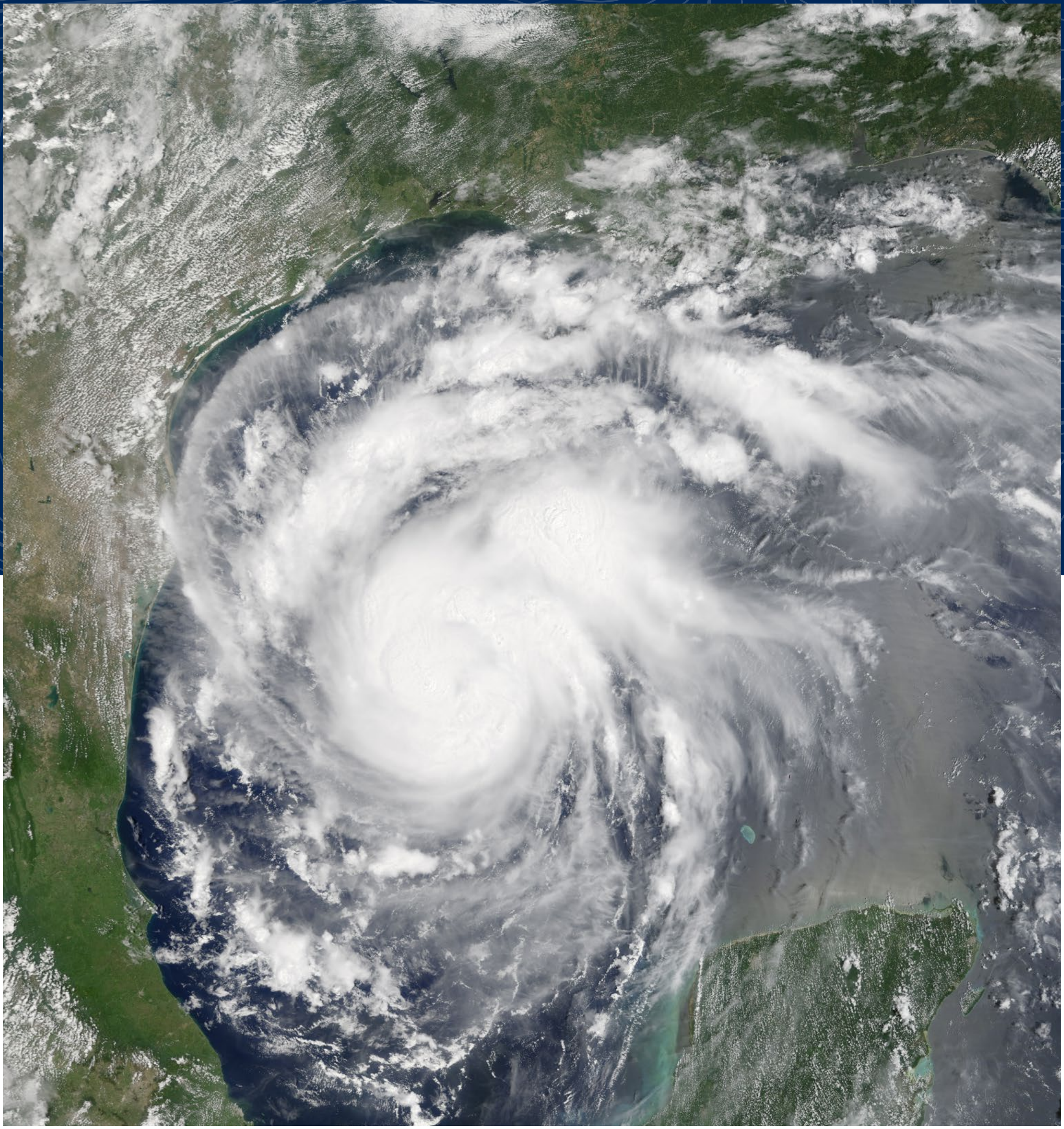
Texas Integrated Flooding Framework

2021-2022 ANNUAL REPORT



Texas Integrated Flooding Framework

Texas Water Development Board

USGS science for a changing world

US Army Corps of Engineers

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2021-2022 ANNUAL REPORT

Contract # 21-127-000-C778
Community Development Block Grant
Disaster Recovery Program –
Harvey Round 1 Funding

Cover Photo: 3D illustration of a hurricane approaching Texas © National Aeronautics and Space Administration

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Welder Flats in San Antonio Bay at Matagorda Island, Texas © Maresa Pryor/Danita Delimont, Adobe Stock

Acronyms

ADCIRC	Advanced Circulation
API	Application Programming Interface
BLE	Base Level Engineering
CHARM	Community Health and Resources Management
CHL	Coastal Hydraulics Lab
CO-OPS	Center for Operational Oceanographic Products and Services
CRS	Community Rating System
CSRM	Coastal Storm Risk Management
CSTORM-MS	Coastal Storm Modeling System
ERDC	Engineering Research and Development Center
FEMA	Federal Emergency Management Agency
GLO	Texas General Land Office
HCFCD	Harris County Flood Control District
HEC-HMS	Hydrologic Engineering Center Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center River Analysis System
InFRM	Interagency Flood Risk Management
InSAR	Interferometric Synthetic Aperture Radars
LiDAR	Light Detection and Ranging
M3	Map and Model Management
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
PRMS	Precipitation-Runoff Modeling System
RFPG	Regional Flood Planning Groups
S2G	Sabine Pass to Galveston Bay
SC	Steering Committee
STWAVE	Steady State Spectral Wave
SWAT	Soil & Water Assessment Tool
SWL	Storm Water Level
TAT	Technical Advisory Team
TCOON	Texas Coastal Ocean Observation Network
TCRMP	Texas Coastal Resiliency Master Plan
TDIS	Texas Disaster Information System
TIFF	Texas Integrated Flood Framework
TWDB	Texas Water Development Board
TxDOT	Texas Department of Transportation
UI	User Interface
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WAM	Wave Modeling Project


Flooding in Port Arthur, Texas on August 31. © Sgt. Daniel J. Martinez, U.S. Air National Guard

Executive Summary

As the most expensive and most common natural disaster in the U.S., flooding is a risk that state and local governments cannot ignore. In Texas, major coastal flood events are becoming increasingly frequent, often leaving billions of dollars in damage to coastal infrastructure in their wake. Compound flooding events, in particular, can produce some of the most destructive floods due to their length, spatial coverage, and the combined force of multiple flooding processes. A compound flooding event is a simultaneous or sequential combination of flooding from meteorological, oceanographic, and hydrologic drivers.

Recent hurricane events, including Hurricanes Ike and Harvey in Texas, have highlighted the need to better understand and predict flooding as a continuum of processes across the landscape and coastal ocean. For example, Hurricane Harvey (2017), in addition to creating a storm surge (up to six feet in Corpus Christi), broke the U.S. record for rainfall from a single storm, dumping 51 inches of rain in parts of Texas, and was noted as the second-most costly hurricane to hit the U.S. mainland since 1900. Flooding from extreme storm events, like Harvey, uncovers a glaring need to provide state and regional flood planners with a more accurate understanding of coastal flood risks and reliable tools to prepare for and respond to the state's floods.

The Texas General Land Office (GLO), through its Community Development Block Grant Disaster Recovery Program, funded the Texas Water Development Board (TWDB) in 2020 to serve as the lead agency to coordinate the Texas Integrated Flooding Framework (TIFF), a comprehensive flood risk reduction planning project, in partnership with the U.S. Geological Survey (USGS) and the U.S. Army Corps of Engineers (USACE) – Galveston District.

In its first two years of implementation, the TIFF planning project has made significant strides toward creating an integrated framework to provide local, regional, and state entities with the compound flood risk information and planning tools necessary for comprehensive regional flood planning and mitigation in the coastal zone. Guided by a Steering Committee (SC) composed of members from each project partner (TWDB, USGS, USACE), TIFF mobilized

Flooding in Port Arthur, Texas on August 31. © Sgt. Daniel J. Martinez, U.S. Air National Guard

and engaged four Technical Advisory Teams (TAT) involving experts from governmental agencies, academia, and regional stakeholders to build out the four components of the framework, which include: 1) data and monitoring gap analysis, 2) data management and visualization, 3) integrated flood modeling framework, and 4) planning and outreach.

This report captures TIFF's progress related to the project's objectives to: 1) develop guidelines and processes for implementing a comprehensive framework to model, visualize, and plan for the risk of flooding in counties affected by Hurricane Harvey, 2) build relationships among agencies to improve coordination and collaboration, and 3) complement the many ongoing efforts to enhance flood science, mapping, modeling, warning, response, and planning in Texas.

The report is organized into six sections:

- **Section One** provides an overview of the TIFF planning project's purpose, goals, and structure.
- **Section Two** describes applicable data structures for creating a data availability tool and shares findings from data inventory workshops on bathymetry and subsidence.
- **Section Three** provides an overview of the available coastal flood-related user interfaces (UIs).
- **Section Four** presents an initial inventory of existing and proposed meteorologic, hydrologic, hydraulic, estuarine, and surge models that support inland and coastal hazard identification.
- **Section Five** discusses the creation of a comprehensive outreach plan to engage regional planning groups and other stakeholders regarding flood planning and mitigation efforts.
- **Section Six** documents preliminary findings and recommendations related to investing in the quality control and quality assurance of the historical Texas Coastal Ocean Observation Network (TCOON) datasets and bathymetry data acquisition for 20 identified high-priority areas along the Texas coast.


A home in Gilchrist, Texas, designed to resist flood waters survived Hurricane Ike in 2008 © FEMA/Joselyne Augustino

1 TIFF Structure and Development

For Texas to implement state and regional flood planning, decision-makers need a more accurate understanding of coastal flood risks and the tools for effective mitigation planning. The GLO, through its Community Development Block Grant Disaster Recovery Program, funded TWDB to serve as the lead agency to coordinate a comprehensive flood risk reduction planning project in partnership with USGS and USACE – Galveston District.

TIFF is a collaborative planning project that is developing recommendations, guidelines, and frameworks to improve the modeling, data collection, data management, visualization, planning, and outreach efforts in counties affected by Hurricane Harvey. The GLO Community Development and Revitalization Department funded this four-year planning project

1.1 Identity, Roles, Execution, and Priorities

TIFF is a coordinated effort to leverage expertise and resources to find the best information (both available and future needs) and capture that information into a framework to enhance flood risk planning and mitigation efforts on the Texas coast. TIFF is constantly gathering the best available information about coastal flooding to make recommendations to stakeholders on how the state could improve the current procedures (e.g., spatially, temporally, technologically, periodically, scientifically, and fundamentally) in data gathering/collection, data management/visualization, modeling, planning, and outreach These science-based recommendations are based on the needs of the communities (experts and public) to improve flood risk planning and mitigation. Most importantly, TIFF is forging relationships between state, federal, and local authorities to create a network for solving many of the complex issues that may arise in the future and provide sound, reliable recommendations for the improvement of development of new products and data that will meet the needs of coastal stakeholders.

TIFF is not an effort to produce specific models or datasets or to solve a particular problem. Instead, the outcomes of TIFF will be recommendations, guidelines, and frameworks to improve the state's modeling, data collection, data management, visualization, planning, and outreach efforts in the future. As TIFF gains a deeper understanding of what information is available, it has become apparent that TIFF's role in the sustainability of Texas coastal communities under threat of flood is in advancing flood science for future needs. If existing data, information, products, or models to best meet those needs do not yet exist, TIFF will recommend their creation or development. As TIFF continues to evolve to meet the future resiliency needs of Texans, the SC will continue to look for opportunities to fill gaps in flood science by recommending continuous improvements into the future.

1.1.1 Mission and Vision

With the assistance of the TIFF Facilitation Team led by The Meadows Center for Water and the Environment at Texas State University (the Meadows Center) and feedback from the GLO, the SC defined the project's mission and vision as follows:

Mission: TIFF leverages expertise and resources to bring about the best information to enhance coastal flood risk planning and mitigation.

Vision: TIFF empowers Texans with reliable information to increase flood resiliency.

1.1.2 Project Components

There are four primary components to the TIFF planning project, which include data and monitoring gap analysis, data management and visualization, integrated flood modeling framework, and planning and outreach. TIFF will perform each of the component tasks described below in collaboration with the TIFF TATs.

Component 1 – Data and Monitoring Gap Analysis. Component 1 is identifying available data and data gaps and establishing a plan for obtaining data critical for successful coastal flood analysis. This component will support the expansion and improvement of data observations for inland, coastal, and ocean systems.

Component 2 – Data Management and Visualization. Component 2 is ensuring that any coastal flood related data and model outcomes can be properly visualized for technical and non-technical end-users. Furthermore, TIFF will support the effort led by the Texas Disaster Information System (TDIS) regarding coastal flood analysis data management and visualization.

Component 3 – Integrated Flood Modeling Framework. Component 3 is developing an integrated conceptual modeling framework to support inland and coastal flood hazard identification.

Component 4 – Planning and Outreach. Component 4 is ensuring the data and modeling frameworks incorporate the various end-users' flood planning and mitigation needs. This component will also ensure that the findings from various efforts are well communicated. Close collaboration among TIFF, Community Health and Resource Management (CHARM), the Regional Flood Planning Groups (RFPGs), and the Combined River Basin Flood Studies (Combined Flood Studies) is required to achieve such a goal. TIFF also supports the expansion and improvement of flood planning in Texas by incorporating the new findings into the existing planning tools or recommending the creation of new tools. Finally, TIFF will try to balance and communicate between project-based and regional planning scale solutions.

1.1.3 Roles and Responsibilities

1.1.3.1 STEERING COMMITTEE

The SC is composed of six members, with two members from each partner agency (TWDB, USGS, and USACE) that meet biweekly.

- **Caimee A. Schoenbaechler**, M.E.M., Coastal Science Manager – TWDB
- **Amin Kiaghadi**, Ph.D., P.E., Coastal Modeling Team Lead – TWDB
- **Mohammad "Shahidul" Islam**, Ph.D., P.E., Subject Matter Expert, Coastal Engineering Section – USACE-Galveston District
- **Patrick Corbitt Kerr**, Ph.D., P.E., D.WRE, Hydrology and Hydraulics Branch Chief – USACE-Galveston District
- **Michael Lee**, Gulf Coast Branch Chief – USGS, Oklahoma-Texas Water Science Center
- **Sam Rendon**, Hydrologist – USGS, Oklahoma-Texas Water Science Center

The SC leverages the strengths and resources of each partner agency to ensure the project complements the ongoing efforts to enhance flood science, mapping, modeling, warning, response, and planning in Texas. In addition, the SC helps to facilitate, coordinate, and integrate concerns, ideas, early findings, and recommendations into TIFF's rapidly evolving activities. Specifically, the SC's role includes guiding the framework and identifying issues in advance for technical discourse and deliberation by each TAT. The SC is committed to working diligently to keep the process on schedule and to bring forth any concerns that may affect the schedule as quickly as possible.

1.1.3.2 FACILITATION TEAM

The Facilitation Team is responsible for providing pre- and post-meeting facilitation support and preparing for, facilitating, debriefing, and supporting offline collaboration and stakeholder engagement. This includes:

- Coordinating, drafting, and finalizing meeting agendas and meeting materials in consultation with the SC
- Assisting in developing meeting handout packets
- Shepherding content development and maintaining records of agendas and action items
- Providing and operating webinar platforms
- Identifying scheduling needs and notifying participating members of scheduling needs
- Facilitating TAT meetings, including meetings to prepare and debrief TAT meetings
- Taking notes during TAT meetings, summarizing decisions and action items at the end of the meeting, developing internal/external facing meeting materials, and summary reports
- Providing process design services on best practices for eliciting expert opinion
- Detailing meeting minutes, including high-level summaries of technical information generated or received during TAT meeting discussions and "lessons learned" or "next steps" documentation
- Creating additional outreach materials

With consensus among the SC, the TWDB selected the Meadows Center to assist the TIFF planning project with the facilitation services mentioned above. The Facilitation Team meets regularly with the SC to ensure that facilitation needs are fully met.

1.1.3.3 TECHNICAL ADVISORY TEAMS

TIFF incorporates a collaborative approach to engage experts from governmental agencies, academia, and stakeholders with regional experience through the formation of four specialized TATs. These four teams correspond to and are helping develop each of the four components of the framework. The TAT members include technical experts selected by the SC based on their technical expertise and institutional knowledge of flood mitigation in Texas and beyond. TATs serve as the source of expertise guiding the TIFF project from vision to execution.

The SC identified 172 nominees for the four TAT teams based on the project needs, requirements, and suggestions from GLO. Between February and March 2021, the SC conducted initial outreach to determine whether a nominee had the availability and capacity to serve. The SC sent official invitations between March 18-26, 2021 to nominees who agreed to serve, via email using the TIFF@twdb.texas.gov address, which is used for all official TIFF communications. A sample of an invitation is provided in Supporting Information 1-1. The invitation included additional information about the TIFF planning project to assist nominees in making an informed decision about joining a TAT (Supporting Information 1-1). After carefully discussing the expertise and background of the identified nominees and receiving confirmation from the approached nominees, the SC confirmed membership for 96 people (Table 1). A list of all confirmed TAT members is provided in Supporting Information 1-2. The TAT members (96 people among the four components) are well-known experts in various aspects of coastal flooding, including data monitoring, new monitoring technologies, data management and visualization, modeling, planning, and outreach.

TAT members serve voluntarily and participate in meetings at the beginning of the project, throughout the project based on specific needs and milestones, and at the end of the project. TAT members receive summary information, data, and project materials before TIFF meetings to ensure well-informed and productive discussions. Members are invited to share information and insights on the best available science, state-of-the-art models, methods, and emerging technologies.

Table 1: List of the four TIFF components, including the number of initial TAT nominees and final TAT members as of June 2021

Teams	Nominees	Confirmed Technical Advisory Team Members*
Component 1: Data and Monitoring Gap Analysis	43	20
Component 2: Data Management and Visualization	33	19
Component 3: Integrated Flood Modeling Framework	48	28
Component 4: Planning and Outreach	48	29

* The number of people in each TAT varies and changes based on project needs and the availability of experts to continue their participation.

