GUIDANCE ON MODELING METHODOLOGY

IN SUPPORT OF THE LOUISIANA WATERSHED INITIATIVE WATERSHED MODELS

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Prepared by the LWI Technical Design and Quality (TDQ) Team

Submitted to:

Office of Community Development (OCD)

and

Department of Transportation and Development (DOTD)

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LIST OF ACRONYMS

1-D: One-dimensional
2-D: Two-dimensional
ADCIRC: ADvanced CIRCulation model
AEP: Annual Exceedance Probability
ARI: Average Recurrence Intervals
BFE: Base Flood Elevation
BLE: Base Level Engineering analysis
CFL: Courant–Friedrichs–Lewy
CMP: (CPRA) Coastal Master Plan
CNMS: Coordinated Needs Management Strategy
CoNED: Coastal National Elevation Database
CPRA: Coastal Protection and Restoration Authority (of Louisiana)
CSI: Coastal Studies Institute
CRMS: (Louisiana) Coastwide Reference and Monitoring System
CWOP: Citizen Weather Observer Program
DDF: depth-duration-frequency
DHS: Department of Homeland Security
DOTD: Department of Transportation and Development
ET: Evapotranspiration
FEMA: Federal Emergency Management Agency
FIS: Flood Insurance Study
GIS: Geographical Information System
GOHSEP: Governor's Office of Homeland Security and Emergency Preparedness
HCFCD: Harris County Flood Control District
HEC: Hydrologic Engineering Center
HEC-DSS: Data Storage System
HEC-FIA: Flood Impact Analysis
HEC-HMS: Hydrologic Modeling System
HEC-LifeSim: Life Loss Estimation
HEC-MetVue: Meteorological Visualization Utility Engine
HEC-RAS: River Analysis System
HEC-SSP: Statistical Software Package
HEC-WAT: Watershed Analysis Tool
HMR-52: Hydrometeorological Report No. 52
HTab: Hydraulic Property Tables
HUC: Hydrologic Unit Code
HWM: High-water marks

ISO: International Organization for Standardization
IDF: intensity-duration-frequency
IHA: index of hydrologic alteration
JPM: Joint Probability Method
km: kilometer
LBLD: Lafourche Basin Levee District
LCA: Louisiana Coastal Area
LDEQ: Louisiana Department of Environmental Quality
LDWF: Louisiana Department of Wildlife and Fisheries
LiDAR: Light Detection and Ranging
LPA: Local Public Agency
LULC: Land-Use/Land-Cover
LWI: Louisiana Watershed Initiative
ModClark: Modified Clark Method
MRMS: Multi-Radar/Multi-Sensor
NCDC: National Climatic Data Center
NCEP: National Center of Environmental Prediction
NCF: National Channel Framework
NFF: National Flood Frequency
NFIP: National Flood Insurance Program
NLCD: National Land Cover Dataset
NOAA: National Oceanic and Atmospheric Administration
NRCS: Natural Resources Conservation Service
NSS: National Stream Statistics
NSSL: National Severe Storms Laboratory
NWS: National Weather Service
OCD: Office of Community Development
PFDS: Precipitation Frequency Data Server
QG: Training Quick Guide
QPE: Quantitative Precipitation Estimates
RESTORE: Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act (of 2012)
RMSE: Root Mean Squared Error
RTK: Real-time kinematic positioning
SMA: Soil Moisture Accounting
SSURGO: Soil Survey Geographic Database
STN: Short-Term Network
SWAN: Simulating WAves Nearshore model
TDQ: Technical Design and Quality Team

USACE: United States Army Corps of Engineers
USGS: United States Geological Survey
WBD: Watershed Boundary Dataset

DEFINITIONS

This section will be developed in future versions of the document.

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1 EXECUTIVE SUMMARY

This document provides general guidance on the modeling methodology and approach of the Louisiana Watershed Initiative (LWI). The guidance was developed by LWI as part of the activities of the Technical Design and Quality (TDQ) team. The primary goals of the guidelines are to: a) ensure consistency among the hydrologic and hydraulic models and outputs developed across the seven modeling regions; b) ensure the models are constructed and designed with the proper attributes to meet program objectives; and c) provide sufficient latitude to harness the innovation, skills, and experiences of the modeling consultants. This document is also intended to inform scope development and to set the expectation of the LWI modeling effort with respect to the desired features and level of quality control of the models. In addition to this modeling guidance, Task Orders issued by Department of Transportation and Development (DOTD) will provide more details and guidance to the Modeling Consultants on the scope and approach of the various activities.

The modeling consultants shall construct the hydrologic and hydraulic models in a manner that will ensure that the models meet the primary objectives of the LWI immediately and support, in the future, the value-added objectives of the LWI. The overall modeling strategy will be based on the Hydrologic Unit Code 8 (HUC8) watershed scale where hydrologic and hydraulic models will be developed making use of different resolutions as necessary. The modeling consultants should use hybrid one-dimensional (1-D) and two-dimensional (2-D) River Analysis System (HEC-RAS) models. The hydrologic calculations (rainfall/runoff transformation) will be performed using the Hydrologic Modeling System (HEC-HMS). The recommended modeling approach in this document emphasizes the importance of customizing the attributes of each HUC8 model to accommodate the substantial heterogeneity of this statewide modeling effort. It will accommodate regional and some local objectives, while maintaining, to the extent possible, computational efficiency.

Three state agencies, namely, Louisiana Department of Wildlife and Fisheries (LDWF), Louisiana Department of Environmental Quality (LDEQ) and Coastal Protection and Restoration Authority of Louisiana (CPRA) have keen interest in evaluating the impact of potential flood mitigation projects on low flows. To accommodate this need, the guidance outlines an approach to setup HMS models using a loss method that would support future continuous simulation approaches, which is a value-added objective. As part of the scope of modeling Task Orders issued by DOTD, the TDQ will provide guidance to the modeling consultants on the setup and calibration of the HMS models using this loss method.

The guidance also describes an overview on how the inland hydrologic and hydraulic models will be used in HUC8s falling within the transition zone.

The modeling approach will accommodate flood mitigation and watershed management alternatives and will have the needed resolution and specificity to support the analysis of future developments, drainage improvement projects, and evaluation of drainage ordinances at a regional scale. This modeling guidance will be updated periodically (as a living document) to reflect lessons learned through various LWI task orders and dialogue with the modeling consultants.

2 BACKGROUND ON MODELING OBJECTIVES AND EXPECTATIONS

In March and August of 2016, Louisiana experienced two historic rain events. The rising floodwaters reached more than 145,000 homes throughout the state, leaving behind an estimated $10 billion in damage resulting in recovery efforts that will take years to complete. These devastating events identified key opportunities to strengthen Louisiana's approach to floodplain management and risk-reduction planning at all levels of government. Louisiana is moving to address these weaknesses through the establishment of the LWI, wherein Governor John Bel Edwards charged several state agencies, including DOTD, CPRA, LDWF, the Governor's Office of Homeland Security and Emergency Management (GOHSEP), and the Office of Community Development (OCD), with coordinating their efforts to develop a new approach to reducing flood risk throughout Louisiana. A primary component of this unprecedented effort is the development of hydrologic and hydraulic models covering most watersheds in the state. These models will be used to support holistic watershed management approaches and strategies.

This modeling guidance was developed by LWI as part of the activities of the TDQ team. The TDQ is comprised of a core group of technical experts from the University of Louisiana at Lafayette, Tulane University, and the Water Institute of the Gulf. The TDQ team is also supported by representative members from some of the LWI state agencies such as CPRA, LDWF, and DEQ, as well as LWI federal partners including United States Army Corps of Engineers (USACE), Federal Emergency Management Agency (FEMA) Region 6, and the National Weather Service (NWS). The TDQ team also leverages existing experience from AECOM as part of the LWI program management team. Staff from DOTD and OCD were also instrumental in the development of LWI modeling guidance. Further, feedback from the modeling consultants was sought by DOTD and the TDQ throughout the development and revision of the modeling guidance.

The TDQ is providing this guidance document to support the overall framework for model design and implementation, including guidelines on hydrologic and hydraulic model setup, linkage, and calibration/validation processes. This guidance report is in accordance with the Advertisement for Engineering and Related Services issued on May 15, 2019, in regard to LWI Modeling Contracts, which states that "DOTD will provide a comprehensive document illustrating a modeling approach to support their development of a detailed scope of work." To ensure consistency among all hydrologic and hydraulic models produced through this program, the LWI modeling consultants shall use the guidelines and recommendations provided in this document to develop their detailed modeling design (i.e. resolutions, level of details, etc.) and a scope of services for each HUC8 task order.

2.1 PRIMARY AND ADDED-VALUE OBJECTIVES OF LWI MODELS

LWI hydrologic and hydraulic models are considered to be baseline models that will immediately deliver on LWI primary objectives (first column in Table 1) but are also expected to support future added-value objectives (second column in Table 1). Therefore, the LWI model design attributes (bottom half of Table 1) are tailored to the overall goal of achieving the primary objectives while supporting future added-value objectives.

Table 1. Primary and future added-value objectives of the LWI baseline hydrologic and hydraulic models. Tables 2 and 3 provide detail regarding the difference in Regional- and Local-scale objectives.

Primary Objectives of LWI Models	Future Added-Value Objectives of LWI Models
Flood mitigation feasibility studies No adverse impact assessments Consequence and risk assessment Management of future developments and community growth Support evaluation of proposed projects, watershed management strategies and policy development	Inform assessment of habitat suitability and impacts on water quality Inform assessment of ecological consequences (e.g., index of hydrologic alteration (IHAs) Support development and update of FEMA flood insurance rate maps Support future development of flood forecasting warning systems
Model Design Attributes to Meet Primary Objectives	Model Design Attributes to Meet Added-Value Objectives
Tiered resolution approach to accommodate various spatial scales while maintaining computational efficiency Sufficient topographic and bathymetric resolution to capture linkages among drainage channel networks and floodplains Inclusion of key hydraulic structures and road crossings Adequate calibration and validation of models to ensure accuracy and realistic representation of watersheds	Continuous-mode hydrologic setup to allow future ecological assessment and flood forecasting Calibration for multiple-peak events

2.2 MODELING GUIDELINES

While it is critical to recognize that individual watersheds have their specific characteristics, a consistent modeling strategy and approach must be deployed by all modeling consultants to ensure that LWI program goals can be met. It is important to note that all watershed modeling software products applied as part of the LWI (e.g., HEC-RAS for hydraulics and HEC-HMS for hydrology) are on FEMA's list of accepted numerical models.

The LWI minimum modeling guidelines are based on guidance and minimum standards employed in the development of FEMA hydrologic and hydraulic models. The DOTD and TDQ developed these minimum modeling guidelines, based on the primary and added-value objectives of the LWI models listed in Table 1. Given the hydrologic complexity of some watersheds in Louisiana, (e.g., lack of topographic relief; hydraulic connectivity across watershed divides), some of our recommendations regarding spatial resolution, general model setup, and model performance may exceed the standards of current FEMA hydrologic and hydraulic models.

3 RELATION TO FEMA MODELING STANDARDS

As noted in Table 1, an added-value objective of the LWI statewide modeling effort is to produce models that will facilitate future updates to flood insurance rate maps (FIRMs) if desired. Where feasible, existing FEMA studies should be used as a starting point for the work undertaken in this effort. These studies include base level engineering products (BLE), and hydraulic and hydrologic models associated with the effective flood insurance studies (FISs) in the LWI regions (Savage & Howe, 2017; FEMA, Guidance Document 99: Base Level Engineering (BLE) Analyses and Mapping, 2018). Models approved by local communities and other stakeholders (e.g., USACE) should also inform modeling efforts in each region.

