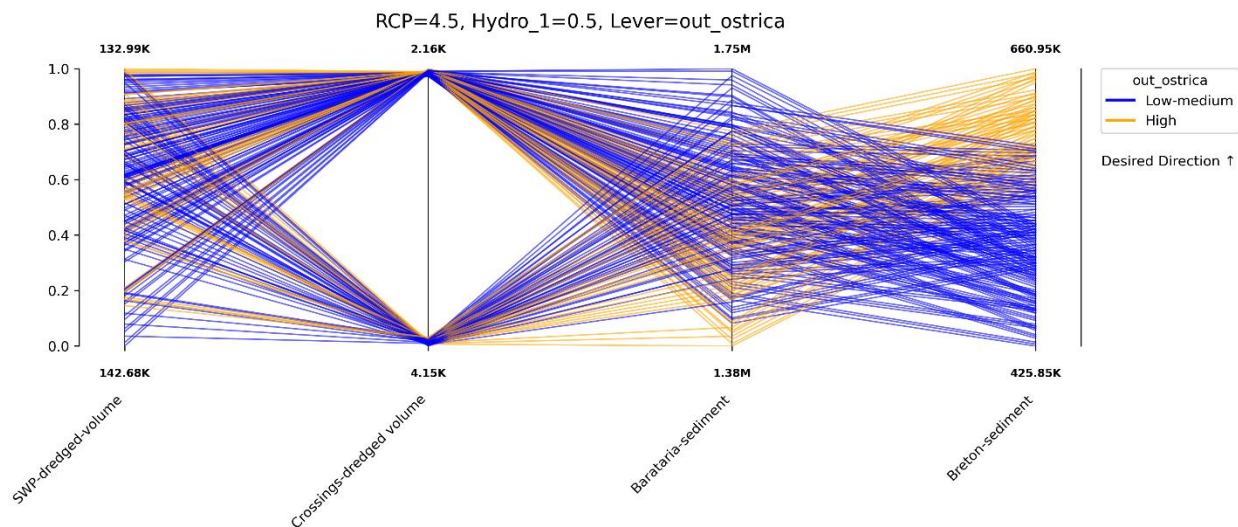


Figure F-39. Policies within the environmental scenario are highlighted by the level of discharge allowed from the Neptune Pass (high: orange, not high: blue)

Figure F-40 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Turn Right strategy. Among these, the scenarios with high discharge allowed from the Unmanaged outlets are highlighted in orange and not high levels (low-medium) are highlighted in blue. The graph shows that high levels of discharge from Unmanaged outlets resulted in an average to good performance in both Breton and Barataria sediment metrics but led to variable performance in Crossings and low to average performance in SWP dredge volume metrics.

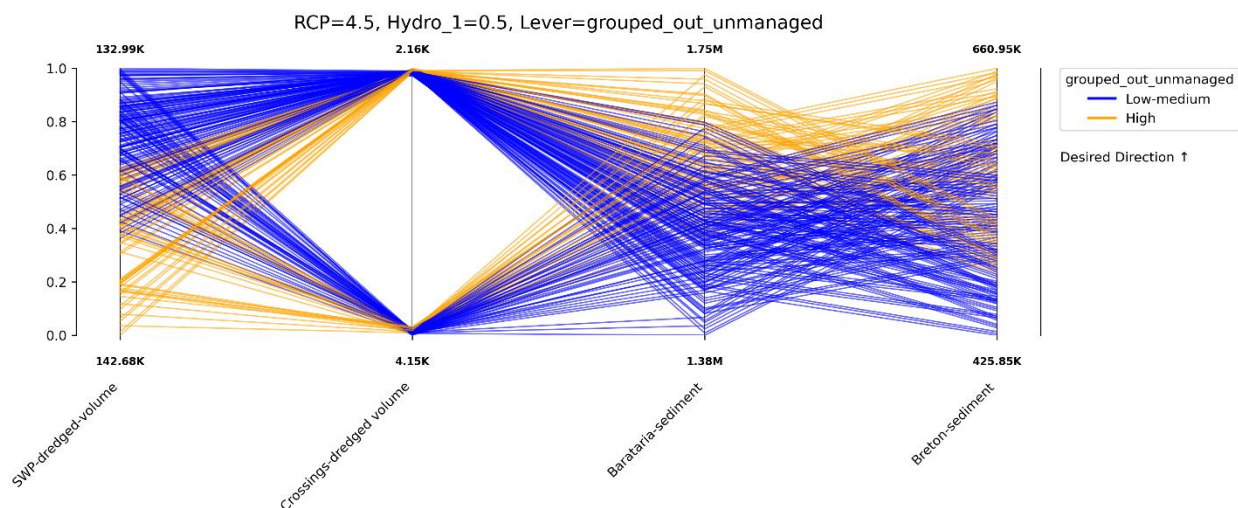


Figure F-40. Policies within the environmental scenario are highlighted by the level of discharge allowed from the Neptune Pass (high: orange, not high: blue) : Policies within the environmental scenario are highlighted by the level of discharge allowed from the Neptune Pass (high: orange, not high: blue)

In summary:



- Not-high discharge from Bonnet Carré can help Crossings dredging needs
- High discharge from Neptune Pass can help Breton sediment delivery
- High discharge from Diversions can slightly help Barataria sediment delivery
- High discharge from unmanaged outlets generally supports sediment delivery metrics but may increase dredging needs in SWP.
- The outlet discharge levels for specific outlets do not show as distinct an impact on performance as they did in the BAU and adjusted flow strategies.

*What do the scenarios that perform best across SWP dredge volume and basin sediment delivery metrics have in common regarding the level of outlet discharge?*

To address this question, the project team looked at these three metrics to understand what combinations of outlet discharge levers the top-performing scenarios have in common. This is done using a two-step process to screen the top scenarios; 1) Scenarios are ranked using the composite score to find the top ones, and 2) Within those top solutions, the “Pareto” set is identified.

