2023 DRAFT COASTAL MASTER PLAN

PLANNING TOOL APPROACH

ATTACHMENT G1

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COASTAL PROTECTION AND RESTORATION AUTHORITY

This document was developed in support of the 2023 Coastal Master Plan being prepared by the Coastal Protection and Restoration Authority (CPRA). CPRA was established by the Louisiana Legislature in response to Hurricanes Katrina and Rita through Act 8 of the First Extraordinary Session of 2005. Act 8 of the First Extraordinary Session of 2005 expanded the membership, duties, and responsibilities of CPRA and charged the new authority to develop and implement a comprehensive coastal protection plan, consisting of a master plan (revised every six years) and annual plans. CPRA's mandate is to develop, implement, and enforce a comprehensive coastal protection and restoration master plan.

CITATION

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EXECUTIVE SUMMARY

The Louisiana Coastal Protection and Restoration Authority (CPRA) Planning Tool was developed to help formulate the 2012 Coastal Master Plan. It was revised and used for the 2017 Coastal Master Plan. As part of the 2023 Coastal Master Plan, the Planning Tool is being updated to use more detailed modeling data, including a structure-based asset inventory, and to respond to new CPRA planning priorities. This report describes the methods and functions of the 2023 Planning Tool. Major improvements include, but are not limited to: (1) annual estimation of project benefits, (2) development of two implementation periods with an intermediate modeling step that considers initial restoration projects in the future landscape for period two, (3) evaluation of a new land sustainability constraint, (4) consideration of sediment borrow costs, (5) optimization of a robust set of project alternatives to ensure good performance across considered scenarios, and (6) exploration of equity-based decision drivers.

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LIST OF ABBREVIATIONS

ADCIRC+SWAN................ADVANCED CIRCULATION-SIMULATED WAVE NEARSHORE
CLARA ....COASTAL LOUISIANA RISK ASSESSMENT MODEL
CPRA .... COASTAL PROTECTION AND RESTORATION AUTHORITY
DMDU .... DECISION MAKING UNDER DEEP UNCERTAINTY
E&D.. ENGINEERING AND DESIGN
EADD...EXPECTED ANNUAL DAMAGE IN DOLLARS
EASD .... EXPECTED ANNUAL STRUCTURAL DAMAGE
ESLR ....EUSTATIC SEA LEVEL RISE
EWE .... ECOPATH WITH ECOSIM
FWA ....FUTURE WITH ACTION
FWOA ....FUTURE WITHOUT ACTION
GAMS .... GENERAL ALGEBRAIC MODELING LANGUAGE
HSI .... HABITAT SUITABILITY INDEX
ICM ....INTEGRATED COMPARTMENT MODEL
IP1 AND IP2 ....IMPLEMENTATION PERIOD 1 AND 2
IPET .... INTERAGENCY PERFORMANCE EVALUATION TASKFORCE
K.. THOUSAND
LMI .... LOW-TO-MODERATE INCOME
M .... MILLION
M .... METERS
MT ....MEDIUM-TERM
MCDA .... MULTI-CRITERIA DECISION ANALYSIS
MIP .... MIXED-INTEGER PROGRAMMING
NRC..NATIONAL RESEARCH COUNCIL
O&M .... OPERATIONS AND MAINTENANCE
RDM ....ROBUST DECISION MAKING
SQ KILOMETERS .... SQUARE KILOMETERS
SQ METERS .... SQUARE METERS
SQL .... STRUCTURED QUERY LANGUAGE

USACE .... US ARMY CORPS OF ENGINEERS

1.0 INTRODUCTION

Coastal Louisiana faces long-term sustainability challenges due to severe coastal land loss and increasing flood risk. For more than four decades, national and state government agencies, state and local organizations, corporations, and citizen's groups have invested significant resources in ecosystem restoration and levee protection. Coastal Louisiana has experienced a net change in land area of approximately -4,833 km^2 from 1932 to 2016 (Couvillion et al., 2017). Tremendous impacts from the 2005 hurricanes re-emphasized that more action was required and would need to be coordinated as part of a comprehensive plan. Following the devastating 2005 hurricane season, the Louisiana State Legislature passed Act 8, which created the Coastal Protection and Restoration Authority (CPRA) and stipulated that CPRA develop a Master Plan to be updated regularly to ensure that the state was effectively building on success and taking advantage of new science and innovation. The 2023 Coastal Master Plan leverages the approach adopted in previous plans.

The 2007 Coastal Master Plan set a new course for Louisiana by defining high-level objectives to guide development of a comprehensive strategy. These objectives have been refined and added to in subsequent plans:

- Flood Protection. Reduce economic losses from storm surge-based flooding to residential, public, industrial, and commercial infrastructure.
- Natural Processes. Promote a sustainable coastal ecosystem by harnessing the natural processes of the system.
- Coastal Habitats. Provide habitats suitable to support an array of commercial and recreational activities coast wide.
- Cultural Heritage. Sustain the unique cultural heritage of coastal Louisiana by protecting historic properties and traditional living cultures and their ties and relationships to the natural environment.
- Working Coast. Promote a viable working coast to support regionally and nationally important businesses and industries.

The 2007 Coastal Master Plan (CPRA, 2007) laid out strategies to achieve a sustainable coast. The 2012 Coastal Master Plan (CPRA, 2012) introduced a new planning framework to formulate a 50-year, $50 billion investment plan. To guide the planning process, CPRA supported the development of systems models and a Planning Tool to evaluate and compare projects and formulate groups of projects (i.e., alternatives) objectively (Groves et al., 2012). CPRA used the Planning Tool in an iterative process with stakeholders to evaluate differences among various alternatives and define the final 2012 Coastal Master Plan.

The 2017 Coastal Master Plan represented an iterative update of the 2012 Coastal Master Plan (CPRA, 2017). It re-estimated coastal conditions out 50-years, based on new conditions reflecting the prior five years of changes and project implementation. It then re-evaluated a wide range of risk reduction and restoration projects across updated future scenarios. Lastly, it used an updated Planning Tool to reprioritize $50 billion worth of projects to be implemented over the subsequent 50 years (Groves & Panis, 2017).

Between the 2012 and 2017 plans, CPRA secured funding for and implemented projects on the ground using the 2012 Coastal Master Plan analysis as a guide. Projects constructed or funded for construction before the 2017 plan were added to the future without action (FWOA) landscape and removed from consideration as candidate projects for the 2017 Coastal Master Plan analysis. However, in order to continue providing guidance to support flexibility across various funding sources with different goals and rules, CPRA chose to maximize benefits for a $50 billion plan over 50 years again, adding new candidate projects for consideration.

The 2023 Coastal Master Plan will continue this iterative process and update the 2017 Coastal Master Plan in a similar way. As with the previous applications, the Planning Tool will assist CPRA in reviewing model projections of future conditions, compare estimated effects of risk reduction and restoration projects, and propose alternatives composed of individual projects for consideration as part of the 2023 Coastal Master Plan.

1.1 CHALLENGES IN FORMULATING A LONG-TERM MASTER PLAN FOR LOUISIANA

There are numerous challenges that CPRA is addressing to update its long-term coastal master plan.

DIVERSE COMMUNITIES AND NATURAL RESOURCES

Coastal Louisiana is a working coast. It is home to over two million people and is endowed with a large diversity of natural resources, many of which support economic and recreational activities. The dynamic deltaic coast provides vital habitat to hundreds of aquatic and terrestrial species. The coast is also home to large cities and regional centers, such as New Orleans, Lake Charles and Thibodaux-Houma. Some of these are protected by significant existing flood control infrastructure constructed by the federal government, while others have no protection. Within the urban centers, communities face different amounts of risk and vulnerability to storms, with many people facing disproportionately high risks relative to their capacity to recover. There are also numerous rural and isolated communities that are highly vulnerable to storm surge-based flooding. Any decision that affects a community and the environment is subject to debate over goals, priorities, and resource allocation.

COMPLEXITY AND UNCERTAINTY

The coastal system is dynamic and interconnected. Many aspects of future change are highly uncertain. Drivers of change, such as rates of sea level rise, subsidence, and erosion; future hurricane activity; hydrologic fluctuations and trends; and the effects of future human activities are difficult to predict long-term, despite the best scientific understanding of these processes. The ecosystem, species, and societal responses to these drivers thus will remain difficult to predict. The specific effects that coastal investments in restoration or risk reduction projects could have on the coast are therefore similarly uncertain, and choices about how to address coastal issues need to consider this uncertainty.

WIDE RANGE OF OPTIONS TO ADDRESS CHALLENGES

There are many investments or projects that could be implemented to help address these challenges, each with different costs and potential effects on the coast. Options to reduce coastal land loss include projects that mechanically move sediment to rebuild land as well as more process-based approaches of diverting sediment-rich floodwaters to wetlands in need of sediment nourishment. Other projects target specific areas of need, including hydrologic and ridge restoration. Similarly, flood risk can be reduced by physical structures, such as levees and floodgates that are designed to block or reroute water. Nonstructural risk reduction measures, such as floodproofing or elevating structures, can reduce risk by increasing the resistance of structures to flooding. Voluntary acquisitions of property can also reduce risks by removing assets from areas subject to flooding. Some projects are best conceived as integrated projects that include different elements that work together to improve ecosystem function or reduce risk.

IDENTIFYING A ROBUST STRATEGY

Given the significant uncertainty over how the coast will change over time and the multitude of different approaches to improve ecosystem function and manage risks to flooding, CPRA must seek a robust strategy — a set of projects that will best address the coastal challenges however they manifest over the coming decades. Practically, this means first identifying a set of near-term projects that science and judgement suggest would provide the best contribution to sustaining land and reducing flood risk under specific assumptions about future conditions. Based on this analysis, CPRA can then identify the set of projects that are shown to perform well under different potential future conditions. Projects for later decades can then be selected similarly, based on how they interact with the first set of projects implemented. Consistent with the 6-yearly master planning cycle, projects selected for later implementation will be re-evaluated in future master plans, using updated models and information, ensuring that the best available information is considered prior to committing to a course of action. Together, these elements define a robust strategy for the master plan.

HARD DECISIONS

Louisiana faces hard decisions; there is no single solution that will solve every challenge facing the coast. Certain activities and ecosystems face greater sustainability challenges than others. In some cases, decisions to focus investment in some areas and not in others will need to be made. As for previous master plan efforts, CPRA is committed to using the best available science in a transparent manner to help inform these necessary decisions for the 2023 Coastal Master Plan.

1.2 CPRA PLANNING FRAMEWORK AND PLANNING TOOL

The Planning Tool is a computer-based decision support software system, composed of a database of predictive model results, an optimization model to define collections of projects (or alternatives) subject to planning constraints, and an interactive visualization package to support deliberations between different alternatives and elicit stakeholder preferences. The Planning Tool helps enable the state to formulate a long-term plan objectively and transparently. In this framework, a suite of predictive models developed by CPRA are used to estimate how the coastal system and associated flood risks would change over the next 50 years under different scenarios, reflecting uncertainty about key drivers, such as sea level rise. The models also estimate the effects of different restoration and risk reduction projects on a wide range of landscape-, ecosystem-, and risk-related outcomes.

SUPPORTING THE FORMULATION OF THE 2012 AND 2017 COASTAL MASTER PLANS

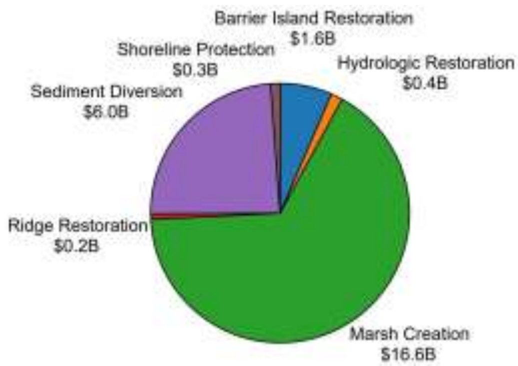
The 2012 Coastal Master Plan used the Planning Tool to compare hundreds of restoration and risk reduction projects and define a 50-year, $50 billion master plan (CPRA, 2012; Groves, Sharon, & Knopman, 2012). To help arrive at this outcome, the Planning Tool was used to support four sets of deliberations:

1. Comparison of individual risk reduction and restoration projects: Which flood risk reduction and restoration projects are most consistent with the objectives of the 2012 Coastal Master Plan?
2. Formulation of alternatives: What alternatives (made up of groups of individual projects) can be implemented over a 50-year period to best achieve the objectives of the 2012 Coastal Master Plan, given constraints on funding, sediment resources, and river flow?
3. Comparison of alternatives: When compared across all the objectives of the 2012 Coastal Master Plan, which alternative is preferred?
4. Evaluation of uncertainty: How will the 2012 Coastal Master Plan perform, relative to its objectives, across several future environmental scenarios?