> THE GUIDANCE DOES…
> - Define goals and objectives of LWI models
> - Describe overall modeling approach to meet objectives
> - Cite relevant standards from FEMA, USACE, etc.
>
> AND DOES *NOT*…
> - Provide procedural instructions for model implementation
> - Replace the expertise and judgement of experienced modelers
> - Define regulatory or statutory modeling standards

The consultants are also expected to employ typical quality control measures used in the development of hydrologic and hydraulic models (FEMA, 2016):

- All channel bathymetry surveys, cross-sections along with the data collection methodology shall be documented and reviewed by licensed engineers;
- Reach lengths must be determined and adjusted based on floodplain characteristics;
- Roughness coefficients can be obtained from land-use/land-cover (LULC) and field data. Channel roughness can be estimated and should be calibrated where possible; and
- All hydraulic structure data must be obtained from field survey, as-builts, or engineering design or permit plans (FEMA, 2003).

Additional details (e.g., HEC-RAS modeling study limits, topographic resolution, scope of the survey effort) will be determined in the task orders.

Disclaimer: the LWI models and the guidance provided herein do not represent regulatory products or standards nor do they modify or supersede any official regulations, models, ordinances, or flood hazard boundaries currently in force under the National Flood Insurance Program (NFIP) or state and local flood damage prevention ordinances in respective jurisdictions.

3.1 NAMING CONVENTION AND OTHER STANDARDS FOR MODEL COMPONENTS

In addition to FEMA standards, other standards adopted by collaborating agencies such as Harris County Flood Control District (HCFCD, 2009) can be helpful for LWI statewide modeling efforts. These standards include establishing requirements to ensure uniform and consistent watershed domains across regions (HUC8 for the LWI). The standards also include: naming conventions for hydrologic and hydraulic model components (e.g. streams, reaches, and sub-watersheds); producing detailed documentation for all model parameters and providing an explanation for modeling approaches (e.g., using 2-D instead of 1-D models). Model component naming conventions are detailed in Appendix A.

This section will be updated in future versions of the document.

4 DELIVERABLES, DOCUMENTATION AND METADATA

Model documentation shall include specifications of model components (e.g., naming convention, horizontal projection, vertical datum and geoid, unit system for all variables, and data sources and their web locations). As a quality assurance step, each modeling consultant shall develop a logbook to document the key decisions made throughout the model development and calibration tasks (The specific details on the format of the logbooks will be addressed in the task orders). Deliverables must include these sets of documentation along with the models, model inputs and calibration datasets (e.g., high-water mark (HWM), LULC, field surveys), the data collected from the analysis of existing data process (e.g., historical records and where were they obtained from), and a Training Quick Guide (QG) for the model and its outputs as per the scope of work defined in the relevant task order. The specific deliverables will be specified in each Task Order.

Documentation, model data and metadata to be delivered by consultants must include the following:

- Description of comprehensive end-to-end processes for delivery of compiled and processed data and metadata to the LWI program for the data collected in this task order.
- Detail the compilation, quality control, metadata cataloging (using International Organization for Standardization, ISO, format), validation, reprocessing, storage, retrieval, and dissemination of data to the LWI program.
- Digital, machine-readable data shall be stored by the Consultant and delivered to the LWI program in a timely manner. Analog/non-machine-readable data shall be digitized and delivered.
- Both raw and processed (including any databases, Geographical Information System (GIS) or otherwise, that are developed) must be stored by the Consultant and delivered to the LWI program in a timely manner.

The consultants shall use North American Vertical Datum 1988 (NAVD 88) GEOID12B and State Plane Coordinates (horizontal) for all elevation deliverables, unless otherwise directed by DOTD.

This section will be updated to include more details about the required documentation and metadata in future versions of the document.

5 PART I: INLAND WATERSHEDS

5.1 MODEL STRUCTURE, HIERARCHY AND SCALING

5.1.1 Overall Modeling Approach and Structure

All LWI hydrologic and hydraulic models will be developed for specific HUC8 watersheds. The model domains will be decomposed using a tiered approach making use of different resolutions as necessary (e.g., 1-D, 2-D and hybrid 1-D/2-D) depending on key hydrologic and hydraulic drivers. Consideration of watershed-specific hydrologic and hydraulic drivers (e.g., major levees, diversion structures, urban development, tailwater influence, storage areas, and reservoir operations) will help to develop the models that are consistent with local hydrology.

At the time of writing this document, we recommend using HEC-RAS v6.0.0. The modeling consultants should use hybrid 1-D and 2-D HEC-RAS models where the hydrology calculations (rainfall/runoff transformation) are performed using HEC-HMS. The details of how consultants should use 1-D and 2-D components of HEC-RAS are described below. Further, the modeling consultants should perform hydrologic calculations using HEC-HMS and produce runoff hydrographs that will be fed into HEC-RAS as: a) point source locations at the upstream terminus of 1-D channels; b) distributed lateral flow along the length of channel segments; and/or c) distributed hydrograph to select cells in 2-D HEC-RAS areas. The exact connectivity between the HMS and RAS is site-specific and shall be discussed and reviewed carefully among modeling consultants, DOTD, and the TDQ. The modeling approach will be fine-tuned and revised to capture and reflect lessons learned from the various task orders and through dialogue with among modeling consultants, DOTD, and the TDQ.

5.1.2 Tiered-Resolution Approach

Given the substantial spatial extent of this statewide modeling effort, a tiered resolution approach is needed to capture hydrologic and hydraulic complexity, allow for effective evaluation of proposed projects, while maintaining computational efficiency (Figure 1, Tables 1 and 2). The overall modeling strategy will be based on the HUC8 watershed scale. The modeling consultant should develop a strategic design of hydraulic model resolution (e.g., 1-D, 2-D, hybrid 1-D/2-D) to meet basic performance standards and project evaluation requirements at different temporal and spatial scales. Specifically, this approach will accommodate regional-scale flood mitigation and watershed management alternatives. It will also have the needed resolution and specificity to support the analysis of cumulative impacts from development, drainage improvement projects, and evaluation of drainage ordinances at a regional scale. The details of the consultants' proposed approaches will be worked out and coordinated in the individual task orders.

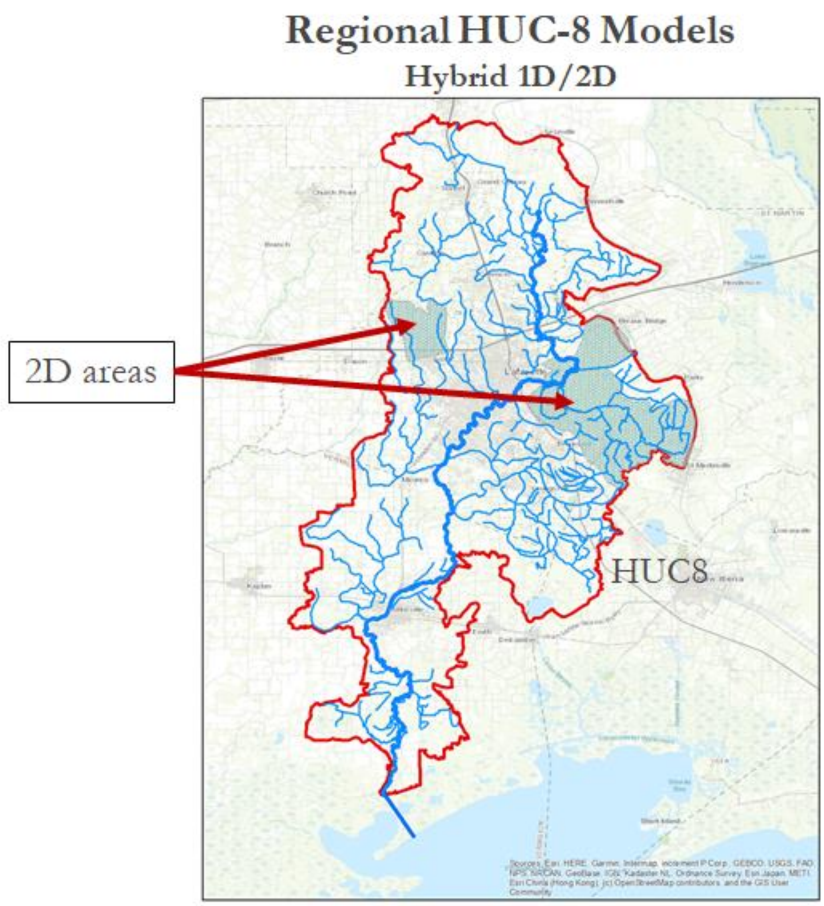

Figure 1. Illustration of modeling approach for the regional HUC8 scale models.

To this end, a hydrologic and hydraulic model suite for a given watershed will consist of a hydrologic model (HEC-HMS) and a hydraulic model (HEC-RAS 1-D and 2-D) and will consider time variability (unsteady modeling).

The modeling consultants shall perform analyses to determine the grid resolution and details of the 2-D areas, as well as the inclusion and resolution of channels included in the 1-D approach. Due to the nature of the landscape in Louisiana (e.g. flat topography, especially in southern Louisiana), the modeling Consultants should consider, unsteady modeling approach (1-D or 2-D) to capture the effects of storage areas and vast floodplains since it more accurately describes the hydraulics of these features compared to steady models. Further, 2-D models are particularly applicable in the following situations (FEMA, 2016):

- Wide and flat floodplains;
- Shallow-depth flooding;
- Areas behind levees;
- Bays and estuaries;
- Braided streams; and

- Inactive alluvial fans.

The modeling consultant should keep in mind the usability and computational efficiency of the HUC8 models to allow the ability to simulate numerous scenarios and applications while maintaining accuracy in the computed water surface elevations and flows. General attributes of these regional HUC8 models include (additional details including model break-out plan to be developed in the task orders):

- Varying level of details 1-D for representation of rivers and major/minor tributaries. The consultant should determine these details for the HUC8 watersheds in their respective regions.
- Varying level of resolutions and details for the 2-D areas to capture the hydrologic and hydraulic complexity (e.g., to represent large floodplain areas, natural storage areas, detention ponds, transition zones, large shallow surface/pluvial flooding, etc.). The consultant should determine the appropriate resolutions while keeping in mind the computational efficiency of these regional HUC8 models to ensure usability and efficiency.

These HUC8 models are to be used for evaluating regional-scale projects such as:

- Major Channel improvements (e.g. widening, reshaping, or dredging)
- Large scale regional detention projects
- Impact of future large-scale developments and substantial land use changes
- Road crossing upgrades (bridges, culverts, etc.)
- The HUC8 models can also be used, by the LWI program or by local entities in the future, as the foundation for developing local detailed models to serve the local needs; e.g., in providing tailwater boundary conditions (Table 2). If a particular project spans across two or more HUC8 watersheds, the respective models for these HUC8 watersheds could be combined for project evaluations.