For calculating the composite score, each metric is converted to a 0–1 scale based on whether the metric desired state is to be maximized or minimized then add them up into a single “composite score.” Then the project team picks N scenarios with the highest composite score and within those top solutions, the project team finds non-dominated or Pareto scenarios where no other scenario is strictly better on all metrics. A solution is dominated if another is at least as good in every metric and strictly better in at least one.

Figure F-41 shows the 15 top performers based on the composite score in 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Hang-a-right strategy. The blue lines show the top 15 scenarios based on the composite score.

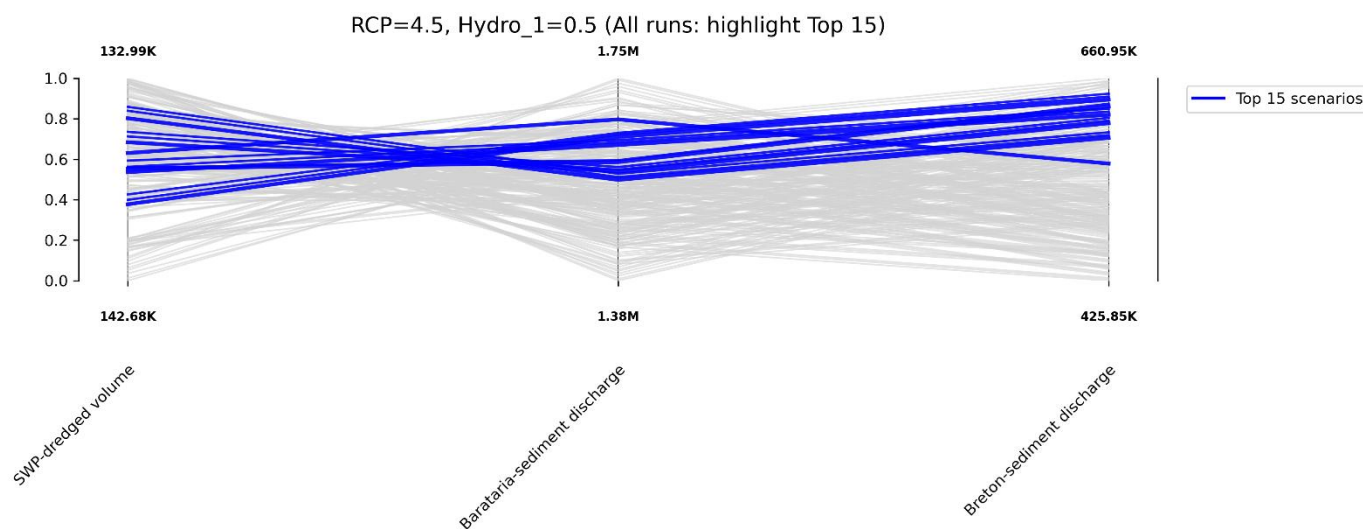


Figure F-41. Top 15 scenarios based on the composite score



Table F-18. Outlet discharge levels allowed in Pareto scenarios

Diversion outlets	Lower outlets	Unmanaged outlets	Bonnet Carré	Neptune Pass
2	0	2	1.1	1.5
2	0	1	1.1	1.5
2	0	2	0.9	1
2	1	1	1.1	1.5
2	2	1	1	1.5
2	1	2	1.1	1.5

Table F-18 shows the combination of the outlet discharge levels allowed in 6 Pareto scenarios in the Top 15 scenarios based on the composite score. As can be seen, all of these scenarios except one share the highest level of discharge allowed from Diversion outlets and Neptune Pass. The levels are mixed in all other outlets, showing their less direct impact on the overall performance of these three metrics in the Turn Right strategy.

In summary:

- The scenarios that perform best across SWP dredged volume and basin sediment delivery metrics generally have high discharge allowed from diversion outlets and Neptune Pass.

## F.2.4 Turn Left Strategy

*How does improved performance in one metric affect performance in the others?*

Here, the project team looks at the performance tradeoff between the metrics of interest.

**When minimizing SWP dredging needs, what are the trade-offs with other management metrics?**

Figure F-42 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Turn Left strategy. Among these, the scenarios in the lowest 10th percentile for SWP dredging volume are highlighted in blue (Best 10%). The graph indicates that scenarios with the best performance in terms of dredged volume at SWP (25 scenarios) perform low to



average in sediment delivery metrics at both Barataria and Breton as well as in the Crossings dredged volume metric.

