2023 COASTAL MASTER PLAN

OVERVIEW OF IMPROVEMENTS TO LANDSCAPE MODELING (ICM) FOR 2023

APPENDIX D

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COASTAL PROTECTION AND
RESTORATION AUTHORITY
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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.

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LIST OF ABBREVIATIONS

BIMODE .... 2017 BARRIER ISLAND MODEL

BISM ....BARRIER ISLAND SYSTEM MANAGEMENT PROGRAM

BITI... BARRIER ISLAND TIDAL INLET MODULE

CPRA .... COASTAL PROTECTION AND RESTORATION AUTHORITY

CRMS .... COASTWIDE REFERENCE MONITORING SYSTEM

FFIBS . FRESH **F**ORESTED WETLANDS, **F**RESH HERBACEOUS MARSH, **I**NTERMEDIATE MARSH, **B**RACKISH MARSH, AND **S**ALINE MARSH

GAMMS ....GENERALIZED ADDITIVE MODELS

GLMMS ....GENERALIZED LINEAR MIXED MODELS

HPC ....HIGH-PERFORMANCE COMPUTER

HSI ....HABITAT SUITABILITY INDEX

HUC .... HYDROLOGIC UNIT CODES

ICM ....INTEGRATED COMPARTMENT MODEL

ICM-BI.. BARRIER ISLAND DIGITAL ELEVATION MODEL

MPDV ....MASTER PLAN DATA VIEWER

MP-DAP...MASTER PLAN DATA ACCESS PORTAL

NHDPLUS .... NATIONAL HYDROGRAPHY DATASET

OMAR ....ORGANIC MATTER ACCUMULATION RATES

SI .... SUITABILITY INDEX

QAQC ....QUALITY ASSURANCE/QUALITY CONTROL

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1.0 OVERVIEW OF MODEL IMPROVEMENTS

1.1 IMPROVEMENT PLAN

Prior to the development of the 2023 Coastal Master Plan, a list of potential improvements was compiled for the numerical models used in the plan development process. Some suggested changes to the models had to first undergo study and analysis to determine the best path forward. The full details of the processes, tests, and analyses conducted are included as attachments to this appendix. Please refer to the referenced attachments and appendices listed throughout this document. Additionally, Appendix C: Use of Predictive Models in the 2023 Coastal Master Plan (Reed & White, 2023) and its attachments provide documentation on the final version of the improved models that were ultimately used to develop the 2023 Coastal Master Plan.

The Integrated Compartment Model (ICM) contains a primary control program and a suite of subroutines. The control program is written in Python and handles nearly all of the pre- and post-processing of model output files for use in each subroutine. This program calls the ICM subroutines:

- **ICM-Hydro**: Coastal Hydrology Model
- **ICM-LAVegMod**: Wetland Vegetation Dynamics Model
- **ICM-BI**: Barrier Island and Tidal Inlet Model
- **ICM-Morph**: Wetland Morphology Model
- **ICM-HSI**: Habitat Suitability Indices

1.2 MODEL CODE REPOSITORY

Source code for the ICM, all subroutines, and a variety of pre- and post-processing programming scripts are freely available, open source, and publicly posted to the CPRA Master Plan Team GitHub repository: www.github.com/CPRA-MP. The GitHub repository has many software versions tagged. The versions used for the 2017 Coastal Master Plan and the final updated code versions used for the 2023 Coastal Mater Plan are provided below. Refer to each subroutine's repository for a full tracking of additional versions, software branches, and other software edits.

ICM: INTEGRATED COMPARTMENT MODEL

- Final 2017 code release version **MP2017_ICMv3**:
  - github.com/CPRA-MP/ICM/releases/tag/MP2017_ICMv3
- Final 2023 code release version **v23.0.0**:
  - github.com/CPRA-MP/ICM/releases/tag/v23.0.0

ICM-HYDRO: COASTAL HYDROLOGY MODEL

- Final 2017 code release version **MP2017_ICMv3**:
  - github.com/CPRA-MP/ICM_Hydro/releases/tag/MP2017_ICMv3
- Final 2023 code release version **v23.4.1**:
  - github.com/CPRA-MP/ICM_Hydro/releases/tag/v23.4.1