Table 2. Summary of regional HUC8 modeling features and applications

HUC8 Model Structure and Features	Applications/Projects
Hybrid 1-D/2-D 1-D representation (with varying degree of detail) of rivers and major/minor tributaries, extending into HUC12's Strategic 2-D areas as needed (e.g., large floodplains, natural storage/detention areas, transition zones) Can incorporate existing sub-models from FEMA and USACE Incorporates dynamic operations of water control structures	Major channel improvements (e.g. widening, reshaping, or dredging) Large-scale regional detention projects Cumulative impacts of improvements in major tributaries on downstream flooding Effect of major impoundments on downstream flooding Impact of future large-scale developments and substantial land use changes

Unsteady models handle complex reverse flows Usability and efficient run time (e.g., run time should be in the order of hours and not days)	Upgrades to major control structures and road crossings (bridges, culverts, etc.) Flood extent analysis

In a future phase of the LWI modeling initiative, local models may be developed at smaller spatial extents such as HUC12 watersheds. The need for these local models will be driven by the needs of local users/communities (while coordinating with regional analysis to ensure consistency). These local models will be high-resolution hybrid 1-D and 2-D models. Local models could be purely 2-D; but certain features need to be available for that to be possible; e.g. ability to represent culverts, bridges and other road-crossing types, ability to incorporate hydrologic processes (rain, hydrologic losses, etc.). Overall, these models could be developed separately or broken-out of HUC8 models. The local models will be forced by observations when available or by boundary conditions from the larger HUC8 models. General attributes of local models include:

- If Hybrid 1-D/2-D is used, then:
    - Detailed 1-D representation of streams and tributaries
    - Refined/detailed 2-D representation of detention ponds, and floodplain areas
- If full 2-D is used, then:
    - Variable mesh resolution to capture channels geometry and areas with complex inundation boundaries
    - Strategic coarsening in areas with lower or no population density or without records of flooding – (this strategy is needed to reduce the overall computational burden and speed up model run time)
- These detailed HEC 1-D/2-D models (Table 3) can be used to evaluate local projects such as:
    - Flood inundation mapping
    - Local drainage improvement projects
    - Impacts of local developments (either through direct use or by providing boundary conditions for even more localized models covering smaller spatial extents)

Table 3. Summary of local modeling features and applications

Local Model Structure and Features	Local Model Application
Full 2-D or Hybrid 1-D/2-D Full 2-D: Variable mesh resolution to capture channels geometry and regions with complex inundation	Flood inundation mapping Local drainage improvement projects Impacts of local developments

Strategic coarsening in areas with lower or no population density or without records of flooding This strategy is needed to reduce the overall computational burden and speed up the run time Hybrid 1-D/2-D: Detailed 1-D representation of streams and tributaries Refined/detailed 2-D representation of detention ponds, and floodplain areas Usability and computational efficiency (e.g., run time should be in the order of hours and not days)	

5.1.3 Watershed (Hydrologic) Representation

Watershed representation refers to the resolution of subbasins within the overall HUC8 study area. When designing the size of subbasins, consultants should consider factors such as runoff volume production, population density, and historic/repetitive flood damage. For those watersheds that include flood transition zones, influenced by both rainfall and coastal processes, subbasin sizes should be defined taking flood transition zone guidance into consideration (see Section 6 of this document for further information). Additional guidance is summarized below (Table 4).

Table 4. Recommendations on key aspects of watershed representation.

Component	Recommendation
Minimum subbasin resolution	Separate subbasins should be delineated for each channel reach included in the hydraulic model. Where feasible, apply a maximum of 1 square mile for subbasin delineations.
Additional factors in subbasin resolution	Account for natural and man-made ridge features (e.g. elevated roadways or railroads), spatial LULC patterns, and the overall target resolution (1-D or 2-D) of the hydraulic models
Compatibility with hydraulic models	Special care should be taken when implementing flows at internal boundaries such as bridges and culverts or junctions
Field visits and coordination with local drainage experts	Review previous local studies and locally accepted subbasin delineations, major landscape alterations since the preparation of the digital elevation model and survey data

5.2 ANALYSIS OF EXISTING WATERSHED DATASETS AND STUDIES

The statewide modeling effort will build upon existing work, where applicable, by incorporating valid models and data sources. Such existing models may include efforts conducted by local and federal entities (e.g., watershed master plans, FEMA FIS and BLE data). Previous studies and data sources shall be documented by the modeling consultant indicating the source, year of production, original application scope, and justification for use. The relevant elevation datum should also be documented for each dataset showing elevations. The modeling consultants shall conduct a data quality assessment of all relevant data to determine relevance and accuracy. This evaluation shall also account for changes since the time the data and studies were originally published. A summary of typical data sources is provided in Table 5 below.

Table 5. Summary of examples and types of data to be collected and analyzed for LWI hydrologic and hydraulic models.

Data Types	Examples
Existing Models	FEMA effective hydraulic models and BLE models; locally developed hydraulic models
Previous Watershed Studies	FIS, watershed master plans, regional drainage assessments
Digital Elevation Models (DEMs)	Coastal National Elevation Database (CoNED) Applications Project
Channel Surveys	USACE National Channel Framework (NCF) program, existing surveys from local projects
Precipitation Data	National Oceanic and Atmospheric Administration's (NOAA) NWS Stage IV radar product; NWS and local rain gauges; NOAA's National Severe Storms Laboratory (NSSL) Multi-Radar/Multi-Sensor (MRMS) radar product
Land Use and Soils	National Land Cover Dataset (NLCD); Natural Resources Conservation service (NRCS) digital soil survey data Soil Survey Geographic Database (SSURGO)
Hydraulic Structures	As-builts, previously conducted surveys, design plans, permit drawings, measurement-based sketch
Streamflow and Stage	United States geological Survey (USGS) streamflow database, USACE river gages database, NOAA tides and currents, Coastwide Reference Monitoring Program (CRMS), locally collected and validated water level data
Historical High-Water Marks (HWMs)	High-water mark databases collected by local, state, and federal agencies; Short-Term Network (STN) monitoring website
Historical Streamflow Flood Frequency Analysis	Guidelines for Determining Flood Flow Frequency – Bulletin #17C with Pearson Type III distribution with log transformation (Log-

Data Types	Examples
	Pearson Type III) (USGS, 2019); Statistical Software Package (HEC-SSP) and PeakFQ analysis; other sources which factor in trends due to urbanization and regulation may be considered (Kilgore Consulting & Management, 2016).
Historical Flood Information	USGS post event database flood inundation layers; FEMA claims data, other locally sourced information
Elevation Datum	NAVD 88 Geoid 12B

5.2.1 Summary of Existing Gauge Data in Louisiana

Precipitation over Louisiana is monitored by a sparse network of rain gauges as well as four NWS Doppler Radars. The rain gauges, which are operated by agencies like USGS, NOAA, and the NWS, have varying data collection frequencies, e.g. daily, hourly, and 15 minutes. Hourly precipitation data is often required to calibrate hydrologic models for flood events. Most of the rain gauges in Louisiana provide daily rainfall accumulations with fewer rain gauges reporting hourly and sub-hourly rainfall accumulations.

Other rain gauge data can be obtained from networks such as Citizen Weather Observer Program (CWOP) network, nevertheless, data obtained from such networks will require extensive quality control measures. Regarding the use of other sources, there are no restrictions as long as modeling consultants can establish confidence in these rain gauge stations (e.g., quality of network, comparison with neighboring gauge, comparison with radar). The consultants should generally avoid networks that are not quality-controlled.

Radar rainfall products with high temporal resolution and low data latency are based on the timely conversion of reflectivity retrievals to rainfall intensities. NWS radars have a typical coverage of about 126 miles (203 kilometers; km), nevertheless the quality of radar retrievals deteriorate considerably outside the 9- mile (150 km) range. The most commonly used radar rainfall dataset is the Stage IV product (Eldardiry et al., 2015; Habib et al., 2009), which is produced by the National Center of Environmental Prediction (NCEP) based on merging regional products from the regional NWS River Forecasting Centers. The resolution of the Stage IV is ~1.54x1.54 mi^2 (4x4 km^2) spatially and 1-hour temporally. Another recent radar rainfall product is the NOAA’s NSSL MRMS (Sharif et al., 2020). MRMS has a spatial resolution of 0.386x0.386x mi^2 (1x1 km^2) and hourly temporal resolution. The Stage IV product has a longer historical data record than MRMS.

Streamflow and stage data are typically available from the USGS and can be used for model setup, calibration, and validation. These data can also be used for flood frequency analysis if needed. Figures 2 and 3 show the existing USGS gauges that report stage observations only, and those that report stage and rated flow estimates, respectively. It is noted that these figures only show active gauges; however, data from discontinued gauges should be collected and processed by modeling consultants as needed. These records are primarily relevant when they span a considerable number of years and if there haven't been major changes in the stream morphology and other hydrologic conditions (e.g., LULC) since their discontinuation date. Additional details (e.g., minimum years for a gauge to be considered valid) will be determined in the task orders.

Through a parallel effort, the LWI is developing a comprehensive river and rain gauge monitoring network to gather water level (stage – i.e., water surface elevation), precipitation, and water discharge data. The purpose of this statewide network is to augment the existing monitoring stations and ensure availability of data needed for model calibration and long-term model updates. The design of the network will be done in close coordination with LWI stakeholders. The modeling consultants are expected to identify specific locations where additional monitoring stations could be added to address modeling needs and data gaps in their respective watersheds.

Figure 2. Distribution of the existing USGS flow gauges in Louisiana.

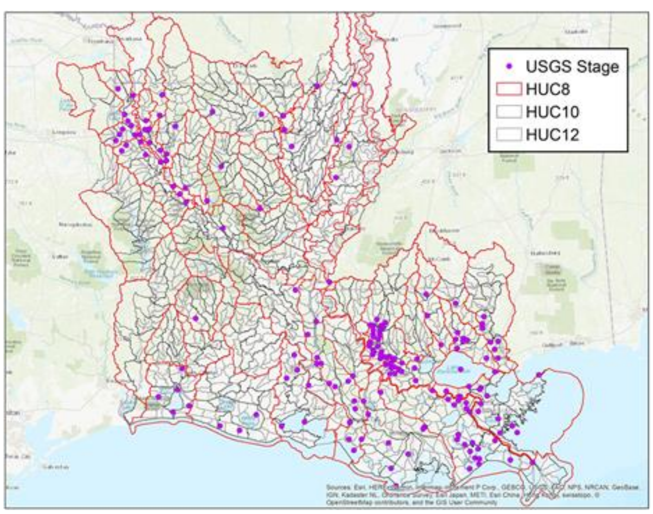

Figure 3. Distribution of the existing USGS stage only gauges in Louisiana.

Flood frequency analysis using streamflow data shall be undertaken to estimate peak flows for different Annual Exceedance Probabilities (AEPs). Flood frequency analysis is also useful for checking and validating the model results, mainly in simulating design storms. Peak-flow estimates from flood frequency analyses will also help the modeling consultants to iteratively select the spatial configuration of design storms (location and coverage) in such a way that the modeled peak flows match those from the flood frequency analysis. Special care must be exercised when selecting a gauge site and using its data for flood frequency analysis (e.g., gauges with less than 10 years of data are not recommended for flood frequency analysis). Also, flood frequency analysis may not be reliable in watersheds that have undergone significant changes over the gauging record (e.g., urbanization, detention and infrastructure development).

We also recommend that consultants obtain local flood information including flooded homes and businesses, road closures, repetitive loss structures, and other pertinent data that could help both in the development of models and in mitigation strategies. Additional information should include coordination with local stakeholders to obtain water control plans and pump management schemes, past operation records of control structures, and stage-storage information for lakes and other impoundments.

5.3 TOPOGRAPHIC AND BATHYMETRIC SURVEYS

New datasets may be required to supplement model development and calibration. Topographic and bathymetric survey information is one of the most critical components in the development of high-quality numerical models for hydrologic and hydraulic evaluations (Table 6). The modeling consultants shall determine the need and conduct topographic and bathymetric surveys as necessary to support model development.