For the 2017 Coastal Master Plan, CPRA updated its 50-year estimates of coastal conditions reflecting projects that had begun to be implemented since the 2012 Coastal Master Plan, and to account for improved data and modeling. The Planning Tool was used to re-evaluate the projects selected for the 2012 Coastal Master Plan, but not yet implemented, along with new projects solicited from stakeholders in 2014. In addition, a few projects that were high performing but not selected in 2012 due to the budget constraint, were also re-evaluated. The Planning Tool was used to help formulate and evaluate a set of nonstructural risk reduction projects. In total, CPRA evaluated the performance of 155 specific risk reduction and restoration projects and nonstructural options for 54 coastal regions with respect to more than 50 ecosystem and risk metrics.

Lastly, the Planning Tool was used in an iterative process to define risk and restoration alternatives over three environmental scenarios, six funding scenarios, and a range of different other planning considerations. The final alternatives then provided the basis for the 2017 Draft Coastal Master Plan and the 2017 Coastal Master Plan.

The following three figures summarize key decisions and final outcomes of the 2017 Coastal Master Plan. Figure 1 shows how 2017 Draft Coastal Master Plan funding was allocated across different restoration project types for the entire 50-year planning period (left) and structural and nonstructural risk reduction projects over two implementation periods (IPs, right). Notably, a bit more than 75% of restoration funding is allocated to Marsh Creation projects, and just about 25% of risk reduction funding is directed toward nonstructural investments.



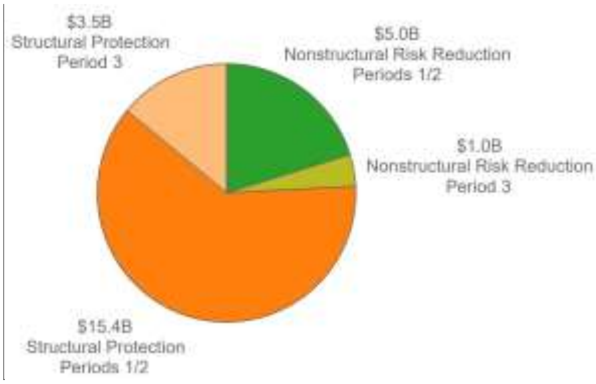


Figure 1. Summary of costs of selected restoration projects (left) and risk reduction projects (right) by type for the year 2017 Draft Coastal Master Plan alternative.
Note: indicated values are in 2010 U.S. dollars.

Figure 2 shows that without the implementation of the master plan projects, expected annual damage in dollars (EADD) from coastwide flooding was projected to increase dramatically in the FWOA condition from a currently estimated annual level of $2.7 billion for 2017 to between $12 billion and $19 billion in Year 50 under two environmental scenarios. With the full implementation of the 2017 Draft Coastal Master Plan, risk would be reduced 69% for the medium environmental scenario and reduced 61% for the high environmental scenario.

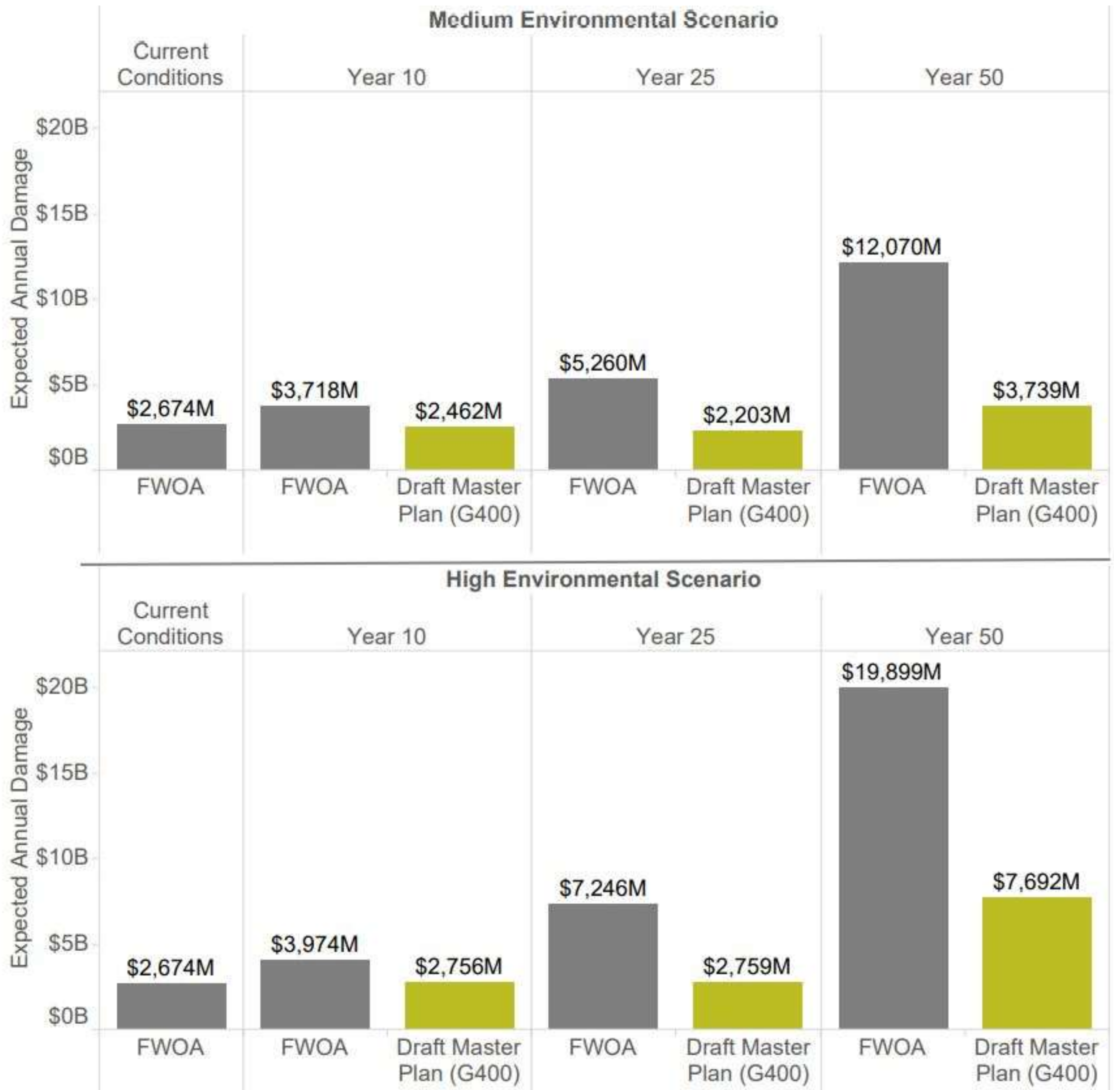


Figure 2. Coastwide expected annual damage results in Year 25 and 50 for the medium and high environmental scenario for FWOA, the draft master plan alternative.
Source: Groves and Panis (2017). G400 is the model ID for the draft master plan.

Figure 3 shows coastwide land area over time and its change from the FWOA condition for the 2017 Draft Coastal Master Plan under the Medium and High environmental scenarios. The colors refer to the 11 ecoregions defined for the 2017 Coastal Master Plan. The top graphs show that the 2017 Draft Coastal Master Plan builds significant land, as compared to the FWOA condition, with Year 50 land being lower in the High environmental scenario than the Medium environmental scenario. The bottom graphs show that change in land is greatest under the High environmental scenario and in the Upper Pontchartrain, Upper Barataria, and Breton ecoregions.

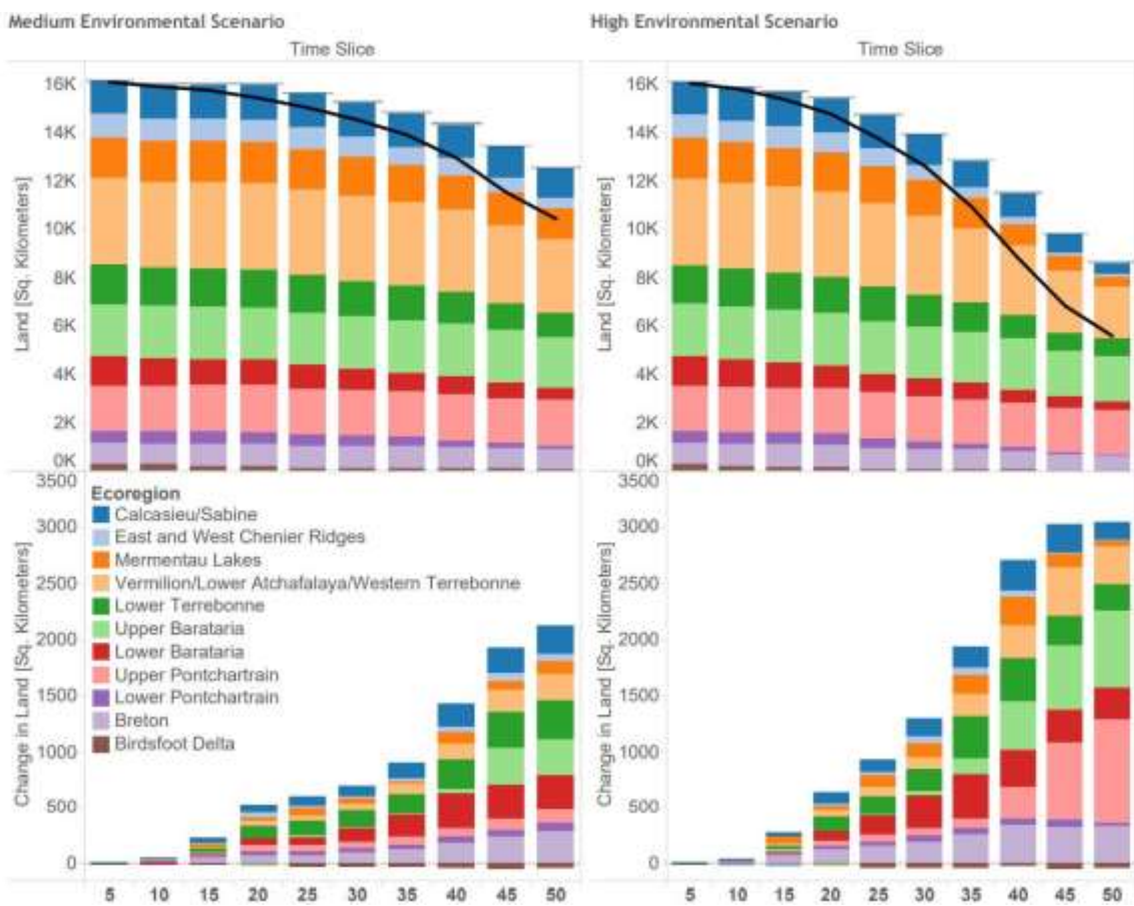


Figure 3. Annual average land area outcomes (bars) and FWOA (black line) over time by ecoregion for 2012 Coastal Master Plan under Medium environmental scenario (left) and High environmental scenario (right).
Source: Groves and Panis (2017).

USE OF PLANNING TOOL TO SUPPORT THE 2023 COASTAL MASTER PLAN

Since the 2007 Coastal Master Plan, CPRA has procured over $20 billion to support planning, engineering and design, and construction of hundreds of restoration and protection projects. Scientific understanding of coastal processes, how the coast will evolve in the future, and the effects of coastal investments continue to be incomplete. As such, CPRA has continued to invest in data, modeling, and the Planning Tool.