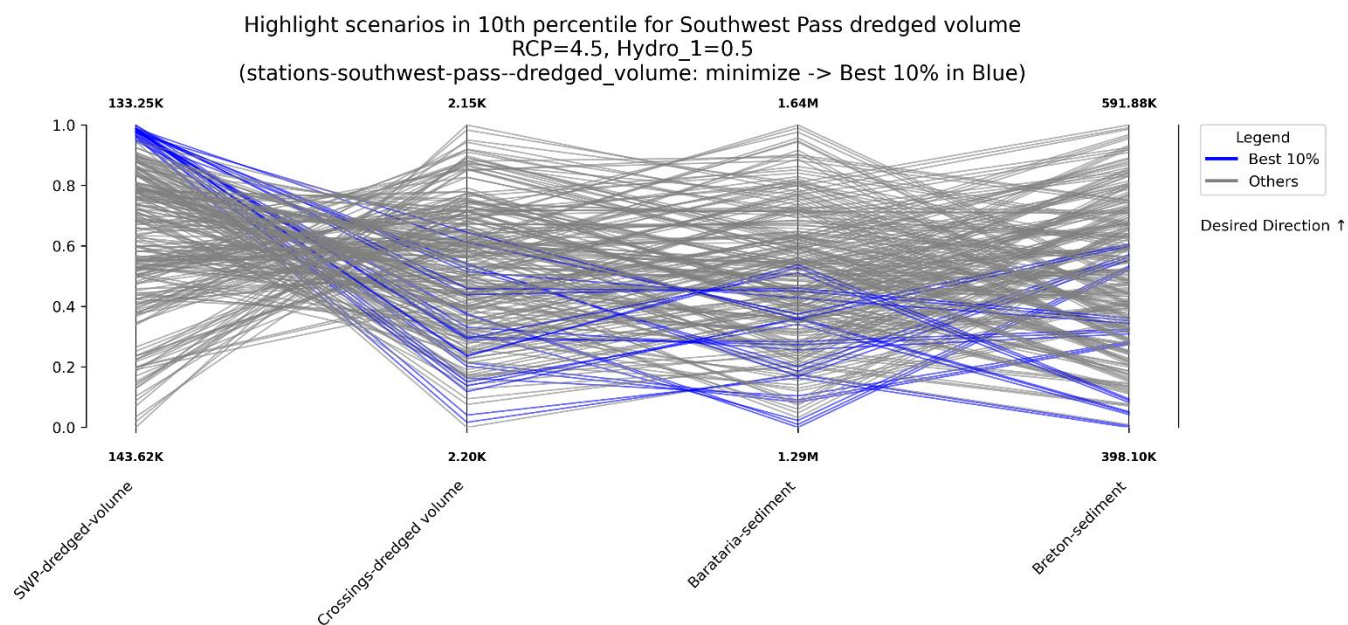


Figure F-42. Tradeoff analysis focused on high-performing scenarios in SWP dredge volume

Figure F-43 is a summary statistic and distribution plot of the metric of focus for reference. It shows the distribution of southwest pass dredge volume values under the Turn Left strategy, for 1) all runs, 2) the environmental scenario subset, and 3) the 10 best percentile scenarios within the subset (Table F-19).

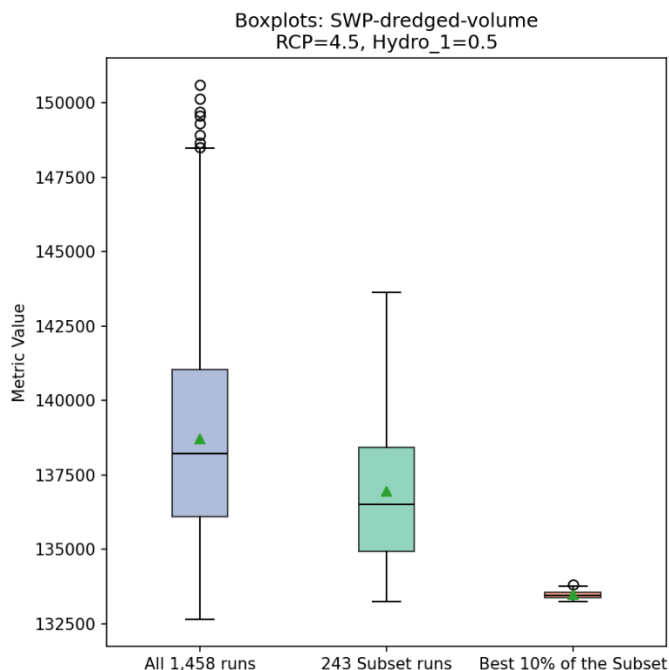


Figure F-43. Distribution of SWP dredge volume metric values

Table F-19. Distribution of southwest pass dredge volume values under the Turn Left strategy

Metric	Group	Mean (yd <sup>3</sup> )	StdDev (yd <sup>3</sup> )	N
SWP-dredged-volume	All Global	138,697.873	3470.75	1458
	Subset	136,947.685	2526.39	243
	Subset Best 10%	133,478.843	135.831	25

**When minimizing Crossings dredging needs, what are the trade-offs with other management metrics?**

Figure F-44 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Turn Left strategy. Among these, the scenarios in the lowest 10th percentile for Crossings dredging volume are highlighted in blue (Best 10%). The graph indicates that the 25 scenarios with the best performance in terms of dredged volume at Crossings also perform relatively



well in both Breton and Barataria sediment metrics. However, their performance in the SWP dredged volume is low to average.