A survey plan should be developed and reviewed during consultant meetings coordinated by DOTD and TDQ. The survey plan must articulate the proposed level of effort including a layout of the cross-sections and structures to be surveyed and the surveying techniques employed (e.g., real-time kinematic positioning (RTK), conventional, single and/or multi-beam survey, autonomous instruments, etc.). The survey plan should also indicate the anticipated level of vertical and horizontal accuracy, benchmark control points, and a plan for securing access to the survey locations. Care should be taken to consider subsidence issues with vertical datum and benchmark control points. In all cases the survey data collection and digital elevation models shall meet or exceed established minimum acceptable standards for the preparation of detailed FEMA flood hazard maps (FEMA, 2003) and land surveys. We also refer the consultants to the FEMA data capture reference for additional guidance (FEMA, 2019).

Table 6. Minimum survey requirements for LWI models.

Survey Type	Minimum Requirements
Channel Cross-Section	Shots at slope breaks including the channel invert, centerline, low-flow toe and bank, and main channel bank while also picking up the overall shape, geo-photos

Survey Type	Minimum Requirements
Culvert	Bounding channel cross sections, road top lengthwise profile, inverts and mudline elevations, shape, size, material, condition, headwall type, completion year (on state highways) geo-photos
Bridge	Similar to culvert but including pier spacing, shape, size, and skew; guardrail height, length, and type – open/solid, top and low chord elevations, completion year (on state highways), geo-photos
Control Gate	Opening size, inverts, type (underflow, sluice, screw gate, variable crest weir, combination structure, etc.); management plan including average gate opening and closing rates for floodgates, geo-photos
Pump	Pump capacity and system curves, intake/outlet invert elevation, "highest elevation" in the pump line, published control schemes control points and targets and time-series records of pump operations, geo-photos
Dams and weirs	Top elevation profile, drawdown structure details, spillway details, operations records; dates placed in service
Levees	Top elevation profile, cross sections at select locations; NOTE: use published levee survey data where available (e.g., USACE)

5.3.1 Data Collection Requirements

Modeling consultants shall perform all topographic and bathymetric surveys using feature codes in accordance with DOTD Location and Survey Division's current version of the Survey Feature Code Guide Book (Hodges, 2011). The consultants shall use North American Vertical Datum 1988 (NAVD 88) GEOID12B and State Plane Coordinates (horizontal) when performing topographic and bathymetric surveys, unless otherwise directed by DOTD. It is recommended that the modeling consultants use a networked-based Global Positioning System (GPS), such as LSU's C4G GPS/GNSS Real-Time Network and/or Leica Geosystems Smartnet, for survey control. Both of these GPS networks are interchangeable using GEOID12B. GPS receivers receive the Ellipsoid height and perform all conversions automatically within the data collector. As such, DOTD recommends that the modeling consultant survey crews remove all other Geoids from their data collectors to prevent use of an incorrect Geoid.

Detailed field notes and geo-referenced photos should also accompany the raw survey cross-section points. The field notes should explain the use of survey codes to facilitate incorporation of the survey data into the hydraulic model. The surveyors should use DOTD survey feature codes for professional topographic surveys. Additional requirements may be added in the individual task orders based on conditions specific to individual watersheds.

5.4 HYDROLOGIC MODELING SETUP

5.4.1 Overall Hydrologic Model Approach

HEC-HMS shall be used as the basis of the rainfall-runoff hydrologic analysis. HEC-HMS allows for two loss simulation approaches: an event-based loss mode and a continuous loss mode. This distinction applies primarily to models of rainfall-runoff processes. An event model simulates a single storm with a duration of a few hours to a few days. A typical use of this mode is simulation of design storms. On the other hand, a continuous loss approach enables long-term simulations (weeks, months, and seasons) to predict watershed response both during and between rainfall events. The continuous loss approach alleviates the need for setting initial conditions and provides a more realistic simulation of flow conditions between events. Continuous loss methods allow for distributed parametric representation of the watershed and can also be used if event-based simulations (e.g., design storms) are desired.

The HUC8 regional extent requires a hydrologic modeling approach that accommodates non-uniform rainfall patterns and flow regulation effects. These factors (e.g. slow receding floodwaters, successive storms, flow regulation) play a significant role in the flood response (e.g., peak water surface elevations) over the HUC8 scale. For practicality and model efficiency purposes, the modeling teams should use the simple loss method, known as “Deficit and Constant Loss”, which provides the advantages of continuous loss simulation, while maintaining a reasonable level of data and calibration requirements. The method has four parameters, namely: initial deficit, maximum deficit, and constant loss (percolation) rate, and percent (%) of directly-connected imperviousness cover (% impervious). Two of these parameters (maximum deficit, constant loss rate) can be estimated from surficial soil texture available from the SSURGO soil GIS database.

A canopy method is required for continuous hydrologic simulations and the choice of an appropriate method (i.e., dynamic vs. simple) will depend on the modeling calibration requirements and data availability in a given region. The canopy characteristics can be inferred from current land use datasets and a consideration of site-specific conditions (e.g., impervious cover, woody wetlands) occurring within a given study region. Moreover, the input parameters for the deficit and constant loss rate method can be derived from the same datasets as are the event-based hydrologic parameters. When calibrating the hydrologic and hydraulic models, the modeling consultants should keep in mind that some areas could have experienced dramatic LULC changes over the past years. This means that the choice of the LULC dataset corresponding to historic storms used in calibrating the models should be done carefully. Similar to other key model setup and calibration decisions the selection of the LULC datasets should be articulated in the modeler’s logbook.

In the Deficit and Constant Loss method moisture is extracted from the soil at the rate of evapotranspiration (ET). Therefore, the meteorological model in HMS should be configured for both precipitation and ET. Two approaches to ET are available: values of potential ET to be provided directly by the user (e.g., monthly average values or time series data provided by the LSU AgCenter), or potential ET to be calculated by HEC-HMS using the Priestly-Taylor or Penman Monteith methods (gridded or point-based depending on the watershed representation) based on user inputted net radiation and temperature data. The modeling consultants should justify their decision on which ET method they choose to use (documentation both in the modelers' log and technical report submittals in addition to discussions during the monthly meetings).

The loss model parameters should be adjusted by calibration against observed hydrograph data. For a good example of setting up and calibrating the coefficients of the Deficit and Constant Loss method, modeling consultants are encouraged to review the USACE Columbia River technical report (USACE, Mainstem Columbia River HEC-HMS Model Development Report, 2019) especially Table 4-10. Gridded-based loss parameter approaches should be selected since they generally provide better resolution of the hydrologic processes associated with dynamic flood events compared to lumped parameter approaches. A summary of the guidance is provided in Table 7. Regardless of the methods pursued, a modeler's logbook should be developed and maintained to document the key decisions made throughout the model development and calibration tasks. This is a critical aspect of quality assurance of the LWI models.

The Deficit and Constant Loss method can be combined with baseflow to improve model calibration results, primarily to calibrate HMS runoff volume were applicable, or to support future application of added-value objectives and related applications. For model calibration purposes, baseflow can be simulated using the Linear Reservoir method. It is recommended that incorporation of baseflow be treated as a secondary calibration parameter with preference given to Deficit and Constant Loss parameters. Incorporation of baseflow for calibration should, in general, be limited to locations where flow hydrograph data is available and then only applied when hydrologic and meteorological conditions support its use. Such conditions can include antecedent storms and seasonal or soil conditions where groundwater exchanges with surface flow.

Table 7. Requirements and recommendations for hydrologic model setup and quality control.

Component	Required	Recommendations
Hydrologic modeling system	HEC-HMS	Use version 4.7.1.
Loss method	Gridded Deficit and constant	Requires soil and land use/cover data; time-varying ET; crop cover coefficients – derivable from land use data and FAO Irrigation and drainage paper 56 (Allen et al., 1998). When using the Priestly-Taylor method, use of observed data (pan or lysimeter-based) should be used to ensure no significant over or under-estimation of the ET. Review the Columbia River Technical Report (USACE, Mainstem Columbia River HEC-HMS Model Development Report, 2019)

Component	Required	Recommendations
Initial Conditions	Model should be run for a “spin-up” period to reduce uncertainty/error due to initial conditions when modeling events.	Uncertainty in specifying initial conditions is a commonly acknowledged challenge in hydrologic simulations.
Rainfall-Runoff Transformation	Modified Clark (ModClark)	Grid spacing to be determined by consultants based on watershed conditions; time of concentration can be obtained using the TR-55 manual (USDA, 1986), for example.
Channel Routing	Modified Puls	Routing can help calibrate HMS while RAS is being setup; use of other methods (e.g., Muskingum Cunge) can be proposed in response to specific task orders with justification.
Storage and diversions	Storage areas and diversions with dynamic operations during floods should be modeled in HEC-RAS where possible; HMS may be used to handle simple storage and diversion scenarios with sufficient justification.	RAS is better suited to handle these features in general compared to HMS; however, RAS may be limited if the regulation policy is complex.
Baseflow	Linear Reservoir	Baseflow can help calibrate HMS runoff volume were applicable.
Quality control/documentation (to be specified in the task orders)	Maintain a modeler’s log for the duration of the modeling effort to document key decisions, approximations, logic behind simplifications, and unexpected challenges encountered throughout the effort.	Emphasis should be on content– i.e., capturing key information in a clear way - over formatting and style. The modeler’s log can also facilitate QA/QC reviews and help inform future modeling upgrades.

5.5 HYDRAULIC MODELING SETUP

5.5.1 Hydraulic Model Methods

The hydraulic models will be developed in the 6.0.0 version of HEC-RAS to ensure consistency with LWI program objectives. A summary of requirements and recommendations for hydraulic model setup and quality control are provided in Table 8. HEC-RAS has the capability to model 1-D and 2-D unsteady hydraulics at various scales. The HEC-RAS model uses the St. Venant shallow water model for 1-D hydrodynamics and provides an option for dynamic or diffusion wave approximations for 2-D hydrodynamic simulations. Modeling consultants should perform sensitivity tests to inform the selection of the dynamic wave approximations in the 2-D modeling framework. Relevant considerations in the selection of the 2-D approximation method include physical accuracy, numerical stability, execution time, and future applications. In general, the faster method which strikes the balance between accuracy and stability should be used. The latest HEC-RAS reference manuals provide a detailed description of the various dynamic wave approximations and the numerical solution procedures employed in the RAS modeling package (USACE, Hydrologic Engineering Center Documentation, 2020). Regardless of the methods pursued, a modeler's logbook should be developed and maintained to document the key decisions made throughout the model development and calibration tasks.

For those watersheds that include flood transition zones, modeling consultants should follow the additional guidance provided in Section 6 of this document.

Table 8. Requirements and recommendations for hydraulic model setup and quality control.