The SC has asked TAT members to support the following general and component-specific tasks:

General Tasks:

- Establishing SMART (Specific, Measurable, Attainable, Relevant, and Time-based) goals for the flood modeling framework
- Guiding the selection of best technological solutions to ensure a strategic flood modeling framework
- Providing technical feedback and professional advice
- Reviewing and commenting on deliverables

Component 1 Tasks (Data and Monitoring Gap Analysis):

- Identifying available data and establishing a plan for obtaining critical information for successful flood monitoring and modeling
- Guiding the expansion and improvement of observational data and data archives for atmospheric, inland, coastal, and ocean systems.
- Assisting with an inventory analysis of all currently available hydrologic, hydrodynamic, meteorological, and planning data, including data necessary for model calibration and verification
- Helping develop a gap analysis methodology using geospatial and analytical tools to identify and prioritize data needs for monitoring, modeling, and planning
- Guiding the development of a priority list of monitoring systems and locations
- Recommending new monitoring technologies for testing and a decision matrix for evaluating new monitoring technologies
- Advising on data sharing, archiving, and best practices for quality assurance and quality control in close cooperation with the Component 2 TAT

Component 2 Tasks (Data Management and Visualization):

- Identifying uniform data standards and methods for interoperability that can be integrated into the systems maintained by agency partners, including TDIS, Interagency Flood Risk Management (InFRM) initiatives, and the TWDB's Data Hub and Flood Decision Support Toolbox
- Assisting with designing the conceptual framework for data transmission, management, and dissemination, including a data visualization system
- Guiding the design of an operational framework for data flow between models
- Recommending computational hardware/software requirements for implementation

Component 3 Tasks (Integrated Modeling Framework):

- Developing the integrated modeling framework to support inland and coastal flood hazard identification
- Assisting with an inventory analysis of existing and proposed models for planning, real-time simulation, and forecasting purposes
- Providing support to assess and vet potential meteorological, hydrologic, hydraulic, and hydrodynamic models for the evaluation and mitigation of flood risk for Texas
- Assisting with developing a conceptual model-coupling strategy, including the coupling of hydrologic-hydraulic and estuarine-surge models
- Performing literature review for suitable probabilistic analysis method identifications for flood hazard estimation
- Recommending scenarios and an evaluation matrix to test the effectiveness of the conceptual model integration strategy

Component 4 Tasks (Planning and Outreach):

- Guiding the SC on best practices for conducting outreach focused on regional and state flood planning and mitigation needs and generating guidance documents for tools that support flood planning in Texas
- Supporting coordination with RFPGs, stakeholders, and TATs for Components 1 – 3 to identify flood planning and mitigation scenarios consistent with regional flood planning efforts

- Helping the SC to find recommendations on how the data and modeling frameworks could incorporate the various end-users' flood planning and mitigation needs and ensuring that the findings from various efforts are well communicated
- Assisting with the expansion and improvement of flood planning in Texas by incorporating the new findings into the existing planning tools or recommending the creation of new tools
- Providing support to balance and communicate between project-based and regional planning scale solutions

As of December 2022, TIFF hosted a total of ten meetings and workshops with TAT members. The SC plans to hold the next series of TAT meetings in March 2023.


Houston flooding during Hurricane Harvey © Trong Nguyen, Adobe Stock

1.1.4 Project Execution

Figure 1 shows the general approach used by TIFF to execute project efforts and the process for gathering feedback from the TATs. The SC seeks to collaborate with experts in the field of coastal flooding to leverage critical knowledge and expertise. Feedback on end-user needs and collaboration with experts across many disciplines will ensure valued and relevant TIFF products. TIFF engages with technical end-users through interactive meetings and other direct forms of communication (i.e., surveys, workgroups, emails). The ultimate goal of TIFF is to pioneer new collaborative efforts that address compound flooding impacts in Texas and to establish the TIFF project as a benchmark for future efforts in this field.

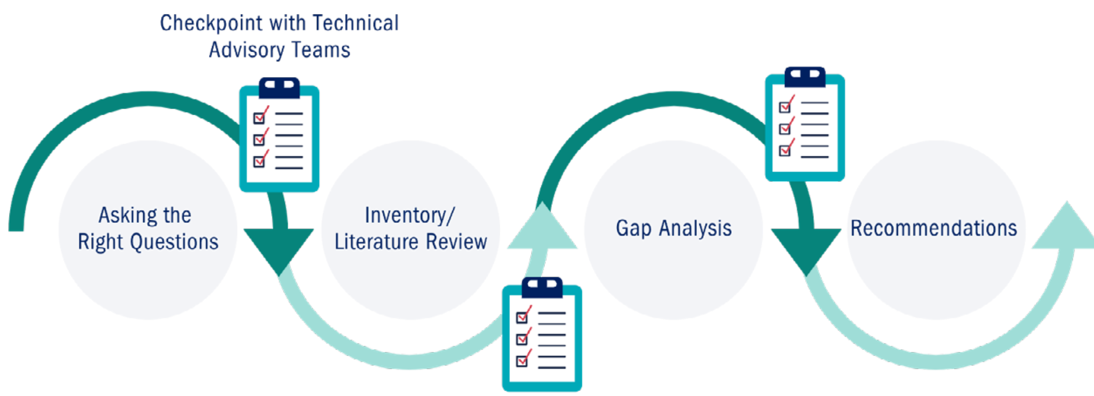


Figure 1: The TIFF execution plan for working with stakeholders and obtaining information for useful and trusted recommendations

Before the SC engaged the TAT members in the project, the SC conducted an inventory analysis for all existing and ongoing flood-related modeling and data-driven projects in Texas to avoid redundancies. The inventory analysis uncovered several questions that have not been answered through existing projects, which TIFF used to form the questions this project seeks to answer. The following section details this process which was also a TIFF deliverable to the GLO.

1.2 Existing and Ongoing Statewide Flood-Related Modeling and Data-Driven Studies/Projects

As a part of the project, TIFF collected information on current and recent statewide flood-related modeling and data-driven studies/projects. This information was assembled for interested stakeholders and contains basic project information, project funding sources, and a point of contact for the various projects across the state. The projects included in this inventory focus on coastal flooding. The list does not include all projects in the state, only those that have a state-wide focus or involve more than one coastal county. However, a few local projects of interest are included as well. Pilot projects with the potential to expand the focus to include larger areas will also be considered. Information on physical or infrastructure projects are not included (unless it is digital infrastructure). Projects with one of the aforementioned criteria will be called “statewide” for the rest of this report.

Initially, TIFF made a concerted effort to gather available project information from websites and reports. Next, the SC shared the initial list of 87 projects with TAT members from all four TIFF components for their review. An email was sent to the TAT members on January 3, 2022, and all responses were collected by January 14 (edits submitted after the deadline were also collected). After reviewing the edits from TAT members, the inventory identified

132 projects that fall within our definition of "statewide," along with 15 additional projects that are considered "local."

Figure 2 shows the breakdown for the collected projects. The statewide projects with a brief description, source of funding, and their point of contact information are provided in Supporting Information 1-3. All projects, including the local projects, are also listed in an online Excel file that will be updated frequently.

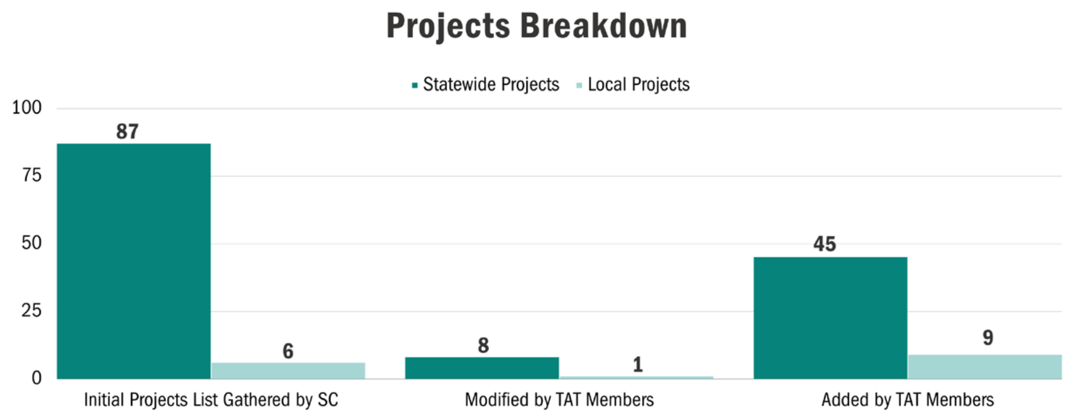


Figure 2: The The breakdown of statewide and local projects based on the contributors

1.3 Initial Meetings

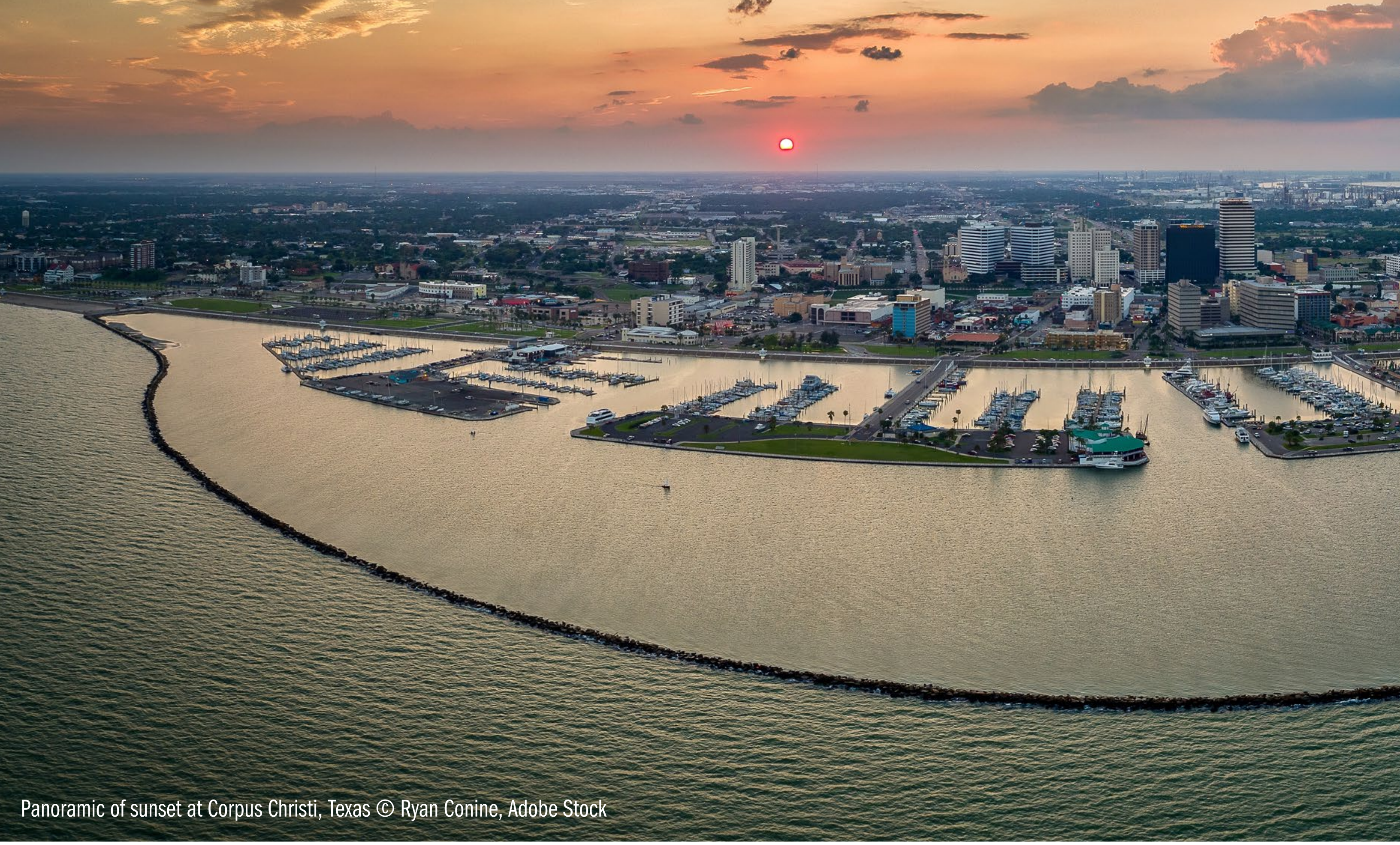
After carefully reviewing the existing coastal flood-related projects identified in the inventory analysis, the SC initiated meetings with TAT members and RFPGs to introduce TIFF and gather feedback about their needs.

1.3.1 TAT Kickoff Meeting

TAT members were invited to participate in the kickoff meeting by email invitation sent March 29, 2021. Fifty-six people accepted the invitation and 71 participated in the TAT kickoff meeting virtually in Zoom on Monday, April 5, 2021, from 1 to 2:30 p.m.

A copy of the agenda is attached as Supporting Information 1-4, a roster of attendee is attached as Supporting Information 1-5, and meeting notes are provided in Supporting Information 1-6. After the meeting, on April 8, 2021, a follow-up email was sent to all the participants to thank them for their participation and to share meeting materials (Supporting Information 1-7).

During the kickoff meeting, GLO provided a big picture overview of the ongoing flood-related efforts in the state and how the TIFF planning project complements these efforts. The three TIFF partners (TWDB, USGS, and USACE-Galveston District) described the TIFF planning project's goals, visions, and provided details about each of the four components. The SC members also shared their respective agency's vision of TIFF, challenges related to coastal flooding (with an emphasis on compound flooding), and how the TIFF planning project can help to address some of these challenges. The Meadows Center was introduced as the TIFF Facilitation Team that assists the SC with stakeholder collaboration outreach, specifically to facilitate the TAT meetings. Following a 30-minute question-and-answer session, the meeting was adjourned.



Panoramic of sunset at Corpus Christi, Texas © Ryan Conine, Adobe Stock

1.3.2 Meeting with RFPGps and Coastal Liaisons to Identify End-Users

The TIFF planning project incorporates a collaborative approach by engaging experts from governmental agencies, academia, and stakeholders with regional experience. To identify TIFF's end-user needs, and to leverage the existing efforts in Texas, the SC held a meeting with the coastal liaisons of the RFPGs. The SC sent a calendar invite with the meeting agenda on July 20, 2021. A total of 38 people received the invitation. A copy of the agenda is attached as Supporting Information 1-8. The Meadows Center hosted the coastal liaison RFPG Meeting virtually in Zoom on Wednesday, September 1, 2021, from 9 to 11 a.m.

A sample of the emailed invitation is provided in Supporting Information 1-9. A total of 36 people (coastal liaisons, other interested RFPG members, TWDB employees who support RFPGs, TIFF Facilitation Team, and SC members) participated in the meeting (Supporting Information 1-10). The meeting successfully opened dialogue between the RFPG coastal liaisons and TIFF. The liaisons identified several important issues that will be considered in the development of the TIFF deliverables. The coastal liaisons also expressed their willingness to be informed on TIFF milestones and to continue providing feedback to the TIFF. Meeting notes are provided in Supporting Information 1-11.

TWDB and GLO began the coastal liaison RFPG meeting (Supporting Information 1-11 provides more information on the RFPGs) by sharing background information on the TIFF planning project, compound flooding, and a big picture overview of how the TIFF project connects with ongoing statewide flood planning efforts. The three TIFF partners were all present at the meeting and expressed the crucial role that the coastal liaisons and RFPG members play in helping to identify the end-users of the TIFF project. The SC emphasized that the outcome of this meeting and the future involvement of TIFF in state flood planning efforts were not meant to generate any additional workload for the RFPGs. However, the

Panoramic of sunset at Corpus Christi, Texas © Ryan Conine, Adobe Stock

SC members stated that they believe the more input from the RFPGs, especially the coastal liaisons, given during this collaborative process, the more likely the TIFF recommendations could support the flood planning process for all that participate in the future.

During the meeting, various participants shared their thoughts and concerns about flood planning for the communities they serve and talked about the challenges, both unique to their region and/or common across the coast, to flood planning efforts throughout the state. A summary of these points is provided below:

- Local drainage districts and regional flood planners indicated there are often challenges faced by those groups downstream from decisions made by upstream groups. Furthermore, the ability to include these decisions from upstream planners into local models for flood planning in downstream districts would be very helpful.
- Concerns were expressed throughout the meeting about avoiding redundancy and duplication in flood planning efforts. One of TIFF's goals is to avoid these duplicative efforts through careful documentation and cataloging of flood planning efforts throughout the state and building relationships at local, regional, state, and federal levels.
- Some participants expressed concerns about more isolated or rural communities not being able to receive financial or planning assistance from state or federal sources due to a complex application process and lack of resources available to those communities. It was agreed that this concern was a problem and efforts are being made to improve processes going forward.
- Participants would like to keep up with TIFF progress and stay updated but were unsure on the best way to communicate. A quarterly to bi-annually communication effort was suggested. The virtual meeting platform works well for almost all.

1.3.3 TAT Individual Component Meetings

TIFF held its first series of TAT individual component meetings in December 2021. The meetings introduced TAT members to the Component Champions (a member of the SC designated to champion each Component). The theme for each of these meetings was "are we asking the right questions?" and the Component Champions each provided the questions that TIFF is trying to answer in each component.

1.3.3.1 COMPONENT 1

TIFF held its first series of TAT individual component meetings in December 2021. The meetings introduced TAT members to the Component Champions (a member of the SC designated to champion each Component). The theme for each of these meetings was "are we asking the right questions?" and the Component Champions each provided the questions that TIFF is trying to answer in each component Supporting Information 1-12.

This first meeting provided an overview of the component's objectives, introductions of the Technical Advisors, and background information regarding TIFF's structure and direction. TIFF's collaboration with TDIS to develop a framework and software to show data availability for mitigation of coastal floods was also introduced and described. The TAT members reviewed and updated the results of Survey One (Supporting Information 1-13), which asked participants to refine a list of datasets relevant to coastal flood analysis. The datasets were divided into ten different data classes, including:

- Built Environment
- Ecological
- Hazards/Engineering
- Imagery
- Literature Source
- Mitigation Support
- Models/Parameters
- Soils
- Topography/Bathymetry
- Natural Environment

Participants made recommendations regarding the structure and approach of future work, including their preference to work in small groups. Concerns were expressed about the standardization for data collection, categorization of the data as it is inventoried and methodologies by which the data was collected prior to being inventoried. It was suggested that data for the inventory be categorized and tagged multiple ways and that multidimensional categories, as well as tiered use cases for each dataset would be best. There was a recommendation to continue gathering datasets and to refine these datasets as needed while tiering the data into use cases as it is collected.

The questions compiled by TIFF on Component 1 goals were:

1. What datasets are important to coastal analysis?
2. How do we classify each of these datasets?
3. What metadata are required?
4. Do we need to refine the lists, or is having more datasets better?
5. Should we create data classes?
6. Should we tier the datasets into groups by importance?

A comprehensive list of the questions and comments posed by participants during the meeting can be found in Supporting Information 1-12. For more information on Component 1, see section 2.1.

1.3.3.2 COMPONENT 2

The first Component 2 TAT meeting was held virtually in Zoom on Wednesday, December 8, 2021, from 9 a.m. to 12 p.m. A total of 19 Component 2 TAT Members accepted the November 1, 2021 calendar invitation, and a total of 20 people attended the meeting. Meeting notes and the participant list are provided in Supporting Information 1-14.

Component 2's first meeting included an overview of the TAT's objectives, introductions of the Technical Advisors, remarks from the TDIS, and a discussion of the needs for data management and better visualization tools for coastal and compound flooding. The Component Champion (TWDB) discussed the need to make sure the right questions are being asked when it comes to understanding collecting information on who the end-users of these visualization tools (and data) are, and what those end-users ultimately need most to make decisions. Moreover, it was concluded that standardization of visualization tools becomes more critical when decisions made from the information are meeting a more immediate need. Going forward, all agreed that working groups would be a good way to continue working on these issues and there was a lot of interest in seeing presentations from TAT members that have experience and information that would be useful for developing these tools.

The seven questions compiled by TIFF on Component 2 goals were:

1. What information should be available to the technical and non-technical users to have a better understanding of compound flood, its risk, and mitigations strategies?
2. What are the best ways to visualize compound flooding risk scenarios? What types of choices should be available?
3. What resolution should be available for the technical and non-technical users?
4. What types of analysis/data manipulation should be available to the technical and non-technical users?
5. What end-users and for what purposes might need uniform map legend?
6. Could the current hardware/software handle the visualization and analyses both for UIs and technical community?
7. What considerations should be given when designing operational framework for data flow/exchange among models?

The participant responses to a survey that asked "are we asking the right questions?" is shown in Figure 3.