For the 2023 plan, the Planning Tool has been updated to take advantage of advancements in the predictive models and improved to better account for new planning considerations. The major updates include:

- Increased resolution in how project benefits are evaluated over time from twice in 50-years to annually
- Introduction of a new land sustainability constraint through a new constraint
- Exploration of additional decision drivers to account for equity in risk assessment
- Reduction in project implementation periods from three to two — Years 1 to 20 and Years 21 to 50
- Addition of an intermediate modeling step in which restoration projects selected for Implementation Period 1 (IP1) are assumed to be on the future landscape for the basis for evaluating the remaining projects for Implementation Period 2 (IP2)
- Development of new environmental scenarios for evaluations of FWOA and project effects
- Consideration of the costs of different borrow sources for restoration projects
- Development of robust alternatives that seek to ensure good performance across scenarios

1.3 PURPOSE OF THIS REPORT

This report describes the planning framework and Planning Tool, details the methodology, and describes how it has developed. It is designed to augment the 2023 Coastal Master Plan and its other relevant appendices by providing analytic details relevant to the plan's development and serving as a reference for the underlying analysis. The intended audience of the report includes CPRA planners, decision makers, stakeholders, and any reader of the 2023 Coastal Master Plan interested in better understanding the technical details of the Planning Tool analysis.

2.0 PLANNING TOOL METHODOLOGY

CPRA's planning framework combines two sets of analytic capabilities: integrated predictive models of the coastal system and a Planning Tool. Together, they iteratively support the development of the master plan. Figure 4 illustrates the framework in flowchart form, which has remained conceptually the same since 2012.

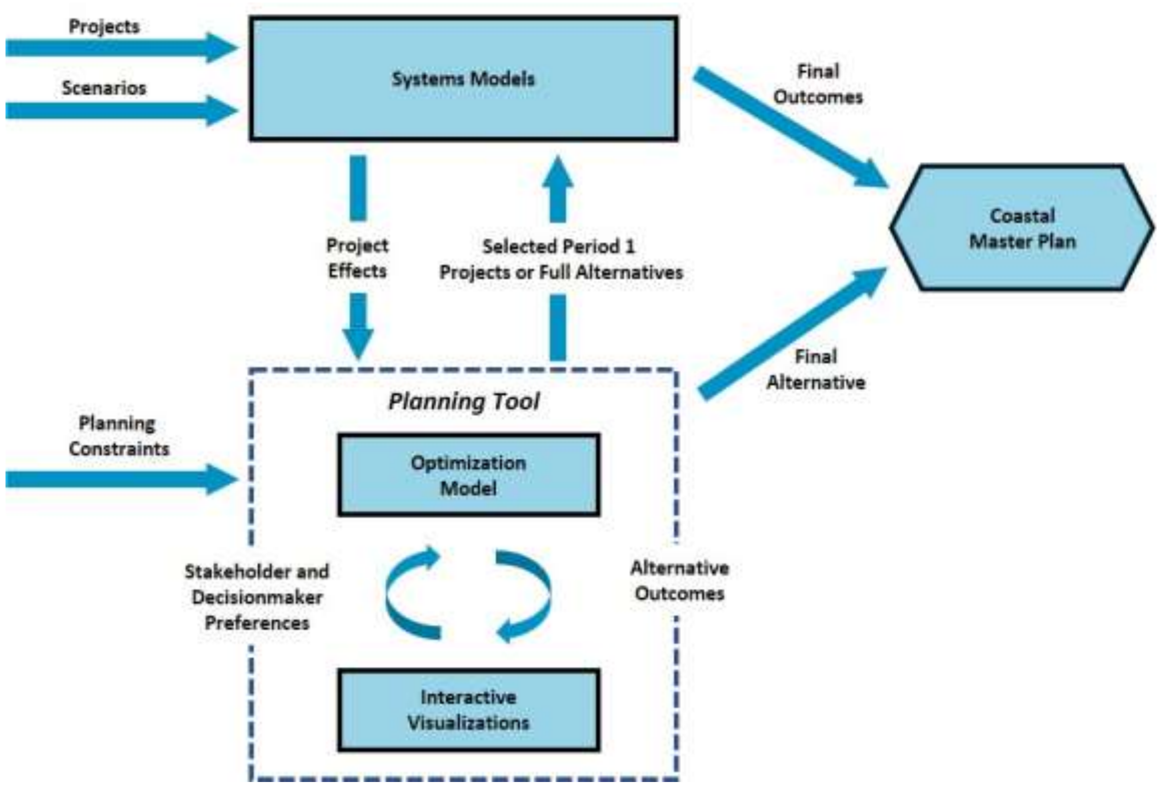


Figure 4. CPRA analytic framework.
Based on: Groves et al. (2013).

The beginning of the process is represented at the top left of the flow chart. Analysis begins by using a set of predictive models to evaluate how proposed coastal restoration and risk reduction projects would individually affect the coast over the next 50 years relative to FWOA for multiple future scenarios. Specifically, the models estimate the effects that each project would have on the coastal landscape, including barrier islands and wetlands; on future storm surges, waves, flooding, and flood damage; and on ecosystem characteristics, including habitats for different aquatic and land-based species. Additional calculations provide rough assessments of impacts on navigation, communities, industry, and other key assets.

The model results serve as inputs to the Planning Tool, a computer-based decision support software system, along with planning constraints such as availability of sediment, amount of potential funding over the next five decades, and decision-maker goals, and stakeholder preferences. The Planning Tool uses optimization to identify alternatives comprising the projects that build the most land and reduce the most storm surge-based flood risk while meeting funding and other planning constraints. The Planning Tool generates interactive visualizations that summarize information about individual projects and alternatives.

In the last step, the predictive models evaluate one or a few alternatives defined by CPRA, informed by stakeholders and the Planning Tool. The specific projects included in the final alternative (selected by the Planning Tool) and the outcomes estimated by predictive models provide key information to describe the master plan and its effects on the coast. For 2023, alternatives will be defined based on two iterative steps of predictive modeling. Once restoration projects are identified for the first implementation period they are fixed on the landscape and therefore included in the predictive models when run to evaluate the effects of the remaining candidate projects. This approach assumes that remaining candidate projects are only eligible to be selected for the second implementation period (Years 21-50) and the new project evaluations will be used to determine which remaining candidate projects to select.

This section describes the Planning Tool's theoretical basis, scope of analysis, structure, key inputs, and specific methods for performing its key functions to support the 2023 Coastal Master Plan.

2.1 THEORETICAL BASIS

The Planning Tool brings together several well-established planning methodologies in a customized way to meet Louisiana's planning needs. Specifically, the Planning Tool combines elements of Multi-Criterion Decision Analysis (MCDA) and Robust Decision Making (RDM) within an overarching deliberation-with-analysis process.

The National Research Council (NRC) recommends a deliberation-with-analysis approach to support complex environmental planning challenges (NRC, 2009). This approach uses data and models not to recommend a specific course of action, but rather to help articulate potential outcomes among different reasonable courses of action over plausible futures. These results are then presented to decision makers and stakeholders to support their deliberations. The Planning Tool facilitates this process by using the results of the predictive models and other planning data to make comparative calculations, formulate alternatives, and then present interactive visualizations to CPRA and stakeholders as they make decisions about which projects to include in the 2023 Coastal Master Plan.

The Planning Tool generates alternatives that maximize the goals of the 2023 Coastal Master Plan while satisfying a wide range of constraints. MCDA is a standard approach to defining alternatives that conform to a set of preferences, as reflected by a corresponding set of weights (Keeney & Raiffa, 1993; Lahdelma, Salminen, & Hokkanen, 2000; Kiker et al., 2005; Linkov et al., 2006). Challenges applying standard MCDA to Louisiana's coastal planning problem include:

- Evaluating interactions, synergies, and conflicts among different projects,
- Developing quantifiable coastal performance metrics that can be placed on a consistent scale for comparison,
- Interpreting the meaning of a single objective function comprised of tens of different metrics, and
- Deriving weights for each metric that represent the wide range of stakeholder views.

The Planning Tool, therefore, uses a simplified MCDA methodology. Rather than including all decision drivers within an objective function, the Planning Tool uses a simple and easily understood objective function. The objective function for the 2012 and 2017 Planning Tools were made up of only near-term and long-term risk reduction and land building, with a corresponding set of weights that equally balanced across the four factors. It considered other coastal outcomes as constraints (Romero, 1991). The Planning Tool then used standard mixed-integer programming (MIP) methods to maximize the objective function subject to funding and other planning constraints (Schrijver, 1998). For the 2023 Coastal Master Plan the near-term and long-term risk reduction and land building terms in the objective function are replaced with equally weighted yearly damage reduction and equally weighted yearly land building. For risk reduction projects, expected annual structural damage (EASD, a term that captures how many structures are impacted by flooding and to what degree, as opposed to the value of assets impacted by flooding) is added to the EADD metric to reflect equity in risk reduction investments better. The weighting of the EASD term, relative to average annual EADD reduction, will be determined as part of the Planning Tool analysis.

To address the significant uncertainty in estimating future coastal conditions, the Planning Tool supports the comparison of projects and formulates alternatives based on estimates of future coastal conditions for different future scenarios. RDM techniques help evaluate the various alternatives and suggest a robust, adaptive alternative (Groves & Lempert, 2007; Lempert et al., 2013; Lempert, Groves, Popper, & Bankes, 2006; Lempert, Popper, & Bankes, 2003). Specifically, RDM helps identify near-term projects for implementation and specific pathways for future investment based on the evolution of future conditions. The following sections describe how these methodologies will be used to support the 2023 Coastal Master Plan.

2.2 SCOPE OF ANALYSIS

The master plan framework, predictive models, and Planning Tool are designed to help CPRA design a $50 billion, 50-year investment plan to address coastal land loss and flood risk challenges in

Louisiana. To do so, they consider how the coast would change in the coming five decades with respect to a wide range of ecological and flood outcomes. The drivers of coastal change are impossible to predict with certainty, so the framework, models, and Planning Tool evaluate different scenarios representing different plausible futures. The predictive models evaluate hundreds of different projects individually and then as groups of projects – or alternatives. Summaries of these results are provided to the Planning Tool. The Planning Tool presents the results of these analyses to CPRA and stakeholders through interactive computer-based visualizations to support deliberations over the many different approaches and possible outcomes.

TIME HORIZON AND GRANULARITY

The Planning Tool evaluates projects and alternatives over a 50-year time horizon, starting from an initial condition, representing 2020, out to 50 years into the future.

For the 2017 Coastal Master Plan, the Planning Tool evaluated the effects of projects twice during the planning period — in Years 20 and 50 for restoration projects and in Years 25 and 50 for risk reduction projects. When formulating restoration alternatives, the Planning Tool maximized an objective function subject to funding, sediment, and other constraints. For the restoration alternatives, this was problematic because modelled project benefits varied over time considerably, and thus the timing of benefit peaks and troughs relative to the 20- and 50-year time periods could favor some projects over others.

For the 2023 Coastal Master Plan, the Planning Tool has been reconfigured to use a new objective function that maximizes the annual average land area and risk results over the entire 50-year time period. In practice, this is done using annual results from the predictive models.

For both restoration and risk reduction projects, for the 2023 Coastal Master Plan the Planning Tool uses two defined periods of implementation:

- Implementation Period 1 (IP1): Years 1 – 20
- Implementation Period 2 (IP2): Years 21 – 50

This represents a shift from 2012 and 2017, when projects were selected for three different implementation periods. CPRA specified this adjustment to accommodate an intermediate modeling step in which restoration projects selected in IP1 will be assumed on the future landscape for a second modeling step to evaluate remaining restoration projects for IP2 (Figure 5).