Component	Required	Recommendations
Hydraulic modeling approach	HEC-RAS 1-D and 2-D	Use Version 6.0.0
Model setup	Standard data assembly and input for hydraulic model development	A modeler's log should be developed for documentation of the model setup and decision-making; the choice of how wide to extend the cross sections should be determined by the consultants based on the conditions in their watershed.
Physically-based model coefficients	Use of site-specific information (e.g., field notes, photographs, as-built or design plans) – values should fall within the range of published values.	Examples: flow resistance, pier drag, expansion and contraction losses, and head loss or structure discharge factors; flow-varying Manning's *n* values may be considered in certain regions.
Computational stability factors	Selection should be based on standard stability requirements (e.g., Courant–Friedrichs–Lewy (CFL)	Examples: computational point spacing, 1-D to 2-D linkage scheme, mixed flow

Component	Required	Recommendations
	condition, boundary compatibility, smooth transitions in channel properties and invert slope, oscillation control, artificial flows being kept to a minimum)	regime, coefficients related to hydraulic structure stability, and adaptive timesteps.
Topobathy morphometry (light detection and ranging (LiDAR) topography and underwater channel survey bathymetry and 2-D terrains)	Removal of false water surfaces and merging bathymetry or survey contours (e.g., lakes and bays) with LiDAR information or enforcement of hydraulic consistency (e.g., stream networks “burning” procedures). In some cases, manual addition of narrow ridge features may be required (e.g., roadways, levees, floodwalls). Identification of other major obstructions (e.g., from new developments or based on field visits) beyond standard LiDAR DEM	A single vertical datum must be employed for all elements of the grid. Subsidence should also be pointed out and discussed in meetings with TDQ and DOTD if deemed significant in the region.
Hydraulic structures	Incorporate all known hydraulic structures occurring throughout the detailed study area. Where feasible, field visit notes and photographs should be linked to the hydraulic structures in the model to ensure accurate coding of the structures and to assist in the model calibration and quality control efforts. The operations scheme and past known operation records of all active structures should be obtained and	Hydraulic structures will be surveyed, approved as-built, or based on field measurements (e.g., photos/measured dimensions) where a full topographic survey is not possible/warranted - for all structures included in the model. The decision to exclude certain hydraulic structures from the analysis or to obtain approximate field measurements will be based on discussions with DOTD/TDQ and addressed in task orders. For active water control structures, the modeling consultants should seek to obtain information on gate opening and closing speed and other site-specific operations parameters (including ad-hoc

Component	Required	Recommendations
	incorporated into the hydraulic model.	deviation from published operations schemes) from local drainage authorities.
Levees and dams	Locate and identify all known levees and dams deemed significant in the modeling effort in respective regions. Incorporate information from the national levee database as a starting point. Certified levees should be identified as such if this information is available. May also include non-levee features such as raised roads, railroads, and berms, etc.	The decision on whether to conduct a natural valley analysis on uncertified levees or to evaluate overtopping of dams will be case-specific and require further discussion with DOTD/TDQ.
Boundary conditions	Standard linkage procedures with HEC-HMS via DSS	Mass balance evaluations should be conducted to ensure proper linkage and numerical stability.
Quality control/documentation (to be specified in the task orders)	Maintain a modeler's log for the duration of the modeling effort to document key decisions, approximations, logic behind simplifications, and unexpected challenges encountered throughout the effort.	Emphasis should be on content– i.e., capturing key information in a clear way - over formatting and style. The modeler's log can also facilitate QA/QC reviews and help inform future modeling upgrades.

5.6 METEOROLOGICAL FORCING

A summary of guidance on using both historical and design storms in driving the LWI models is shown in Table 9.

5.6.1 Historical Storms for Model Setup and Calibration

Models shall be setup and calibrated using a number of recent and historical rainfall events that represent various climatological and hydrological conditions of the watershed, such as:

- Different seasons to capture natural variability in storm types, atmospheric, and antecedent soil moisture conditions (e.g., convective and frontal systems)
- Different flood conditions to calibrate roughness of various parts of the floodplain (e.g., channel discharge, bank-full discharge, overbanks)

- Extreme events such as the 2016 March and August floods.
- Recent events that better reflect the current watershed physical conditions.
- Short-term events (e.g., a few hours to 1-2 days) as well as multi-storm periods that may span a few weeks.

The modeling teams shall perform an analysis of past storms and document how they meet these criteria and submit their recommendations on the selected storms for review and approval by DOTD and TDQ.

SOURCES OF RAINFALL DATA FOR HISTORICAL STORMS

Models should use rainfall data available from radar-based products produced by the NOAA, primarily the NWS Stage IV Quantitative Precipitation Estimates (QPE). The Stage IV product covers the entire conterminous US and is available at 1-, 6- and 24-h temporal resolutions, with a spatial resolution of ~1.54 x 1.54 mi^2 (4 x 4 km^2). The Stage IV product is available starting from 2002-present from the NCEP and can be readily accessible via the UCAR online archives (http://data.eol.ucar.edu/codiac/dss/id=21.093). The Stage IV dataset has been used extensively in a wide suite of scientific and engineering applications, including hydrologic and hydraulic modeling analyses (Habib et al., 2008; Habib et al., 2009; Eldardiry, 2015a,b). A more recent product, the MRMS, is produced by the NOAA's NSSL, and can also be used by the Consultant whenever available. The final MRMS gage-corrected product has a spatial resolution 0.01°(~ 1 km × 1 km) and a temporal resolution of 1 hour and can be obtained from the Iowa State University archive at http://mtarchive.geol.iastate.edu. Both products, Stage IV and MRMS, have been recently evaluated over Louisiana (Sharif et al., 2020; Habib et al., 2013). While both radar products use a gauge-based bias adjustment algorithm, the modeling teams should also acquire rain gauge observations (e.g., through the National Climatic Data Center, NCDC) for cross-comparison and validation of the Stage IV estimates, especially during periods where rainfall-runoff inconsistencies may arise. Tools for processing the radar-rainfall data for HEC modeling applications are available from US Army Corps of Engineers Hydrologic Engineering Center, the NWS and other sources, and can be provided by the TDQ. The Meteorological Visualization Utility Engine (HEC-MetVue) software can also be used to process rainfall datasets with various formats.

For years prior to 2002, modeling consultants should rely on rain gauge data available from various federal and state agencies (e.g., NWS, NCDC, USGS, USACE). Consultants should also seek additional rainfall data from local and regional entities that often operate their own rain gauges. Due to the nature of rain gauge observations, the modeling teams should perform a quality assessment analysis to ensure the value of the local data prior to being used for model forcing inputs.

5.6.2 Design Storms

Design storm shall be developed using the NOAA Atlas 14 precipitation frequency estimates, which are available through the online Precipitation Frequency Data Server (PFDS). The Atlas 14 provides such information in the form of tabular and graphical depth-duration-frequency (DDF) or intensity-duration-frequency (IDF) relationships.

DESIGN STORM FREQUENCY AND DURATION

All models shall include the 50%, 20%, 10%, 4%, 2%, 1%, 1%+, 0.2%, 0.1% mean value AEPs (2, 5, 10, 25, 50, 100, 100+, 500, 1000-year Average Recurrence Intervals (ARI)). Design storms shall cover a span of durations. While a 24-hour design storm is typically used for most watershed evaluations, the analysis shall also cover shorter storm durations (e.g., 1-6 hours) since some areas may experience more flooding during short storms, depending on their concentration times. An example that illustrates flooding at smaller durations is shown below in Figure 4. Longer storm durations (48-hour) should also be included to ensure full runoff concentration over large watersheds. A prime example of the importance of including a multitude of durations was during the August 2016 storm event, where the storm was classified as an extreme event of 500-1000 ARI only for the longer durations (>12 hours), but not necessarily for shorter durations (<6-hours); see Figure 5. The combination of multiple storm durations can then be used in the future to produce a composite highest-stage map that represent floodplain inundation for different AEP conditions.

Table 9. Recommended considerations for storm characteristics and meteorological dataset selection.

Component	Recommendations	Notes
Calibration to historical storms	Calibrate to at least six (6) short-term storms, and two (2) multi-storm periods	Will depend on data availability
Meteorological data sources	Use radar-based products produced by the NOAA, primarily the NWS Stage IV QPE; modeling teams shall also acquire rain gauge observations (e.g., through NCDC) for cross-comparison and validation of the Stage IV estimates	For years prior to 2002, the modeling teams shall rely on rain gauge data available from various federal and state agencies (e.g., NWS, NCDC, USGS, and USACE). Consultants shall also seek additional rainfall data from local and regional entities that often operate their own rain gauges
Design storm development	NOAA Atlas 14 precipitation frequency estimates, available through the online PFDS	Atlas 14 is based on additional years of data since the publication of the traditionally-used TP-40 manual and is therefore recommended for

Component	Recommendations	Notes
		hydrologic and hydraulic design purposes.
Design storm recurrence intervals and duration	All models shall include the 50%, 20%, 10%, 4%, 2%, 1%, 1%+, 0.2%, 0.1% AEPs (2, 5, 10, 25, 50, 100, 100+, 500, 1000-year ARI)	Besides a typical 24-hour design storm, the analysis shall also cover shorter storm durations (e.g., 1-6 hours) and longer durations (e.g., 48 hours and greater) since some areas may experience more flooding during short storms, depending on their concentration times. The combination of multiple storm durations can then be used to produce a composite highest-stage map that represents floodplain inundation for different AEP conditions. Also for more on the 1%+ event, see (Rucker and DeGroot, 2016).
Temporal distribution	AEP frequency-based temporal distribution of the rainfall design storms (hyetographs) should be developed using standard methods (e.g., Alternating Block Method) available within the HEC-HMS software	Other methods for temporal distributions, such as those specified in the NOAA Hydrometeorological Report No. 52 (HMR-52) should also be considered. Selection of the temporal distribution should also be based on review of actual historic storm data in the HUC8 watershed.
Spatial distribution	Spatially uniform rainfall can be used for small basins (<10 square miles); An analysis shall be performed to determine the optimal storm distribution (e.g., to produce maximum precipitation over the basin) in comparison to observed patterns of past storms over the watershed The analysis shall also include multiple scenarios (3 or more) of storm locations that	HMR-52 provides a detailed approach for developing ellipsoidal spatial distributions of design storms, which is the same method used in developing PMP. Further information on the development of region-specific spatially-distributed design storms are available from the

Component	Recommendations	Notes
	place the center of the storm at different locations within the watershed	InFRM Watershed Hydrology Assessments program.
Time series type from NOAA Atlas 14	Partial Duration Series (PDS) can have more extreme events (as it picks the maximum from all the data and not only the maximum annual as in Annual Maximum Series. However, PDS lacks the independence of consecutive events (it might pick multiple peaks from same event). Such independence is required when applying extreme value distributions analysis. Also, for long return periods, the two approaches, PDS and AMS, become very similar because the chance that two such events will occur within any year is very small.	The choice between the two approaches is not universal and can depend on the return period and length of record. Comparison between the two and assessment of differences in light of the return period will provide some guidance on which one to use.

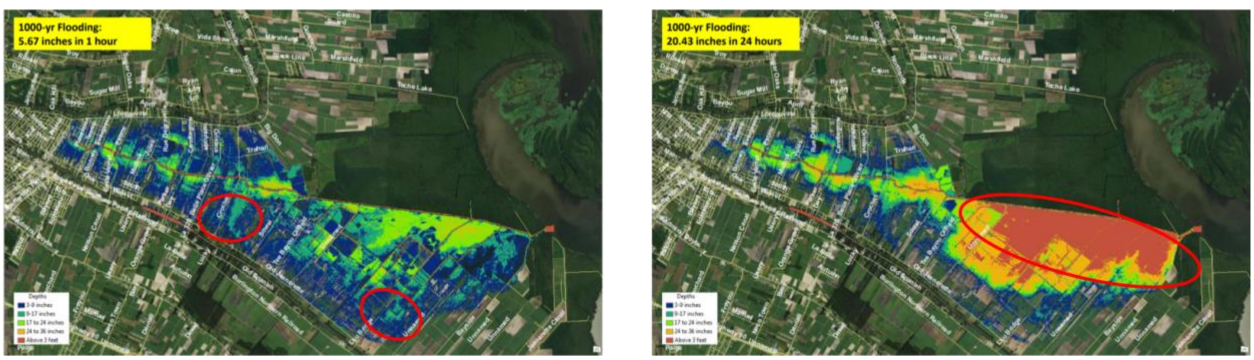

Figure 4. Example illustrating how different watershed areas experience flooding at different design durations

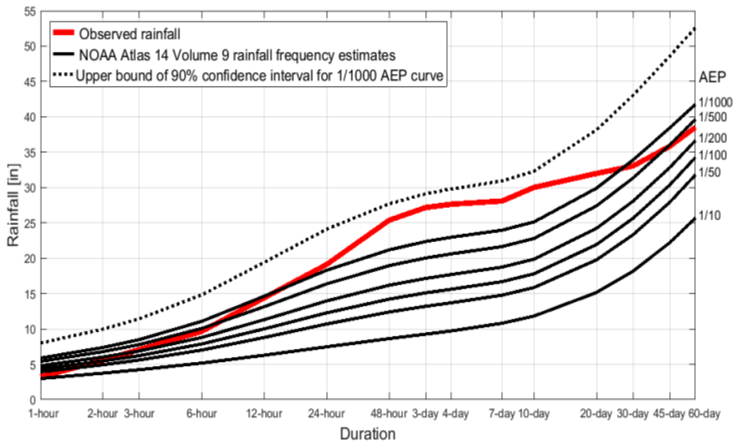

Figure 5. Maximum observed rainfall amounts at a rain gauge in Zachary, LA, during the August 2016 storm (NWS, 2020) in relation to corresponding rainfall frequency estimates.