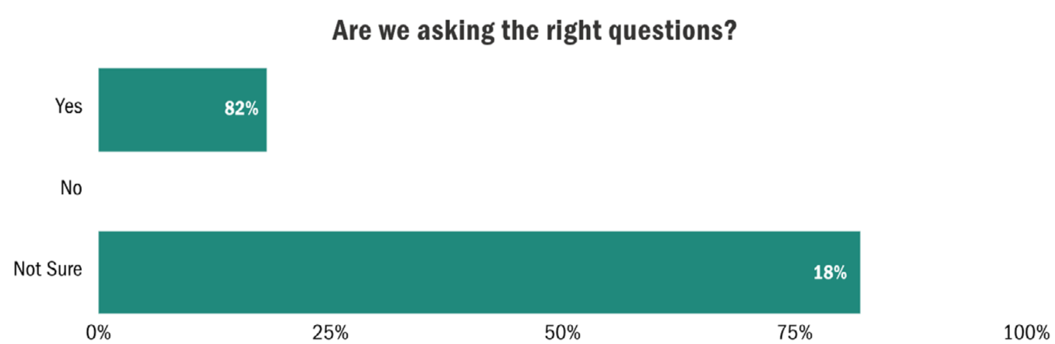


Figure 3: Participants' responses to a survey asking "are we asking the right questions?" for Component 2

Since the majority of participants were not sure about the questions provided by the SC, they were asked if there are any other questions we should ask. See Supporting Information 1-14 to view all of the participant's feedback captured during the meeting.

1.3.3.3 COMPONENT 3

The first Component 3 TAT Meeting was held virtually in Zoom on Tuesday, December 7, 2021, from 9 a.m. to 12 p.m. A total of 25 Component 3 TAT Members accepted the October 22, 2021 calendar invitation, and a total of 29 people attended the meeting. Meeting notes and the participant list are provided in Supporting Information 1-15.

The Component 3 Champion (USACE-Galveston) shared that TIFF is creating a network of people working together to solve a number of problems related to coastal and compound flooding. It is not thought that this network will solve any specific issue but rather a host of issues and problems associated with flooding in this country. TIFF should work to identify a better way to communicate flood risk and uncertainty in model outcomes to communities and decision-makers. Communicating risk through a "risk flow" concept where risk is shown to change for different areas at different times may be a better way to help the public understand how risk can change. Human intervention, data assurance and certainty, and lack of automation processes for data processing into models are some of the challenges modelers face in trying to find the best models for flood management.

The 12 questions and challenges compiled by TIFF on Component 3 goals were:

1. What are the challenges of current approaches to compound flooding?
2. What features do we need to consider while developing the model coupling framework?
3. What criteria should we consider while selecting the testbed for the model framework evaluations?
4. What points should we consider while performing literature review to assess each component model (meteorological, hydrologic, hydraulic, hydrodynamic, wave) suitability for their inclusion in the modeling framework?
5. What parameters are critical for evaluating compound flooding hazard within a probabilistic framework?
6. The lack of holistic literature review on probabilistic flood hazard estimation.
7. Which scenarios do we need to simulate for evaluating the model framework performance in capturing the compound flooding hazard?
8. What metrics should we consider for evaluating model performance?
9. What points should we consider addressing relative sea level rise and future climate change scenarios?
10. What are suitable methods currently available for model grid development?
11. The need to identify transitional regions.
12. What are the other key components and questions we need to address to meet the present and future flood modeling needs?

See Supporting Information 1-15 to view the participant responses to these questions and other comments and questions raised during the meeting related to the integrated framework.

1.3.3.4 COMPONENT 4

The first Component 4 TAT Meeting was held virtually in Zoom on Thursday, December 9, 2021, from 9 a.m. to 12 p.m. A total of nine people accepted the November 1, 2021 calendar invitation, and a total of 22 people attended the meeting. Meeting notes and the participant list are provided in Supporting Information 1-16.

The first meeting of the Component 4 TAT included an overview of the TAT's objectives, introductions of the Technical Advisors, an overview of USACE's role in TIFF's planning and outreach, and background information regarding the structure and direction of TIFF. The TAT also provided feedback on the SC's approach to TIFF's planning and outreach strategies. Different audiences require different outreach strategies, so defining the end-users of the TIFF products will be a major step in shaping how TIFF is developed and designed. Understanding the target end-user groups, working directly with communities to learn what information they need and the best way to communicate with them will facilitate building trust with the end-users. Effectively communicating risk and uncertainty in model predictions to all who use them, especially the general public, will also be an important element to building trust.

The five questions compiled by the TIFF on Component 4 goals were:

1. Who are the end-users of TIFF products?
2. How should TIFF exchange information and receive feedback from both end-user groups?
3. How can we build trust with the end-user groups to establish the TIFF project as a reliable and trusted source for recommendations, guidelines, standards, and as a comprehensive framework for compound flood information and assistance?
4. What new flood communication methods should TIFF utilize to better translate model outputs in a way that is accessible and understandable to the general public?
5. How should we incorporate compound flooding into the state's existing planning tools?

The participant responses to a survey that asked "are we asking the right questions?" is shown in Figure 4.

Since half of participants were not sure about the questions provided by the SC, they were asked if there are any other questions or comments the SC should be asking and considering. Refer to Supporting Information 1-16 to view the participant responses related to communication, education, and the TIFF Outreach Plan.

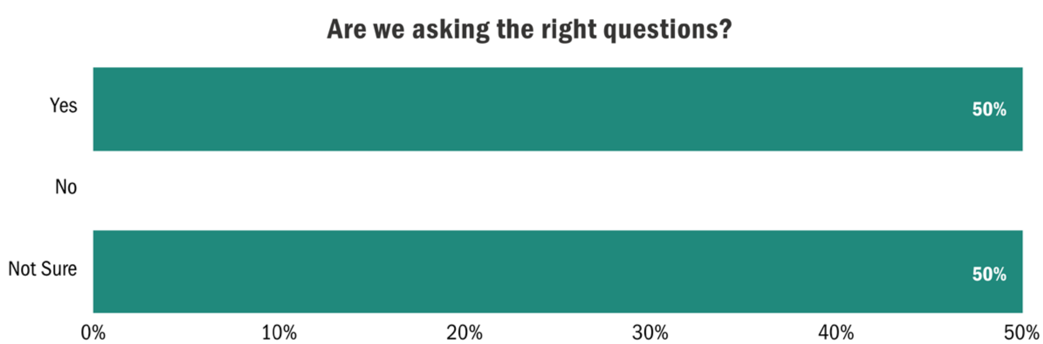


Figure 4: Participant responses to a survey asking "are we asking the right questions?" for Component 4

The SC had a debriefing with the Facilitation Team to discuss feedback resulting from the first round of TAT meetings. The SC and the Facilitation Team used the new information gathered from the TAT members and coordinating agencies to make amendments to the GLO contract to better reflect the TAT-informed project goals, objectives, and envisioned structure.

Road collapsed following Hurricane Ike on September 15, 2008 in Galveston, Texas © Scott Olson

2 Component 1 - Data and Monitoring Gap Analysis

This component aims to identify available data and data gaps and establish a plan for obtaining data critical for successful coastal flood analysis. Component 1 supports the expansion and improvement of data observations for inland, coastal, and ocean systems. This effort is broken down into individual tasks, as listed below. The SC is performing each of the following tasks in collaboration with the Component 1 TAT. Initial results for tasks one, two, eight, and nine are described in this report.

1. Establish a Data and Monitoring TAT to support Component 1
2. Assist TDIS in determining the appropriate data structure for creating a tool to display and evaluate the availability of all data applicable to flood-related analyses used for planning and mitigating coastal floods
3. Provide TDIS with associated data linkages for critical coastal flood analysis use cases as determined by the TIFF TATs
4. Evaluate and provide feedback to the GLO on
    a. the initial data inventory provided by the Study Providers, and the associated data availability tool provided by TDIS.
2. Perform a gap analysis for use cases with the feedback of the TATs to identify data needed to improve observations for coastal flood analysis
3. Develop and recommend a plan to periodically update the data inventory
4. Develop and recommend a plan to periodically perform data gap analyses
5. Evaluate and provide updates on new monitoring technologies
6. Provide recommendations pertinent to data and monitoring for coastal flood analysis to the GLO
7. Prepare, at a minimum, the findings and compilation of Component 1 tasks performed for inclusion in the Annual Report for Years One, Two, and/or the Final Report. All reports shall be presented to the GLO for its review and approval

The creation of a Data and Monitoring TAT was discussed previously in Section 1.1.3.3. This chapter will describe the applicable data structure for the creation of a data availability tool provided to TDIS, the data inventory related workshops on bathymetry and subsidence hosted by Component 1, and updates on new monitoring technologies.

2.1 Applicable Data Structure for the Creation of a Data Availability Tool Provided to TDIS

In collaboration, TDIS, Components 1 and 2 TATs, and GLO's Combined Flood Studies are developing the framework, infrastructure, and software to display and evaluate the availability of all datasets applicable to coastal flood analyses used for planning and mitigation of coastal floods. The first step in this endeavor included developing an inventory of all models and datasets applicable to mitigating coastal floods.

As with all inventories, a data inventory should start with an understanding of what is being inventoried and why. Component 1 engaged the TATs by asking for volunteers to join a Data Workgroup to determine what datasets apply to coastal flood analysis. The SC created a list of approximately 100 datasets split into ten major data classes. Then, the SC asked the Data Workgroup participants to review each data class and its associated datasets and add any additional datasets that apply to that data class. As a result, an additional 53 datasets were identified. Next, TIFF curated the results into a list of 143 individual datasets that are shown in column three (TIFF Initial Dataset Name) of Supporting Information 2-1.

The next step in a data inventory is to create a well-defined organizational structure, called a data taxonomy. A data taxonomy is the classification of data into hierarchical groups to create structure, standardize terminology, and populate an inventory within an organization. The taxonomy described herein is the initial product of cooperation between TDIS, TIFF, and the RFSGs. The RFSGs, as part of their initial work orders, created Data Collection Plans for each of their four regions. The creation of a database was required to provide centralized access to an authoritative catalog of data for use in their projects. The complex nature of the many types and uses of data required for coastal flood analysis presents challenges for the development of rigid categories. In many cases, a singular dataset may be categorized differently based on the use case, the background of the data collector, or various other reasons. The RFSGs developed a set of discrete categories to limit this as much as possible using standardized criteria for organizing data. However, after further investigation, TIFF found differences between the RFSGs in what was determined to be critical data, data categorization, and naming conventions. Due to these differences in the taxonomies used by each RFSG, it was determined that a single standardization system was needed.

TIFF then created a single RFSGs-TIFF Data Classification Map, relating the curated list of critical datasets created by the Data Workgroup with the lists and categories developed by the RFSGs, while taking care to as closely as possible mirror the initial schema presented by the RFSGs. This Data Classification Map also included a TIFF Data Themes field to relate datasets that may fall into different categories based on the use case or other reasons. TIFF then asked the Data Workgroup to determine any other names that may apply to each dataset and select the appropriate keywords that best described each of the 143 datasets, shown in column three: TIFF Initial Dataset Name of Supporting Information 2-1. Columns 5-12 of Supporting Information 2-1 shows the results of these efforts, with a summary of the TIFF Data Classification Workshop provided in Supporting Information 2-2.

Additionally, TDIS and TIFF have determined that a purpose-driven hierarchical structure is the most effective way of organizing the information needed to create the data availability tool by linking the purpose of analysis to each dataset. An initial iteration of the conceptual schematic for a purpose-driven structure is shown in Figure 5, with explanations of each term described below.

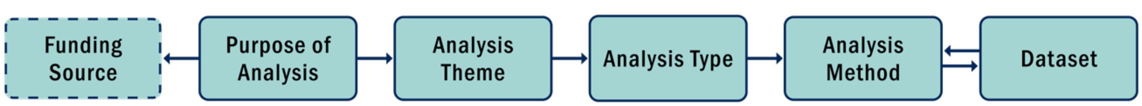


Figure 5: Schematic of the purpose-driven inventory structure

Funding Source: A source of funding that may require particular analyses, such as "Federal Emergency Management Agency (FEMA) Grant Application" or a "USACE Planning Study." A list of known funding sources will be provided, and we request the addition of a funding source where one has been omitted. Information about analyses may be added without relating them to a funding source, "None" is an option if no funding source is relevant to an analysis.

Purpose of Analysis: Indicates the aim of analyses. A "Purposes of Analysis" may be associated with particular funding sources. For example, an "USACE Planning Study" could be submitted for "Infrastructure – Flood Risk Reduction" or "Improvement in Navigation."

Analysis Theme: Designates a broad classification of the topic area to be studied in support of the "Purpose of Analysis." For a "Purpose of Analysis" of "Infrastructure – Flood Risk Reduction" a few "Analysis Themes" include "Hydrology," "Hydraulics," and "Cost-Benefit." Each "Analysis Theme" can be investigated using one or more "Analysis Types."

Analysis Type: A specific type of analysis associated with an "Analysis Theme." "Analysis Types" are not constrained to numerical models, they should include any analyses used for an "Analysis Theme". For example, the "Analysis Theme" of "Hydrology" has "Analysis Types" that include "Flood Frequency Analysis," "Hydrologic Modeling," and "Precipitation Analysis."

Analysis Method: Indicates the methodology used to perform a particular type of analysis. For the "Analysis Type" of "Hydrologic Modeling" many "Analysis Methods" are possible. Examples of software-dependent analysis methods include "the Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS)," "Soil and Water Assessment Tool (SWAT)," or "the Precipitation-Runoff Modeling System (PRMS)."

Dataset: The data that relate to a specific topic and are collected or generated for a particular purpose. Examples include "Land Use/Land Cover." A "Dataset" can be the input to or the output of an "Analysis Method."

Figure 6 shows a possible example of how the "Analysis Method" of HEC-HMS may be used in support of a particular "Purpose of Analysis." This example generally illustrates the connections to be made and the expected branching structure as each "Purpose of Analysis," "Analysis Theme," etc., is filled out to "Dataset" inputs and outputs. TIFF then held a workshop with the Data Workgroup to gather feedback on the framework, focusing on the areas of "Purpose of Analysis," "Analysis Type," and "Analysis Method."

The workshop included an interactive, facilitated discussion to solicit feedback on the purpose-driven structure and determine what analysis types and methods are important to workshop participants. TIFF asked participants to answer the questions associated with each framework element and consider whether their contributions are high priority (important in the near term) or low priority (important in the long term). Participants contributed their feedback and responses verbally or by using Miro, a virtual and collaborative white boarding tool. Supporting Information 1-15 includes a summary of this workshop.

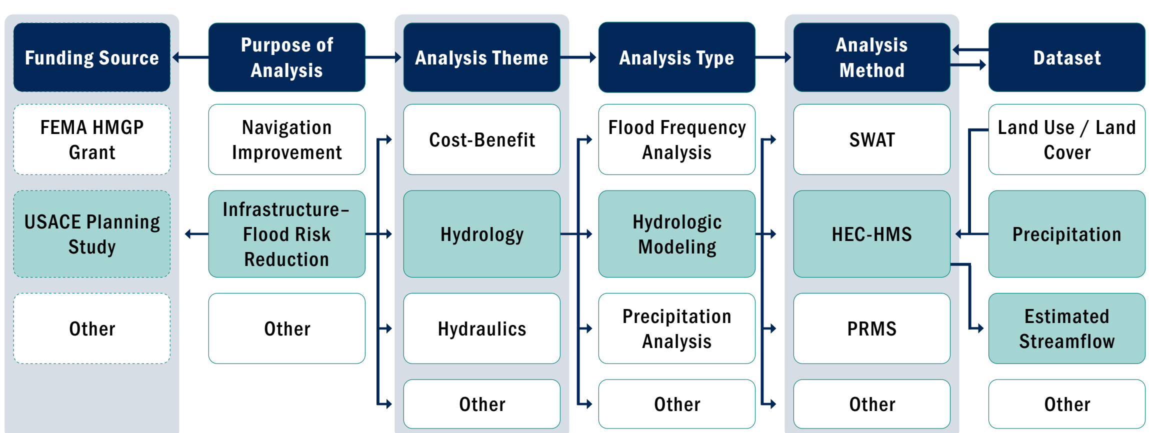


Figure 6: Example of hydrologic modeling using the HEC-HMS within the purpose-driven structure

2.2 Data Inventory Related Workshops

2.2.1 Bathymetry Workshop

Bathymetric data is one of the most important datasets for coastal modeling, but there are obstacles to collecting high-quality data. Bathymetry represents the three-dimensional features of underwater terrain, or bed elevation, which is dynamic and changes with natural and anthropogenic influences. Data must be collected regularly to ensure it is current, accurate, and useful for coastal modeling. Additionally, collecting bathymetry data is generally costly, and agencies collecting bathymetry data could improve collaboration to better coordinate data acquisitions and leverage limited funding resources.

While numerous agencies collect and share bathymetry data, it can be difficult for end-users, like modelers or the general public, to access the data. To address this, TIFF used insights from its TAT members and other experts to identify the highest priority areas for bathymetric data needs along Texas coast. The TIFF recommendation for priority areas considers only the feedback from survey participants; thus, is limited with respect to representing the broader stakeholder community.

The SC hosted a virtual bathymetry workshop with 90 participants (Supporting Information 2-3) on May 18, 2022, to improve statewide collaboration and expand bathymetry data collection in Texas. The workshop gathered insights from the TAT members, other bathymetry experts, and end-users to develop a statewide priority map for bathymetry acquisition needs and to target available resources.

To provide attendees with a broad overview of the bathymetric data landscape in Texas, the workshop opened with a screening of nine pre-recorded presentations from bathymetry data experts. Each presenter described the tools and data sets available from their respective agencies and their organization's plans for data in the coming years. The SC allowed attendees to view the pre-recorded presentations before the workshop, which collected 98 views across the nine presentations before the event. The links to view the pre-recorded presentations are provided in Supporting Information 2-3.

The second half of the workshop focused on the need for bathymetry data in Texas, current obstacles for data acquisition and management, and how TIFF could address these issues for the state, followed by an open discussion.

TIFF asked attendees to use an online Bathymetry Mapping Survey (developed by TWDB) to submit information about areas where they have the highest need for bathymetry. TIFF also asked attendees to send any files that they have available. This information was used to conduct an inventory and gap analysis for bathymetry data, which resulted in a TIFF recommendation for the areas needing immediate data acquisition and the estimated costs to complete the work, as presented in the next sections.

2.2.1.1 INVENTORY ANALYSIS

After receiving the participant's survey responses, TIFF exported the results as a shapefile for analysis. A total of 15 Areas of Interest (AOI) were received: 13 through the survey and two via email. Among the 15 AOI, one was not along the coast, so it was sent to the TWDB's River Science and Hydrosurvey Departments for future reference.

Figure 7 shows all AOI along the Texas coast. The bathymetry acquisition justification for each AOI and any information provided by the TIFF Bathymetry Workshop participants are shown in Table 2.