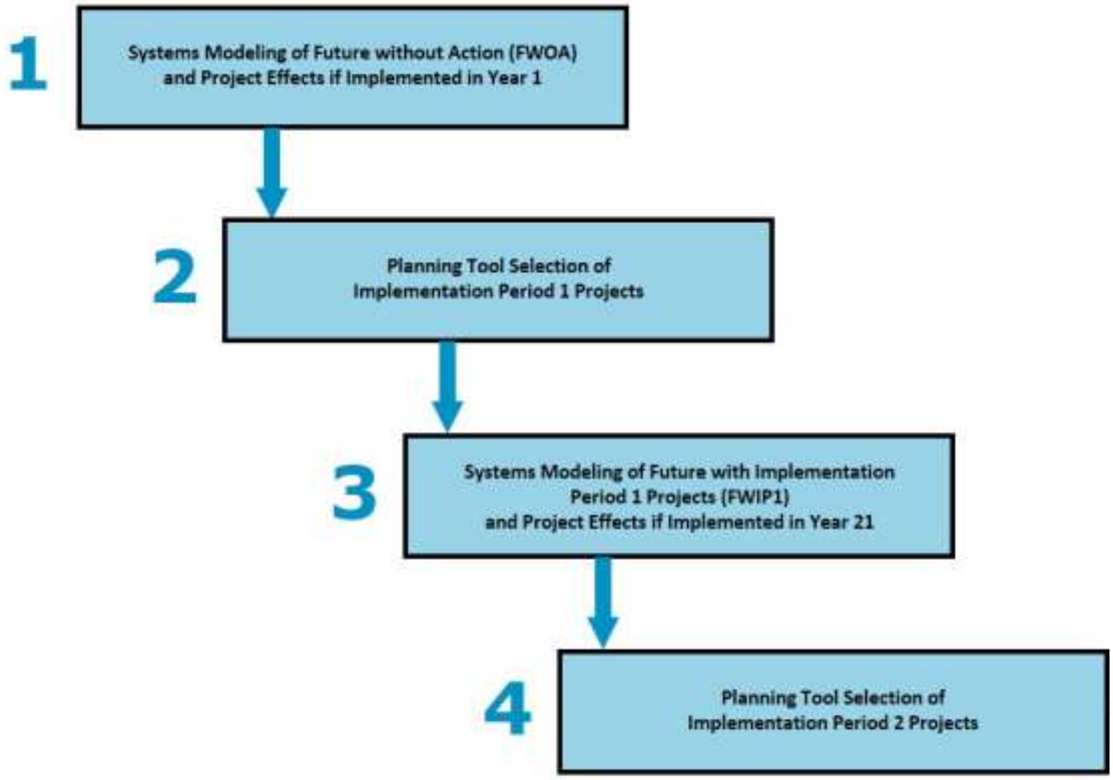


Figure 5. Four-step modeling and Planning Tool process to define an alternative.

PREDICTIVE MODELS

A suite of predictive models provides input to the Planning Tool related to coastal ecosystem and flood risk conditions (see Brown, et al. 2017 for details on the modeling for the 2017 Coastal Master Plan).

The Integrated Compartment Model (ICM) analyzes landscape and ecosystem performance under different environmental scenarios. It estimates hydrodynamic changes and response in land-water and vegetation (report in progress). A set of Habitat Suitability Indices (HSIs) for 13 fish and wildlife species (some analyzed for multiple life stages) are integrated into the ICM for the 2023 Coastal Master Plan and provide estimates of a variety of aquatic and terrestrial species habitat (Lindquist et al., 2020).

On the flood risk side, the Advanced Circulation-Simulated Wave Nearshore model (ADCIRC+SWAN) estimates storm surge and waves for a large set of simulated tropical storms and hurricanes. The surge and wave results then serve as input to the Coastal Louisiana Risk Assessment Model (CLARA), which translates storm surge into flood depths, as influenced by levees and other structural risk reduction projects and using future landscapes predicted by the ICM (Fischbach et al., 2021). The CLARA model then calculates the resultant damages to a wide array of coastal assets. By evaluating the results of different modeled storms, CLARA computes statistical flood risk metrics such as EADD.

DECISION DRIVERS AND METRICS

The Planning Tool evaluates projects and outcomes based on a large set of metrics that are related to the five master plan objectives listed in the introduction above. For the 2012 and 2017 Coastal Master Planning process, CPRA defined two factors as decision drivers — land area and flood risk reduction — represented by the land and EADD metrics, respectively. CPRA used the decision drivers to guide the alternative formulation because they are key requirements for all five of the master plan objectives, are well understood, and were shown to simplify the analysis without losing the flexibility for refining the plan. CPRA then used additional ecosystem and risk metrics to shape the alternatives by constraining the optimization to meet different outcome thresholds. Outcome thresholds were defined through the iterative alternative formulation approach, as described in the Evaluating Alternatives section (p. 47). This approach will be continued for the 2023 Coastal Master Plan, although the EASD decision driver will additionally be considered to better account for equity considerations in risk reduction. A wider array of ecosystem and risk metrics are used to describe the varied effects of restoration and risk reduction projects.

DECISION DRIVERS AND OBJECTIVE FUNCTION

The 2023 Planning Tool uses a new objective function that includes one term that represents the average annual land area over the entire 50-year period. This approach considers fluctuations in the benefit stream over time and allows projects that provide substantial benefits that diminish by Year 50 to compete better for funding. However, the 'balance' between near-term and long-term benefits that was central to project selection for the 2012 and 2017 Coastal Master Plans is no longer present. For example, it is conceivable that project selection using the continuous benefit stream could result in an alternative with no net benefit at Year 50 or near the end of the planning period.

The concept of sustainability is central to the master plan; Master Plan Objective #2 is to "Promote a sustainable coastal ecosystem by harnessing the processes of the natural system." Therefore, for 2023, the Planning Tool also includes an additional metric representing land that would be built in later decades, e.g., Years 41-50 that is applied as a constraint to ensure that land building is also sustainable. The value of the constraint, i.e., amount of land building targeted in Years 41-50, will be determined through the Planning Tool analysis.

For risk reduction projects, EADD at Year 25 and Year 50 is replaced by average annual EADD from Years 1 to 50 to better reflect risk over time. The 2023 Coastal Master Plan seeks to better consider equity concerns that arise when assessing flood risk by reduced value only. For example, accounting for reduced value alone favors projects that protect houses that are more valuable over those that may protect more, but less valuable houses. The Planning Tool thus includes a new metric, EASD reduction, which is a measure of flood damage that weights flood damage by the number of structures instead of the value of the structures. By including both terms in the objective function, the Planning Tool could balance between the traditional value-based approach for assessing risk with newer equity-aware approaches. Tests will be conducted to consider the effects of EASD on project selection and to determine how they could be combined, if at all.

ECOSYSTEM METRICS

The ICM calculates and supplies to the Planning Tool a wide range of ecosystem metrics including land, which is used as the restoration decision driver (Table 1).

Table 1. Ecosystem Metrics

Source	Ecosystem Metrics
ICM	Land by year (square kilometers) Species habitat (habitat units) • Eastern Oyster, Brown Shrimp (small and large), White Shrimp (small and large), Blue Crab, Crayfish, Gulf Menhaden (juvenile and adult), Spotted Seatrout (juvenile and adult), Largemouth Bass, American Alligator, Gadwall, Mottled Duck, Brown Pelican, Seaside Sparrow, and Bald Eagle. Wetland type (square kilometers) • Forested Wetlands, Fresh Marsh, Intermediate Marsh, Brackish Marsh, Saline Marsh, Bare Ground, Open Water Habitat Diversity • Index

All the metrics are aggregated by 25 ecoregions — defined to have similar geomorphology and ecological function — and provided yearly from initial conditions to Year 50 (Figure 6).

Figure 6. Ecoregions for 2023 Coastal Master Plan.

RISK METRICS

Risk results are provided to the Planning Tool by the CLARA model in terms of EADD, EASD, and the level of exposure for groups of assets (by depth). The CLARA model reports a mean and standard deviation value for both EADD and EASD, as this is a probabilistic calculation in CLARA. The Planning Tool analysis focuses on the mean statistics when evaluating projects and formulating alternatives, but also reports residual damage outcomes (Table 2). Results are aggregated by 344 master plan communities that represent 142 named places by basin and structural protection and provided yearly from initial conditions to Year 50 (**Error! Reference source not found.**). See Fischbach et al. (2021) and Johnson et al. (2021) for details on the risk metrics and project areas.

Table 2. Risk Metrics.

Source	Risk Metric
CLARA	Expected Annual Dollar Damage – EADD • 50^{th} Percentile, mean, and standard deviation Expected Annual Structural Damage – EASD • 50^{th} Percentile, mean, and standard deviation • Exposure to Flooding - number of structures • Depth of flooding and types of structures TBD

Note: CLARA also generates 10^{th} and 90^{th} Percentile metrics, but these are used for QA/QC purposes, and are not planned to be visualized in or assessed by the Planning Tool.

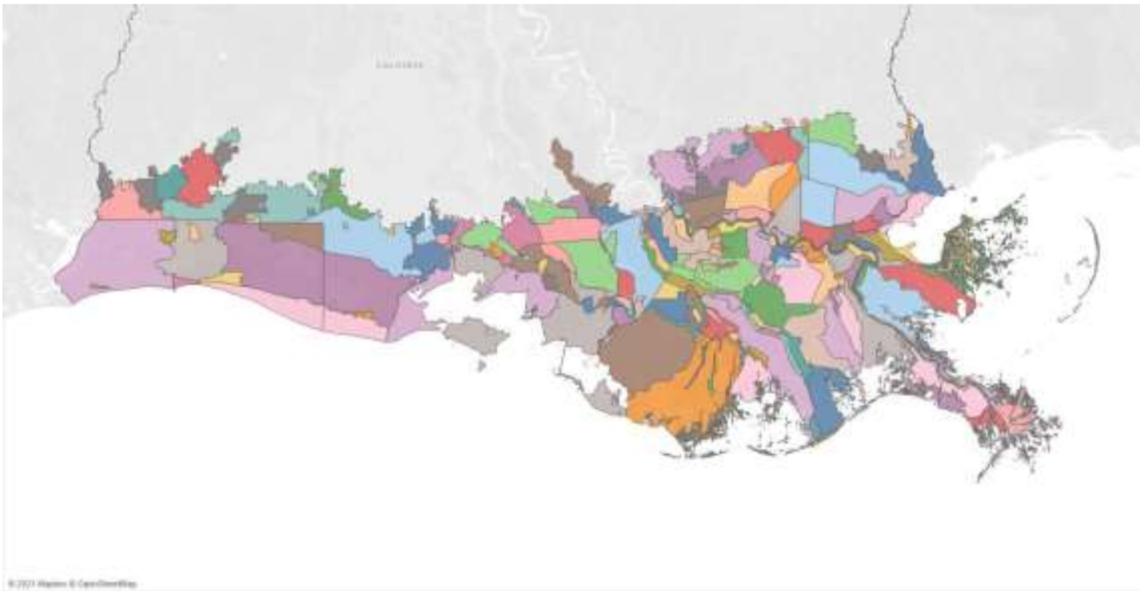


Figure 7. 344 communities for 2023 Coastal Master Plan.

ADDITIONAL DERIVED METRICS

There are additional metrics used to represent the effects of projects and/or alternatives that are derived from project attributes or results for the ecosystem metrics, risk metrics, or both metrics. They include:

- Agricultural Communities - Risk Reduction
- Agriculture - Sustainability
- Current vs. Future Flood Risk
- Demographics (age, sex, race, income)
- Flood Protection of Strategic Assets
- Historic Properties Inundated
- Land loss around Archeological sites
- Navigation - Inland Protection
- Navigation - Inland Shoaling
- Navigation - River Steerage
- Navigation Channel Access
- Oil and Gas Activities
- Oil and Gas Communities - Risk Reduction
- Traditional Fishing Access to Resources
- Traditional Fishing Communities - Risk Reduction
- Use of Natural Processes

SCENARIOS AND SENSITIVITY ANALYSIS

For 2023, scenarios and sensitivity analyses are used to evaluate uncertainty about the future. The scenarios relate to environmental drivers that affect future landscapes predicted by the ICM, which in turn affect ecosystem function and flood risk from tropical cyclones. Two "environmental scenarios" are defined for 2023 and used to evaluate FWOA conditions as well as future with project conditions for both risk reduction and restoration projects. The Planning Tool formulates alternatives for each of the two scenarios and informs the formulation of a single final robust alternative – one that would perform well across both scenarios.

Additional uncertainty analysis is performed through sensitivity analysis over assumptions related to:

- Land Building Certainty — different assumptions about how confident the landscape model is about land building
- Structural Protection Project Fragility — two assumptions about assumed fragility of the existing and future structural protection systems (i.e., levees and walls)
- Project Costs — different assumptions about the costs of projects.