TEMPORAL AND SPATIAL DISTRIBUTIONS OF DESIGN STORMS

Starting from the point-rainfall depths (or intensities) for the selected AEPs, a frequency-based temporal distribution of the rainfall design storms (hyetographs) shall be developed using standard methods (e.g., Alternating Block Method) available within the HEC-HMS software. Other methods for temporal distributions, such as those specified in the NOAA HMR-52 should also be considered. The modeling consultants shall provide adequate analysis and justification on how they selected a specific temporal distribution approach (e.g., by comparison against actual historical storm patterns in their watersheds).

Spatially uniform rainfall are typically used for small basins; however, spatial distribution of design storms shall be developed for large, watershed-scale analyses, such the case for LWI models. More realistic spatial distributions place storm cells with heavy rainfalls concentrated over smaller areas with bands of lighter rainfall extending outward. The HMR-52 provides a detailed approach for developing ellipsoidal spatial distributions of design storms, which is the same method used in developing Probable Maximum Precipitation (PMP). Further information on the development of spatially distributed design storms are available in recent studies by the InFRM Watershed Hydrology Assessments program (https://webapps.usgs.gov/infrm/). The modeling consultants can also use the HEC-MetVue software that allows the user to test different storm orientations, sizes and spatial scaling factors. An analysis shall be performed to determine the optimal storm distribution (e.g., to produce maximum precipitation over the basin) in comparison to observed patterns of past storms over the watershed. Adequate documentation on justification for the selected storm distributions shall be provided for review and approval prior to using them in the model runs. The analysis shall also include multiple scenarios (3 or more) of storm locations that place the center of the storm at different locations within the watershed. This will allow the model to produce different scenarios that mimic storm locations and distributions that cover possible flooding conditions.

Future versions of this document will include more details about the recommended approaches for developing regional-specific spatial and temporal distributions for the design storms.

5.7 MODEL OUTPUT AND PRODUCTS

The hydrologic and hydraulic models will be used to evaluate a variety of projects and strategies for a wide spectrum of temporal and spatial scales. Clearly the output of the models will require customization to thoroughly explore benefits and potential impacts of proposed projects. Nonetheless, consistency among the modeling consultants is critical so that the evaluation process can be broadly applied across LWI regions. In this document we communicate the basic information that are expected from the hydrologic and hydraulic models. Ultimately, DOTD through the TDQ, will coordinate with the modeling consultants the specifics and format of the output needed during the monthly meetings. The output identified below is for each storm/scenario examined by the modeling consultants. The modeling consultants are required to organize and store key datasets identified in the analysis of existing data task order phase. These historical datasets will be stored and clearly identified as “previous data” so it can be distinguished from the output and products delivered as part of the LWI effort.

5.7.1 Model Primary Outputs: Hydrology

- Flow and runoff volume time series at select locations.
- All HEC-HMS configuration files used to perform each of the different model runs for different scenarios/storms.
- All DSS input files and HEC-HMS parameter files shall be provided with clear metadata.
- All DSS output files that include the HEC-HMS results from each run with clear metadata about each corresponding run.
- Text files of all HEC-HMS DSS input and output data to help future users to meet added value objectives.
- GIS and excel files used in development of sub-basins and parameters.
- For additional guidance, see the FEMA data capture reference (FEMA, 2019).

5.7.2 Model Primary Outputs: Hydraulics

- Water surface elevation, discharge, and velocity time series at key locations identified by the modeling consultants, in consultation with DOTD and TDQ.
- Peak water surface profiles or rasters (e.g., RASPlot).
- Time series model outputs at intermediate locations such as gaging stations where calibration is conducted
- GIS evaluation line (e.g., 1-D cross sections or 2-D transect) shapefiles containing peak water surface elevation and discharge values.
- GIS rasters containing 2-D peak water surface elevations and velocity components at all locations where a 2-D model was used; this raster information can also be derived from 1-D models as well.

- Head differential and peak flow rates across key hydraulic structures (to evaluate their status and capacity) in table format with geospatial coordinates.
- Raster terrain files used to construct the grid as well as survey input data.
- All HEC-RAS configuration files for each run scenario (e.g., plan files, unsteady files) shall be provided including detailed metadata.
- All DSS input files obtained from HEC-HMS with clear metadata on how they are linked to the HEC-RAS plan files.
- Details about the boundary conditions and Hydraulic Property tables (HTab) curves for bridges.
- All DSS output files with detailed metadata about each corresponding HEC-RAS run.
- Formatted text files containing 1-D model output for future analysis.
- For additional guidance, see the FEMA data capture reference under the specification for spatial files and grids (FEMA, 2019).

5.8 HYDROLOGIC AND HYDRAULIC MODEL CALIBRATION AND VALIDATION

The hydrologic and hydraulic models will be calibrated and validated using recently collected and historical data, where available (Table 10). The modeling consultants shall coordinate closely with DOTD and TDQ on the calibration and validation criteria and performance metrics. *For ungauged watersheds and streams, the modeling consultants are recommended to follow calibration guidelines established by FEMA and the USACE.* Prior to initiating the calibration process, the modeling consultants should perform careful sensitivity analyses on key hydrologic and hydraulic model parameters.

At the conclusion of the sensitivity analyses, the modeling consultants should finalize the HEC-HMS calibration against best available information. Hydrologic model calibration will focus on matching the magnitude and timing of the observed peak flows and matching the overall shape of the hydrographs. Special attention should also be given to performance during multi-storm historical events such as the August 2016 storm. The calibration should be performed starting at the upstream gauges and working downstream.

5.8.1 Model Calibration: HEC-HMS

The following is a (non-exhaustive) list of model parameters that can be used for the HMS calibration:

- Loss parameters (e.g., initial deficit, maximum deficit, constant rate)
- Unit hydrograph parameters
- Topographic slope

The following metrics are a set of performance metrics that should be used in calibrating and evaluating the LWI HEC-HMS models:

- Coefficient of Determination (R^2)
- Nash-Sutcliffe Efficiency (NSE)

- Standardized Root Mean Square Error (RMSR)
- Percent Bias (PBIAS)

A full definition of these metrics, with overall guidance on acceptable levels of performance and calibration strategies, is available in Moriasi et al. (2007) and the USACE guidance, EM-1110-2-1417 (USACE, 1994).

5.8.2 Model Calibration: HEC-RAS

The following is a (non-exhaustive) list of model parameters that can be used for the RAS calibration:

- Roughness
- Head loss at hydraulic structures

Table 10. Recommended considerations for hydrologic and hydraulic model calibration.

Component	Recommendation
Parameter adjustment	Focus on adjustment of parameters that are calculated or assumed, and less on parameters that are primarily based on physical data (e.g., impervious cover, soil types).
Calibration datasets	Use water level and discharge data obtained from valid discontinued or current stream gauge records, as well as any additional gauges that may become available. The modeling consultants should consider (after verifying the quality) known HWMs, flood images, witness accounts, satellite-based estimates of flood inundation, and emergency response records as supporting information for the calibration and validation process. Qualified data from social media, civil air patrol, or other novel sources may also be considered.
Flood frequency analysis	Design storm flow peaks produced by the hydrologic and hydraulic models should be consistent with the corresponding results from the flood frequency analysis.
Ungauged basins and inadequate gauges for frequency analysis	Use published regional studies and reports based on the USGS regional regression equations
Incremental calibration	Calibrate from smaller flow events to higher flow events. For example, the vertical variations in Manning's *n* option shall be used for 1-D model cross-sections by incrementally calibrating to known HWMs beginning with smaller events and progressively calibrating to the flood of record. If necessary, seasonal variations shall also be considered and included in the HEC-RAS model. Special care shall be taken to consider the potential impacts of aggradation and degradation that occurred during the recent 2016 floods.

For the gauged watersheds and channels, it is important to establish a set of metrics to help identify acceptable model performance in such a way as to support the primary and added-value objectives of the LWI. In 2012, FTN Associates ltd. established a set of model performance metrics for the LCA Medium Diversion at Myrtle Grove study (FTN, 2012). Model performance metrics were produced for the Mississippi River Hydrodynamic Study (Meselhe and Rodrigue, 2013). These metrics were intended to establish acceptable model performance using three goodness-of-fit statistics. Data scarcity, data uncertainties, and inconsistencies must be considered when the performance metrics are used or applied. As a result, the parameters with the most observed data were given the most stringent criteria and vice versa. For example, there are typically more robust records of stage data than discharge/velocity. Following the recommendations established by FTN (2012) and Meselhe and Rodrigue (2013), metrics for the LWI modeling efforts are suggested below (Table 11 and Table 12).

Table 11. RMSE Metrics for One and Two-dimensional Models.

One-dimensional Models		
Model Output	Target – Desired	Target – Acceptable
Water Surface Elevation	< 15% for all stations	< 15% for 50% of stations
Water discharge	< 20% for all stations	< 20% for 50% of stations
Two-dimensional Models		
Model Output	Target - Desired	Target - Acceptable
Water Surface Elevation	< 15% for all stations	< 15% for 50% of stations
Water Discharge	< 20% for all stations	< 20% for 50% of stations

Table 12. Correlation Coefficient Metrics for One and Two-dimensional Models.

One-dimensional Models		
Model Output	Target - Desired	Target - Acceptable
Water Surface Elevation	> 0.9 for all stations	> 0.9 for 50% of stations
Water discharge	> 0.8 for all stations	> 0.7 for 50% of stations
Two-dimensional Models		
Model Output	Target - Desired	Target - Acceptable
Water Surface Elevation	> 0.9 for all stations	> 0.9 for 50% of stations
Water Discharge	> 0.8 for all stations	> 0.7 for 50% of stations

Table 13. Percent (%) Bias Metrics for One and Two-dimensional Models.

One-dimensional Models

Model Output	Target - Desired	Target - Acceptable
Water Surface Elevation	< 10 for all stations	< 10 for 50% of stations
Water discharge	< 15 for all stations	< 15 for 50% of stations
Two-dimensional Models		
Model Output	Target - Desired	Target - Acceptable
River Water Depth	< 10 for all stations	< 10 for 50% of stations
Water Discharge	< 15 for all stations	< 15 for 50% of stations

5.9 CONSEQUENCE MODEL

This section will be included in future versions of the document.

6 PART II: CONSIDERATIONS FOR COASTAL AND FLOOD TRANSITION ZONES

In low-gradient coastal regions and river deltas, flooding can be caused by extreme rainfall, coastal surges or a combination of these factors occurring in tandem or in close succession. For the purposes of the LWI analyses, these transitional areas, where flooding can occur from compounded rainfall, wind setup, high tides, and coastal inundation, are referred to as flood transition zones (Bilskie & Hagen, 2018) as exemplified in Figure 6b below.