Table 2: AOI identified by the TIFF Bathymetry Workshop participants and justification for the bathymetry acquisition

AOI	Why should bathymetry data be collected in this location?	Information to narrow or expand the selected area	Is the water transparent enough to use LiDAR?
1	We have a Texas General Land Office project and San Bernard River bathymetry (Below water where U.S. Geological Survey elevation maps do not capture) has been very hard to find	Lower Reach of San Bernard	I don't know
2	Very poor representation of the Rio Grande River and nearby floodplains		I don't know
3	There is an active design project by Texas A&M University that requires survey ASAP and will lead to a permitted construction project. Project is included in the USACE Texas Coastal Plan and has been submitted for Tier 1 status in Texas General Land Office Texas Management Plan	Could expand further into Matagorda Bay and Keller/Lavaca for other interests, if needed.	No
4	Support design modeling and flood forecast modeling efforts in the region. The Harris County Flood Control District currently runs riverine flood forecast models that do not take into consideration the coastal boundary and have diminishing performance in tidally influenced areas.	Goal is to include tidally influenced portions of major channels that drain through Harris County	I don't know
5	Sedimentation deposits from Baffin Bay	Expand area downstream based on tidal flows	I don't know
6	Ongoing hydrologic and hydraulic characterization of primary drainage pathways (TWDB) and coastal (Laguna) hydrodynamic circulation (Texas General Land Office/Coastal Management Plan) and water quality (Texas Commission on Environmental Quality)	Lower Rio Grande Valley Development Council/Cameron County	No
7	Ongoing in-shore High frequency-Radar coastal circulation study (Texas General Land Office/Coastal Management Plan)		Yes
8	Ongoing High frequency-Radar in-shore hydrodynamic circulation study (Texas General Land Office/Coastal Management Plan)		Yes
9	Not the whole area, but hydrography of channels in this area seems to be hard to find. These areas were heavily impacted by Harvey. Chemical contamination in this area is also a problem.	Generally, where the National Oceanic and Atmospheric Administration's National Centers for Environmental Information elevation data and the U.S. Geological Survey's coastal digital elevation models lack below water definition	I don't know
10	In order to support total water level forecasting and the NextGen initiative of the National Water Model, bathymetry data along the Colorado River would be extremely useful. Multiple partners would benefit from this data	Colorado River from the Intracoastal Waterway to at least Matagorda but ideally Bay City	I don't know
11	High risk zone for surge and rainfall and sediment movement	More resolution is needed at the interface between coastline and further into ocean and also at the interface with Galveston Bay	Yes
12	Bay bathymetry data is old, currently developing a 2D model to look at sediment transport, so having the Keller Bay would be helpful for that analysis	Entire Keller Bay	No
13	Bathymetry data in this area would be extremely useful for total water level forecasting for Trinity River and for surge modeling on the back side of Bolivar Island	The area can be split into two zones. The priority is Bolivar Island and then Lake Anahuac	I don't know
14	There is no bathymetry data available for this area		Mostly No

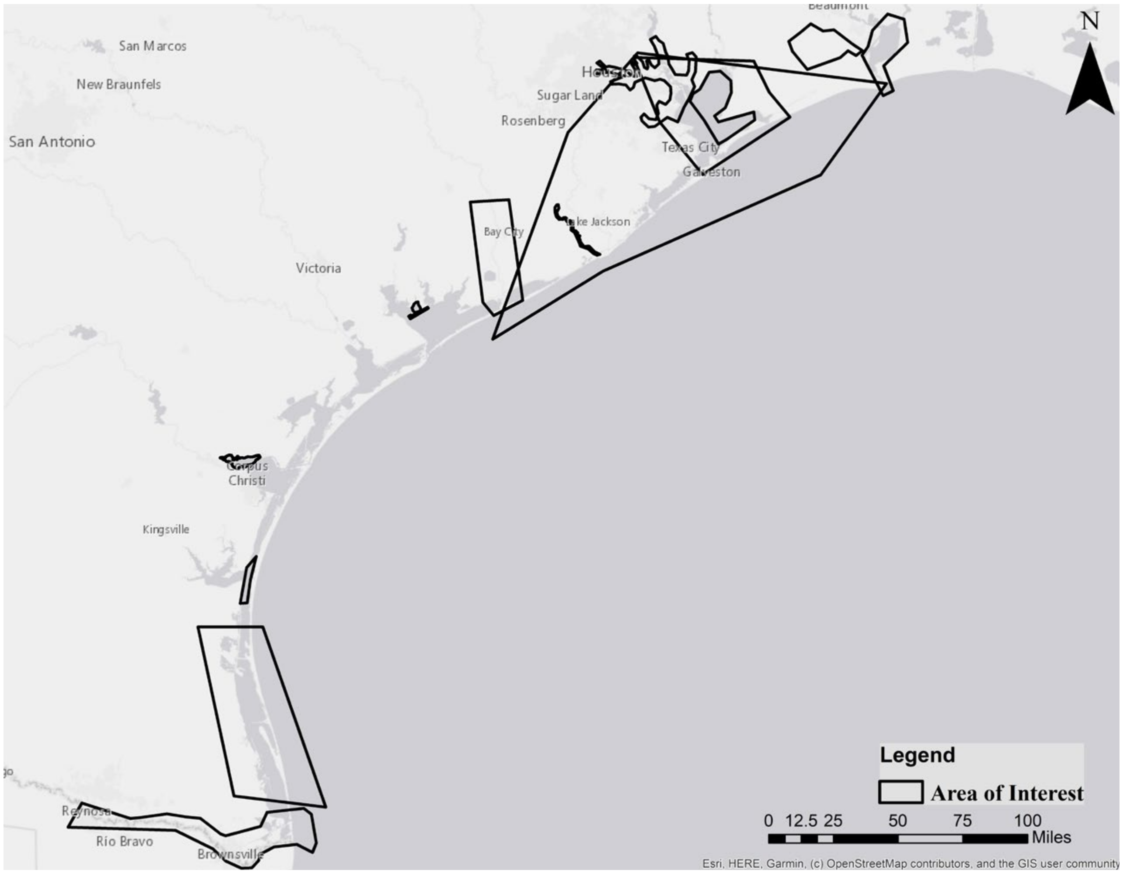


Figure 7: AOI along the Texas coast identified by Bathymetry Workshop participants

The inventory analysis was based on data from the National Oceanic and Atmospheric Administration's (NOAA) BlueTopo program, TWDB, and Texas Parks & Wildlife Department (TPWD). The BlueTopo product is a compilation of the nation's best available bathymetric data. TIFF used a Python script developed by NOAA to find and download the best available bathymetric data within each of the identified AOI. Supporting Information 2-4 provides a brief guideline on how to use this script to acquire bathymetry data for a given area. For some AOIs, TIFF acquired additional bathymetric data from various sources (details provided in Supporting Information 2-4) based on the SC's knowledge of the area and available data. For each of the AOI, TIFF generated three separate ArcMap files; in the "Bathy" files, all Elevation raster layers downloaded for the associated AOI were imported and formatted, while in the "Year" files, the Contributor raster layers were loaded and formatted. Finally, the "Gap" files include the initially suggested areas for each of the AOI. Any of the AOI spatially very close to each other were merged into a single file. All the GIS files can be found here.

2.2.1.2 GAP ANALYSIS

TIFF manually conducted a gap analysis for each of the AOI using two main criteria to suggest areas for bathymetry acquisition: 1) existing data availability and 2) the year of the last measurement. In other words, an area was suggested if there was no bathymetric data available (based on the analysis conducted in this effort) or if the last effort to collect bathymetric data was more than 20 years ago. TIFF used various tools and datasets to accurately represent suggested areas with no or old bathymetric data. For rivers, in particular, TIFF used the assessment units provided by the Texas Commission on Environmental Quality that offer a detailed shapefile for the shapes of the rivers. A buffer tool with a linear width of 50 meters was used to represent the entire river waterbody. This estimate may cause under or over-estimation of suggested areas for rivers. As mentioned earlier, TIFF generated a separate GIS file for each of the AOI that contains the suggested areas.

2.2.1.3 PRIORITY ANALYSIS

Once workshop participants identified areas with an immediate need for bathymetry acquisition within the AOI, TIFF sent a follow-up survey to the participants to prioritize the identified areas considering funding and resource limitations. The survey asked participants to rank (one to five with one being the highest) the areas they believe have the highest needs for data collection. As noted, the TIFF recommendation for priority areas considers only the feedback from survey participants; thus, it is limited with respect to representing a broad stakeholder community. TIFF received a total of 13 survey responses and calculated the importance of each area using a relative weighted sum method:

$$Importance_i = \frac{\sum_{j=1}^{13} W_{i,j}}{Maximum\ AOI\ Weight}$$

Where “i” is the location of interest, “j” is the participant’s number, and “W” is the weight which is defined as follows:

- Priority 1 = 5 points
- Priority 2 = 4 points
- Priority 3 = 3 points
- Priority 4 = 2 points
- Priority 5 = 1 point
- Not included = 0 points

In other words, the importance for a specific location was calculated as the sum of number of responses for Priority 1 multiplied to five, number of responses for Priority 2 multiplied to four, and so on for each AOI divided by the maximum weight among all of the AOI.

In addition to the TIFF post-survey results, the SC the results of the nationwide Spatial Priorities Studies conducted by NOAA’s Interagency Working Group on Ocean and Coastal Mapping Working Group in December 2021. Several federal agencies conducted the Interagency Working Group on Ocean and Coastal Mapping Spatial Priorities Studies, including:

- Bureau of Ocean Energy Management
- Department of Energy -Water Power Technologies Office
- U.S. Environmental Protection Agency - Ocean Dumping Program
- NOAA
- U.S. National Park Service
- U.S. Coast Guard
- U.S. Department of Agriculture -Natural Resources Conservation Service
- USGS

Organizations were limited to selecting 10% of the submission area, using a ten-kilometer fishnet grid, as “High”, 25% as “Medium”, and 50% as “Low.” Using the “Spatial Join” tool in ArcMap, the average values of Weighted Score were calculated within each of TIFF suggested areas.

The Interagency Working Group on Ocean and Coastal Mapping Spatial Priorities Studies used a similar method in calculating the weighted sum scores using the following criteria:

- High Priority: 3 points
- Medium Priority: 2 points
- Low Priority: 1 point

Thus, a similar approach was used to normalize the scores and calculate the importance of each suggested area based on the maximum reported score.

2.2.1.4 ESTIMATED COST

Although the cost of bathymetry acquisition depends on the type of waterbody, size of project, and method of collection we estimate, on average, it would cost $6,000-$9,000 (2021 U.S. dollars) to collect bathymetry data per square mile ($9-$14 per acre) using sonar techniques in shallow waterbodies. This estimate is based on previous contracts managed by the TWDB in 2021. We used the same estimate for all types of water (shallow, deep, and rivers), but the cost could be significantly different for various waterbodies. The actual project cost could be significantly different from the estimated cost provided here due to the aforementioned reasons.

2.2.1.5 RESULTS

Table 3 provides a summary of the gap analysis for the received AOI and Figure 8 shows the location of the suggested areas. For further investigations and acquiring the collected datasets, all the GIS files can be found here. More details and descriptions for each of AOI are provided in Supporting Information 2-4.

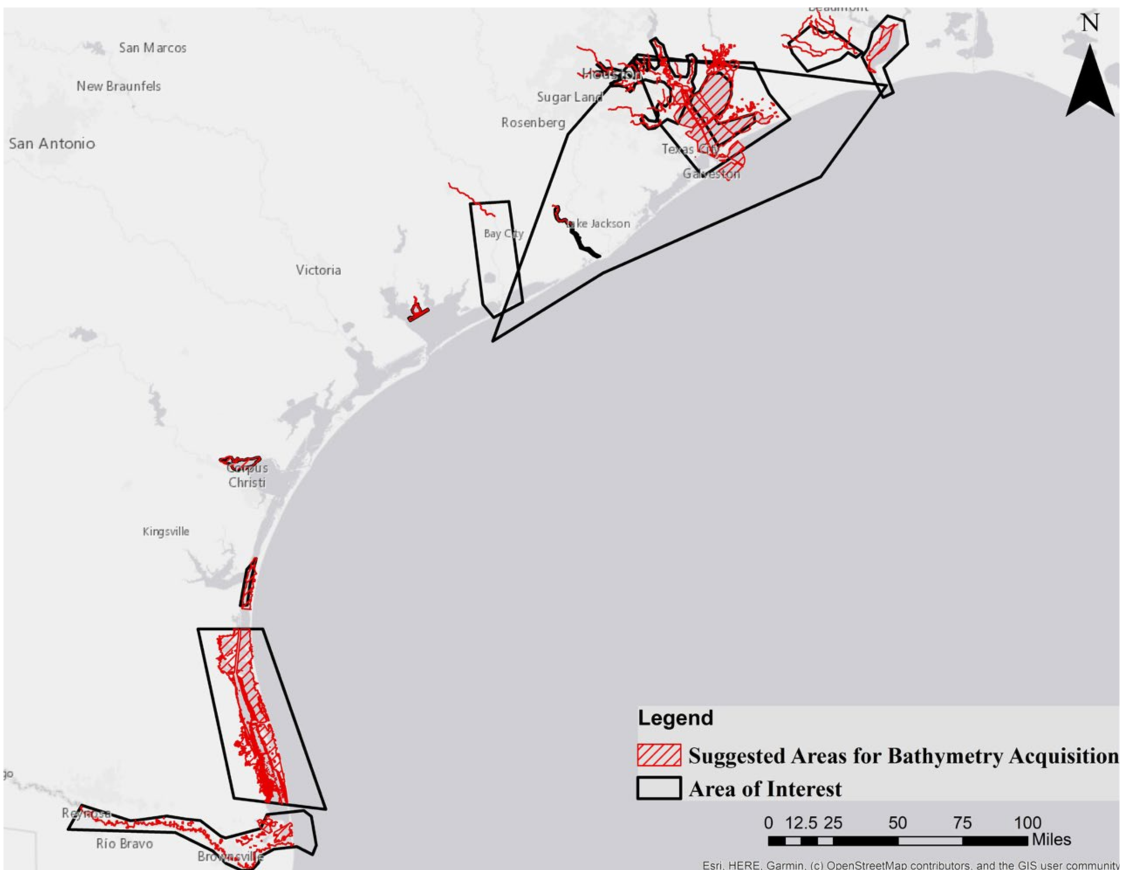


Figure 8: AOI provided by the Bathymetry Workshop participants overlayed with the suggested areas identified in the gap analysis with a need for bathymetric data collection within the AOI

Table 3: Summary of the gap analysis for the received AOI

AOI	Area Description	Waterbody Type	Reason for Suggestion	Suggested Area (mi^2)	Estimated Cost*
1	San Bernard River Tidal	River	No Data	1.16	$7-11K
2	Rio Grande River	River	No Data	13.62	$82-123K
		Shallow Water	No Data	56.91	$342-512K
3	Part of Matagorda Bay	Shallow Bay	Old Data (1991-1992)	5.11	$31-46K
4	Houston Ship Channel System and part of the Upper Galveston Bay	River	No Data	15.80	$95-142K
		Shallow Water	Old Data (San Jacinto River delta (1984 & 1995), Burnet Bay (1931), Crystal Bay (1931), Scott Bay (1931 & 1965), San Jacinto River Bay (1965 & 1996), Black Duck Bay (No data in some areas,1931 & 1965), and Tabbs Bay (1965))	13.97	$84-126 K
5	Baffin Bay Entrance	Shallow Waters	No Data	48.44	$291-436K
6	Laguna Madre[1]	Shallow Waters	No Data	446.18	$2.7-4M
7	Houston Ship Channel, San Jacinto River, Galveston Bay, Trinity Bay, East Bay System and Gulf of Mexico entrance [2]	Shallow Waters Upper GB	Old Data (1995-1996)	139.05	$835K -1.25M
		Shallow Waters Lower GB	Old Data (1962 and 1995-1996)	110.23	$661-992K
		Deep Waters GOM Entrance	Old Data (1963, 1965, and 1995)	69.30	$416-624K
8	Sabine Lake System[3]	Shallow Waters	No and Old Data (shallower parts of Sabine Lake on the Texas side: 1885)	51.43	$309-463K
9	Taylor and Hillebrandt Bayous[4]	Rivers	No Data	10.19	$61-92K
10	Colorado River	River	No Data	2.17	$13-20K
11	Houston Ship Channel, Galveston Bay, San Jacinto River, Trinity Bay, East Bay System, and Gulf of Mexico entrance[5]	Shallow Waters	Old Data (East Bay (1965))	76.16	$457-685K
		Small Lakes	No Data	9.96	$60-90K
12	Keller Bay	Shallow Bay	Old Data (1935)	10.14	$61-92K
13	Trinity Bay-East Bay system	Shallow Bay	Old Data (Trinity Bay (1965))	167.61	$1.00-1.51M
		Lakes, and Rivers	No Data and Old Data (Lake Anahuac and Trinity River delta (1933))	46.28	$278-417K
14	Nueces Bay	Shallow Bay	No Data	42.30	$254-381K

* The actual cost of the project could be significantly different from the estimated cost provided here because bathymetry acquisition cost depends on the type of waterbody, size of project, and method of collection. It is estimated that, on average, it would cost $6,000-$9,000 (2021 U.S. dollars) to collect bathymetry data per square mile ($9-$14 per acre) using sonar techniques in shallow waterbodies. This estimate is based on some of the previous contracts managed by TWDB in 2021.

[1] The suggested areas are very shallow, and the new LiDAR study funded by TWDB might cover some of the suggested areas.

[2] Please also see Areas of Interest 4, 11, and 13.

[3] Sabine Lake bathymetry is a priority for the Sabine to Galveston project conducted by USACE. More bathymetric data might become available or be collected in the near future.

[4] USACE-Galveston District might have some data for the Taylor and Hillebrandt Bayous (Area of Interest 9). An active search is being performed at the time of writing this report.

[5] See also Areas of Interest 4, 7, and 13.

2.2.2 Subsidence Workshop

Subsidence is a multi-faceted problem that affects not only land but also groundwater and surface water systems. Many agencies, universities, and organizations across the state are advancing their knowledge and data related to subsidence, but efforts are needed coordinate these efforts. The SC and TWDB hosted a virtual subsidence workshop with 177 participants (Supporting Information 2-5) on September 7, 2022, to improve statewide coordination for subsidence data collection and sharing. The goal of the workshop was to gather insights from subsidence experts, including the TAT members and faculty from various universities, about acquisition and resource needs for advancing subsidence data in Texas. The workshop served as a starting point to tackle this problem and initiate a coordinated effort to improve collaboration among experts working on subsidence issues.

The workshop opened with the screening of nine pre-recorded presentations from subsidence data experts to provide a broad overview of the current state of data availability and science related to subsidence in Texas. Presenters from academia, and state and federal agencies, described the tools and data sets available from their respective organizations and their plans for subsidence data in the coming years. Presenters from academia also provided an overview of their subsidence research and initiatives in geology, Interferometric Synthetic Aperture Radars, global positioning systems, and tide gauges. Participants had the option to view the pre-recorded presentations before the workshop, which accumulated a total 720 views before the event. The links to view the pre-recorded presentations are provided in Supporting Information 2-5.

The second half of the workshop included an open discussion and question-and-answer among the presenters and participants to uncover participants' needs and goals related to subsidence data in Texas. Some key takeaways from the discussion include:

- While the USGS has limited funding for subsidence work, they have collected groundwater level and subsidence data in Harris, Galveston, and Fort Bend counties since 1931. Many reports published by the USGS also document changes in water levels and land subsidence in the greater Houston area. The USGS is releasing a new Groundwater-Flow Model in November 2022 that will simulate current groundwater flow and land subsidence in the Gulf Coast Aquifer system and replace the Houston Area Groundwater Model.
- TWDB is currently undergoing a statewide flood planning process. The 15 RFPGs are creating flood plans for their respective geographic areas that will incorporate future flood risk. Though very little data is available to project future risk, TWDB and the RFPGs are estimating topographic changes to build subsidence into the planning process. TWDB also regularly updates topographic information for the state to better understand and project flood risk, which is available on the Texas Natural Resources Information System website. Recently, TWDB achieved statewide LiDAR coverage.
- TWDB has dedicated funding for specific program areas, but does not have a program area dedicated to subsidence. However, discretionary funds available to further the causes of flood science could fund some research related to flooding and subsidence. TWDB is actively working with TDIS to collect and display where current subsidence data is located in Texas.
- Prior to the 2015 passage of California's Sustainable Groundwater Management Act, California had been very similar to Texas in that there had not been a single entity responsible for collecting subsidence data. That act was the catalyst that funded the State of California's Department of Water Resources to operationalize the collection and reporting of ground-based and air/space-based subsidence data. While many other California agencies use it for other purposes, their data is primarily used for sustainable groundwater management planning. The annual cost to collect and maintain their subsidence data set is about $1.5 million.