ICM-LAVEGMOD: WETLAND VEGETATION DYNAMICS MODEL

- Final 2017 code release version **MP2017_ICMv3**:
  - github.com/CPRA-MP/ICM_LAVegMod/releases/tag/MP2017_ICMv3
- Final 2023 code release version **v3.0.0**:
  - github.com/CPRA-MP/ICM_LAVegMod/releases/tag/ICM-LAVegMod_v3.0.0

ICM-MORPH: WETLAND MORPHOLOGY MODEL

- Final 2017 code release version **MP2017_ICMv3**:
  - github.com/CPRA-MP/ICM_Morph/releases/tag/MP2017_ICMv3
- Final 2023 code release version **v23.3.1**:
  - github.com/CPRA-MP/ICM_Morph/releases/tag/v23.3.1

ICM-BI & ICM-BITI: BARRIER ISLAND AND TIDAL INLET MODELS

- Final 2017 code release version **MP2017_ICMv3**:
  - github.com/CPRA-MP/ICM_BIDEM/releases/tag/MP2017_ICMv3
- Final 2023 code release version **v23.1.0**:
  - github.com/CPRA-MP/ICM_BIDEM/releases/tag/v23.1.0

ICM-HSI: HABITAT SUITABILITY INDICES

- Final 2017 code release version **MP2017_ICMv3**:
  - github.com/CPRA-MP/ICM_HSI/releases/tag/MP2017_ICMv3
- Final 2023 code release version **v23.0.0**:
  - github.com/CPRA-MP/ICM_HSI/releases/tag/v23.0.0

2.0 ICM-HYDRO UPDATES

The fundamental numerical methods and code for ICM-Hydro remain unchanged from the 2017 Coastal Master Plan methods. While no methods were removed from the model, some additional functionality was added such as a new method for modeling one-dimensional channel flow. Additional updates were made to both the model grid resolution and extent. Finally, additional updates were made to how ICM-Hydro calculates water level variability for use as an input variable to ICM-LAVegMod.

2.1 UPDATED MODEL GRID AND RECALIBRATION

Substantial resolution was added to the ICM-Hydro model grid for the 2023 Coastal Master Plan. A concerted effort was undertaken to identify as many local hydraulic control structures and flow restrictions as possible. A combination of data sources were leveraged for this effort including CPRA project design details, satellite imagery, field survey data, and Google StreetView imagery. Upon collation of all identified structures, all efforts were made to ensure that these structures were located on the border (not the interior) of the ICM-Hydro compartments.

In addition to known control structure locations, ICM-Hydro compartment boundaries were first delineated using catchment boundaries from the National Hydrography Dataset (NHDplus). These NHDplus catchments are categorized using the NHD standards and are easily related to the federal Watershed Boundary Dataset Hydrologic Unit Codes (HUC), which are widely used for hydrologic and hydraulic modeling purposes. Specifically model development for HUC watersheds is ongoing across the state of Louisiana, under the purview of the Louisiana Watershed Initiative. Using the NHDplus catchment boundaries allows for seamless future connectivity between these HUC watershed models and the ICM.

Once the entire ICM-Hydro domain was redelineated and linked to the 1-D channel models (see below), the model was calibrated and validated against observed data. The same calibration process used for the 2017 models was used for the updated 2023 version. However, newly available data, up to the end of 2018, was used for model training purposes. The calibration period was from 1/1/2010 through 12/31/2018. The validation period was unchanged from the 2017 methodology: 1/1/2006 through 12/31/2009.

2.2 1-D CHANNEL ROUTING

For the 2023 Coastal Master Plan, a new one-dimensional hydraulic routing model was developed for four primary waterways and navigational channels. The following channels were modeled using a one-dimensional dynamic wave routing algorithm:

- Mississippi River from Belle Chasse to Southwest Pass,
- Atchafalaya River from Simmesport to the Gulf,
- Wax Lake Outlet, and
- Calcasieu River and Ship Channel from the saltwater barrier upstream of Lake Charles to Calcasieu Pass.

Each 1-D channel reach was linked to the two-dimensional ICM-Hydro compartments via either lateral, downstream, or upstream connecting links or boundary condition timeseries. The Wax Lake Outlet was the only channel that had an upstream connection that was dynamically linked to a 2-D compartment; all other channels had observed timeseries as an upstream boundary condition. Proposed sediment and/or freshwater diversions were treated as a lateral boundary condition into 2-D compartments.