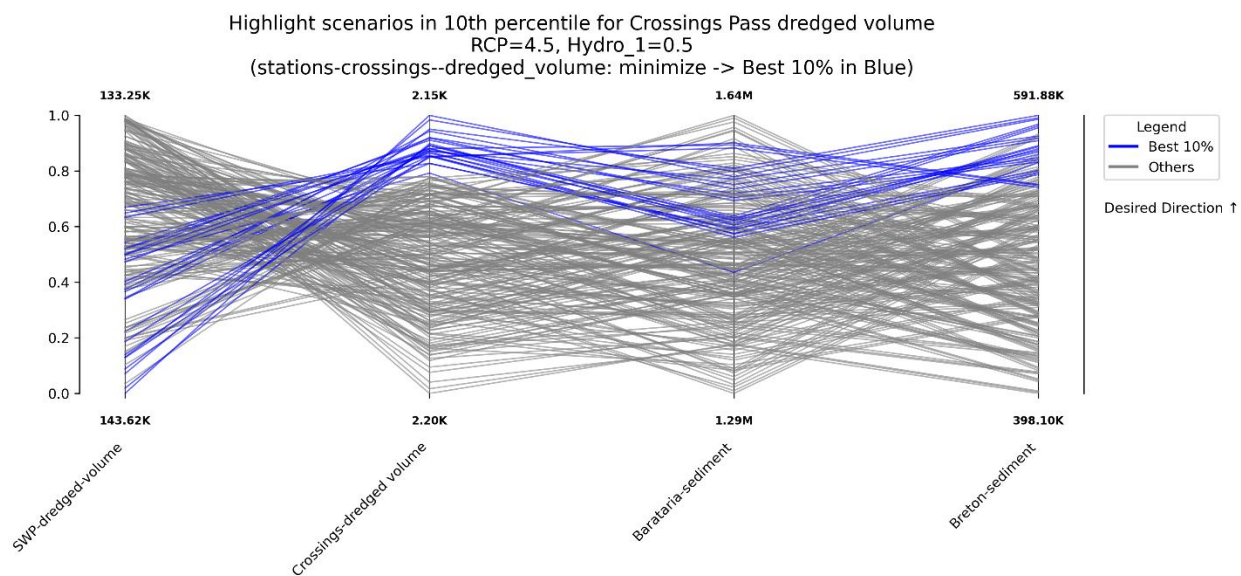


Figure F-44. Tradeoff analysis focused on high-performing scenarios in Crossings dredge volume

Figure F-45 is a summary statistic and distribution plot of the metric of focus for reference.

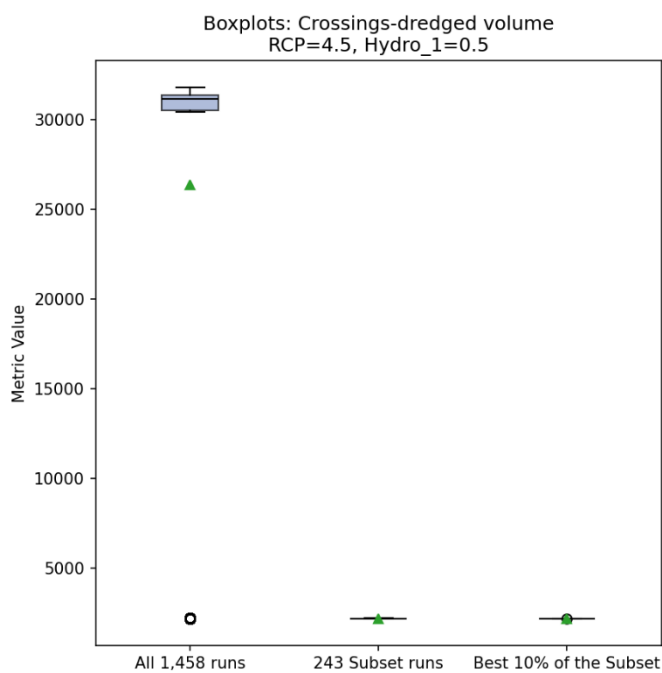


Figure F-45. Distribution of Crossings dredge volume metric values



This figure shows the distribution of Crossings dredge volume values under the Turn Left strategy, for 1) all runs, 2) the environmental scenario subset, and 3) the 10 best percentile scenarios within the subset. As it can be seen the environmental scenario shows relatively very low Crossings dredged volume. Future work is needed to investigate the underlying reason (Table F-20).

Table F-20. Distribution of Crossings dredge volume values under the Turn Left strategy

Metric	Group	Mean (yd <sup>3</sup> )	StdDev (yd <sup>3</sup> )	N
Crossings-dredged volume	All runs	26,364.94	10,829.79	1458
	Subset	2,169.056	10.828	243
	Subset Best 10%	2,150.934	2.417	25

### When maximizing sediment delivery to the Barataria Basin, what are the trade-offs with other management metrics?

Figure F-46 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Turn Left strategy. Among these, the scenarios in the highest 10th percentile for Barataria sediment delivery are highlighted in blue (Best 10%). The graph indicates that scenarios with the best performance in terms of Barataria sediment delivery (25 scenarios) perform average to good in Breton sediment discharge and crossings dredged volume metrics but exhibit lower performance in the SWP dredged volume metric.

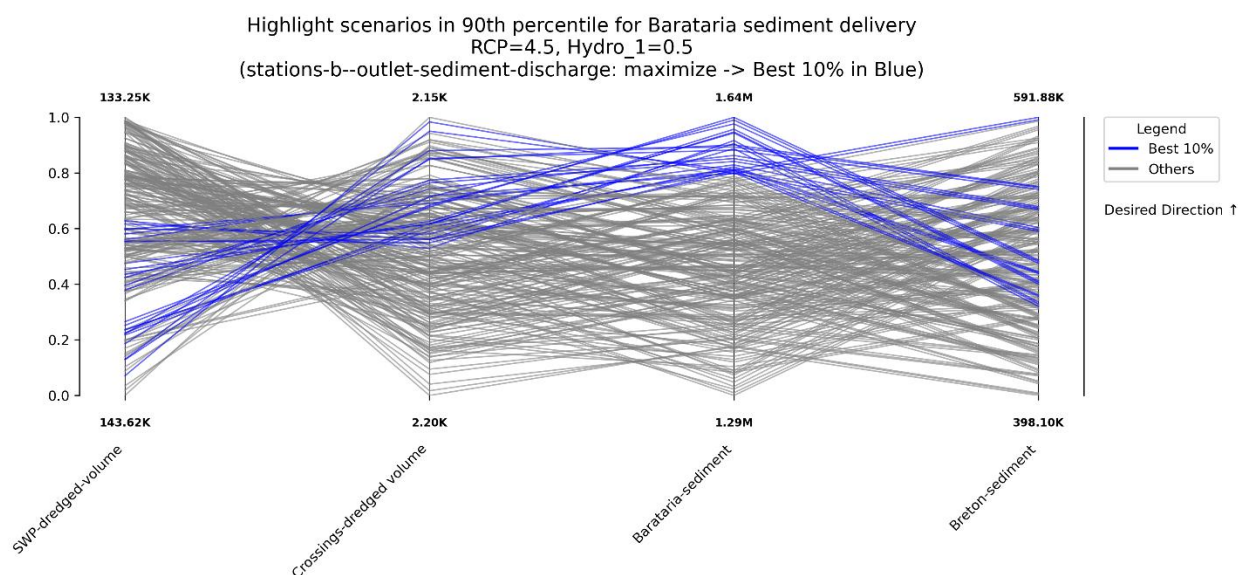


Figure F-46. Tradeoff analysis focused on high-performing scenarios in Barataria Sediment delivery