Flooded coastal streets, houses, and fields after Hurricane Ike passed through Texas © USGS, Karen L. M. Morgan

The workshop concluded with a poll to gather participant feedback and gauge interest in their continued involvement with the collaborative subsidence efforts. TIFF and TWDB plan to continue hosting similar events to better understand how the state agencies can support and help advance subsidence data in Texas.

2.3 Evaluation of New Monitoring Technologies

2.3.1 Near Shore Wave Radars

One of the more important datasets that is lacking along the Texas coast identified by the TATs is wave data. Component 1 has coordinated with and has received updates from the USGS Coastal Storm Team on the project progress. The USGS deploys hundreds of storm-tide and wave sensors ahead of hurricanes and other coastal storms. The bulk of these sensors are small, internally logging pressure sensors which are installed at pre-established locations along the coast.

Collecting wave data requires much different considerations than collecting tidal or simple water level data. The Nyquist theorem states the sampling rate or sampling frequency must be twice the frequency of the signal to be measured. A rate that is twice the frequency of the measured signal works well for repetitive signals. This oversampling allows better recreation of the measured signal. Measuring wave action of water can be difficult based on the non-repetitiveness and varying shape of the waves. Thus, frequencies greater than six hertz are required to define near shore waves.

Pressure sensors have long been the primary sensor type used for collecting wave and tide data. Non-contact sensors using radar technology have been used for tide gauges for some time, but few have been used for wave analysis due to the inability to sample at the frequency necessary to define wave action. Near shore wave radars allow the system to be mounted on a structure well above the water surface and out of the way of harm that could be caused by wave energy. In the case of rapid deployment of sensors ahead of a coastal storm, they are also able to be mounted at multiple different points along a pier or other structure to better suit the data collection objectives. Near shore wave radars directly measure the water surface at sufficient frequencies to describe the wave action so there is no need to apply linear wave theory for wave calculations. They may also be mounted on the end of a structure away from pier pilings and outside of the intertidal zone to capture the full tidal cycle. As of now, USGS is in the preliminary stages of testing this equipment and the findings of this study will be made available in the next TIFF annual report. Additional technologies will be chosen for evaluation after the Wave Workshop which is planned for April 2023.

Marshland In Port Aransas, Texas © Ryan Conine, Adobe Stock

3 Component 2 – Data Management and Visualization

Component 2 ensures that technical and non-technical end-users can properly visualize any coastal flood-related data and model outcomes. This component is also supporting the data management and visualization efforts led by TDIS. Specifically, TIFF is performing each of the following tasks in collaboration with the Component 2 TAT:

- Establish a Data Management and Visualization TAT to support Component 2
- Assist TDIS with designing and testing the conceptual framework for managing, visualizing, and disseminating large volumes of coastal flood-related datasets, including data visualization system(s)
- Conduct an inventory on coastal flood-related UIs and recommend guidelines for a coastal flood UI for Texan decision-makers
- Make recommendations for UIs, including the level of end-user access, analysis capability, visualizations, and included datasets
- Assist TDIS with identifying and recommending computational hardware/software requirements for flood-related analysis and visualization
- Make recommendations pertinent to future data management and visualization needs to GLO as they are identified

3.1 Coastal UIs

Proper visualization of processed coastal flood-related data and model outputs is critical for enabling technical and non-technical end-users to make well-informed decisions. The specification required for a successful visualization of UIs that maximize the usability (to make a decision) of shared information and minimize any confusion and misunderstandings could be the use of general or specific to end-user groups. An example of a general specification is Miller's (1956) "seven, plus or minus two" (7±2) visual information capacity limits, which posits that a fundamental aspect of human cognition is that we can only process information in small chunks between five to nine bits. This property of the human brain greatly affects the design aspects of websites, computer programs, and graphic design. Once a collection of items exceeds nine on a website, the design appears 'cluttered' to the user. Therefore, for various end-user groups, more specific criteria should be defined (e.g., velocity, water surface elevation, risks, etc.) The level of access to data and modeling outcomes (including temporal and spatial resolutions) for each end-user group, analysis capability (running scenarios, generating reports, etc.), and visualization methods (2D mapping, 3D capability, animations, etc.) should be considered.

In addition to the required criteria for coastal flood UI, the TAT members identified some gaps (see Supporting Information 1-14) in our understanding of:

- the visualization methods to demonstrate uncertainty in the models that is understandable for both technical and non-technical end-users, and
- the visualization of compound flooding risk that accounts for all components (i.e., storm surge, rainfall, relative sea level rise, king tides, etc.) that TIFF will investigate in this project.

As a first step to finding the answers to the abovementioned questions and filling the identified gaps, the TAT members created an inventory of flood-related UIs. Such an inventory could help future endeavors by TIFF in defining general and specific rules/criteria.

3.1.1 Inventory of Coastal UIs

As an initial step of the inventory, the SC members generated an inventory matrix to help create a uniform list (metadata) of comparable attributes among UI sites. The matrix contains 20 attributes, as shown in Table 4. The attribute includes the basic information such as name, interface links, partner agencies, mission and vision statements (if any), as well as other properties and characteristics of interfaces such as spatial and temporal resolution and the existence of real-time data and the application programming interface (API).

TIFF began the inventory by preparing a list of 44 interfaces with a variety of visualization functionality. However, only 34 interfaces were related to the inventory and were still functional at the time of preparing this report. The original table generated for the inventory is very large (35 rows and 21 columns) and can be found in Supporting Information 3-1 and in an online Excel file. Thus, and for the ease of illustration, we broke down the original table into a total of three tables (Tables 5 through Table 7) to show the results of the UI inventory analysis. Attributes 1 and 2 are shown in all tables. The table presented in Supporting Information 3-2 shows attributes 3-5. Attributes 6-10, 11-15, and 16-21 (shown in Table 4) are presented in Table 5 through Table 7, respectively.

The inventory revealed the followings points:

- The majority of the 34 investigated coastal UIs are only offered in English.
- Only two of the 34 UIs let the users upload shapefiles.
- None of the UIs let the users conduct new analyses.
- There are many overlaps among various UIs with regard to the data type, source, and the visualization method they use to present the data.
- Many UIs do not have/provide metadata.
- Most UIs do not have/provide a coverage map (preferably as a downloadable shapefile).
- An API is only provided in some of the UIs.
- Visualization methods are limited to basic functions such as zoom in/out, turn on/off layers, print/share map, pop-up attribute table, legend, charts, base map options, address search, and transparency. There are a few UIs with more advanced methods, such as sliding maps.
- Downloading the data is not offered by many of the UIs.

TIFF will use the results of the coastal UI inventory as a foundation for upcoming Component 2 tasks.

Table 4: Generated inventory matrix for conducting an inventory analysis on the existing coastal UIs

No.	Criteria	Description
1	Platform Name	The actual name of the platform or website
2	URL	URL address
3	Partner Agencies	Who is/are hosting the interface and actively providing the information to the site? Is it a collaborative effort? If yes, name all partners.
4	Mission	Is there a mission statement for the interface? If yes, what is it?
5	Vision	Is there a vision statement for the interface? If yes, what is it?
6	Available Data	What type of data is available to view/download
7	Data Sources	ALL sources of data need to be listed. This should be specific (i.e., from a U.S. Geological Survey stream gauge) 'Various' if there are a lot of sources (4 or more)
8	Data Type	Modeled, measured, reports, or other types of data
9	Real-Time Data?	Yes or no. If yes, in what intervals (i.e., every 15 minutes or every 2 days)?
10	Data Download Option	Can the user download data from the site? Yes or No
11	Spatial Coverage	What areas are covered by the map? What counties? Is it the whole state that's covered? Are other state(s) covered?
12	Spatial Resolution	The lowest resolution the map can go to for information (i.e., county, zip code, property boundary) Needs a value a dimension (i.e., 100m resolution) If points such as gages or stations are used use 'sparce points'
13	Temporal Coverage	A range of time that the data is available This can be 'varied' if the data is gathered from different sources with no specific time coverage range This can also be real time but need specifics on time (i.e., hourly to 2 weeks or steady state).
14	Available Visualization	This can be all the things in the map that one could see and things one could do. Example: turn on/off layers; transparency/overlay; adding symbols/drawings; base map options; zoom in/out of map; measurements (area/latitude and longitude/distance); tabulate attribute table; swiping function
15	Flood Scenario Visualization	How is flooding shown in the legend? Is it 100-year flood, 500-year flood? Or is it broken down into flood depth or duration?
16	User Freedom	Can the user upload data? Yes or No Can the user preform independent analysis? Yes or No
17	Metadata	Is there metadata? Can the user access it? Yes or No
18	Metadata Link	A link, if available to the metadata page/info
19	Coverage Map?	Is there a summary map to show where data is/is not available for whatever data that the interface has? For example, an index map to show areas in state where data sets are representing.
20	Ease of Use	How easy is it to get around and find information? Very Easy, Moderately Easy, Not Easy, Difficult
21	API	Is the application programming interface available for this interface? Yes or No

Table 5: Inventory of the existing coastal UIs using Attributes 6-10 defined in Table 4

Platform Name	Available Data	Data Sources	Data Type (measurement or model output)	Real-Time Data?	Download Option?
InFRM AKA Flood Decision Support Toolbox (Click Here)	River, watersheds, rainfall and snow, wind speed and direction, pressure, temperature, humidity, radar, forecast and hindcast, cloud cover, reservoirs, flood risk, flood infrastructure, buildings, simulated river flooding, road condition	USGS stream gauges, hydrologic models, USACE, County Appraisal District parcel data, NOAA	Measurement and model output	Yes	Yes
Texas Coastal Atlas (Click Here)	Flood risk maps: damage plain, damage plain flood scale, damage plain comparisons	Various (external)	Model output	No	No
Texas Coastal Atlas: Rebuild Texas (Click Here)	Census data, census tracts borders, hurricane frequency and tracks, zip codes, losses, various types of insurance and FEMA claims, loans, flood zones, wind risk	Various (FEMA, Census, NOAA, etc.)	Measurements, reports, and model output	No	No
TexMesoNet (Click Here)	Air temperature and humidity; wind, soil, dew point, heat index, precipitation, solar radiation, river flow/stage, alerts, seasonal data	MesoWest and SynopticLabs Mesonet Application Programming Interface, independent meteorological stations	Measurement and model output	Yes	Yes
Coastal Emergency Risk Assessment (Click Here)	Water surface elevation above MSL, wind speed	NOAA Global Extratropical Surge and Tide Operational Forecast System, Advanced Circulation Surge Guidance System, USACE-Engineering Research and Development Center	Model output	Yes (modeling results)	Yes
Estimated Base Flood Elevation Viewer (Click Here)	Flood depth (feet), flood extent	FEMA	Model output	No	Yes
MAAP Next (Click Here)	Historical flood loss and inundation, white papers and reports, links to other tools, educational information on flooding and flood insurance	HCFCD, FEMA, NOAA, USACE	Report and white papers	No	Yes
Flood Education Mapping Tool (Click Here)	Channels, watersheds, flood risk (1%, 0.2% and coastal 1%), flood infrastructure, watersheds, ponding	FIRM for Harris County	Model output	No	No
FEMA Region 1 Coastal Erosion Map (Click Here)	Potential extent of coastal erosion hazards	NOAA Sea Level Rise Reports	Model output	No	No
Historical Hurricane Tracks (Click Here)	Historical hurricane tracks worldwide with their associated category, wind, and pressure data	NOAA hurricane data, Office of Coastal Management	Measurement and model output	Yes	Yes

Platform Name	Available Data	Data Sources	Data Type (measurement or model output)	Real-Time Data?	Download Option?
Sea Sketch (Click Here)	Proposed mapping priorities for topographic Lidar 3D Elevation Program (3DEP), federal 3DEP, state/local/academic/other 3DP, acoustic sonar; digital imagery, layers for mapping projects that are funded and ongoing and for federal agency projects, existing data/inventories/collections include topographic LiDAR, global multi-resolution topography, topo bathymetric LiDAR, acoustic/sonar (hydro, bathy, water column), digital imagery, elevation data projects	This is a collaboration site, so data comes from anyone who has an account and contributes to the project map	Measurement and model output	No	No
Coastal Flood Exposure Mapper (Click Here)	Coastal flood hazard composite, high tide flooding, FEMA flood zones, tsunami, storm surge, sea level rise, population density, poverty, elderly, employees, development, critical facilities, development patterns, natural areas and open spaces, potential pollution sources, natural protection, wetland potential	NOAA, FEMA, Census American Community Survey Topologically Integrated Geographic Encoding and Referencing system/line data, Bureau of Labor Statistics, Coastal Change Analysis Program, Facility Registration Service	Census, measured, and model output	No	No
Coastal County Snapshots (Click Here)	Information and layers for marine economy, coastal economy, sea level rise, and flood hazards, with community specific information for each layer for each county	NOAA Economics: National Ocean Watch and Office for Coastal Management, Bureau of Labor Statistics, Bureau of Economic Analysis, census, sea level rise technical reports	Measurement and model output	No	Yes
SE Texas R.A.I.N (Click Here)	24-hour rainfall, rainfall Year to date, river level and flow, lake and tide elevation, air temperature, basins and sub-basins of Sabine and Neches River Basins, gauge adjusted radar rainfall, river gauge current and forecasted flood stages, Texas-Louisiana counties, USGS hydrography, NOAA radar, links to additional resources, public emergency information by county	Lamar University Center of Resiliency, USGS, National Weather Service	Measurement and model output	Yes	No
Public MOVES Viewer (Click Here)	Rainfall totals, satellite and aerial imageries in selected location during and immediately after Hurricane Harvey	Different satellite and aerial imaging surveys from various sources and Texas Civil Air Patrol photography (342,000 images), NOAA, National Flood Insurance Program	Measurement	No	Yes
LCRA Hydromet (Click Here)	Rainfall radar, county boundaries, drought, soil moisture, streams and watershed boundaries, rainfall, flow, lake Level	Lower Colorado River Authority river gauges	Measurement	Yes	Yes

Platform Name	Available Data	Data Sources	Data Type (measurement or model output)	Real-Time Data?	Download Option?
Sea Level Rise Viewer (Click Here)	Inundation levels caused by the sea level rise, projected sicarios, mapping confidence, marsh migration, vulnerability to sea level rise, high tide flooding	NOAA technical reports; Census	Model output	No	Yes
TexasFLOOD.org (Click Here)	Information, resources, and support regarding flood awareness and preparedness, links to useful tools	TWDB, GLO, Texas Division of Emergency Management	Text	No	No
TNRIS Flood Viewer (Click Here)	flood gauge stages, lake level flood percentages, NOAA advisories alerts and weather radar	National Weather Service, TWDB, Aerisweather Service, Amazon Web Services	Measurement and model output	Yes (5 minutes to 1hour)	Yes
Texas Coastal Resiliency Master Plan (Click Here)	Regional project maps where all projects for a region are displayed with information on each project	Data on each project comes from contributing partners and GLO	Measurements and reports	No	Yes
NOAA Tides and Currents (Texas) (Click Here)	Tide (water surface elevation) in various vertical datums (observation and prediction), water and air temperature, wind speed and direction, barometric pressure, water conductivity, nautical charts	NOAA	Measurement and model output	Yes	Yes
USGS Texas Water Dashboard (Click Here)	Stream discharge, lake elevation, well level, water quality, rainfall gauges and radar cloud cover, air and sea surface temperature, rainfall forecast, warnings and alerts, twitter	USGS and Other Sources	Measurement and model output	Yes	No
Flood Quilt Viewer (Click Here)	Inventory of existing BLE Models, links to download the flood hazard dataset for the 15 Regions in Texas	TWDB, FEMA, Fathom	Model output	No	Yes
TxDOT Drive Texas (Click Here)	Road information including accident, ice/snow, closure, damage, flood, and construction, traffic information including traffic maps, traffic cameras, alerts	TxDOT	Measurement	Yes	No
National Flood Hazard Layer Viewer (Click Here)	digital effective flood data	FEMA	Model output	No	Yes
Harris County Flood Warning System (Click Here)	Rainfall amounts, water levels in bayous and major streams, river and watershed boundaries	HCFCD Gauges	Measurement	Yes	Yes
HCFCD Map & Model Management (Click Here)	FEMA's effective floodplain models for Harris County, information on changes to the models, city limits, watershed boundaries	HCFCD, FEMA	Model output	No	Yes
Harris County Flood Education - Active Construction Projects (Click Here)	Information on active capital and maintenance projects	HCFCD	Report	No	Yes

Platform Name	Available Data	Data Sources	Data Type (measurement or model output)	Real-Time Data?	Download Option?
ATXFloods (Click Here)	Stationary gauges at roadways at low water areas and crossings, road closure status, useful links	City of Austin, Lower Colorado River Authority, USGS	Measurement	Yes	No
ATXFloodSafety (Click Here)	information, resources, and support regarding flood awareness and preparedness; links to useful tools	City of Austin, Lower Colorado River Authority	Text	No	No
FloodPro (Click Here)	Floodplain boundaries, floodplain models, storm drain models, elevation certificates, storm drain infrastructure, parcels, elevation contour, letter of map revision	City of Austin, FEMA	Measurement and model output	No	Yes
Flood Factor (Click Here)	information and statistics on past, current, and future flooding risks, other risks such as fire and heat	First Street Foundation, U.S.. Forest Services, NOAA, USGS, NASA, U.S Department of Homeland Security	Model Output	No	No
Northern Gulf of Mexico Operational Forecast System (Click Here)	Nowcast and forecast guidance for water level, wind, current, temperature, and salinity	NOAA; University of Massachusetts and Dartmouth	Measurement and model output	Yes	Yes
HCFCD Floodplain Reference Marks (Click Here)	description of site location, plus a photograph and sketch of the site to help in locating the marker within the site	HCFCD	Measurement	No	Yes

Table 6: Inventory of the existing coastal UIs using Attributes 11-15 defined in Table 4