ENVIRONMENTAL SCENARIOS

For the 2023 Coastal Master Plan, two environmental scenarios have been developed (report in progress). They are based on variations of the following six variables across plausible ranges established through a review of the literature (see Chapter 2 of Meselhe et al., 2015):

- Eustatic Sea Level Rise (ESLR)
- Subsidence
- Precipitation
- Evapotranspiration
- Tropical Storm Frequency
- Tropical Storm Intensity

Table 3 summarizes the differences between the two environmental scenarios.

Table 3. Environmental Scenarios for the 2023 Coastal Master Plan

SCENARIO	EUSTATIC SEA LEVEL RISE (M/50-YEAR)*	SUBSIDENCE	PRECIPITATION, EVAPOTRANSPIRATION, TRIBUTARY FLOWS	TROPICAL STORM INTENSITY
	USED IN ICM			USED IN CLARA
LOWER	0.5	DEEP SUBSIDENCE + 1ST QUARTILE OF SHALLOW SUBSIDENCE	RCP 4.5 50TH PERCENTILE	+5% INCREASE
HIGHER	0.77	DEEP SUBSIDENCE + MEDIAN OF SHALLOW SUBSIDENCE	RCP 4.5 50TH PERCENTILE	+10% INCREASE

* Rate of change is not linear.

LEVEE FRAGILITY SENSITIVITY

Estimates of future risk depend on assumptions about the fragility of the structural risk reduction systems (Fischbach et al., 2021 and Johnson et al., 2021). The Planning Tool is configured to evaluate risk under two different assumptions about how structural risk reduction projects would perform:

- No fragility
- With fragility, consistent with the USACE IPET Low scenario, that allows breaches to occur at times other than peak surge along each levee segment.

UNCERTAINTY IN LAND AREA PREDICTIONS

There is uncertainty related to how the ICM modeling estimates landscape functions and changes over time. As information is passed from one ICM subroutine to another, the effects of uncertainties on model outputs may grow and amplify or could dampen or be reduced due to temporal or spatial integration (e.g., use of two-week mean salinity in the morphology subroutine based on daily outputs from the hydrology subroutine). This uncertainty is assumed to be independent of the factors accounted for in the environmental scenarios. For example, if the magnitude of relative sea level increases substantially in later decades under a higher scenario, the model prediction of land area will likely be much more sensitive to sea level rise rates than a temporally static model error in mean water level predictions. Severe future environmental scenarios overwhelm and mask uncertainties in the model output caused by model errors.

The ICM modelers will conduct an uncertainty analysis on the FWOA condition for each of the two environmental scenarios by varying different ICM modeling parameters such as annual water level, water level variability, annual mean salinity, organic accretion, and total suspended solids (Meselhe et al., 2021). This analysis will determine the confidence that each 30 m pixel used in the ICM will be land versus water. By aggregating this information to the ecoregion level, the ICM can estimate land outcomes based on different confidence levels:

- Ecoregions where land area that is not sensitive to uncertainty
- Ecoregions that include areas that are sensitive to uncertainty

This information will allow the Planning Tool to explore project selection based on land benefits that are not sensitive to uncertainty – a conservative low-land estimate – and land benefits that include areas that are more sensitive to ICM uncertainty.

PROJECT COST UNCERTAINTY

There is always uncertainty when estimating the costs of projects. In standard construction planning, this is handled by including a contingency factor, generally specified as a percentage of the estimated cost. For the master plan, the scale, scope, and novelty of the projects suggest that the uncertainty could be larger than would be reasonably reflected by a single or fixed contingency factor.

The Planning Tool is thus configured to consider different uncertainty factors for different types of projects as part of a sensitivity analysis. For example, the Planning Tool might compare project selection under two assumptions about the cost uncertainty factor for sediment diversion projects.

PROJECTS

The predictive models are evaluating 141 structural risk reduction and restoration projects and several nonstructural project variants for each of the nonstructural project areas. These projects are distributed across the coast, as shown in Figure 8.

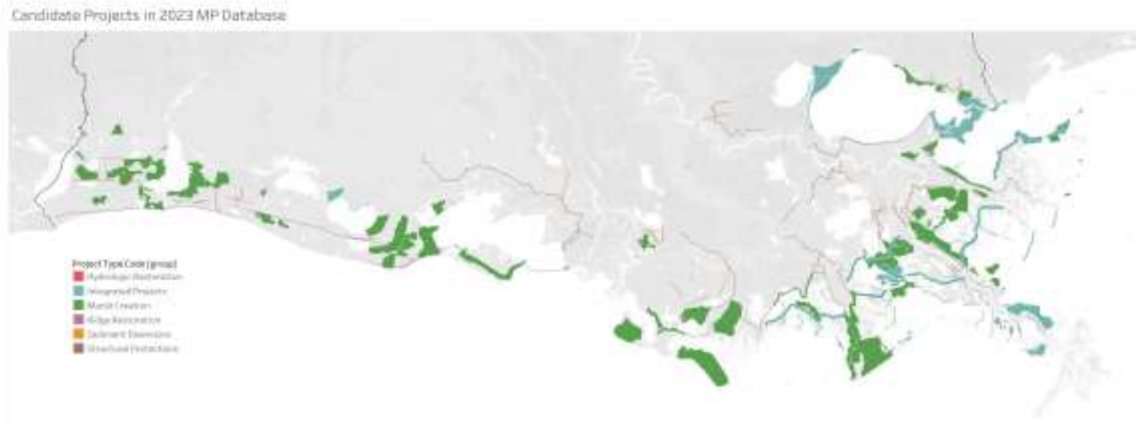


Figure 8. Restoration and structural risk reduction projects to be evaluated.

Individual risk reduction projects are initially evaluated relative to FWOA risk conditions (assuming the FWOA landscape) by the risk models (ADCIRC+SWAN and CLARA), and individual restoration projects are evaluated relative to FWOA landscape conditions by the ICM. After the Planning Tool has selected IP1 projects, these are included on the landscape for evaluation of the remaining restoration projects assuming their implementation in Year 21 (the start of IP2). The remaining structural protection projects will not be re-evaluated, but ADCIRC+SWAN and CLARA will be used to develop a revised future condition with the IP1 restoration projects in place.

When evaluating alternatives, the ICM can evaluate all restoration and risk reduction projects together. ADCIRC+SWAN and the CLARA model can then use the resulting coastal landscape including restoration project effects to evaluate storm surge flooding and risk with selected risk reduction projects implemented. In this way, the modeled alternatives can capture the effects that landscape changes due to restoration projects would have on risk reduction, and/or the effects that structural risk reduction projects would have on ecosystem metrics.

RISK REDUCTION PROJECTS

The 2017 Coastal Master Plan evaluated 20 structural risk reduction projects. For 2023, 18 structural risk reduction projects will be evaluated.

While the restoration and structural risk reduction projects evaluated in the 2012 and 2017 Coastal Master Plans were specific and discrete, the nonstructural projects were a representation of mitigation measures that would apply to numerous structures in a specific project area. For 2017, nonstructural projects were formulated for each of the 54 nonstructural project areas. Each nonstructural project area identified the number of structures and costs for elevating, floodproofing, and acquiring properties to reduce flood risk. For each project area, several different project variants were defined to represent different ways of determining how many and which structures need nonstructural risk reduction measures.

To improve on the evaluation of risk reduction projects for the 2023 Coastal Master Plan, risk areas, or communities, have been defined that better represent similar risk conditions and community characteristics.

The CLARA model estimates the effects on flood risk of both types of risk reduction – structural and nonstructural – in terms of flood depths, EADD, etc. using the same approach.

For the 2023 Coastal Master Plan, nonstructural projects will be considered in two ways:

- Nonstructural projects will be identified and their benefits compared to those of structural protection projects by community. This analysis will be used to support the selection of structural risk reduction projects, i.e., if the Planning Tool selects nonstructural rather than structural protection for a community the structural project may not be considered for selection. For this purpose, nonstructural projects will be identified similarly to the 2017 approach, using an elevation standard based on 1% annual exceedance probability for a given year/scenario from the flood depth analysis.
- The potential for nonstructural projects to contribute to coastal flood risk mitigation, and the associated costs and benefits, will be characterized across the coast to define an appropriate level of investment for nonstructural projects across the coast. This level of funding, and the range of flood risk benefits that it could deliver, will be identified as part of the 2023 Coastal Master Plan but it will not be associated with specific nonstructural projects or communities. This characterization will involve exploration of a range of different factors related to how nonstructural projects are implemented (e.g., freeboard, elevation standards, use of selected nonstructural project approaches). Within the Planning Tool, this level of investment for nonstructural risk mitigation will reduce the amount of funding available for structural projects.

RESTORATION PROJECTS

For the 2023 Coastal Master Plan, 123 restoration projects of the following types will be evaluated:

- Hydrologic Restoration
- Ridge Restoration
- Marsh Creation
- Diversion
- Integrated Projects - these incorporate several different types of projects features within a single project (e.g., marsh creation and ridge restoration).

Other project types such as shoreline protection, oyster barrier reefs, and barrier island restoration are considered programmatically in the 2023 Coastal Master Plan. These projects require site-specific information for effective evaluation making it difficult to compare performance at different locations across the coast based on idealized attributes. Treating them programmatically allows for flexibility in the scope and timing of their implementation. Specific projects of these project types will not be evaluated using master plan modeling, but the project types are still considered consistent with the plan. To account for this, funding will be set aside in the budget for the 2023 Coastal Master Plan to account for their programmatic inclusions.

In some cases, the individual projects are composed of project elements. Some project elements are prerequisites for others, and some elements represent portions of the project that could be independently selected.

2.3 PLANNING TOOL STRUCTURE

The Planning Tool consists of three discrete elements – a database, an optimization model, and an interactive visualization package. Information is provided to the Planning Tool via structured input data sheets with summarized predictive model outputs and user specifications of alternatives (Figure 9).

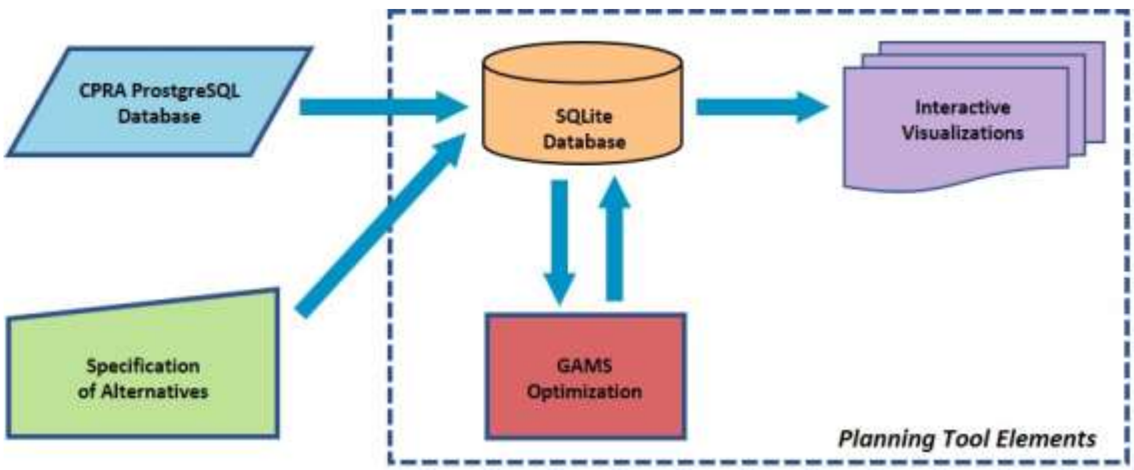


Figure 9. Planning Tool structure.

2.4 DATA

To describe the functions of and calculations performed by the Planning Tool, it is helpful to first define and describe the data that are used as inputs as well as those generated by the Planning Tool. There are several different types of data:

- Project attributes – information about projects
- Outcomes – estimates of coastal conditions (for specific metrics) without and with

the implementation of projects by predictive models

- Constraints – information about limitations that affect how projects can be selected as part of an alternative (e.g., mutually exclusive or prerequisite projects as well as land sustainability or other metrics)
- Alternative formulation specifications – descriptions of how the Planning Tool is configured for each alternative
- Alternative results – estimated outcomes for each alternative

For the 2023 Planning Tool, all this information is stored in a structured SQLite database.[1] The SQLite database consists of a series of tables containing data structured around a defined variable naming convention. The database structure supports the easy development of derived tables through specific database queries. The Planning Tool optimization engine and visualizations use these derived tables as input. All data stored in the database includes metadata detailing the origin and date of the data. The SQLite database format is also portable, allowing it to be transferred to other systems for archiving or analyses.