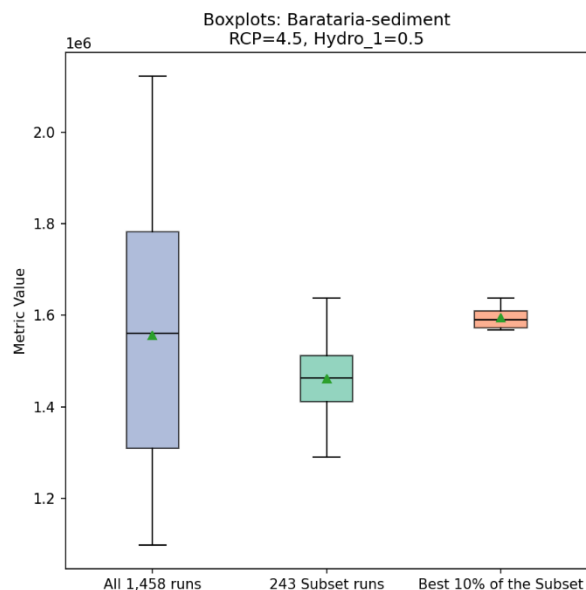


Figure F-47. Distribution of Barataria sediment delivery metric values

Figure F-47 shows the distribution of Barataria sediment delivery values under the Turn Left strategy, for 1) all runs, 2) the environmental scenario subset, and 3) the 10 best percentile scenarios within the subset (Table F-21).

Table F-21. Distribution of Barataria sediment delivery values under the Turn Left strategy

Metric	Group	Mean (yd <sup>3</sup> )	StdDev (yd <sup>3</sup> )	N
Barataria-sediment	All Global	1,556,512	260,510.8	1458
	Subset	1,461,199	77,788.67	243
	Subset Best 10%	1,593,981	22,966.12	25

### When maximizing sediment delivery to the Breton Sound Basin, what are the trade-offs with other management metrics?

Figure F-48 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Turn Left strategy. Among these, the scenarios in the highest 10th percentile for Breton sediment delivery are highlighted in blue (Best 10%). The graph indicates that the 25 scenarios with the best performance in Breton sediment delivery also perform well in the Crossings dredged volume metric, achieve average to good performance in Barataria sediment delivery, but exhibit low to average performance in the SWP metric.



Figure F-48. Tradeoff analysis focused on high-performing scenarios in Breton Sediment delivery

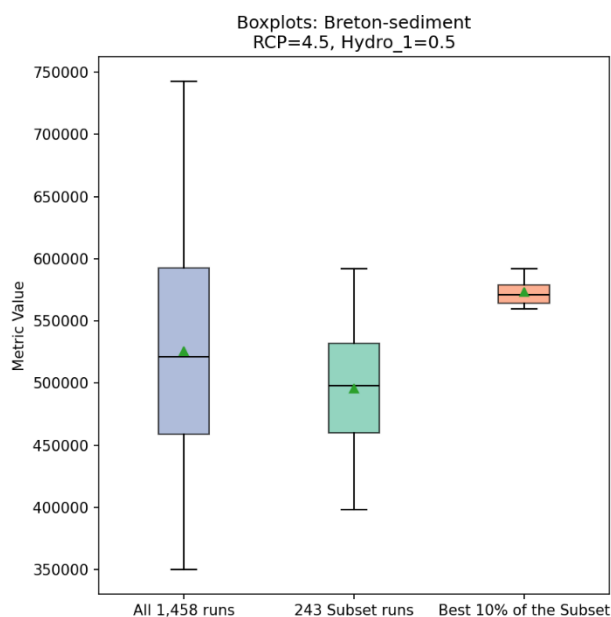


Figure F-49. Distribution of Breton sediment delivery metric values

Figure F-49 shows the distribution of Breton sediment delivery values under the Turn Left strategy, for 1) all runs, 2) the environmental scenario subset, and 3) the 10 best percentile scenarios within the subset (Table F-22).



Table F-22. Distribution of Breton sediment delivery values under the Turn Left strategy

Metric	Group	Mean (yd <sup>3</sup> )	StdDev (yd <sup>3</sup> )	N
Breton-sediment	All Global	525,734.4	86,871.96	1458
	Subset	495,767.4	47,406.4	243
	Subset Best 10%	573,061.5	10,126.13	25

**When maximizing sediment delivery to the Deltaic Plain (BA + BS), what are the trade-offs with other management metrics?**

The project team also looked at the same tradeoff but with combined Barataria and Breton Sediment as Delta Plain sediment delivery. Figure F-50 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Turn Left strategy. Among these, the scenarios in the highest 10th percentile for Delta Plain sediment delivery are highlighted in blue (Best 10%). The graph shows a general tradeoff between Delta Plain sediment delivery and SWP dredged volume, in which the highest performing scenarios in Delta Plain sediment delivery show relatively low to average performance in SWP dredged volume. The same scenarios show mostly average performance in Crossings dredged volume.