Platform Name	Spatial Coverage	Spatial Resolution	Temporal Coverage	Available Visualization	Flood Scenario Visualization
InFRM AKA Flood Decision Support Toolbox (Click Here)	FEMA Region 6 (Texas, Oklahoma, Alaska, New Mexico, Louisiana)	Sparce points, 100 meters for continuous rasters	Hourly, steady state		simulates flood scenario from minor to high in 0.5 foot increments
Texas Coastal Atlas (Click Here)	16 Southeast Texas counties	Sparce parcel, continu-ous rasters	Steady state	zoom in/out, slider bar compari-son map, address search	high to low damage probabil-ities; 50/100/250/500 year flood
Texas Coastal Atlas: Rebuild Texas (Click Here)	Hurricane Harvey affected areas	zip code	varied	zoom in/out, turn on/off layers, bookmark, print/share map, pop up attribute table, legend, charts under development	FEMA 100 and 500 year flood, Hurricane Categories, Flood Zones
TexMesoNet (Click Here)	Multi State (Texas, Oklahoma, New Mexico, Colorado, Kansas, Alaska) and Mexico	Sparce points, continu-ous rasters	Real time, varied (5min - 2weeks)	zoom in/out, turn on/off data collection stations, pop up info box, base map options	Not available
Coastal Emergency Risk Assessment (Click Here)	Global	ADCIRC mesh resolution 30 meters to 2 kilome-ters	Hourly	zoom in/out, turn on/off layers; base maps options, print/share map, legend; historical strom events	Past hurricanes and tropical storms; forecast for real-time
Estimated Base Flood Elevation Viewer (Click Here)	Multi State (Texas, Oklahoma, Alaska, New Mexico)	Sparce points, 100 meters for continuous rasters	Steady state, hourly model outputs	zoom in/out, turn on/off layers, pop up info windows, transpar-ency/overlay, base map options, address search, dual automated map view	Different flood frequencies (1%, 0.2%, 10%)
MAAP Next (Click Here)	Harris County	Not Applicable	Not Applicable	no interactive map available	no interactive map available
Flood Education Mapping Tool (Click Here)	Harris County	250 meters	Steady state	Zoom in/out; turn on/off layers for watersheds/flood zones, legend, address search	Mapped floodplains (FEMA 100/500 year flood); water-sheds and ponding areas
FEMA Region 1 Coastal Erosion Map (Click Here)	New England Counties	County	2030, 2050, 2100	Zoom in/out; turn on/off layers for different counties/different sea level rise scenarios, legend	High, Intermediate High, Intermediate, Intermediate Low, Low
Historical Hurricane Tracks (Click Here)	Global	Sparce points, 5 feet for continuous rasters	1842-2021	Zoom in/out; turn on/off storm tracks for storms in selected area, legend, base map options	Not available

Platform Name	Spatial Coverage	Spatial Resolution	Temporal Coverage	Available Visualization	Flood Scenario Visualization
Sea Sketch (Click Here)	Global	continuous rasters	varied based on project	Zoom in/out; turn on/off layers for projects/years/etc., base map options, legend	Not Available
Coastal Flood Exposure Mapper (Click Here)	East Coast, West Coast, Gulf of Mexico, Great Lakes, islands in the Pacific, and Caribbean	500 feet	Steady state	Zoom in/out; turn on/off layers for hazard areas/flooding, save/ export maps, base map options, legend	Change in flood depth with: sea level rise/storm surge for hurricanes/high tide events (color from blue to yellow to orang and then red for increased risk)
Coastal County Snapshots (Click Here)	Coastal U.S. counties	County	Steady state	Individual tables, charts, and maps for each topic of vulnerability listed in the snapshot	"Special Flood Hazard" is a snapshot topic. If chosen, information and graphics on flooding are shown for multiple topics.
SE Texas R.A.I.N (Click Here)	5 Southeast Texas counties; Sabine and Neches River Basins	Sparce points, 200 feet for continuous rasters	Steady state, hourly	Zoom in/out; turn on/off layers sensors, charts and figures (time series), base map options, legend	Not Available
Public MOVES Viewer (Click Here)	Areas affected by Hurricane Harvey	Sparce points	2017 Hurricane Harvey	Zoom in/out; turn on/off layers for images, legend	Not Available
LCRA Hydromet (Click Here)	Colorado River basin	Sparce points and polygons	Real time (20min updates)	Zoom in/out, turn on/off layers for gauges, base map options, charts (rainfall time series), legend	Not Available
Sea Level Rise Viewer (Click Here)	North America Gulf Coast, Atlantic and Pacific Coasts	Continuous raster, sparce points	2020-2100	Zoom in/out, turn on/off layers for sea level rise, capability to change the sea level rise scenario using a sliding scale (1ft increments up to 10ft), base map options, legend	Sea level rise scenario (1ft increments up to 10ft
TexasFLOOD.org (Click Here)	Not Applicable	Not Applicable	Not Applicable	Tabs, text	Not Available
TNRIS Flood Viewer (Click Here)	Texas	Sparce points, continuous raster for radar data	Real time (apx 5 minutes to 1 hour updates)	Zoom in/out; turn on/off layers for weather radar, flood gage stages, lake level, base map options, weather alerts, address search	Flood levels shown by gauge stages: major, moderate, minor, action, no flooding, low, stage not defined (in different colors).

Platform Name	Spatial Coverage	Spatial Resolution	Temporal Coverage	Available Visualization	Flood Scenario Visualization
Texas Coastal Resiliency Master Plan (Click Here)	Texas coast	Sparce points	Steady state	Zoom in/out; turn on/off project information/location	Not Available
NOAA Tides and Currents (Texas) (Click Here)	U.S. Coastal States	Sparce points	Real-time;5 minutes to annual	Zoom in/out; turn on/off layers, base map options, summary information, plots, address search, legend	Not Available
USGS Texas Water Dashboard (Click Here)	Texas	Sparce points, rasters for rainfall radar	Real time for rain 1 hour, 1, 2, and 3 days	Turn on/off layers, address search, base map options, pop up figures, transparency of layers, Twitter feed, legend	Not Available
Flood Quilt Viewer (Click Here)	Texas	Varies	Steady state	Turn on/off layers, transparency of layers, moving layers, attribute table, address search, base map options, legend	Not Available
TxDOT Drive Texas (Click Here)	Texas	Sparce points and lines	Real time and future	Turn on/off layers, address search, base map options, legend	Not Available
National Flood Hazard Layer Viewer (Click Here)	USA	Varies	Not Applicable	Turn on/off layers, address search, base map options, data download, measurement (Ruler), legend	Flood zones 100 and 500 years
Harris County Flood Warning System (Click Here)	Harris County and close outside area around Harris County	Sparce points	Real-time, Historical Data (1980s)	Turn on/off layers, address search, base map options, data download, information at gauges, legend	Not Available
HCFCD Map & Model Management (Click Here)	Harris County and close outside area around Harris County	Watershed Level, models' resolutions vary	Steady state	Turn on/off layers, language selection, base map options, data download, legend	Not Available
Harris County Flood Education - Active Construction Projects (Click Here)	Harris County	Sparce points	Near Real Time	Base map options, fixed layer, search for projects, legend	Not Available
ATXFloods (Click Here)	No	Sparce points	Real time	Turn on/off layers, base map options, zoom in/out layers	Not Available
ATXFloodSafety (Click Here)	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable

Platform Name	Spatial Coverage	Spatial Resolution	Temporal Coverage	Available Visualization	Flood Scenario Visualization
FloodPro (Click Here)	Austin	Parcel level	Steady state	Turn on/off layers, zoom in/out, address or Tax ID search, base map options, data download, distance measurement	100 and 500 years
Flood Factor (Click Here)	Entire U.S.	Parcel, zip code, City	Steady state	Text, charts, maps, sliding maps	historical; this year; 15 and 30 years in future
Northern Gulf of Mexico Operational Forecast System (Click Here)	Northern Gulf of Mexico	Sparce points	2 hours	Zoom in/out layers, charts, animations	Not Applicable
HCFCD Floodplain Reference Marks (Click Here)	Harris County and close outside area around Harris County	Sparce points	Not Applicable	Zoom in/out layers, charts, address search, legend	Not Applicable

Table 7: Inventory of the existing coastal UIs using Attributes 16-21 defined in Table 4

Platform Name	User Freedom*	Metadata	Metadata Link	Coverage Map?	Ease of use	Application Programming Interface
InFRM AKA Flood Decision Support Toolbox (Click Here)	No	Not available	Not Available	No	Very easy	No
Texas Coastal Atlas (Click Here)	No	Not available	Not Available	No	Moderately Easy	No
Texas Coastal Atlas: Rebuild Texas (Click Here)	No	Not available	Not Available	No	Easy	No
TexMesoNet (Click Here)	No	Yes	Click Here	No	Moderately Easy	Yes
Coastal Emergency Risk Assessment (Click Here)	No	Not Available	Not Available	Not Applicable	Easy	No
Estimated Base Flood Elevation Viewer (Click Here)	No	Not Available	Not Available	Yes	Moderately Easy	No
MAAP Next (Click Here)	Not Applicable	Not Available	Not Available	No	Unknown	No
Flood Education Mapping Tool (Click Here)	No	Not Available	Not Available	No	Very Easy	No
FEMA Region 1 Coastal Erosion Map (Click Here)	No	Not Available	Not Available	No	Difficult	No
Historical Hurricane Tracks (Click Here)	No	Not Available	Not available	No	Very Easy	No
Sea Sketch (Click Here)	Yes	Yes	Click Here	No	Difficult	No
Coastal Flood Exposure Mapper (Click Here)	No	Yes	Click Here	No	Very Easy	No
Coastal County Snapshots (Click Here)	No	Yes	Multiple Links	No	Very Easy	No
SE Texas R.A.I.N (Click Here)	No	Not Available	Not Available	No	Very Easy	No
Public MOVES Viewer (Click Here)	No	Not Available	Not Available	No	Difficult	No
LCRA Hydromet (Click Here)	No	Not Available	Not Available	No	Very Easy	No
Sea Level Rise Viewer (Click Here)	No	Yes	Click Here	No	Moderately Easy	No
TexasFLOOD.org (Click Here)	No	Not Available	Not Available	No	Very Easy	No
TNRIS Flood Viewer (Click Here)	No	Not Available	Not Available	No	Very Easy	No
Texas Coastal Resiliency Master Plan (Click Here)	No	Not Available	Not Available	No	Very Easy	No
NOAA Tides and Currents (Texas) (Click Here)	No	Yes	Click Here	Yes	Very Easy	Yes
USGS Texas Water Dashboard (Click Here)	No	Not Available	Not Available	No	Easy	No
Flood Quilt Viewer (Click Here)	Yes	Yes	Click Here	No	Moderately Easy	No
TxDOT Drive Texas (Click Here)	No	Not Available	Not Available	No	Easy	No
National Flood Hazard Layer Viewer (Click Here)	No	Yes	Click Here	No	Moderately Easy	Yes

Platform Name	User Freedom*	Metadata	Metadata Link	Coverage Map?	Ease of use	Application Programming Interface
Harris County Flood Warning System (Click Here)	No	Yes	Click Here	No	Easy	No
HCFCD Map & Model Management (Click Here)	No	Yes	Click Here	Yes	Moderately Easy	No
Harris County Flood Education - Active Construction Projects (Click Here)	No	Not Available	Not Available	No	Very Easy	No
ATXFloods (Click Here)	No	Not Available	Not Available	Local	Very Easy	No
ATXFloodSafety (Click Here)	No	Not Available	Not Available	Not Applicable	Very Easy	No
FloodPro (Click Here)	No	Not Available	Not Available	no	Difficult	No
Flood Factor (Click Here)	No	Not Available	Not Available	No	Very Easy	No
Northern Gulf of Mexico Operational Forecast System (Click Here)	No	Not available	Not Available	No	Moderately Easy	No
HCFCD Floodplain Reference Marks (Click Here)	No	Yes	Not Available	No	Moderately Easy	No

* Can users upload any shapefiles or conduct any types of analysis?

Water coming over road in Kemah,Texas during Hurricane Harvey © Eric, Adobe Stock

4 Component 3 – Integrated Flood Modeling Framework

Texas faces numerous challenges in maintaining its coastal natural resources and infrastructure. Significant increases in the state's population, especially in the Texas coastal region, along with relative sea-level change and increases in the intensity and duration of rainfall-runoff and surge events, pose a greater risk to the vulnerable coastal population. Moreover, flooding in Texas coastal regions is exacerbated due to complex interactions of multiple flood drivers, such as rainfall runoff and coastal surges, which can occur simultaneously or sequentially during storm events, leading to compound flooding hazards. State and federal agencies are conducting large-scale studies such as the Coastal Texas Restoration and Protection Study (CTX, 2021) and GLO's Combined Flood Studies, TWDB's Base Level Engineering (BLE) Study for flood hazard assessment and for the development of mitigation and abatement strategies that reduce this risk and increase community resilience. However, flood model development has traditionally been siloed into different research communities with little to no communication. Therefore, a broader perspective is critical to address future flooding challenges, especially along the Texas coast.

Hydrologic, meteorologic, hydraulic, estuarine, and surge models serve as valuable tools to provide information on flooding hazards and guides in planning and implementing structural and non-structural flood risk mitigation solutions for minimizing flood risk. Various flood process models exist, each tailored to address specific challenges related to dominant flooding mechanisms (e.g., pluvial, fluvial, storm surges). These models have grown in complexity, with many simulating increasingly detailed processes occurring within natural and built systems. It is necessary to develop an integrated flood modeling framework to couple different process models (e.g., surge and rainfall-runoff) and accurately resolve total water levels, particularly in the low-lying coastal zones. The coupling processes that use two or more models could be done through three different methods: 1) loose one-way coupling, 2) loose two-way coupling, and 3) dynamic coupling with feedback. The choice among these methods depends on various conditions such as existing flood forces, purpose, the scale of modeling, reliability of the model, computational time, and ease of use. The conditions mentioned above could change significantly across the Texas coast.

Therefore, TIFF Component 3 is developing an integrated conceptual flood modeling framework to support inland and coastal flood hazard identifications and characterizations in the Harvey-impacted Texas coastal region, as shown in Figure 9. TIFF is performing the following tasks as part of the Component 3 efforts to develop an integrated conceptual modeling framework:

- Establish an Integrated Flood Modeling TAT to support Component 3 as discussed in Section 1.1.3.3
- Evaluate and provide feedback on the initial inventory of existing and proposed meteorologic, hydrologic, hydraulic, estuarine, and surge models by the Study Providers (GLO's Combined Flood Studies, TWDB RFPG's project, TWDB's BLE Study, and various studies performed by the USACE Galveston District) to support inland and coastal hazard identification.
- Perform a literature review to identify potential meteorological, hydrologic, hydraulic, estuarine, and surge models for evaluating and mitigating flood risk for Texas.
- Perform a literature review on probabilistic methods for flood hazard estimation.
- Develop recommendations for conceptual model-coupling workflow(s) for assessment of compound flooding hazard in the coastal Texas region.

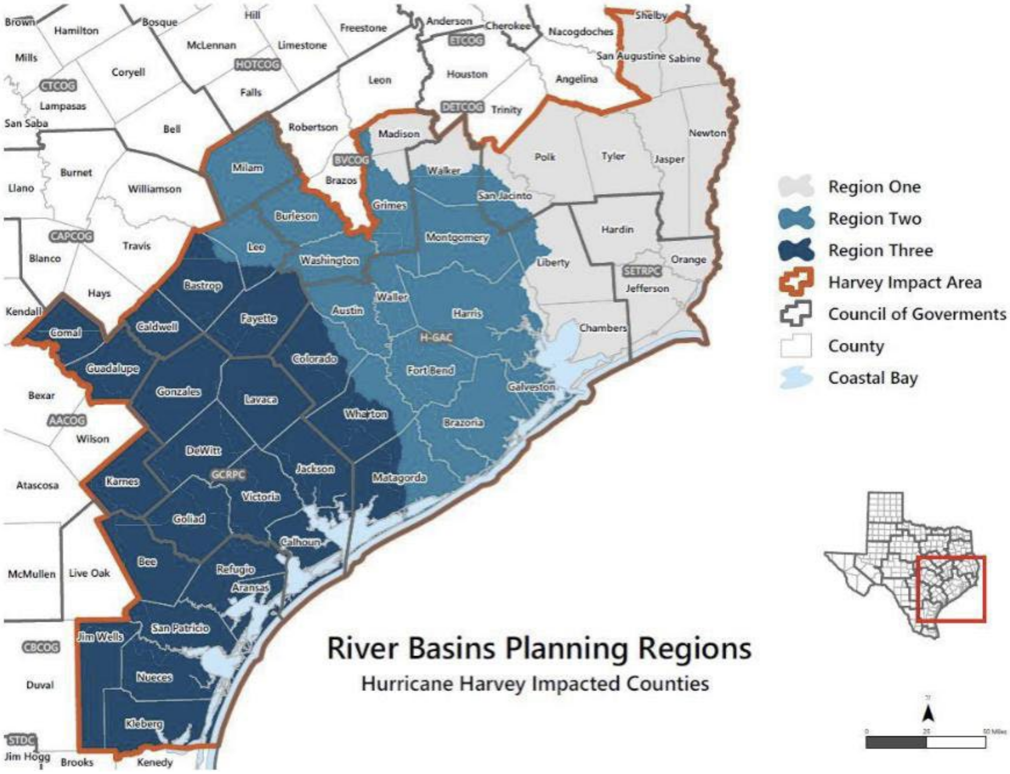


Figure 9: Map of counties impacted by Hurricane Harvey in the Texas Coastal Region, which is the focus of this study (Source: GLO)

This report shares the findings of tasks one and two, whereas tasks three, four, and five will be reported in the second and third TIFF annual reports, respectively. Since the approach to establishing the Integrated Flood Modeling TAT is presented in section 1.1.3.3, this chapter documents the background, approach, and findings of the study provider's model inventory compilation and evaluations. These studies include the GLO Combined Flood Studies, TWDB RFPG's project, TWDB's BLE Study, and different studies performed by the USACE-Galveston District as part of their Flood Risk Management, Coastal Storm Risk Management, and Navigation mission. Further information about these studies will be included later in the report.

4.1 Model Inventory Evaluation

Numerical models are valuable tools for flood analysis studies. When engineers and scientists use models, they devote significant effort to collecting data, constructing model inputs, and calibrating and validating model parameters. Many models also require sophisticated data pre-processing routines, often with many manual steps. These data pre-processing steps must be repeated each time a new model is created to simulate a system.

The limited availability of the model metadata prohibits the sharing and reuse among different stakeholders. The limited metadata availability, and consequently the limited sharing, causes duplication efforts in model development and induces budget increases and delays in the project implementation schedule. While many flooding models use similar methodologies, little information on the model metadata for the study region of interest often forces the modeler to develop a new model from scratch. This causes duplicative effort in model development and prevents modelers from improving the limitations of previously developed models. From a pragmatic perspective, it is an inefficient use of the modeler's time reproducing similar model input files developed previously. One way to address these challenges is by creating a basic model metadata template for sharing and referencing or reusing models, where appropriate, built by others.

TIFF developed a basic model metadata template to make Texas stakeholders aware of the available models. This metadata template was then applied to an inventory of available models in the study regions. This model metadata template is not comprehensive; instead, TIFF prioritized minimizing the efforts of the interested parties who will provide this model information. This simple model metadata will supply key information about the model coverage and the model developers' points of contact so that further detailed model metadata information can be gathered on an as-needed basis during the model development effort. This initial model inventory is laying the foundation for the future development of a detailed model metadata catalog, along with the system for model archiving and sharing with diverse stakeholders.

The main objective of this model inventory evaluation task is to identify available models within the study region for facilitating model sharing/reusing among stakeholders and supporting modeling gap analysis for identifications of regions where improved models are needed for future flood planning analysis. TIFF primarily focused on evaluating the model inventory of different ongoing studies for supporting flood planning, modeling, and mapping in Texas, including:

- USACE's Flood Risk Management, Coastal Storm Risk Management and Navigational program for Texas region,
- GLO's Combined Flood Studies,
- TWDB's RFPG, and
- TWDB's BLE Studies.