2.3 UPLAND RAINFALL-RUNOFF

In addition to the NHDplus catchments being used for adding resolution to the ICM-Hydro domain, they were also used to expand the model domain northward/inland away from the Gulf of Mexico. The upper extent of the ICM-Hydro model domain was moved to be coincident with the location of USGS stream gaging stations on all of the rivers tributary to the Louisiana coastal zone. This allowed for each tributary input boundary condition to be set equal to the observed data; whereas in 2012 and 2017 Coastal Master Plans, areal weighting factors were used to adjust observed stream gage data downstream to the upstream boundary location of the old ICM-Hydro domains.

The areas now located between the USGS gage location and the upstream boundary of the coastal zone (defined by the upper extent of tidally-inundated areas) are used solely maintaining an accurate runoff water balance, as determined by input precipitation forcings.

The upland drainage areas were delineated using the NHDplus catchment boundaries. This ensures that future versions of ICM-Hydro will be able to tie-in, seamlessly, with hydrologic models developed for each NHD HUC-8 watershed catchment under the purview of the Louisiana Watershed Initiative.

2.4 TIDAL RANGE DYNAMICS

Due to memory limitations, ICM-Hydro does not save in memory the full hourly timeseries of water levels. Therefore, only daily water levels are available at the end of the simulated year for determining summary statistics. Input data to ICM-LAVegMod defined water level variability as equal to the standard deviation of hourly water levels during the growing season; but seeing that ICM-Hydro does not have hourly data available, in 2017 the water level variability was calculated as the standard deviation in daily levels. This resulted in a dampening of water level variability values, as calculated by ICM-Hydro.

For 2023, hourly water levels are still not available for summarizing at the end of the simulated year, but the instantaneous minimum and maximum water levels during each simulated day *was* available as the saved values for *tidal range.* Using observed hourly water level data from Coastwide Reference Monitoring System (CRMS) from 2006 – 2018, a linear correlation between the standard deviation in hourly water levels) and the daily tidal range was determined. This relationship is used to assign input water level variability for ICM-LAVegMod from modeled daily tidal range values in ICM-Hydro. The correlation had an R^2 = 0.77 and was defined as:

standard deviation in hourly water levels = 0.0659 + 0.2647(Daily mean tidal range)*

By using this correlation between hourly variation and daily range, calculated values of water level variability were no longer artificially dampened by memory limitations of ICM-Hydro.

3.0 ICM-LAVEGMOD UPDATES

Prior to developing new source code for the 2023 Coastal Master Plan vegetation dynamics model (ICM-LAVegMod) new data analyses were conducted to propose a variety of potential model improvements to the vegetation and wetland soil model processes. Experimental test simulations were also conducted to determine the final set of model improvements to be made to ICM-LAVegMod for use in the 2023 Coastal Master Plan development process. The summary of these analyses are provided in Attachment D2: ICM-Wetlands Vegetation and Soils Model Improvements (Baustian et al., 2020), and the final version of ICM-LAVegMod is summarized in Attachment C8: Modeling Wetland Vegetation and Morphology: ICM-LAVegMod and ICM-Morph (Foster-Martinez et al., 2023).

3.1 MARSH COLLAPSE THRESHOLDS

The most substantial change to the vegetation and landscape dynamic models for 2023 was the removal of acute and categorical marsh collapse thresholds for vegetated wetland areas. In 2017, if a vegetated wetland area was classified as fresh forest or fresh marsh, then it could be converted directly into open water via collapse if an acute salinity threshold was crossed during the model year. Upon review of observational data, this collapse mechanism was not found to be particularly prevalent in coastal Louisiana. Rather, if acute salinity stress occurred, the vegetation may die off, but the wetland vegetation was seen to re-establish in the location before the soil collapsed and converted to open water. Therefore, in 2023 modeling, acute salinity stress would only result in vegetation coverage to go to zero; but vegetation could re-establish in the following year if conditions permitted.

The inundation stress collapse mechanisms in the 2017 version of the ICM were largely kept in the model; if a location is too deep for marsh survival for two years in a row (persistent inundation), the vegetated wetland will collapse directly into open water. However, the depth thresholds used to define "too deep" were updated from the categorical values to a gradient that was a function of a site's salinity and water depth. This relationship was developed from observational CRMS data and is described fully in Attachment D2: ICM-Wetlands Vegetation and Soils Model Improvements (Baustian et al., 2020), and in Attachment C8: Modeling Wetland Vegetation and Morphology: ICM-LAVegMod and ICM-Morph (Foster-Martinez et al., 2023).