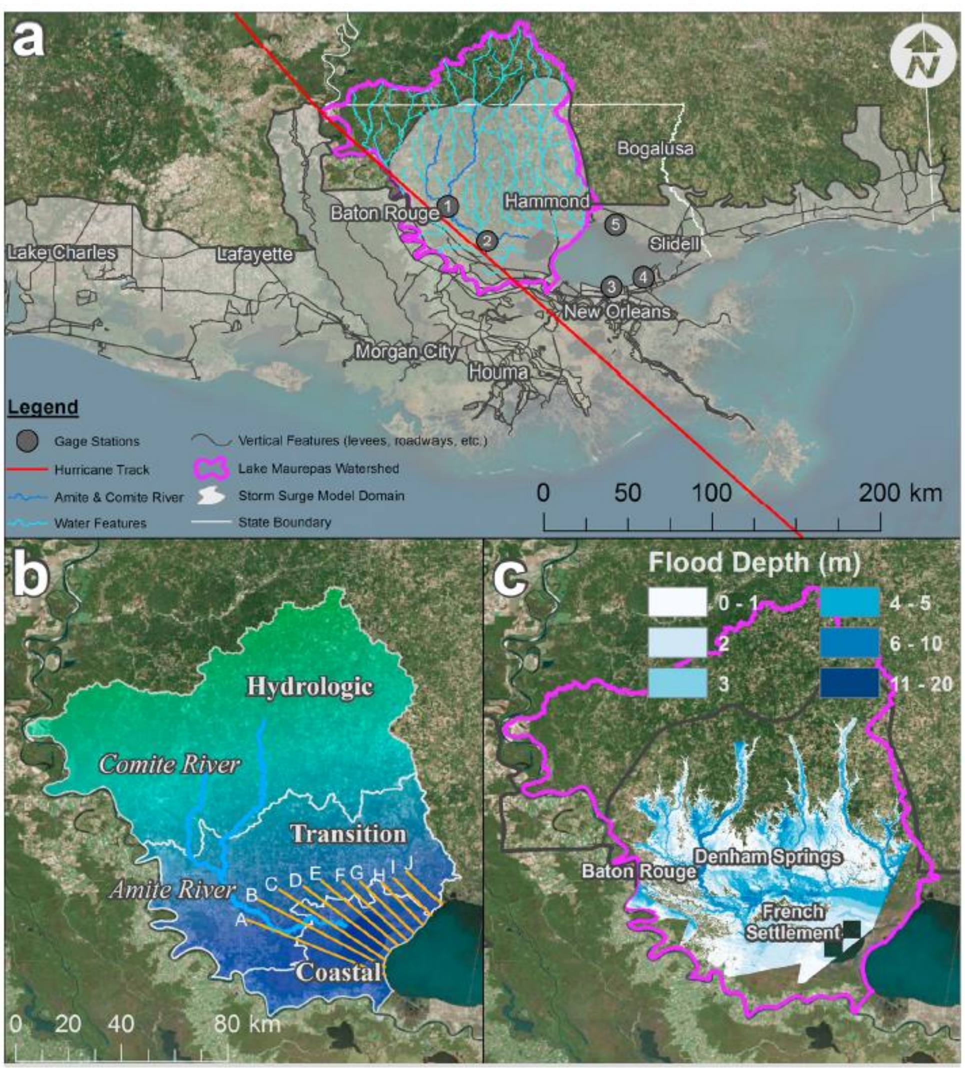

Figure 6. Example flood transition zone for the Lake Maurepas watershed. (a) Coastal Louisiana with focus on the Lake Maurepas watershed (purple polygon). The extent of the ADCIRC model is shaded in gray and includes portions of the Lake Maurepas watershed. Gauge stations shown are listed as (1) Amite River at Denham Springs (USGS 07378500), (2) Amite River near French Settlement (USGS 07380200), (3) New Canal Station (NOAA 08761927), and (4) USGS-DEPL_SSS-LA-ORL-014 and (5) USACE_85575. (b) Zoom-in of the Lake Maurepas watershed with hypothesized regions of coastal (blue) and hydrologic (green) flooding and flooding transition zone between.

The transects labeled A-J were used in Bilskie & Hagen to explain flood transition (Bilskie & Hagen, 2018). (c) Inundation depth (above ground) and extent for the 2016 Louisiana rainfall event derived from FEMA (2016).

As shown in Figure 6b, there are three distinct areas where flood hazards and flood risk require unique considerations. Coastal areas require methods like those developed and typically applied by USACE, FEMA and CPRA. Inland areas (referred to as hydrologic in Figure 6b) require methods like those desciribed in Section 5. Transition zones require methods applied for inland and coastal areas alike. However, as discussed in greater detail in this section, the analysis of flood hazards in the transition zone should be completed using the same numerical models as inland portions of the watershed. Accordingly, HUC8 watersheds that are fully or partially within the transition zone require additional transition zone-specific considerations during HEC model development.

Flood hazards in coastal-dominated zones are being assessed as part of the CPRA 2023 Coastal Master Plan (CMP). The area defined as coastal in Figure 6b is an example region where flood hazards are expected to be asssessed as part of the 2023 CMP rather than as part of the LWI directly. It should be noted that the 2023 CMP models extend inland beyond the coastal zone into the transition zone and further inland in some areas. Though the 2023 CMP models cover transition zone and inland areas, the 2023 CMP models are not designed to capture the compound flood effects to be assessed with the LWI models in the transition zone.

The development of models for HUC8 watersheds that are fully or partially within the transition zone differs from the development of models for HUC8s that are fully inland watersheds because transition zones require the flexibility to incorporate coastal hazards in the model framework to assess compound flooding. That said, the foundational aspects of the model guidance for the transition zone are captured in Section 5 for inland watersheds. Modeling consultants should adhere to the inland guidance, unless otherwise noted in this section, when developing models for HUC8 watersheds that are fully or partially within the transition zone.

This HEC-based approach was chosen to limit the reliance on ADCIRC because ADCIRC has a relatively high computational cost compared to RAS and has limitations for watershed applications. Additionally, ADCIRC has a smaller group of active users in contrast to the HEC software, which is widely applied in Louisiana and throughout the United States.

6.1 OVERVIEW OF TRANSITION ZONE MODELS

To directly achieve LWI primary objectives and establish a modeling framework that can be leveraged to achieve LWI added-value objectives as part of future analyses, the development of models that are fully or partly within the transition zone should be guided by the following principles.

- This section of the guidance is intended to document additional model considerations, beyond those identified in Section 5, that should be taken into account when developing RAS models for HUC8s that are fully or partially falls within the transition zone.

- The analysis of flood hazards in the transition zone should be completed using the same numerical models as inland portions of the watershed. The same RAS models described in Section 5.5 will be utilized, though downstream boundary conditions may vary from those described in Section 5 for the purposes of evaluating events in the transition zone.
- This version of the modeling guidance assumes that the HEC HUC8 models that are fully or partly fall within the transition zone should be used to simulate a discrete set of design storms to assess various compound flooding conditions. Though the design storms to be used for each HUC8 will be defined at a later date (see Section 6.6.2), the modeling consultants should assume that the design storms will be similar in nature to those described in Section 5.6.2 and require a variety of coastal (i.e., downstream) boundary conditions coincident with design storm rainfall.
- The design storm approach is anticipated to be reliant on 2023 CMP data at the coastal boundary, either in the form of individual ADCIRC simulations or AEPs derived from the CLARA model. The 2023 CMP ADCIRC and CLARA models have been recently updated as part of a model improvements phase. The 2023 model improvements version of ADCIRC code (v54.01), ADCIRC model mesh and others input files, model validation inputs and outputs, and a summary report will be available to modeling consultants as part of the LWI model validation and calibration efforts for the transition zone. It should be noted that the 2023 CMP ADCIRC simulations account for storm surge, seasonal Gulf water levels, and Mississippi River and Atchafalaya River flows, but do not account for other streamflow or precipitation over the transition zone.

6.2 ANALYSIS OF EXISTING WATERSHED DATASETS AND STUDIES

See Section 5.2 for general guidance for analysis of existing watershed datasets and studies.

For transition zone watersheds, the modeling consultants should complete an existing data analysis that considers the multiple event types (i.e., tropical and non-tropical storms) that affect the watershed of interest. The existing data analysis should identify previous studies of the region (including previous CMP studies that outline ADCIRC model development and assumptions), high-water marks and historical flood information.

6.3 TOPOGRAPHIC AND BATHYMETRIC SURVEYS

See Section 5.3 for general guidance on topographic and bathymetric surveys.

The topographic and bathymetric data used to setup the 2023 CMP models can be made available once they have been vetted and approved by CPRA.

6.4 HYDROLOGIC MODELING SETUP

The setup and application of HMS hydrologic models in the transition zone will follow those steps described in Section 5.4 for inland models.

6.4.1 HEC-HMS Considerations

A large part of the transition zone may consist of marshes and swamps, which HMS is not well-suited to model. However, these areas typically have high water tables and have a Hydrologic Soil Group classification of D with minimal infiltration thus reducing the number of calibration parameters in HMS. Additionally, for local runoff within the transition zone, the modeling consultants will have the option to use the spatially varying rain-on-grid with initial deficit and infiltration option in RAS v6.0 (RAS 5.07 can apply lumped, rain-on-grid only and relies on HMS to provide the hydrology), as an alternative to HMS.

The modeling consultants are encouraged to consider the possible runoff exchange across HUC8 boundaries in the transition zone and to draft a proposed modeling approach to accommodate such a possibility.

The HMS models will be calibrated and validated to historical tropical and non-tropical storms. Since there is a scarcity of discharge data in the transition zone, water level will be the primary calibration variable; thus, the final calibration can only be completed with the RAS model.

It is possible that multiple adjacent HUC8 HMS models might be required to provide inflows to the RAS models that cover the transition zone across multiple HUC8s. Figure 7 illustrates an example of how HMS and RAS model domains could be configured to evaluate flood hazards across multiple HUC8 watersheds. Figure 7A shows the Amite River watershed or the watershed of interest in this example. Figure 7B shows an example HMS model domain for the evaluation of the Amite River watershed transition zone. The HMS domain in this case is comprised of four HUC8 HMS models, configured to consider possible runoff exchange across the HUC8 boundaries. Figure 7C shows an example RAS model domain for the evaluation of the Amite River watershed transition zone. The RAS domain includes adjacent HUC8s so that storm surge and flood waves can propagate between the Amite River watershed and adjacent HUC8s. Figure 7D shows example RAS model boundary conditions for this illustrative example.