Further details of these programs and a few associated large-scale studies, which were/are being implemented as part of TIFF's model inventory evaluation efforts, are described in the next section. This effort also includes limited evaluation and compilation of other model metadata sets, which were readily available to the USACE-Galveston District Hydrologic and Hydraulic team from their collaboration with local stakeholders, including Harris County and university partners. This model metadata development effort will produce an initial inventory of available models in the study region with the anticipation of periodic updates of the model inventory as more model metadata becomes available to TIFF during the project's duration.

4.2 Texas Flood Planning, Modeling, and Mapping Efforts

TIFF accomplished the model inventory and data collection by analyzing internal and external records and collaborating with points of contact for the various ongoing modeling efforts in the state. The following section describes the models that TIFF evaluated within the study region.

4.2.1 TWDB – RFPGs

In 2019, the 86th Texas Legislature passed several key pieces of legislation which greatly expanded the TPWD's role in flood planning, and financing. TWDB formed 15 RFPGs across the state to conduct planning processes that will result in regional flood plans in January 2023. Figure 10 denotes these planning regions. These plans will contribute to the 2024 State Flood Plan. The RFPG efforts include stakeholder surveys, modeling, data collection, and database development. A Flood Planning Data Hub provides resources from a variety of entities relevant to flood risk assessments to support and populate RFPG efforts.

Resources include datasets and GIS layers that provide insight on existing infrastructure, hydrology, population, property, terrain, flood risk, and more.

A Floodplain Quilt Geodatabase has also been developed to provide existing flood hazard information pulled from other sources including the National Flood Hazard Layer and BLE models. The Flood Planning Data Hub and Floodplain Quilt Geodatabase are verified and updated as the RFPG efforts progress. The regional flood plans are intended to reflect a planning level analysis and aid in determining where to proceed with more detailed analysis in support of project funding and design for riverine, pluvial, and coastal flooding mitigation. The regional flood plans are intended to include an assessment of existing natural features and infrastructure and ongoing or proposed flood risk mitigation projects. For existing infrastructure, the functionality will be evaluated and described. Flood risk analyses completed as part of the RFPGs are intended to incorporate any findings from ongoing studies (e.g., GLO Combined Flood Studies) that become available within the RFPG implementation time frame (TWDB, 2021).

Model metadata sets, which are collected by TWDB RFPGs, are included in Supporting Information 4-1. TDIS, who collected the information from the representative of the RFPGs, provided TIFF with the model metadata datasets.

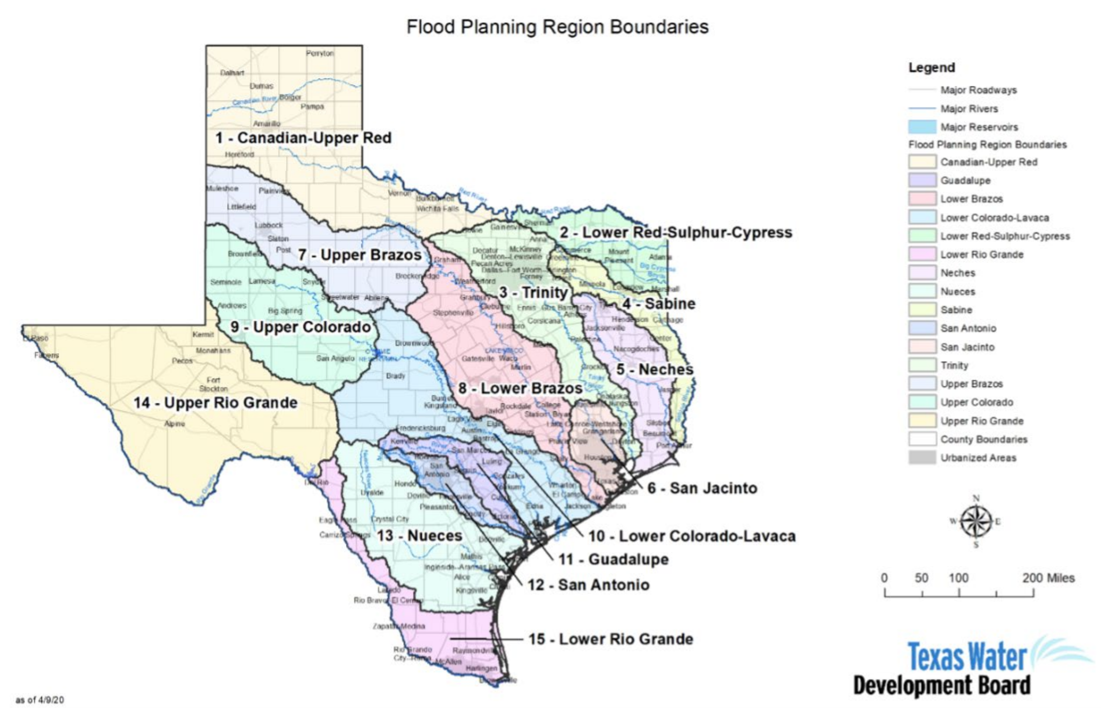


Figure 10: TWDB Regional Flood Planning Regions

4.2.2 TWDB – BLE Models

The TWDB Flood Mapping Program compiles and disseminates flood data to inform regional and local decision-makers. TWDB leverages a BLE approach, described below, to produce improved flood risk mapping in Texas for its efficiency and as a complement to the traditional floodplain mapping approach leveraged by FEMA. They are developed collaboratively by FEMA and other federal, state, and/or local entities. The modeling and mapping information is analyzed at various scales and is intended to be approximate, low-resolution models. For some areas, BLE models may be the only available information, whereas other areas may have more detailed information that should take precedence.

The results may be used to inform flood vulnerability assessments, community-based mitigation strategies, land-use discussions, and prioritization of flood risk reduction projects. BLE models provide risk assessment information where there are gaps in the national flood hazard data inventory that can be accessed before regulatory updates to Flood Insurance Rate Maps. The models assist FEMA in determining the validity of current effective firm panels by characterizing the significance of changes in expected flood flows since the last performed Flood Insurance Study. In most cases, the BLE models can determine the Base Flood Elevation in each area. They are considered the best available information for Zone A (areas with a one percent annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage) designated areas within a given floodplain. The exception is when a more detailed analysis has been done, e.g., Zone AE, in the current effective FIRM.

BLE models leverage high-resolution elevation data (e.g., LiDAR) that "meets or exceeds the USGS 3-D Elevation Program standards" (FEMA, 2021) and recent modeling enhancements to produce flood hazard information. BLE models are typically built on a watershed scale (e.g., hydrologic unit code HUC-8) instead of for individual streams or reaches. The engineering approach follows the modeling and mapping standards outlined in FEMA's Standards for Flood Risk Projects. The hydraulic analysis assumptions for BLE models can vary in complexity based on regional, state, local or modeler preferences. The guidelines summarized in FEMA's "Guidance for Flood Risk Analysis and Mapping, BLE Analysis and Mapping" outline the complexity of options that vary in terms of cross-section (1D)/mesh (2D) refinement, manning's n value resource and calibration effort, and the amount/type of structures include in each model.

TWDB plans to complete statewide BLE coverage by 2024. Figure 11 and Table 8 summarize the status of the BLE model development. Supporting Information 4-1 includes model metadata sets associated with the BLE model. A TWDB Flood Science and Community Assistance Program representative compiled BLE model metadata datasets and provided them to the SC.

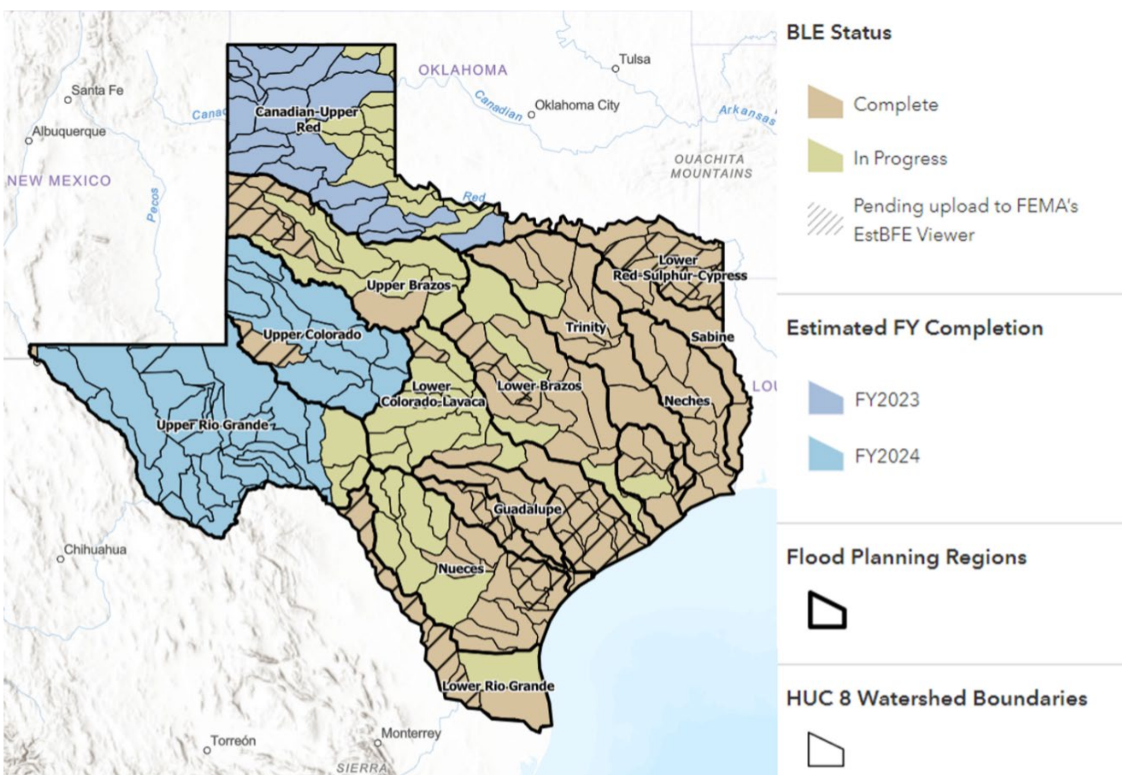


Figure 11: BLE Model Status (Source: https://www.twdb.texas.gov/flood/science/ble-status-viewer)

Table 8: BLE Model Status as of February 8, 2021 (Source: www.twdb.texas.gov/flood/science/ble-status)

BLE Status	TWDB	FEMA
Complete*	4**	31
FY21	25	19
FY22	36	1
FY23	38	7
FY24	45	2
Total	**148**	**60**

*Complete means a BLE Model is already developed.

**Number of projects funded by each agency.

4.2.3 GLO – Combined River Basin Flood Studies

Following the devastating impacts of flooding from recent extreme weather events, the State of Texas received Community Development Block Grants, administered through GLO, from the U.S. Department of Housing and Urban Development. As a result, GLO and TWDB are both undertaking significant steps to contribute to the state's flood resilience. As of September 2020, the GLO implemented the Combined Flood Studies, which will result in detailed flood risk information and mitigation strategies for the 49 counties which received a presidential disaster declaration due to the impact of Hurricane Harvey plus four counties in the Lower Rio Grande Valley that received a presidential disaster declaration for flooding in 2015 and/or 2016.

The GLO's Combined Flood Studies program is a one-time planning effort, and the data and information produced by the GLO will be utilized to support current and future Texas State Flood Plans (led by TWDB) and inform TDIS. TDIS is an interactive, web-based data system designed to support preparedness, response, recovery, and mitigation for the State of Texas. This statewide system provides users with the most current and accurate information available to assess related disaster risks, impacts, and mitigation strategies. TDIS will house critical flood risk information for the state through an accessible online dashboard. Stakeholder engagement will occur throughout the implementation of the GLO and the TWDB's planning processes to ensure the diverse needs and interests of the state are incorporated. These significant steps taken by Texas will result in better prepared and more flood resilient communities throughout our state.

Modeling efforts as part of the GLO Combined Flood Studies will occur over multiple phases for watersheds in three primary Harvey-impacted regions (east, central, and west), and the Lower Rio Grande Valley region (see Figure 12). The resolution and complexity of the models will depend on the area for which they are developed and their level of existing flood risk (i.e., areas with potential for higher risk will warrant greater level of detail). BLE models may be leveraged, where available, to support this effort depending on detail requirements. The complexity differences involve the hydrologic approach (e.g., detailed hydrologic analysis vs. rain-on-mesh), inclusion of significant structures (e.g., levees, dams), and additional efforts to increase confidence in flow estimates (e.g., elliptical storm analysis, storm shifting, reservoir analysis). Pilot, baseline modeling, and alternative analysis are the primary phases of the modeling effort. The pilot phase established a Standard Operating Procedure for the baseline modeling that provides modeling guidelines based on the level of detail and the type of flood risk present in the model area of interest (e.g., inland or coastal). The baseline modeling will inform the subsequent alternative analysis phase, where project prioritization will be evaluated based on existing and expected flood risk.

The modeling efforts are ongoing in each region and shared metadata includes information on existing models, which have been collected through stakeholder surveys and inquiries, and planned models. The planned models will be developed as part of the GLO Combined Flood Studies. Stakeholders that have collected information about existing models have shared the metadata as they become available. For the planned models, stakeholders for each region shared tentative metadata and coverage extents that are subject to change as the model development progresses. The planned models will include hydrologic and hydraulic information developed using modeling software discussed herein (e.g., HEC-HMS, HEC-RAS). As the model development continues, coverage extents and pertinent metadata will be updated to reflect the most up to date information.

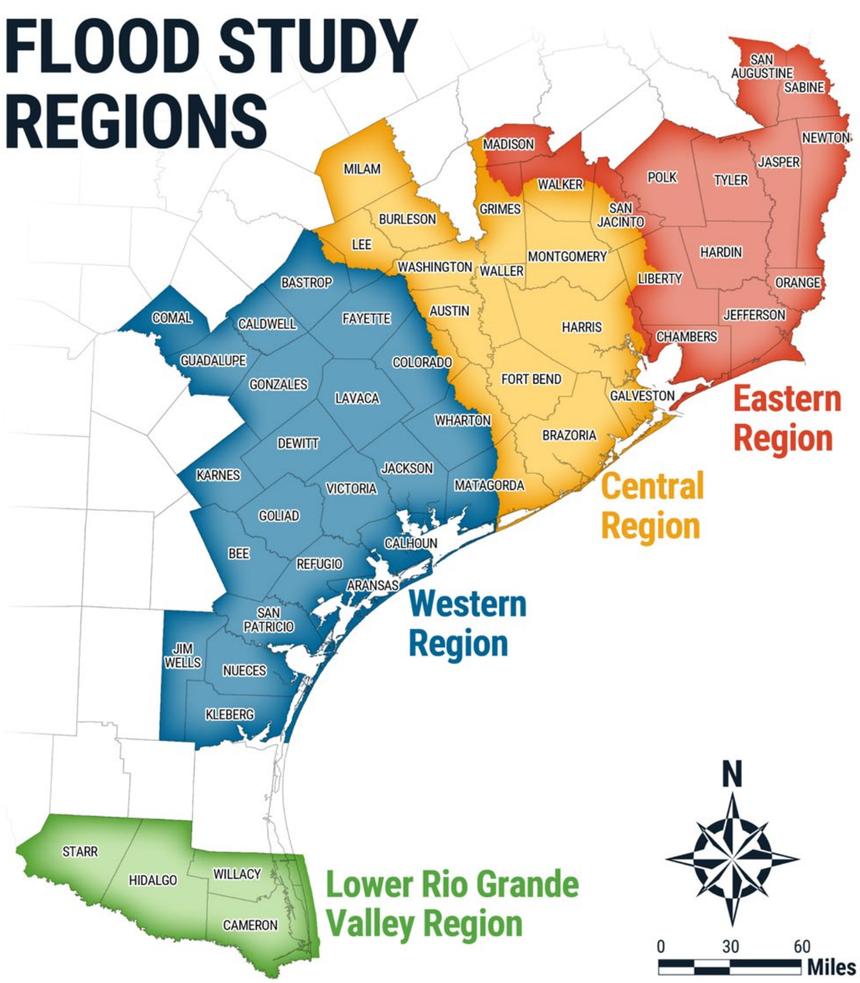


Figure 12: GLO's Combined River Basin Flood Study Regions

4.3 USACE and Other Studies

4.3.1 USACE-Galveston District

The Galveston District of USACE supports several missions, including flood risk management, navigation, ecosystem restoration, beneficial use of dredge material, and emergency management operations. Hydrologic, hydraulic and/or coastal models are developed as needed to support these missions and may be produced during feasibility studies, Pre-Construction Engineering and Design of federal projects, Continuing Authorities Program or Floodplain

Management Services in service of district missions. These models may be developed to perform risk assessments related to federal projects, inform water management operations, support ecosystem restoration projects, or evaluate and compare flood risk reduction solutions. The models developed cater specifically to the project goals they support and vary in level of detail but largely fall into water management, flood risk management and/ or coastal storm risk management categories.

4.3.2 USACE Modeling, Mapping, and Consequences Center

The USACE Modeling, Mapping and Consequences Center is a virtual organization within the Risk Management Center. Their purpose is to support the inundation mapping and consequence assessment throughout USACE for a variety of applications. To support this mission, Hydrologic Engineering Center models are developed for several watersheds to integrate into the Corps Water Management System that is primarily used as a water management tool and assists in forecasting, reservoir operations, and event response.

4.3.3 USACE Engineering Research and Development Center

The Engineering Research and Development Center (ERDC) provides support to USACE missions on a project basis and can provide a variety of modeling and analysis services. The ERDC-Coastal Hydraulics Lab (CHL) has expertise on a variety of coastal and wave modeling platforms. The scope and level of detail of any modeling services provided by ERDC cater to specific USACE project needs.

4.3.4 Coastal Texas Study Project

The USACE, in partnership with a non-Federal Sponsor, GLO, recently completed the Coastal Texas Protection and Restoration Feasibility Study ("Coastal Texas Study"). The purpose of the study was to identify feasible projects that reduce risks to public health and the economy, restore critical ecosystems, and advance coastal resiliency. As part of this study, USACE-Galveston District, worked with the ERDC-CHL to perform coastal storm damage risk assessment for the coast of Texas. Coastal storm numerical modeling, including Advanced Circulation (ADCIRC), Steady State Spectral Wave (STWAVE), and Wave Modeling Project (WAM) models, was performed as a part of this study. ERDC's Coastal Storm Modeling System (CSTORM-MS) was used to tightly two-way couple the ADCIRC and STWAVE models to allow for dynamic interactions between the surge/circulation and waves, to improve the modeling results.

The ADCIRC model was used to simulate two-dimensional depth-integrated surge and circulation responses to storm conditions. The STWAVE model was used to provide near-shore wave conditions including local wind-generated waves. STWAVE produced results for variables such as significant wave height, peak wave period, mean wave period, and mean wave direction. The WAM model was used to generate offshore wave estimates. The ADCIRC model provides the STWAVE model with updated water surface elevations along with wind fields, and in turn the STWAVE model provides ADCIRC with gradients of wave radiation stresses. WAM provides the boundary condition wave estimates to STWAVE as part of the input to the CSTORM-MS simulations. The execution of each model and the interchange of information between the models was controlled by the CSTORM-MS coupling framework (Massey et. al., 2019). For the Coastal Texas Protection and Restoration Feasibility Study, several historical storms and more than 660 synthetic storms were simulated for characterizing storm surge hazards for the entire Texas coastal region. Model simulations were saved over 18,000 save point locations covering the entire Coastal Texas region. In addition to time series water level datasets, peak still water level and wave height for different frequency storm surge events were also stored in those locations.