The subsections below describe each data source.

PROJECT ATTRIBUTE DATA

Attribute data for each project described in Section 2 is developed to support the Planning Tool analyses. Key attribute information includes:

- Project basics
  - Name, location, type, etc.
- Project costs (present $)
  - Planning, engineering, and design (all upfront costs)
  - Construction (upfront costs)
  - Annual operations and maintenance (annual costs)
- Project phase durations (years)
  - Engineering and design
  - Construction
- Project sediment requirements, sources, and costs
  - Projects that require sediment for construction are assigned one or more specific sources from which sediment can be acquired. As described below in the Constraints section (p. 34), sediment may come from multiple sources and different costs are incurred depending on the source used by a project. This information is also stored in the Planning Tool database for use by the optimization routine. Note that in for 2017, sediment costs were independent of the source and thus included in the "project costs".

[1] More information about SQLite can be found at www.sqlite.org.

- Project incompatibilities
    - Some projects evaluated by the Planning Tool are not designed to be implemented in conjunction with others. For example, different nonstructural project variants for the same project region have been developed, but only one of these project variants could be implemented for a given project area. The Planning Tool therefore also receives attribute information indicating which projects cannot be selected to be implemented together. This information is stored in the Planning Tool database for use by the optimization routine.

FUTURE WITHOUT ACTION CONDITIONS

The predictive models estimate coastal conditions without projects for each environmental scenario, and they summarize this information for the Planning Tool. Ecosystem outcomes are aggregated by 25 ecoregions and provided every year to Year 50. Risk outcomes are aggregated by 344 communities and provided every year to Year 50. See the Ecosystem Metrics section (p. 23), above for details about the regions.

FUTURE WITH PROJECT OUTCOMES

The predictive models also estimate coastal conditions for each environmental scenario with each individual project implemented, assuming that engineering and design begins in Year 1 – called the future with action (FWA). For example, a marsh creation project that takes two years to design and engineer and six years to construct is modeled by adding the project into the landscape at the beginning of Year 9. The results at Year 10 thus reflect the effects of the project after two years of completion.

Once the IP1 restoration projects are identified, these projects are added to the future landscape for a second round of modeling to estimate the future with IP1 projects. Then the systems models estimate coastal conditions for each environmental scenario with each remaining restoration project being evaluated to include for IP2, if engineering and design begins in Year 21. The remaining structural protection projects will not be re-evaluated, but ADCIRC+SWAN and CLARA will be used to develop a revised future condition with the first set of restoration projects in place and this can be used to evaluate the effectiveness of nonstructural approaches in IP2.

The data are all stored in the CPRA PostgreSQL database and extracted via scripts and added to the Planning Tool SQLite Database for use.

PROJECT EFFECTS

The predictive models also estimate the individual effects of each project for all project-specific metrics and environmental scenarios. This calculation is based on the difference between the FWA and the FWOA condition.

This information is initially provided assuming that each project would be implemented in Year 1. For projects not selected in the first implementation period, the predictive models then estimate the project effects if they were to be implemented in Year 21.

Note that project effects for some metrics are not estimated in relation to a specific baseline. For example, the systems models do not separately estimate a FWOA support for navigation metric. Rather, the FWOA condition is used as part of the way the metric assesses the effect of the project on support for navigation. For this type of metric, estimates of each project's effect on the metric (e.g., support for navigation) are provided directly.

CONSTRAINTS

The Planning Tool considers two types of constraints – implementation constraints and outcome constraints. Implementation constraints are related to factors that limit how many or which projects could be implemented. The key implementation constraints are funding and sediment.

Funding constraints are defined with respect to risk reduction projects and restoration projects separately and for each of the two implementation periods. For 2017, CPRA provided the Planning Tool team with a table that included an initial set of funding scenarios (Table 4). Funding constraints for the 2023 Coastal Master Plan are not yet developed.

Table 4. Funding Scenarios Evaluated for the 2017 Coastal Master Plan

<table>
<tr><th rowspan="2"></th><th colspan="2">LOW FUNDING</th><th colspan="2">MEDIUM FUNDING</th><th colspan="2">HIGH FUNDING</th></tr>
<tr><th>RESTORATION</th><th>RISK REDUCTION</th><th>RESTORATION</th><th>RISK REDUCTION</th><th>RESTORATION</th><th>RISK REDUCTION</th></tr>
<tr><td>IMPLEMENTATION PERIOD 1</td><td>$6.4B</td><td rowspan="2">$11.6B</td><td>$5B</td><td rowspan="2">$20B</td><td>$6B</td><td rowspan="2">$24B</td></tr>
<tr><td>IMPLEMENTATION PERIOD 2</td><td>$10B</td><td>$15B</td><td>$18B</td></tr>
<tr><td>IMPLEMENTATION PERIOD 3</td><td>$6B</td><td>$6B</td><td>$5B</td><td>$5B</td><td>$6B</td><td>$6B</td></tr>
<tr><td>TOTAL</td><td>$22.4B</td><td>$17.6B</td><td>$25B</td><td>$25B</td><td>$30B</td><td>$30B</td></tr>
</table>

SEDIMENT CONSTRAINTS

For the 2017 Coastal Master Plan, the Planning Tool tracked borrow requirements for specific projects and allocated borrow from individually defined sources to those projects (Groves et al., 2017). Each project could obtain borrow from only one site (usually the closest and thus most cost-effective), and the Planning Tool ensured that sufficient borrow was available for all projects selected. If borrow was not available for a project, that project would not be selected. The cost of required borrow from the designated site was included in the construction costs for a given project and passed to the Planning Tool. Thus, the Planning Tool maximized land area in the selection of restoration projects accounting for their costs and available borrow material.

In some cases, the borrow available to a set of projects was not sufficient to support all the projects, and thus available borrow was a binding constraint. Under such cases it could be beneficial to obtain borrow from another source, even at a higher cost. As such, in a few cases, specific adjustments were made to allow a project to receive sediment from more than one source.

For 2023, the Planning Tool has been configured to allow an individual project or project element to obtain borrow from more than one source, if cost efficient to do so, and to track the cost of using the single or selected combination of borrow sources. To implement this, several changes to the project attribute data and the Planning Tool have been implemented:

- Separate borrow costs from other construction costs: The Construction Cost project attribute excludes the cost of the borrow.
- Develop project element/borrow cost matrix: This matrix specifies for each project element requiring borrow the per volume cost of obtaining borrow from each of the possible sources. There is also a fixed cost independent of volume. For coding purposes, a single matrix lists for each project the plausible sediment sources by element.
- Update the Planning Tool to consider project elements for purposes of calculating borrow costs depending on the source used: The 2023 Planning Tool allows the required borrow for each project element to be met by different sources while maximizing land, subject to the budget and borrow constraints. In practice this means including the per volume borrow costs and the borrow requirements for each project element in the Planning Tool cost constraint.

For the 2023 analysis, 41 individual sediment sources are defined. For sources that are not within the Mississippi River channel, a single amount of sediment is specified which can be drawn upon until exhausted. For Mississippi River-based sources, sediment is considered renewable. These sources are assigned a ten-year renewable fill volume available at any time in those ten years, preventing the sediment – twice the fill volume – to be used at once. Both types of sediment constraints are stored in the Planning Tool database in a simple table containing the amount of sediment available for each implementation period and parameters specifying how the sediment source can be replenished. For example, assuming the demand for sediment is 100 units for Project X in IP1 and the replenishment rate is 10 years with a fill volume of 50, the model forces the sediment to be pulled in two periods, Years 0 to 10, and Years 11 to 20.[2]

[2] The sediment removal time to affect project completion time is not accounted for. For example, this approximation means that if Project X has a five year construction time, yet requires sediment greater than the replenishment rate, the construction time does not change to greater than 11 years.

OTHER CONSTRAINTS

The Planning Tool uses outcome constraints during alternative formulation to consider the effects of a project with respect to outcomes other than land and EADD/EASD. These constraints use the project effects results (see Project Effects section, p.33) together with user-specified outcome constraints (see the following section). The Formulating Robust Alternatives section (p.43) describes how both types of constraints are used in the alternative formulation process.

ALTERNATIVE SPECIFICATIONS

For the alternative formulation function, CPRA and the Planning Tool team developed specifications for each alternative to be formulated. The specifications are recorded in an Excel-based table and include the following information:

- Metadata about the alternative
    - Intent narrative
    - Date of formulation
    - Date/version of data
- Description of objective function
- Budget scenario
- Environmental scenario or robust indicator (for formulation)
- Levee fragility assumption contribution to risk
- Land building certainty assumption (determined through the sensitivity analysis)
- Cost uncertainty assumption (determined through the sensitivity analysis)
- Outcome constraints (if any)
- CPRA-specified project inclusions or exclusions (if any)

In the PT database, each alternative is assigned a unique ID number so that alternative results can be cross-referenced to the specifications used to formulate them. In brief, the alternative ID is a concatenation of variables that track potential optimization decisions across a variety of futures:

1. Budget ID – the size of the budget and how it is distributed between implementation periods
2. Iteration ID – an index used to indicate a set of alternatives used to explore an intended policy outcome such as a robust alternative or set of constraints
3. Objective Function ID – the objective of the optimization balancing between restoration (e.g. maximize land) and risk (e.g. minimize damages)
4. Optimization ID – the process for running the optimization, such as regular optimization, robust first period, robust second period, or all periods fixed
5. Constraint ID – which of the constraints were used to shape the selection of complementary, exclusive, or preferential projects across restoration, risk, sediment, river flow, and other metric constraints

6. Environmental Scenario ID (see p. 26)
7. Fragility Scenario ID (see p. 27)
8. Landscape Uncertainty ID (see p. 27)
9. Cost Estimate Uncertainty ID (see p. 28)

The alternative specification will also include string variables that offer data version controls, plain-text descriptive names, or other process notes.

ALTERNATIVE RESULTS – PROJECTS AND ESTIMATED OUTCOMES

When the Planning Tool formulates an alternative, it defines which projects are implemented in each of the implementation periods. Each project that is specified to be implemented begins accruing engineering and design costs in the first year of the implementation period. Construction costs are incurred immediately following engineering and design. Lastly, operations and maintenance continue through the end of the 50-year planning horizon (Year 50). These results are stored in the Planning Tool database.

The Planning Tool also calculates for each alternative the expected outcomes for land, EADD/EASD, and select metrics annually. See Optimization Calculation section (p. 42) for information on the specific calculation.

Other outputs from the alternative formulation calculations include:

- The cost for all restoration and risk reduction projects by implementation period (constrained by the funding scenarios)
- The required sediment by source and implementation period (constrained by the sediment source volumes)[3]

These outputs will help CPRA and stakeholders understand why the selected projects are selected. These results are stored in the Planning Tool database.

2.5 FUNCTIONS

The Planning Tool performs a variety of functions in support of the CPRA master plan development, as listed and summarized in Figure 10. The subsequent subsections provide more detail for each function.

[3] This information can help determine if limited sediment availability is influencing the selection of projects for a specific alternative.