3.2 WEIGHTED FFIBS SCORE

The 2017 ICM used categorical classifications of habitat types to apply a variety of model calculations. Five habitat classification types were used, Fresh **F**orested Wetlands, **F**resh Herbaceous Marsh, **I**ntermediate Marsh, **B**rackish Marsh, and **S**aline Marsh, or FFIBS. There were also separately tracked categorical classifications of water, upland/developed areas, and flotant marsh. To classify an individual ICM-LAVegMod grid cell, the relative coverages of all species were reclassified to their corresponding FFIBS habitat type, and then the entire cell was categorized based on the predominant

FFIBS habitat coverage.

For 2023, instead of using the predominant FFIBS category, the entire species-mixture was used to determine an areally-weighted FFIBS score. Refer to Sections 2.4 and 2.6 in in Attachment C8: Modeling Wetland Vegetation and Morphology: ICM-LAVegMod and ICM-Morph (Foster-Martinez et al., 2023) for a full description.

A variety of landscape change processes (e.g., organic accretion) are now able to be calculated on a gradient as opposed to using the 2017 approach of categorical thresholds/rates.

3.3 ORGANIC MATTER ACCRETION

The fundamental treatment of organic matter accretion in the ICM is a function of the vegetation coverage of a grid cell. As in 2017, the rate at which wetland soils produce organic matter is assigned from CRMS soil core data. However, for the 2023 Coastal Master Plan, an updated soil core dataset was available. This new data was used to determine regionally-specific organic matter accumulation rates (OMAR) for each FFIBS habitat classification. With the addition of the weighted FFIBS score (above), the assigned OMAR values are now interpolated across category values to provide a gradient of organic accretion across marsh areas.

In addition to the updated input data and new interpolation methods, the assignment of soil bulk density was also improved. An ideal mixing model was used to develop separate self-packing densities for mineral and organic components of marsh soils. This allows for separate treatment of mineral and organic components of soils, which can accommodate the fact that the ICM calculates these two soil components via two separate subroutines. Mineral loading is calculated from suspended sediment and water depth values in ICM-Hydro, and organic loading is calculated from the vegetation coverage, as described above.

Refer to Attachment D2: ICM-Wetlands Vegetation and Soils Model Improvements (Baustian et al., 2020) for details on the ideal mixing model, as well as the OMAR data analysis.

3.4 FLOTANT MARSH UPDATES

The process for updating flotant coverage was improved from the 2017 version of ICM-LAVegMod. There are now two types of flotant considered by ICM-LAVegMod: thick-mat flotant, *Panicum hemitomon*, and thin-mat flotant, *Eleocharis baldwinii*. An intermediate step was also added for the mortality of thick-mat flotant, which reflects that it does not immediately convert to open water when it dies.

3.5 UPDATED DISPERSAL CLASSES

In 2017, all vegetation species available for establishment upon bare ground were limited to a pool of nearby/available species that could disperse into the empty bare ground. For 2023, this same method of *low dispersal* was used for most of the modeled species. However, two additional dispersal classes were added; a *medium dispersal* class for species with the ability to disperse from a further, yet still limited, distance, and a *high dispersal* class. Species in this class are available for establishment without any limits to dispersal distance and are therefore freely available to establish in any location across the model domain.

3.6 UPDATED SUBMERGED AQUATIC VEGETATION ROUTINE

In 2017, submerged aquatic vegetation (SAV) was modeled within ICM-LAVegMod. Additional work for the 2023 plan, however, added complexity to the SAV model. The improvements to the SAV algorithms are described in Attachment D3: ICM-Wetlands – Submerged Aquatic Vegetation (SAV) Updates (DeMarco et al., 2023). The changes were relatively substantial, and as a result of needing to calculate some additional input variables, the SAV model was moved out of ICM-LAVegMod and is now coded, in Fortran, as a subroutine within ICM-Morph, as outlined in in Attachment C8: Modeling Wetland Vegetation and Morphology: ICM-LAVegMod and ICM-Morph (Foster-Martinez et al., 2023).

3.7 CODE, COVERAGE, AND GRID UPDATES

In addition to the model process updates described above, the ICM-LAVegMod Python code was also updated to be compatible with Python 3, whereas the previous 2017 version was written in Python 2.