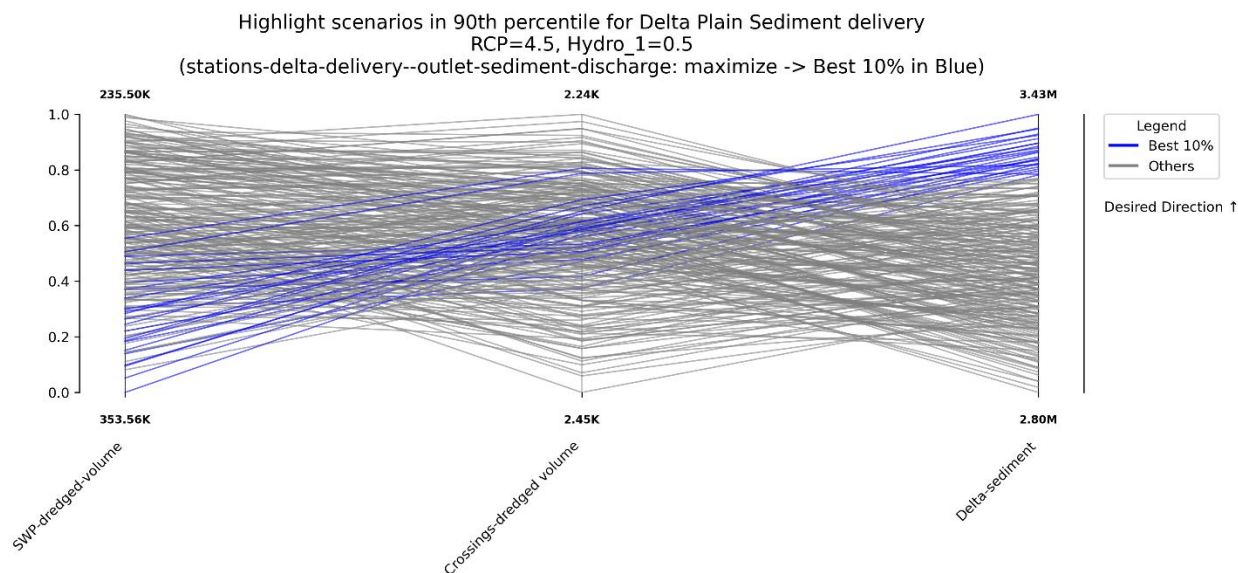


Figure F-50. Tradeoff analysis focused on high-performing scenarios in Delta Plain Sediment delivery

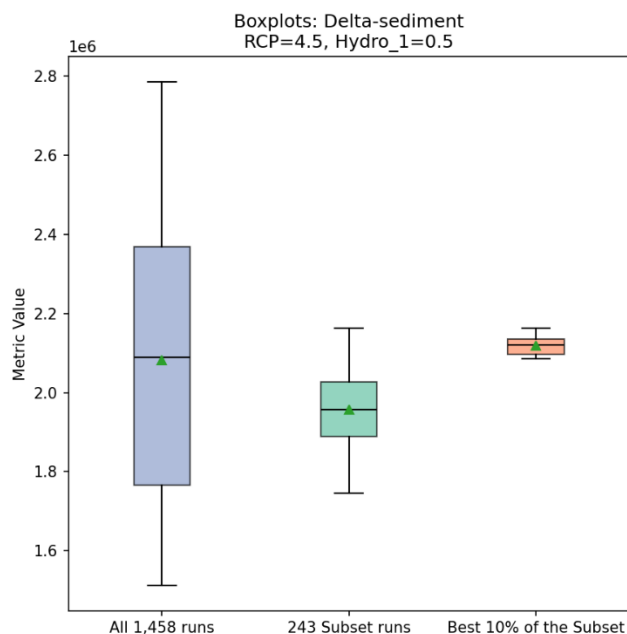


Figure F-51. Distribution of Delta plain sediment delivery metric values

Figure F-51 shows the distribution of Delta plain sediment delivery values under the Turn Left strategy, for 1) all runs, 2) the environmental scenario subset, and 3) the 10 best percentile scenarios within the subset (Table F-23).

Table F-23. Distribution of Delta plain sediment delivery values under the Turn Left strategy

Metric	Group	Mean (yd <sup>3</sup> )	StdDev (yd <sup>3</sup> )	N
Delta-sediment	All Global	2,082,245.986	333,354.993	1458
	Subset	1,956,966.331	95,651.563	243
	Subset Best 10%	2,118,015.864	23,142.563	25

**What are the most influential levers (outlet discharges) for better performance in sediment delivery to Breton and Barataria basins, and for ease of maintenance at SWP for navigation?**

To answer this question, the project team plotted the same set of metrics but highlighted them based on the levels of the outlet discharge policy levers. This analysis showed that the group of unmanaged and diversion outlets and Neptune Pass have a more distinct impact on the performance of these metrics.

Figure F-52 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Turn Left strategy. Among these, the scenarios with high discharge allowed from the unmanaged outlets are highlighted in orange and not high levels (low-medium) are highlighted in blue. The graph shows that high levels of discharge from unmanaged outlets resulted in a relatively good performance in sediment metrics and Crossings dredged volume but did not improve the SWP dredge volume metric.