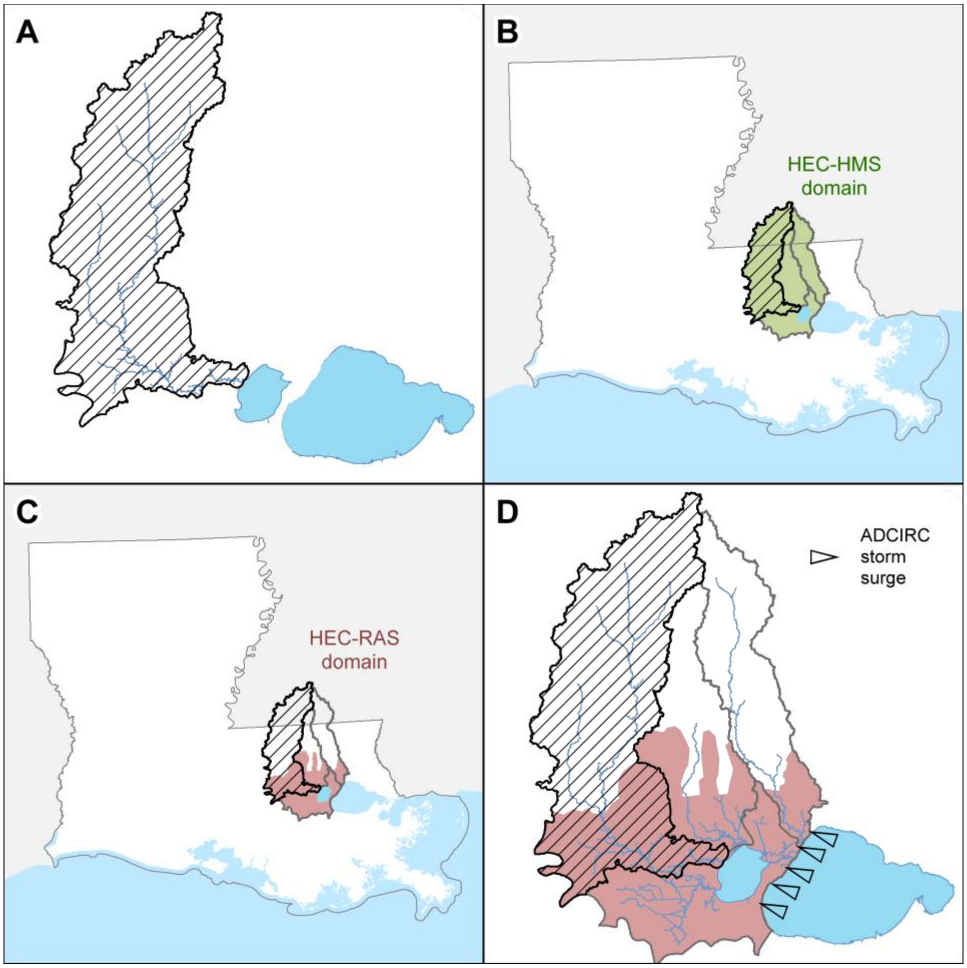

Figure 7. Illustrative example of HMS and RAS model domains. (A) the Amite River watershed (B) an example HMS model domain (C) an example RAS model domain for the full HUC8 with the transition zone area shown in red (D) example RAS model boundary conditions.

6.5 HYDRAULIC MODELING SETUP

The setup and application of RAS hydraulic models in the transition zone will follow those steps described in Section 5.5 for inland models, as well as the additional considerations documented within this section. The considerations noted within are those that modeling consultants should follow in the LWI program so that model development and associated tasks can begin promptly.

6.5.1 HEC-RAS Considerations

The modeling guidance assumes that the HEC HUC8 models fully or partly within the transition zone will be used to simulate a discrete set of historical storms to assess various compound flooding conditions. The modeling consultants should assume that the design storms will be similar in nature to those described in Section 5.6.2 and require a variety of coastal boundary conditions.

The hydraulic models will be developed in the 6.0.0 version of HEC-RAS. The RAS models applied to evaluate flood hazards in the transition zone should be setup with a coastal boundary and upland boundaries where applicable, as well as designed to apply rain-on-grid either though HMS or directly though RAS v6.0. The treatment and placement of boundary conditions is particularly important in the transition zone and is discussed in greater detail in Table 14 at the end of the section.

Because of the additional factors that influence the definition of flood hazards in the transition zone, the model setup in these areas will require close coordination with the TDQ and modeling consultants in adjacent watersheds to ensure consistent assumptions, analysis, and outputs. Consistency will be necessary at HUC8 boundaries to account for the possibility of inter-basin flows that may need to be considered as part of the model setup.

6.5.2 Summary of Considerations

RAS model considerations are summarized in Table 14. Recommendations from Section 5.5, including those found in Table 8, apply in the transition zone as well unless otherwise noted.

Table 14: Considerations for the RAS models applied in the transition zone.

Component	Considerations
Model Version	RAS v6.0 is the preferred model version for the transition zone because of its expanded capabilities compared to v5.0.7 including wind, spatially varying rainfall-runoff, and hydraulic structures in the 2-D domain. RAS v6.0 has improved computation efficiency compared to earlier versions of RAS.
1-D/2-D Model Domains	Follow guidance in Section 5 as appropriate, recognizing that RAS 2-D is expected to be preferred for most of the transition zone to simulate multi-directional flow. It is recommended that RAS 1-D be used selectively in the transition zone except in portions of the domain where longitudinal riverine processes are dominant and vertical variation in Manning's *n* is necessary for model calibration. Based on preliminary discussions between the TDQ and USACE HEC, a full 2-D application is expected to be more stable than 1-D/2-D with a weir type internal connection.
Wind Fields	Based on preliminary discussions between the TDQ and USACE HEC, wind fields are expected to require preprocessing prior to use in RAS v6.0 to account for wind sheltering effects. Based on preliminary discussions between the TDQ and USACE HEC, RAS v6.0 model stability tests have been completed by USACE HEC for wind speeds of up to approximately 70 miles per hour. Hurricane force winds greater than 70 mph have been successfully tested in RAS v6.0 by the New Orleans District USACE. In 1-D areas, wind stresses can only be applied if the 1-D Finite Volume Method (FVM) option is selected.

Model 2-D flow areas	It is recommended that the number of 2-D flow areas is minimized to avoid internal connections such as weirs which do not preserve momentum and lead to errors in tidal and surge propagation. If 2-D subareas are used, the weirs should be located along land features where weir flow is likely to occur (e.g., levees or raised roadways), where possible. Otherwise, for other coastal connections that are in the marshes or waterbodies, a small weir coefficient (e.g., < 1) should be used. Additional guidance on internal connections between 1-D and 2-D as well 2-D to 2-D areas in RAS v6.0 will be provided at a future date.
Model grid and cell spacing/alignment	For RAS 2-D, it is recommended that: • Break lines are utilized to align the model grid cells to be parallel to major channels and structures that direct flow pathways (e.g., berms, levees). • As a minimum, the main river channels should have at least 4 cells across (ideally with the outside cell face aligned to the bank). Minor channels should have at least 2 cells across. RAS v6.0 permits Manning's n to be varied horizontally across the face of the cell which improves the sub-grid resolution of the roughness n. • Locations with relatively small velocity changes and nearly homogeneous roughness (e.g., large open water bodies, continuous marshland, flat floodplains) can use a lower grid resolution.
Model formulation	Dynamic wave solver (i.e., full momentum equations) should be used in 2-D flow areas that have coastally influenced waterbodies or waterways. If the wind stress option is selected, the dynamic wave solver must be used.
Manning's *n*	Same as inland guidance. RAS v6.0 2-D considerations: • RAS v6.0 allows Manning's *n* values to vary horizontally across each 2-D cell face, whereas RAS v5.0.7 uses a single value to represent the roughness across the 2-D cell face. This feature may be beneficial for varying Manning's *n* values along cell faces during model calibration and validation for areas with 2-D cells. • RAS v6.0 does not allow for vertical variation of Manning's *n* value on a cell face.
Computational stability factors	The adaptive time step feature may be used to modify the timestep during prolonged periods of high or low velocities while maintaining the limit on Courant numbers. RAS v6.0 has a direct solver and iterative solver options. Generally, the direct solver is more stable but slower than the iterative solver. The direct solve may be appropriate during the model setup but the iterative option is generally better for production runs.
Inland boundary	The boundary between the transition zone and the inland area will need to extend inland beyond the expected transition zone and coastal flood extents (e.g., ADCIRC outputs) to accommodate other considerations, e.g., backwater effects.

	When applicable, open boundaries should be located at surface water (stage or discharge) gauge locations to provide model boundary conditions and observational datasets to assess model performance during calibration and validation.
Coastal boundary	Boundaries should be placed to leverage ADCIRC model output as well as gauge measurements to aid in model calibration and validation. Boundary placement should consider wave effects, such that the wave radiation stresses are minimized within the transition zone. RAS v6.0 does not include wave setup or radiation effects. Coastal boundaries should be discretized sufficiently to ensure model stability, limit recirculation effects, and limit the variation in water levels (from ADCIRC, gauges or otherwise) along each coastal boundary segment. Modeling consultants should perform sensitivity tests regarding boundary location and discretization.
Rainfall-runoff	RAS v6.0 will accept HMS runoff (excess precipitation) as input to a 2-D subarea, as in RAS v5.0.7. RAS v6.0 has an option to simulate spatially discrete rainfall, initial abstractions, and infiltration within 2-D flow areas. This rain-on-grid hydrology within RAS 2-D is a new option that may be useful for rain on areas like marshes where HMS is not ideal. Additional guidance relative to RAS v6.0 will be provided at a future date.
Quality control/documentation	Same as inland guidance.

6.6 METEOROLOGICAL FORCING

6.6.1 Historical Storms for Model Setup, Calibration, and Validation

The HMS and RAS models will be calibrated and validated to tropical and non-tropical storms. Modeling consultants shall identify a minimum of four (4) historical tropical storms and four (4) historical non-tropical storms types for model calibration and validation. Like inland watersheds, the selected transition zone storms should represent varying conditions including consideration of coastal conditions (e.g., high storm surge, low rainfall; low storm surge, high rainfall).

The 2023 CMP ADCIRC model has been recently updated and validated as part of a model improvements phase. The 2023 model improvements version of ADCIRC code (v54.01), ADCIRC model mesh and others input files, model validation inputs and outputs, and a summary report will be available to the modeling consultants as part of the LWI model validation and calibration efforts for the transition zone. Seven tropical storms were simulated using ADCIRC for model validation for the 2023 CMP model improvements study.

The tropical storm model inputs (atmospheric pressure and wind velocity files) used in the ADCIRC model validation for the model improvements phase of the 2023 CMP can be available to the modeling consultants for select storms. Some tropical storm model input files require a license agreement between the model consultants and the creator of the model input data, Oceanweather Inc.

The model improvements phase of the 2023 CMP did not include model validation using non-tropical storms.

Concurrent to the LWI program, the 2023 CMP team may continue to update the ADCIRC model and associated model outputs. Updated 2023 CMP ADCIRC model data can be made available once they have been vetted and approved by CPRA.

6.6.2 Design Storms

Refer to Section 5.6.2 for general guidance.

This version of the modeling guidance assumes that the HEC HUC8 models fully or partly within the transition zone should be used to simulate a discrete set of design storms to assess various compound flooding conditions. For planning purposes at the onset of Task Order 1, the modeling consultants should assume that:

1. The design storms will be similar in nature to those described in Section 5.6.2 and require a variety of coastal boundary conditions coincident with design storm rainfall.
2. The combination of design storms rainfall fields and boundary conditions will be established by the modeling consultants as part of Task Order 1. The modeling consultants, as part of the methodology development phase, will consult with the modeling leads for Regions 4, 5, 6, and 7, as well as DOTD and the TDQ, to select design storm conditions to be applied in the four regions for the purposes of project evaluation.

6.7 MODEL OUTPUT AND PRODUCTS

Refer to Section 5.7 for general guidance.

6.8 HYDROLOGIC AND HYDRAULIC MODEL CALIBRATION AND VALIDATION

Refer to Section 5.8 for general model calibration and validation guidance. Additional recommendations related to model calibration and validation can be found in Section 6.4 and Section 6.5 for HMS and RAS, respectively.

6.9 CONSEQUENCE MODEL

This section will be included in future versions of the document.

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APPENDICES

APPENDIX A: TECHNICAL MEMORANDUM ON MODEL DATA NAMING CONVENTIONS