The ICM-LAVegMod grid contains 480 m x 480 m orthogonal cells. The size was set to align with the ICM-Morph grid, which has 30 m x 30 m orthogonal pixels. Each of the 173,898 grid cells can contain 46 different coverage types:

- *vegetated wetland* that has relative coverages of 41 vegetation species;
- *water*;
- unvegetated wetland that was created this model year, called *new bareground*;
- unvegetated wetland that was created the previous model year, called *old bareground;*
- dead thick-mat flotant, called *flotant bareground;* and
- upland or developed land, which is not modeled and therefore called *NOTMOD*.

Four of the 41 included vegetation species were added to the model for the 2023 Coastal Master Plan. Refer to Table 16 in Attachment D2: ICM-Wetlands Vegetation and Soils Model Improvements (Baustian et al., 2020) for the list of newly added species and refer to Supplemental Materials Table S1 in in Attachment C8: Modeling Wetland Vegetation and Morphology: ICM-LAVegMod and ICM-Morph

(Foster-Martinez et al., 2023) for the final list of species modeled in ICM-LAVegMod for the 2023 Coastal Master Plan.

4.0 ICM-MORPH UPDATES

For the 2023 Coastal Master Plan, significant software improvements were made to the ICM-Morph subroutine. While one of the improvements made changes to the modeled landscape processes, the majority of improvements were focused primarily on changes to the computational platform and were updates to the model's programming code, without making changes to the underlying modeled processes.

A description of all ICM-Morph subroutines, including descriptions of the necessary model input and output files is provided in in Attachment C8: Modeling Wetland Vegetation and Morphology: ICM-LAVegMod and ICM-Morph (Foster-Martinez et al., 2023).

4.1 MONTHLY SEDIMENT DEPOSITION

The only improvement to ICM-Morph that changed how the landscape processes were modeled was the calculation of mineral sediment deposition on a monthly timestep, as opposed to the annual calculations that were performed in the 2017 version of ICM-Morph. Monthly maximum water surface elevations for each ICM-Hydro compartment were reported out and passed into ICM-Morph, along with the monthly mass of mineral sediment that had deposited either on the marsh surface or the open water body bottom. The extent of marsh that was at an elevation below the monthly maximum water surface elevation was set to be the inundation extent, and the mass of mineral sediment deposition was then applied as an 'blanket' of even thickness across the entire inundation extent. This approach was identical to the determination of inundated extent and mineral sediment deposition thickness as used in 2017, however in 2017 annual maximum water levels and annual sediment deposition masses were used. Note that for bodies of open water, the entire portion was assumed to receive a deposit of uniform thickness. Also note that for open water areas, a negative deposition mass could be applied for erosive areas.

4.2 UPDATES TO THE COMPUTATIONAL CODE ENVIRONMENT

Previous versions of the ICM (2012 and 2017) were run on high-end desktop computers using the Microsoft Windows operating system. However, for the 2023 Coastal Master Plan, simulations were run on a Linux-based high-performance computer (HPC) at the Pittsburgh Supercomputer Center (funded by the National Science Foundation's XSEDE program). The move to a Linux HPC environment necessitated updating the source code used by ICM-Morph. Previous versions of ICM-Morph were coded in Python and heavily relied upon ESRI's ArcPy libraries, which would be cost-prohibitive to run on a Linux server. Therefore, the ICM-Morph code was converted from Python/ArcPy into Fortran so that it could be compiled and run on a Linux HPC system.

The previous ArcPy-based versions of ICM-Morph utilized GeoTIFF rasters and GIS shapefiles for nearly all input, output, and intermediate files; however, those file types are not natively supported within Fortran. Rather, simple XYZ text-based rasters were first read into memory arrays for use in the new Fortran-based ICM-Morph. The initial read of these XYZ text files was quite time consuming (~ 20 minutes), however once they were read in as initial conditions, binary arrays/memory dumps could be utilized for all other simulated years. As long as the binary array files are written and read on the same computer (or any other machine that uses the same memory “endianness” as the original machine) then there was no need to write files to human-readable formats until the end of the simulation. Now, the end of a simulation separate post-processors are used to convert the binary arrays back to XYZ text files, which are subsequently converted to GeoTIFF rasters with the GDAL libraries available on the Linux HPC.