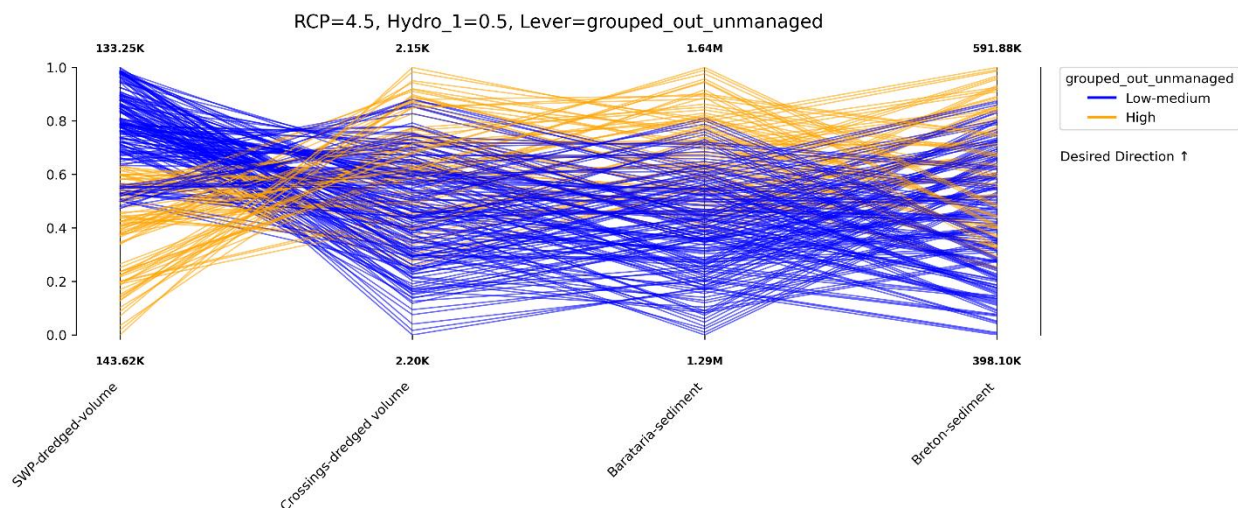


Figure F-52. Policies within the environmental scenario are highlighted by the level of discharge allowed from the unmanaged outlets (high: orange, not high: blue)

Figure F-53 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Turn Left strategy. Among these, the scenarios with high discharge allowed from the Diversion outlets are highlighted in orange and not high levels (low-medium) are highlighted in blue. The graph shows that high levels of discharge from Diversion outlets resulted in a relatively good performance in Barataria sediment delivery and Crossings dredged volume metrics but led to varied outcomes in Breton sediment delivery and SWP dredged volume metrics.

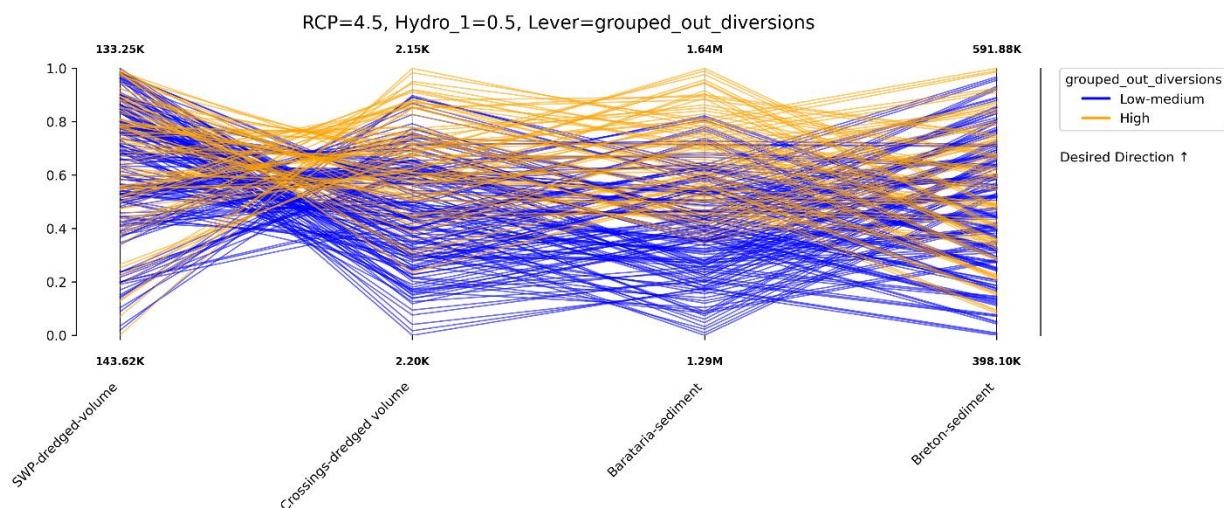


Figure F-53. Policies within the environmental scenario are highlighted by the level of discharge allowed from the Diversion outlets (high: orange, not high: blue)



Figure F-54 displays 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Turn Left strategy. Among these, the scenarios with high discharge allowed from the Neptune Pass are highlighted in orange and not high levels (low-medium) are highlighted in blue. The graph shows that high levels of discharge from Neptune Pass resulted in a relatively good performance in Breton sediment and Crossings dredged volume metrics (although the Crossings metric range is too small to be meaningful) but led to varied outcomes in Barataria and SWP dredge volume.