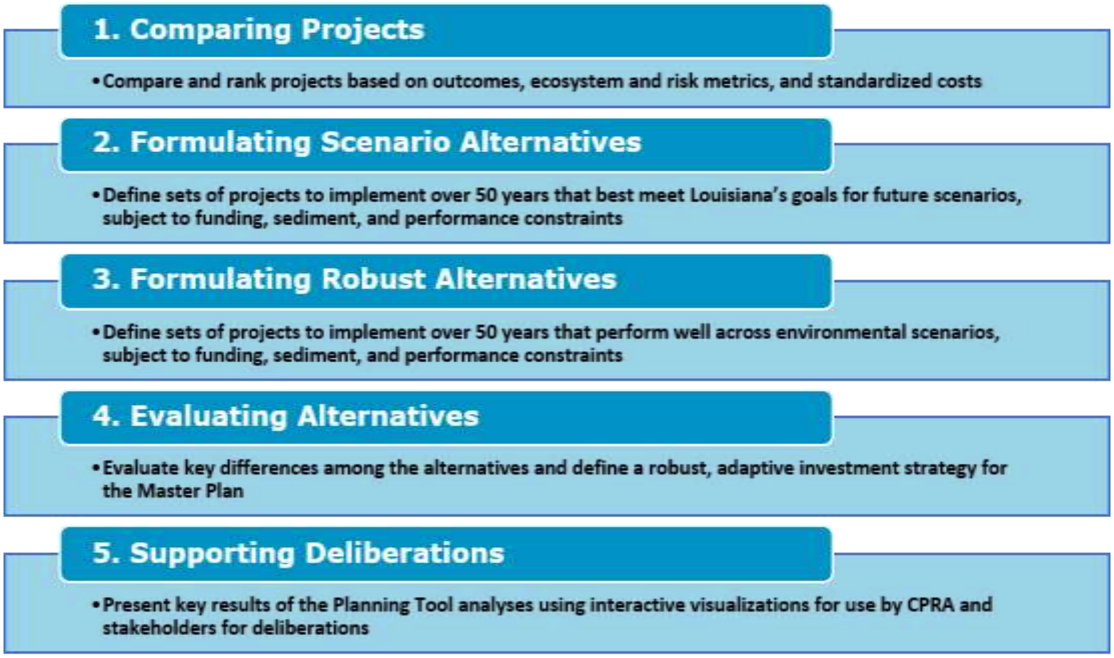


Figure 10. Planning Tool key functions.

COMPARING PROJECTS

The Planning Tool compares individual projects based on predictive model estimates of their effects on the coast and the effects scaled by total project cost. Rankings of projects by outcomes and cost-effectiveness for key metrics provide CPRA and stakeholders with a first-order assessment of which projects could most efficiently help achieve Louisiana's goals (see Project Effects section, p. 33).

The Planning Tool calculates cost-effectiveness for all projects, assuming they each are selectable in IP1, and assuming that projects not selected in IP1 are selectable for IP2.

To calculate cost-effectiveness, the sum of the annual effects is scaled using 50-year project costs, which include planning, design, and construction costs, plus operations and maintenance costs through the 50-year time horizon. The Planning Tool can also consider how alternative estimates of project costs, reflecting uncertainty in the cost estimates, would affect the project rankings.

Cost-effectiveness for each project, p_e, is calculated as:

$$CostEffectiveness_{metric,p_e} = \frac{\sum_{y=1,50} \quad CoastwideProjectEffect_{metric,y,p_e}}{ProjectCost_{p_e}}$$

where the *CoastwideProjectEffect* is equal to *ProjectEffect* summed over all regions. *ProjectCost* is the 50-year cost of the project and is calculated as the sum of the costs for engineering and design (*EDcost*), construction (*Constructioncost*), and operations and maintenance (*OMannualcost*) for the remaining number of years in the 50-year planning period after the project is constructed:

$$ProjectCost_{p_e} = EDcost_{p_e} + Constructioncost_{p_e} + OMannualcost_{p_e} \times \left[50 - \left(EDtime_{p_e} + Constructiontime_{p_e}\right)\right]$$

In general, all restoration projects are compared based on one set of ecosystem metrics and all risk reduction projects are evaluated based on another set of risk metrics. The Planning Tool stores these results in the database and uses them for interactive visualizations (see Supporting Deliberations section, p. 47).

FORMULATING SCENARIO ALTERNATIVES

The Planning Tool develops alternatives — defined as sets of projects to implement in each of the two implementation periods — that best achieve CPRA goals, subject to implementation and performance constraints. There is no “correct” alternative, and the Planning Tool is designed to formulate many alternatives and summarize the key differences among them. Some alternatives vary key implementation constraints such as project funding. Others consider the effects on land or EADD/EASD outcomes if requirements for performance with respect to other metrics, such as long-term land sustainability or shrimp habitat, are added. The Planning Tool is flexible and can be modified to explore and test options in response to CPRA and stakeholders’ interests.

OVERVIEW

In general, the Planning Tool uses an optimization model to select the restoration and risk reduction projects that will maximize land building and risk reduction.

For the 2017 Coastal Master Plan, the Planning Tool selected the optimal restoration projects for each of three implementation periods in turn. This procedure ensures that the best projects are selected in IP1, the next best in the second, and so on. This approach is continued for 2023, although the predictive models will be used to model the restoration projects that are not selected in IP1 against the future with IP1 projects condition.

For both restoration and risk reduction projects, the procedure first selects projects to implement in IP1 (Years 1-20). The Planning Tool assumes that these projects are implemented beginning in Year 1 and that cost and sediment requirements for the first 20 years of each project must be met by IP1 funding and sediment sources. For some projects, construction costs and sediment requirements extend beyond the first 20 years. In this case, the Planning Tool ensures that sufficient budget and sediment are available in IP2. When projects are selected for IP2, the requirements for the projects selected in IP1 must be satisfied first.

The Planning Tool next selects projects to implement in IP2 (Years 21-50). Any project not selected in the IP1 is a candidate for selection. These projects are assumed to begin engineering and design in Year 21 and accrue costs from that year forward. The Planning Tool again ensures that all funding and sediment requirements are met.

The Planning Tool can operate in two modes. The first – *Single Selection Step* – uses FWOA conditions and estimates of projects' effects as if they are implemented in IP1. Projects not selected in IP1 are available for selection in IP2. In this mode, for IP2 the Planning Tool estimates what the future benefits would be if they are implemented beginning in Year 21. For restoration projects, annual effects are shifted forward in time by 20 years. For risk reduction projects, effects for the first 20 years plus engineering, design, and construction time are assumed to be zero. This approach was used in 2012 and 2017.

The second mode – *Iterative Modeling and Selection* mode – includes a modeling step in which restoration projects selected for implementation in the first period are evaluated along with the FWOA condition to form a basis for modeling the effects of restoration and risk reduction projects if they are implemented in IP2. This approach will provide better estimates of the effects of projects when implemented in IP2.

For both risk reduction and restoration alternatives, other performance constraints can also be imposed when formulating alternatives. These constraints can help 1) to better understand whether improvements in other metrics could be achieved at a minimal effect to the decision drivers, land and EADD/EASD reduction, and 2) to ensure that specific outcomes are achieved, e.g., outcomes that are consistent with the master plan objectives, while maximizing land area and EADD/EASD reduction. Iterative alternative formulation and review of these results support CPRA deliberations.

DATA PROCESSING

Project attribute and project effects information are key inputs to the Planning Tool for alternative formulation. Before using these data to formulate alternatives, two sets of calculations are required. First, each project's cost and sediment requirements must be distributed over time to determine how much applies to each implementation period. The Planning Tool distributes engineering, design, and construction costs evenly across the duration of their respective periods. It then applies the annual operations and maintenance cost to each year after construction is complete. Table 5 provides an example for a project's costs and duration for each phase, and Figure 11 shows how these costs are distributed annually depending on the period of implementation.

Table 5. Example Project Phase Costs and Duration

	Costs	Duration
Engineering and Design	$10M	5 years
Construction	$140M	7 years
Operations and Maintenance	$1M/year	Until Year 50

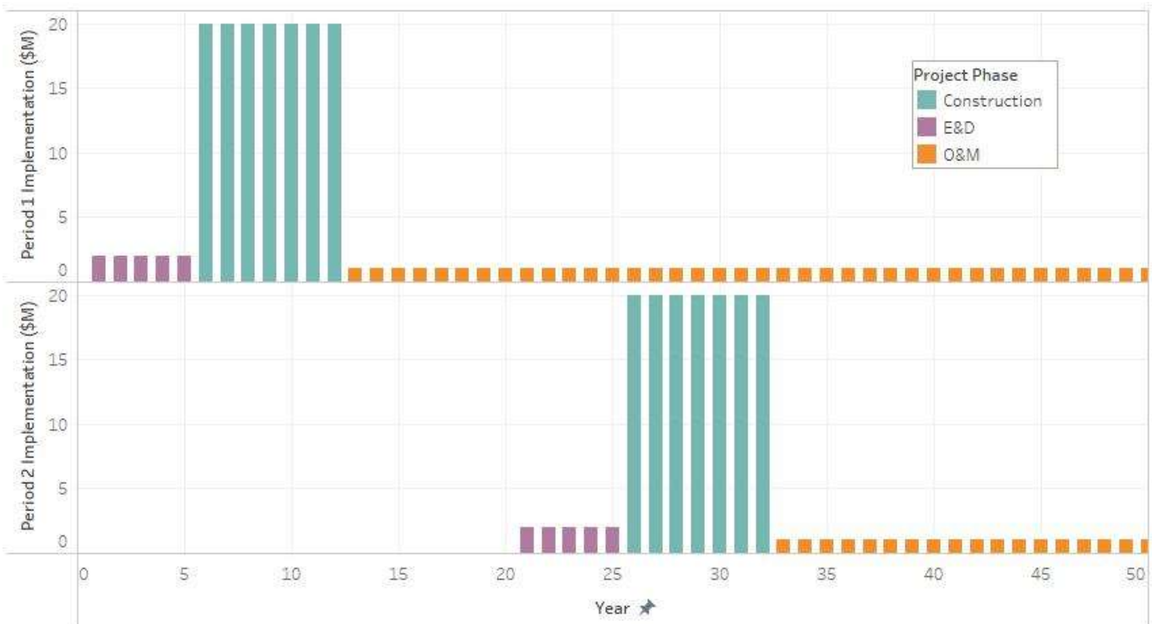


Figure 11. Example distribution of project costs for two periods of implementation.

A project's sediment requirement is given per implementation period, distributed evenly across the years in which the project would be constructed. The available sediment from river sources is limited to the replenishment volume every ten years.

When the Planning Tool is operating in *Single Selection Step* mode, it must offset restoration projects for selection in IP1 by 20 years. The Offset Project Effects matrix specifies a restoration project's effect for each metric when implemented in each of the two implementation periods. Calculating this matrix requires shifting of estimated restoration project effects by 20 years for IP2. Table 6 illustrates how effects are offset for IP1.

Table 6. Modeled Results Used to Approximate Effects of Restoration Projects Implemented in Each of the Two Implementation Periods

	Select years for offset effects						
Implementation Period	Initial condition*	Year 5	Year 10	Year 20	Year 30	Year 40	Year 50
1 (Years 1-20) **	Initial condition	5	10	20	30	40	50
2 (Years 21-50)	n/a	n/a	0	0	10	20	30

* For some metrics, results are provided at the end of Year 1, not initial condition.
** Note that there is no offset of results for Implementation Period 1.

For risk reduction projects, the predictive models report effects annually and adjusting effects to account for an IP1 implementation simply requires zeroing out the effects for the first 20 years plus engineering and design time for the project.

OPTIMIZATION CALCULATION

The Planning Tool selects projects for each implementation period using an optimization model developed in General Algebraic Modeling Language (GAMS).[4] Specifically, GAMS solves a mixed integer program in which the decision variables are binary choices, *I,* to implement or not implement a project in one of the two implementation periods. The objective is a simple function including average annual land, EADD reduction, and potentially EASD reduction. The algorithm maximizes the objective function subject to available funding and sediment, and some additional constraints defined below:[5]

$$Max \sum_{p_r} \left[\left(\sum_{y} \left(W_{EADD} \times EADD\_reduction^{*}_{y,p_r} \right) + W_{EASD} \times EASD\_reduction^{*}_{y,p_r} \right) \times I_{p_r} \right]$$

$$+ \sum_{p_e} \left[- \left(\sum_{y} Land\_building^{*}_{y,p_r} \right) \times I_{p_e} \right]$$

by choosing I_{pr} = {1 or 0}, subject to the following funding constraints:

$$\left(\sum_{p_r} I_{p_r} \times Cost_{p_r} \right) \leq RiskFunding$$

$$\left(\sum_{p_e} I_{i,p_e} \times Cost_{p_e} \right) \leq RestorationFunding$$

and sediment constraints (for restoration projects), for each sediment source, s:

$$\left(\sum_{p_e} I_{p_e} \times SedimentRequirement_{p_e,s} \right) \leq SedimentSource_{s}$$

The Planning Tool includes additional constraints to ensure that only one of a set of mutually exclusive projects is implemented.