4.3 QAQC SAVE POINTS

The final substantive update to ICM-Morph for the 2023 Coastal Master Plan was the creation of a new output file that was used for quality assurance/quality control (QAQC) during model simulations. These files, referred to as QAQC save points, contain a snapshot of all pertinent variables that are used throughout ICM-Morph to define how a given pixel changes in land elevation, and/or landtype, for any given model year. All data is saved for the year and appended as a new row to the end of the file. Therefore, at the end of the multidecade simulation, for each QAQC save point, there will be one file that tracks all elevation and land change data at that point for all model years. The locations used for the QAQC save points were randomly placed throughout the entire model domain. In addition to the random locations, QAQC save points were also placed at select transects that had been pre-identified at areas of interest (Wax Lake Outlet, near proposed diversions, etc.). Finally, QAQC save points were placed at every CRMS location within the model domain. In all, there are 2,941 locations where 16 different variables from across ICM-Hydro, ICM-LAVegMod, and ICM-Morph are all reported out.

5.0 ICM-BI UPDATES

The 2023 Coastal Master Plan relies on realistic predictive modeling of the migration of coastal barrier islands and their effect on coastal basin hydrology, while incorporating periodic maintenance of barrier islands via assumed restoration. The ICM-Barrier Islands Improvement Team was tasked with recommending improvements to the 2017 Barrier Island Model (BIMODE), which were shared Attachment D4: Barrier Island Model Improvements (Georgiou et al., 2020). Two main priorities were highlighted in the technical report, and as a result barrier islands were considered within the 2023 Integrated Compartment Model (ICM) using two separate modules: the Barrier Island Tidal Inlet Module (BITI), which models the evolution of tidal inlets along barrier islands as informed by basin hydraulics, and the Barrier Island Digital Elevation Model (ICM-BI), which models island configuration through time to support storm surge modeling. The BITI module is fully incorporated in the ICM main control program Python code, while ICM-BI is a new ICM subroutine that is coded in Fortran.

The BITI module captures the positive relationship between tidal inlet cross sectional area and back barrier tidal prism. It uses the O'Brien-Jarrett-Marchi law to calculate an inlet's cross-sectional area using the basin's tidal prism. Due to the size of each coastal basin and the presence of multiple barrier island tidal inlets per basin, BITI calculates a fraction of the total tidal prism as it pertains to each tidal inlet using a partitioning coefficient. The module has the capability to evolve inlets as the size of the back barrier basin and tidal prism increases over time and ICM-Hydro compartments convert to open water.

The second module, ICM-BI, has several key components. It uses historic barrier island cross-shore retreat rates under varying sea level rise scenarios to migrate barrier island transects. The transects migrate based on cross-shore retreat rates of index profiles selected to represent key geomorphic features along the coast. The second component of ICM-BI is the auto-restoration feature. This feature reflects the assumption that CPRA will maintain the integrity of the barrier island system through the Barrier Island System Management (BISM) program. In line with BISM, master plan predictive modeling efforts define barrier island integrity as preventing and repairing breaches and maintaining a critical width for each island. The auto-restoration feature represents this assumption by placing sediment on restoration units that drop below a critical width threshold.

For a full accounting of the technical details and analyses behind the 2023 improvements to the barrier island models, refer to Attachment C9: 2023 Barrier Island Model: ICM-BITI and ICM-BI (Dalyander et al., 2021).

6.0 ICM-HSI UPDATES

Habitat suitability index (HSI) models were developed for the 2023 Coastal Master Plan to evaluate the potential effects of coastal restoration and protection projects on habitat for key coastal fish, shellfish, and wildlife species. These species included: eastern oyster, brown shrimp, white shrimp, blue crab, crayfish, gulf menhaden, spotted seatrout, largemouth bass, American alligator, gadwall, mottled duck, brown pelican, seaside sparrow, and bald eagle. Most of these species were included in the 2017 Coastal Master Plan analyses, and the HSI models from that effort were refined and improved following the recommendations described in the technical memorandum: *2023 Coastal Master Plan Habitat Suitability Index Model Improvement Recommendations* (Sable et al., 2019). In addition to model improvements, HSI models were created for seaside sparrow and bald eagle, both of which are new species for the master plan analyses.