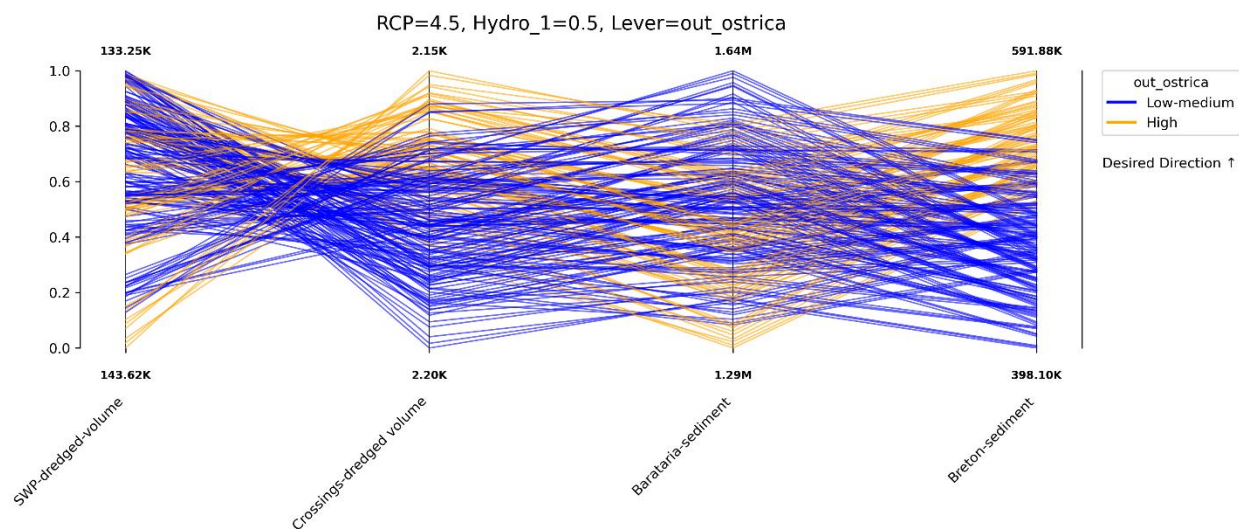


Figure F-54. Policies within the environmental scenario are highlighted by the level of discharge allowed from the Neptune Pass (high: orange, not high: blue)

In summary:

- High discharge from Neptune Pass can help Breton sediment delivery
- High discharge from Diversions can slightly help Barataria sediment delivery
- High discharge from unmanaged outlets generally supports sediment delivery metrics but may increase dredging needs in SWP.
- The outlet discharge levels for specific outlets do not show as distinct an impact on performance as they did in the BAU and adjusted flow strategies.

*What do the scenarios that perform best across SWP dredge volume and basin sediment delivery metrics have in common regarding the level of outlet discharge?*

To address this question, the project team looked at these three metrics to understand what combinations of outlet discharge levers the top-performing scenarios have in common. This is done using a two-step process to screen the top scenarios; 1) Scenarios are ranked using the composite score to find the top ones, and 2) Within those top solutions, the “Pareto” set is identified.



For calculating the composite score, each metric is converted to a 0–1 scale based on whether the metric desired state is to be maximized or minimized then add them up into a single “composite score.” Then the project team picks N scenarios with the highest composite score and within those top solutions, the project team finds non-dominated or Pareto scenarios where no other scenario is strictly better on all metrics. A solution is dominated if another is at least as good in every metric and strictly better in at least one.

Figure F-55 shows the 15 top performers based on the composite score in 243 scenarios within the selected environmental conditions (low sea level rise and average hydrograph) under the Turn Left strategy. The blue lines show the top 15 scenarios based on the composite score.

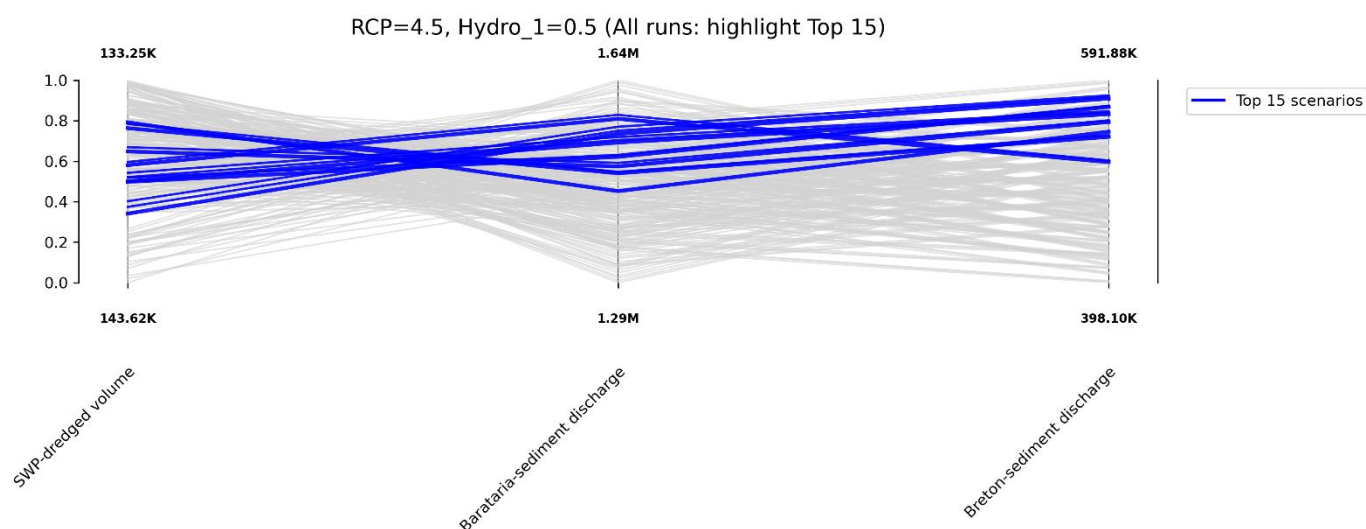


Figure F-55. Top 15 scenarios based on the composite score

Table F-24. Outlet discharge levels used in Pareto scenarios

Diversion outlets	Lower outlets	Unmanaged outlets	Bonnet Carré	Neptune Pass
2	0	2	1.1	1.5
2	0	1	1	1.5
2	1	1	1	1.5
2	2	0	0.9	1.5
2	2	1	1	1.5
2	0	2	1	1

Table F-24 shows the combination of the outlet discharge levels allowed in 6 Pareto scenarios in the Top 15 scenarios based on the composite score. As can be seen, all of these scenarios except one share the highest level of discharge allowed from Diversion outlets and Neptune Pass. The levels are mixed in all other outlets, showing their less direct impact on the overall performance of these three metrics in the Turn Right strategy.



In summary:

The scenarios that perform best across SWP dredged volume and basin sediment delivery metrics generally have high discharge allowed from diversion outlets and Neptune Pass.



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