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[4] GAMS (General Algebraic Modeling System) is a high-level modeling system. It consists of a language compiler and a stable of integrated high-performance solvers. CPLEX is used in this application.

[5] Note, that for some variables, like EADD or EASD reduction, there is a theoretical-maximum that could be achieved in each risk region – zero risk. Therefore, the function above limits the total EADD or EASD reduction for a region to the FWOA level of risk, as indicated by the "*".

Note that for non-Mississippi River sediment sources, the total amount of available sediment is made available in IP1. Sediment not used in IP1 is available in IP2. For river sediment sources, the Planning Tool takes the ten-year renewable amount and sets the total available sediment to be two times the ten-year amount for IP1 and three times the ten-year amount for IP2. There is no carryover of unused sediment between the implementation periods.

The Planning Tool is flexible and can be adjusted to ensure that a desired mixture of projects is selected for the 2023 Coastal Master Plan. For example, if a particular type of project is not as cost-effective in terms of land (for restoration projects) or EADD/EASD (for risk reduction projects) as others, the Planning Tool could define alternatives without sufficient project diversity. While this did not occur in the 2017 Coastal Master Plan process, if it does in the 2023 Coastal Master Plan analysis, additional constraints could be added that require a minimum amount of expenditure on each project type. For example, this approach could be used to ensure that enough investment is made in all regions of the coast.

OPTIMIZATION OUTPUTS

For each alternative, the Planning Tool defines the projects to implement and estimates the expected outcomes coastwide with respect to key metrics for each alternative.

Expected outcomes for alternatives are calculated using an additive assumption, per the following formula:

$$Expected\_outcome_{m,y,r} = FWOA_{m,y,r} + \sum_{p} Project\_effect_{p,m,y,r}$$

where *FWOA* is the future without action outcome; *m* is a specific ecosystem metric (e.g., land); *y* = year; *r* = region; *p* = selected projects from the alternative.

Note that the effects of a risk reduction project on EADD or EASD is generally negative or risk reducing.

The expected outcome calculation is performed only for those metrics that have FWOA values and can be reasonably assumed to be additive. All outputs generated are assessed and stored in the Planning Tool database.

Interactive visualizations show comparisons of the projects selected and the estimated outcome across the alternatives, as described in the Supporting Deliberations section (p. 47).

FORMULATING ROBUST ALTERNATIVES

For both the 2012 and 2017 Coastal Master Plans, an ad hoc process was used to evaluate the project selection under the different scenarios and then decide which alternative to use as the final plan. For 2023, a new approach was developed that is more consistent with best practice from the

Decision Making Under Deep Uncertainty (DMDU) literature (Marchau, 2019).[6]

In brief, this approach first identifies "high-confidence" projects for IP1. The Planning Tool does this by formulating alternatives for each of the two scenarios – called "optimal" alternatives. Selected projects common to both optimal alternatives are high-confidence projects. The Planning Tool then iteratively increases the IP1 budgets for each optimal alternative until a set of common projects (high-confidence projects) are defined that expend that original amount of funding.[7]

Once a full set of high-confidence IP1 projects is selected using all available funds, these projects are passed along to the predictive models to re-evaluate future conditions assuming these projects will be implemented in IP1 (the Iterative Modeling and Selection mode – see the Overview section, p. 39). Note that project costs may differ across the two environmental scenarios, so the process will ensure that final high-confidence projects do not exceed the IP1 budget in either scenario.

Together, the high-confidence projects make up a "robust" alternative that will perform well in both scenarios. Figure 12 shows this process for IP1.

[6] Note that a strategy that adapts over time in response to future conditions would likely be more robust.

[7] Note that any performance constraints applied – such as land sustainability or support for specific species – would be met for both optimal alternatives but may not be met by the high-confidence projects. A check will be performed to ensure acceptable performance with respect to these metrics for the high-confidence projects. If acceptable performance is not achieved, then the constraint used to define the optimal alternatives will be adjusted and the process will be repeated.

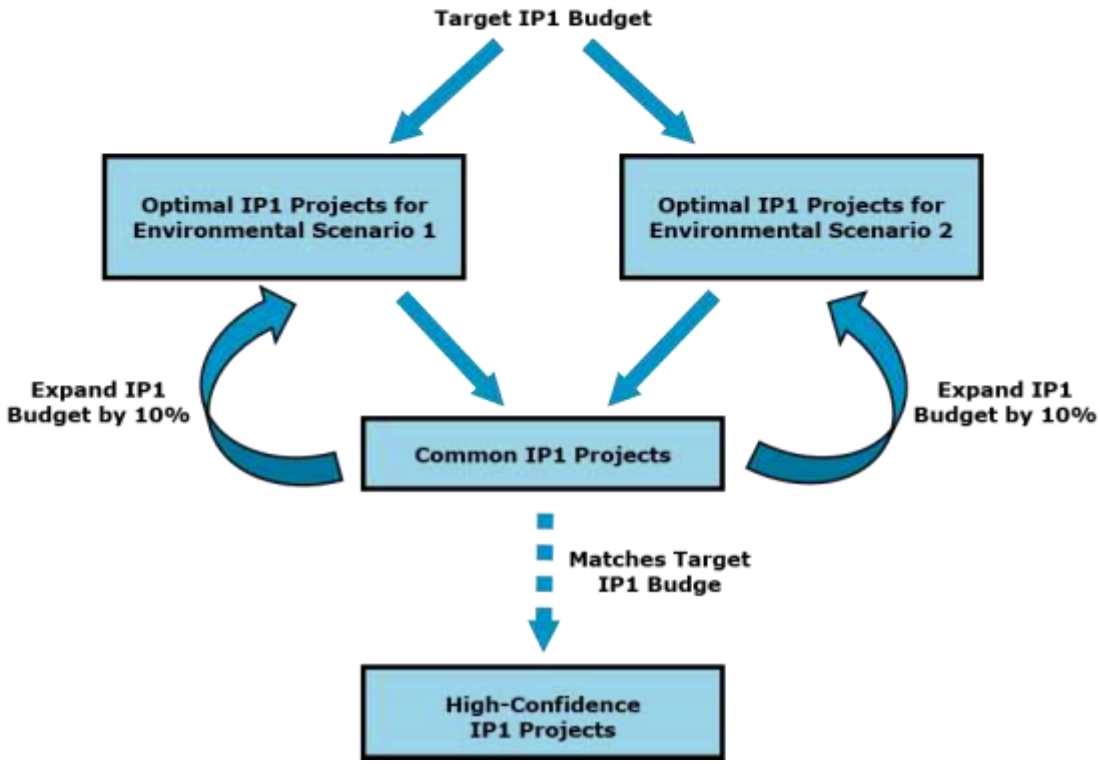

Figure 12. Illustration of iterative process to identify high-confidence projects.

The Planning Tool team evaluated this new approach using 2017 data for both restoration and risk reduction projects. Figure 13 shows the iterative selection of restoration projects for IP1--based on experimentation using 2017 data. The dark squares indicate that a project is selected. Notice that as a project is selected in both scenarios for one budget, it is included in all future budgets (those shown to the right) and the robust alternative (right-most column). For example, the second row corresponds to the Central Terrebonne Hydrologic Restoration project (see 03a.HR.02 (0)) and shows that for the first three budgets, it is only selected under the High scenario. However, once the first period budget is set to $17.5 billion, it is selected in both scenarios and hence included in the Robust Alternative.

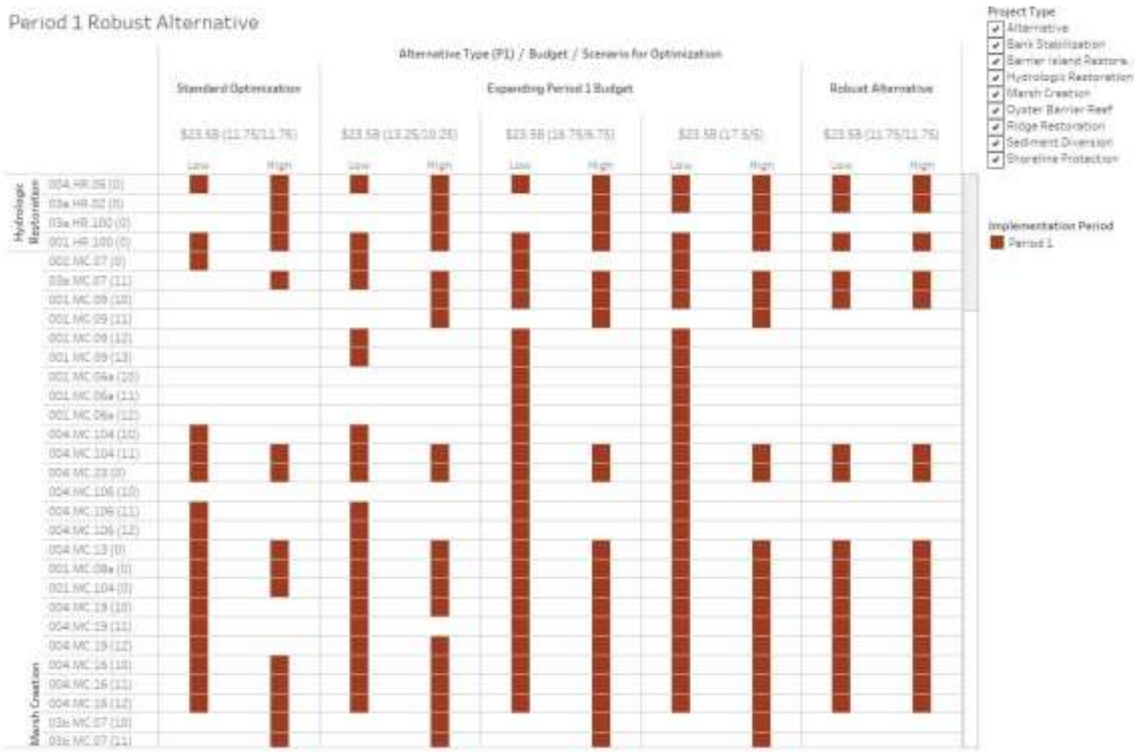

Figure 13. Selected Implementation Period 1 risk reduction projects under increasing budgets and robust alternative.

During the robust project selection process, alternatives are formulated for each environmental scenario to identify a common set of projects that would use the full available budget. The Planning Tool can be configured such that these alternatives meet all other constraints, for example, the land sustainability constraint. However, there is no guarantee that the alternative composed of common high confidence projects across the two scenarios would also meet all the specified constraints. For example, one alternative might meet the sustainability constraint due to a highly sustainable project that is *not* included in the other alternative.

If the robust alternative does not meet the sustainability constraint, the following steps will be taken:

1. Incrementally increase the constraints for the scenario-specific alternatives until the robust alternative meets all constraints
2. Lower the constraints and acknowledge that there may not be a set of projects that meet all constraints in both scenarios
3. Apply ‘rules’ to include projects that may be selected in only one project but can help ensure that the robust alternative meets all constraints.

EVALUATING ALTERNATIVES

The Planning Tool helps CPRA to compare different alternatives through visualizations that compare project selection across implementation periods and expected outcomes. The intent is to define a robust, adaptable investment strategy for the master plan.

SUPPORTING DELIBERATIONS

The Planning Tool analyses, described above, are by nature exploratory and do not present simple conclusions. Projects are numerous and can be compared across different metrics, regions, and time periods. Alternatives are composed of different combinations of projects and have differential effects across the coast. The Planning Tool, thus, helps CPRA and stakeholders explore the analytic results, see the key differences, and support deliberations through interactive visualizations and iteration (Figure 14).

Figure 14. Deliberation with analysis.

The Planning Tool's visualizations are developed using Tableau, a business analytic data analysis and visualization platform.[8] Tableau connects directly to the Planning Tool SQLite database and provides a flexible interface to develop custom interactive graphics. The visualizations are packaged in workbooks and made available via a website. Figure 15 shows the preliminary welcome screen for the 2023 Planning Tool.

8 Details on Tableau can be found at the developer's website: www.tableausoftware.com.

Figure 15. 2023 Planning Tool welcome screen.

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