For the HSI models that are primarily literature-based, literature reviews were conducted for recent studies that could be used to improve the suitability index (SI) relationships that compose the models. As a result of this review, modifications were made to the salinity-related SIs of the oyster model including: expanding the time period used for salinity effects to spawning; adjusting the range of suitable annual average salinity to be more representative of Louisiana populations; and making oyster's minimum salinity tolerance temperature dependent. In addition, a new SI was incorporated in the oyster HSI model that accounts for the effects of sediment deposition on oysters. The crayfish HSI model was improved by adjusting the time periods used for the SIs that describe the hydrology required for the crayfish life cycle, and the soil characteristics SI that was part of the 2017 crayfish model was removed because soil conditions do not appear to be limiting for crayfish burrow construction in coastal Louisiana. The other literature-based HSI models from the 2017 Coastal Master Plan, i.e., American alligator, gadwall, mottled duck, and brown pelican, were unchanged, with the exception of a small adjustment made to the suitability of forested wetlands for gadwall. Lastly, a literature-based HSI model was created for seaside sparrow that consists of SIs related to vegetated habitat type, marsh vegetation coverage, and marsh elevation.

Statistical-based HSI models were developed for brown shrimp (both small and large juvenile stages), white shrimp (small and large juvenile stages), blue crab (juvenile stage), gulf menhaden (juvenile and adult stages), spotted seatrout (juvenile and adult stages), largemouth bass, and bald eagle. The bald eagle HSI model was developed from a bald eagle nest probability of occurrence model that related nest occurrence from survey data with land cover type. The resulting model showed that combinations of forested wetlands, flotant marsh, and open water habitats were most suitable for nesting bald eagles. The 2023 fish, shrimp, and blue crab HSI models were developed using new approaches for the formulation of the water quality and structural habitat SIs that compose the models. For the 2017 models, the water quality SI was derived using only generalized linear mixed models (GLMMs) to estimate the relationship between salinity, water temperature, and species' catch. For the 2023 models, however, multiple GLMMs and generalized additive models (GAMMs) were created for each species or life stage. These alternative models were compared and a single model that performed well statistically and was ecologically reasonable was selected for the species' water quality SI. The structural habitat SI was developed using a meta-analysis of published literature to estimate the relative importance of various estuarine habitats to the fish and shellfish species. The results of this analysis were then used to modify the 2017 structural habitat SI relationship to account for the added habitat value of submerged aquatic vegetation and oyster reefs, which are also important habitats for juvenile fish and shellfish. Similar to the 2017 fish, shrimp, and blue crab models, the water quality and structural habitat SIs were then combined to create the 2023 HSI models.

The 2023 Coastal Master Plan HSI models were integrated with the Integrated Compartment Model (and are referred to as ICM-HSIs) and tested using environmental output from the 2017 Coastal Master Plan future without action scenario. The tests showed that, in general, the models produced reasonable representations of species' habitat distribution. Furthermore, the improvements made to the oyster, crayfish, fish, shrimp, and blue crab HSI models generally yielded more realistic results compared to the 2017 HSI models.

For a full accounting of the technical details and analyses behind the 2023 improvements to the HSI models, refer to Appendix D5: Habitat Suitability Index Model Improvements (Lindquist et al., 2023).

7.0 UPDATED MODEL QA/QC AND DATA VISUALIZATION TOOLS

CPRA developed two new interactive data tools to complement the 2023 Coastal Master Plan: the Master Plan Data Viewer (MPDV) and the Master Plan Data Access Portal (MP-DAP). The Master Plan Data Viewer facilitates effective communication by providing a user-friendly way to visualize potential changes across coastal Louisiana with, and without, the master plan 50 years into the future. The Master Plan Data Access Portal was developed to enable online visualization and download access to many of the modeling data sets used to develop the 2023 Coastal Master Plan. Please see below for more information on each tool. The online data tools were developed by staff at the Pittsburgh Supercomputing Center under support of the NSF XSEDE program (grant # ACI-1548562).

7.1 MASTER PLAN DATA VIEWER (MPDV)

The MPDV was first introduced as a supplemental tool to the 2017 Coastal Master Plan. This tool makes results from the 2023 Coastal Master Plan analyses accessible online. The MPDV, which is an interactive companion to the plan, includes information on land change, vegetation type, flood depth, damage, and projects that helps viewers visualize what change might look like over time in their communities and across the coast.

Important updates to the Master Plan Data Viewer include:

- incorporation of the most up to date model outputs at a higher resolution
- improved user experience including a Guided Tour feature on the landing screen to provide context and to improve the usability of the information for coastal Louisiana residents
- increased accessibility with the viewer now easily accessed on mobile phones and tablets
- added search bar functionality that allows users to search for keywords, such as part of project name or their town
- additional features include:
    - new zoom and highlighting functions
    - map export function to facilitate easy printing
    - expanded data download capabilities via the Master Plan Data Access Portal

The MPDV is available online at mpdv.coastal.la.gov.

7.2 MASTER PLAN DATA ACCESS PORTAL (MP-DAP)

The MP-DAP is a new interactive data tool and central location for all of the modeling data sets used to develop the 2023 Coastal Master Plan. The MP-DAP builds off of the MPDV and further enhances data access and transparency. The portal is intended for those who already have a good grasp on the types of master plan data and their application allowing researchers, academics, and practitioners of all types to be able to dig deeper into the data and select a variety of variables for online visualization. These images are able to be exported, or users can download the data and create graphics to meet their specific needs.

Examples of currently available data include land change, vegetation type, flood depth, storm surge-related damages, salinity, and water level. The portal also includes documentation to explain metadata, links to reference documents, and model geometries. Further data sets and functionality are continually being added.

The MP-DAP is available online at mpdap.coastal.la.gov.

7.3 QAQC PORTAL

In addition to the publicly available MPDV and MP-DAP tools, there was also the development of an online Quality Assurance/Quality Control Portal that was used internally by the modeling teams. The QAQC procedures were followed for all model simulations completed during production of the 2023 Coastal Master Plan. The online portal provided plotting of timeseries data and visualization of annual maps of key model outputs. Available data were selected *a priori* by the modeling teams to be of use in assessing a model simulation's outputs to ensure that the simulation was error free and passed all quality checks. Model reviewers were able to add comments to any pre-prepared, or customized in real-time, data visualization. All model subroutines, for all simulations, had to be reviewed and approved by each modeling team member.

The online portal was designed by staff at the Pittsburgh Supercomputing Center under consultation with the ICM modeling teams so that the QAQC workflow was adequately incorporated.

8.0 REFERENCES

Baustian, M. M., Reed, D., Visser, J., Duke-Sylvester, S., Snedden, G., Wang, H., DeMarco, K., FosterMartinez, M., Sharp, L. A., McGinnis, T., & Jarrell, E. (2020). 2023 Coastal Master Plan: Attachment D2: ICM-Wetlands, Vegetation, and Soil Model Improvements. Version 2. (p. 90). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

Dalyander, S., Foster-Martinez, M., Di Leonardo, D., Georgiou, I. Y., Miner, M.D., & Fitzpatrick, C. E. (2021). 2023 Coastal Master Plan: Attachment C9: 2023 Barrier Island Model: ICM-BITI and ICM-BI. Version 3. (p. 64). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

DeMarco, K., Schoolmaster, D., Couvillion, B. R. (2023). 2023 Coastal Master Plan: Attachment D3: ICM-Wetlands – Submerged Aquatic Vegetation (SAV) Updates. Version 2. (pp. 1-58). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

Foster-Martinez, M., White, E., Jarrell, E., Reed, D., & Visser, J. (2023). 2023 Coastal Master Plan: Attachment C8: LAVegMod Module (ICM-LAVegMod) and Morph Module (ICM-Morph) Updates. Version 2. (p. 59). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

Georgiou, I., Foster-Martinez, M., Fitzpatrick, C., Jarrell, E., Bridgeman, J., Lee, D., Miner, M., Dalyander, S., & Dong, Z. (2020). 2023 Coastal Master Plan: Attachment D4: Barrier Island Model Improvements. Version 3. (p. 41). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

Lindquist, D.C., Sable, S.E., D'Acunto, L., Hijuelos, A.C., Johnson, E.I., Langlois, S.R.M., Michel, N.L., Nakashima, L., O'Connell, A.M., Percy, K., & Robinson, E.M. (2020). 2023 Coastal Master Plan: Attachment D5: Habitat Suitability Index Model Improvements. Version 3. (194 p.). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

Reed, D., & White, E. D. (2023). 2023 Coastal Master Plan: Appendix C: Use of Predictive Models in the 2023 Coastal Master Plan. Version 3. (p. 42). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

Sable, S.E., Lindquist, D.C., D'Acunto, L., Hijuelos, A.C., La Peyre, M.K., O'Connell, A.M., & Robinson, E.M. (2019). 2023 Coastal Master Plan: Supplemental Material D5.1: HSI Model Improvement Recommendations. Coastal Protection and Restoration Authority, Baton Rouge, Louisiana.