4.3.5 Sabine Pass to Galveston Bay Project

The USACE-SWG is executing the Sabine Pass to Galveston Bay (S2G) Coastal Storm Risk Management (CSRM) project for Brazoria, Jefferson, and Orange County regions. The project is currently in the Pre-construction, Engineering, and Design phase. The S2G Project CSRM formulated measures consist of reducing risks of tropical storm water level (SWL) impacts by constructing the new CSRM system in Orange County and increasing the level of risk reduction and resiliency of the existing Port Arthur & Vicinity and Freeport & Vicinity's Hurricane Flood Protection systems. Detailed modeling and probabilistic analysis were performed to develop coastal SWL and wave hazards information for evaluation of the entire CSRM systems for Jefferson, Brazoria, and Orange counties.

Coastal SWL, wave loading, and wave and SWL overtopping are quantified using state-of-the-art hydrodynamic modeling and stochastic simulations. The CSTORM-MS coupled circulation, SWL and wave modeling system was used to accurately quantify SWL and wave hazards. New model meshes were developed from very high-resolution land and bathymetric surveys for with and without-project scenarios. With-project meshes include the new Orange CSRM, deepening of Sabine-Neches Waterway and increased levee and floodwall elevations as authorized under the S2G feasibility study. The new meshes provide the highest resolution regional surge and wave modeling done to-date for the region. The CSTORM-MS model was validated against historical storms and then used to model the 195 synthetic tropical storms.

4.3.6 HCFCD - Model and Map Management System

The Harris County Flood Control District (HCFCD) Map and Model Management (M3) System is an interactive geospatial tool that communicates information to the public and provides the latest FEMA effective floodplain models within Harris County (Figure 13). The system is leveraged to foster communication between Harris County, FEMA, and local floodplain managers and track changes to models from the implementation of flood risk management and/or development projects in the region (HCFCD, 2022). We have gathered model metadata sets for this effort from the M3 System.

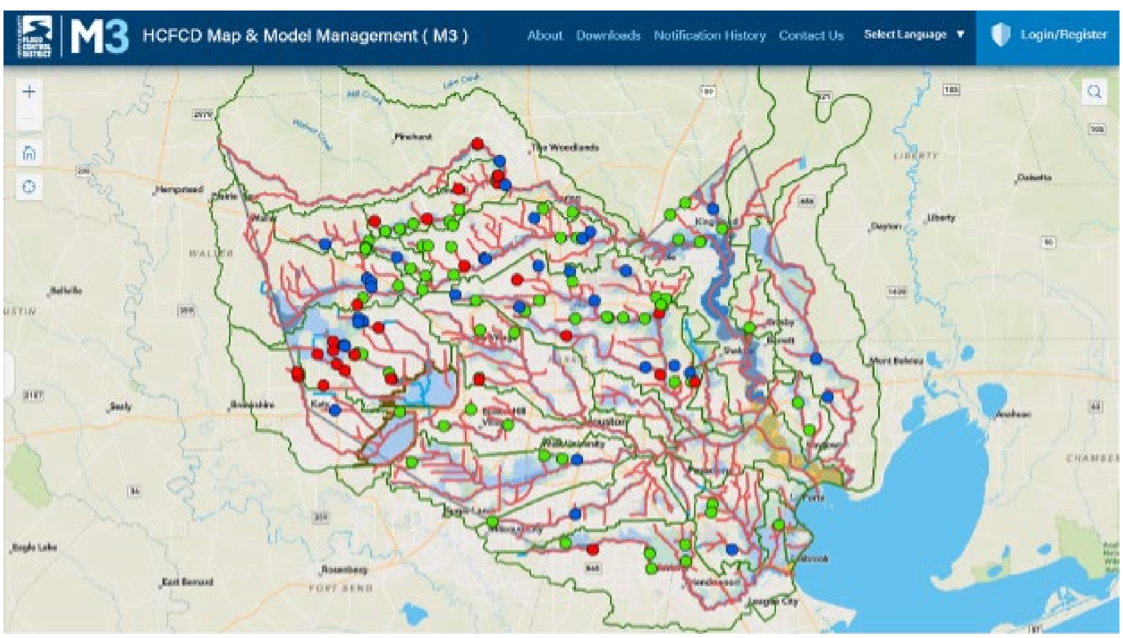


Figure 13: HCFCD's M3 System Interface (Source: https://www.m3models.org/)

4.4 Model Inventory Approach

Model inventory development was executed largely with a collaborative approach. Models have been developed by an array of entities and for a variety of purposes over the years. The first step to creating and populating the model inventory was to determine what metadata is key to provide sufficient context for the end-user to determine the usefulness and/or appropriateness of the existing model for their intended purpose. In some geographic areas, multiple models have been developed over the years that vary in input and output depending upon when it was developed and what type of analysis was deemed necessary for specific efforts. For example, there are models that have been developed to inform the design of a specific flood risk management infrastructure solution or for watershed planning purposes that do not relate to a specific infrastructure action which include analysis of historical events or predictive frequency events, or oftentimes both. Furthermore, models may have been developed to provide flow and stage information, or to inform sedimentation or water quality studies. These factors were considered when selecting which metadata to include in the inventory.

The key metadata parameters were included in the inventory template as an attribute column. This information is summarized in Table 9. The inventory was populated by a combination of outreach, literature review, and existing database integration. These efforts involved communication throughout USACE as well as contacting universities to obtain information for models in Texas. Numerous models have been developed to support the USACE-Galveston District's diverse Civil Works program and were catalogued through surveys and collaboration with respective modeling points of contact. In addition to models developed within or for the USACE-Galveston district, several models have been developed by local drainage districts, state agencies, universities, and consultants. These models were identified through meetings and discussions with engineers/scientists and leveraging existing model and/or publication databases. Other cooperators provided model databases that had previously been catalogued (e.g., BLE models) and that information was integrated into the TIFF model inventory format. TWDB provided metadata and coverage areas, as available, for BLE studies, Texas Rainfall-Runoff models, and what was collected as part of the RFPG efforts. GLO's Combined Flood Study stakeholders provided planned model extents for each region and existing models when available. Other sources, such as HCFCD's M3 system, allowed for direct referencing and downloading of relevant modeling information.

4.5 Inventory Matrix Design

The model inventory metadata requirements were selected by taking into consideration the minimum information needed to characterize flood models with the relevant context to understand their purpose and provide context for use in hazard identification where appropriate. The description of each model inventory metadata field is listed in Table 9. Although this model inventory matrix can be used for compiling relevant metadata for any flood planning and risk assessment models, the focus of this inventory matrix was to compile metadata for meteorologic, hydrologic, hydraulic, and coastal models including estuarine, surge, and wave models which are applied for estimating flooding hazard extent and depth estimations. However, this model inventory matrix was not designed for comprehensive cataloging of model related metadata sets. Rather, this simple inventory matrix will provide relevant high level model metadata. Stakeholders/modelers can use this high-level metadata and follow up with the model developer(s) for the appropriate level of detailed information based on their project needs. Links to documentation (e.g., reports, publications, web pages) associated with each model are included to provide details related to each modeling effort where applicable and/or available. In addition to the metadata, shapefile coverage areas were obtained where available and are indicated in the metadata table in Supporting Information 4-1 and in an online Excel file.

Table 9: Inventory matrix metadata fields and their descriptions

Field	Description
Study Area	Geographic location where model is based.
Software	Type of modeling software used (e.g., Hydrologic Engineering Center Hydrologic Modeling System, Hydrologic Engineering Center River Analysis System, Adaptive Hydraulics, Soil Water Assessment Tool, etc.)
Study Title	Title of study associated with model development
Version	Software version the model is currently compatible with (e.g., Hydrologic Engineering Center River Analysis System 6.0)
Focus	The purpose of model development, i.e., what type of analysis or problem the model is expected to inform and/or be leveraged to solve. Categories include: Flood Risk Management; Coastal Storm Risk Management, Water Management, Water Resources, Groundwater, Ecosystem Restoration
Objectives	Summary of study objectives for associated model
Year Developed	Year in which the model was developed
Flow Condition	Specify flow condition of subject model. i.e., Steady - modeled variable does not change with time; Unsteady - modeled variable changes with time
Dimension	Dimension(s) of model geometry and associated results
Status	Status of model development (e.g., planning, ongoing, complete)
Model Point of Contact	Point of contact for the model developer
Geo-Referenced?	Specify if the model is spatially referenced through a projection system. Yes/No
Shp_ID	Shapefile Identifier
Report	Specify if a report is available that accompanies the model and includes pertinent details, e.g., modeling methodology and results. Yes/No
Location	Location of report and/or model
Calibration Events	Summary of storm events leveraged to calibrate the model
Validation Events	Summary of storm events leveraged to validate the model
Analysis Summary	Summary of what type of analysis the model was used for, e.g., alternatives (with and without-project) analysis, sensitivity analysis, scenario analysis
History	Summary of model update history, e.g., specify if model was adapted from an existing model
Additional Comments	Any additional pertinent information related to model

4.6 Flood Study Models

An inventory of hydrologic, hydraulic, hydrodynamic, meteorological, and coastal models was developed and evaluated in this study. Such models serve as valuable tools to provide information on flooding hazard and guide in planning structural and non-structural flood risk mitigation solutions to minimize flood risk. A large variety of flood models exists, with each model tailored to address specific challenges related to dominant flooding mechanisms (e.g., pluvial, fluvial, storm surge). The effort summarized herein supports an initial inventory of existing and proposed meteorologic, hydrologic, hydraulic, estuarine and surge models to support inland and coastal hazard identification through a literature review and model developer outreach to identify potential meteorological, hydrologic, hydraulic, and hydrodynamic models for evaluating and mitigating flood risk in Texas.

The intent of this model inventory development/evaluation is to create an existing model catalogue with key contextual details for users to leverage when searching for existing information in a particular study area. Key metadata and coverage area shapefiles associated with models were collected. This information also provides insight into the geographic distribution of information, that is, where pluvial, fluvial and/or coastal risk information is abundant and where it lacks. The modeling software and respective number of each catalogued model is summarized in Table 10.

Table 10: Model inventory count by software

Type	Modeling Software	Number of Models
Inland	HEC-HMS	130
	HEC-RAS	305
	SWAT	176
	Riverware	1
	Gridded Surface Subsurface Hydrologic Analysis	5
	Texas Rainfall-Runoff Model	129
	Storm Water Management Model	7
	XP Storm Water Management Model	7
	InfoWorks	8
	Interconnected Channel and Pond Routing Model	1
Coastal	Advanced Circulation Model	3
	Adaptive Hydraulics (Coastal)	7
	Beach-FX	1
	Coastal Modeling System-FLOW and Coastal Modeling System-WAVE	8
	Cornell University Long and Intermediate Wave Modeling	2
	Delft3D	5
	DFLOW-FM/ Delft3D-FM	6
	Fully Nonlinear Phase-Resolving Boussinesq-Type Wave Model	2
	Finite Volume Community Ocean Model	1
	Semi-implicit Cross-scale Hydroscience Integrated System Model	1
	Semi-Implicit Eulerian–Lagrangian Finite-Element Model	2
	Super-Fast Inundation of Coasts Model	1
	TxBLEND	7
	Xbeach	1
	Steady State Spectral Wave	2
	Wind Wave Model	1

4.7 Hydrologic and Hydraulic Models

Hydrologic models use numerical solutions to characterize the behavior of precipitation as it infiltrates into and moves across land to receiving waterbodies. The volume and timing of precipitation events are computed after accounting for watershed characteristics such as soil infiltration and evapotranspiration losses to establish quantity, watershed area, slope, and flow path lengths to establish timing. These parameters are the key drivers in how water behaves as it interacts with and travels through a watershed for a particular precipitation volume and pattern (i.e., storm event). Numerous modeling software packages have been developed for hydrologic modeling. Brief descriptions of hydrologic modeling software, which were applied for watershed modeling in the study region, are noted in the Supporting Information 4-2.

Hydraulic models use numerical solutions to characterize the flow and water surface elevation (i.e., stage) within riverine waterbodies and their surrounding floodplain. This allows the user to determine and extract floodplain extents and depths associated with a particular precipitation volume and pattern (i.e., storm event). Hydraulic models leverage hydrologic information, land use characteristics, terrain/bathymetric data, and downstream boundary conditions as inputs which drive model outcomes. A brief description of hydraulic modeling software, which were applied for hydraulic modeling in the study region, are noted in the Supporting Information 4-2.

While there is generally extensive model coverage in the state (Figure 14-Figure 20), particularly within the Harvey impacted areas, the level of detail and subsequently the usability of models vary. For example, the BLE studies provide broad coverage throughout the state but many of the models are low detail, or broad, and are intended to be applied regionally. Detailed models tend to be specific to projects and generally cover a specific geographical area, limiting their applicability to efforts outside of the intended project. The GLO Combined Flood Studies efforts are intended to develop more detailed models in specific areas as deemed necessary by ongoing baseline modeling efforts to support future flood risk management alternative analysis but are limited to the Harvey impacted areas (i.e., the regions).

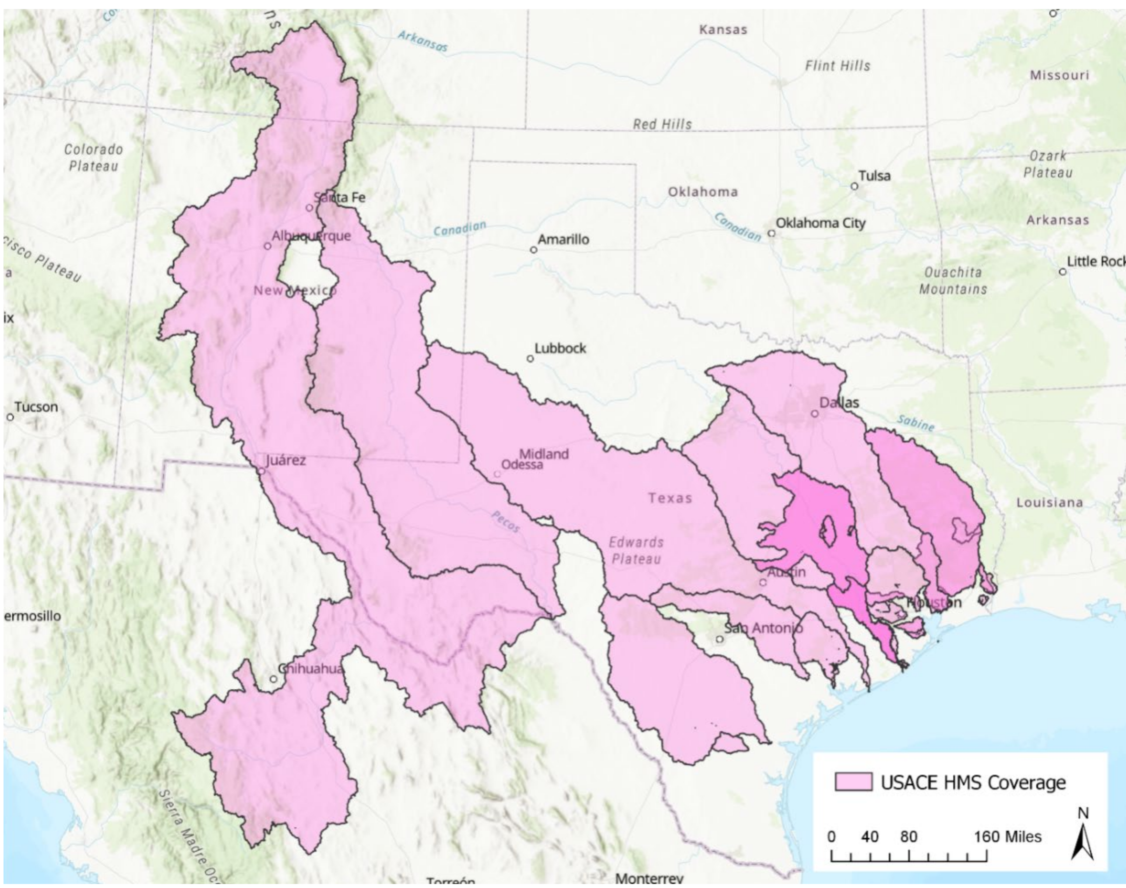


Figure 14: USACE Georeferenced HEC-HMS coverage in Texas

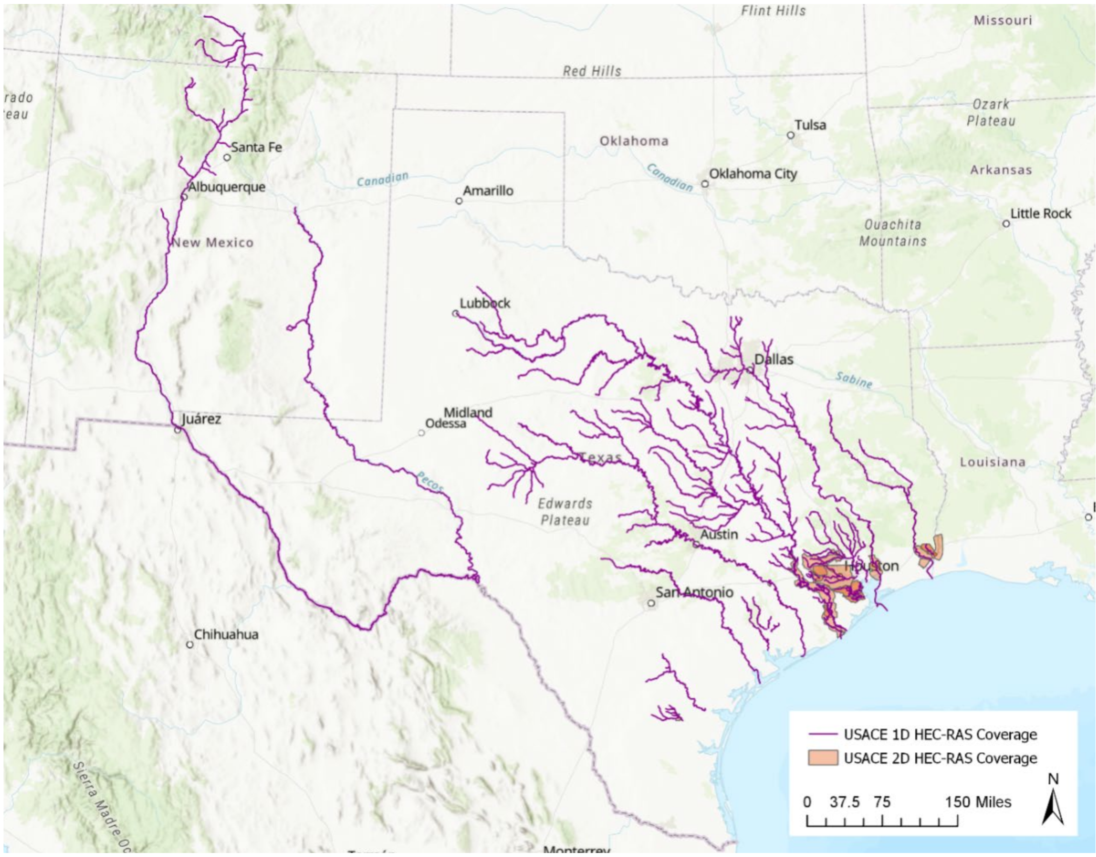


Figure 15: USACE Inland Georeferenced HEC-RAS Model coverage

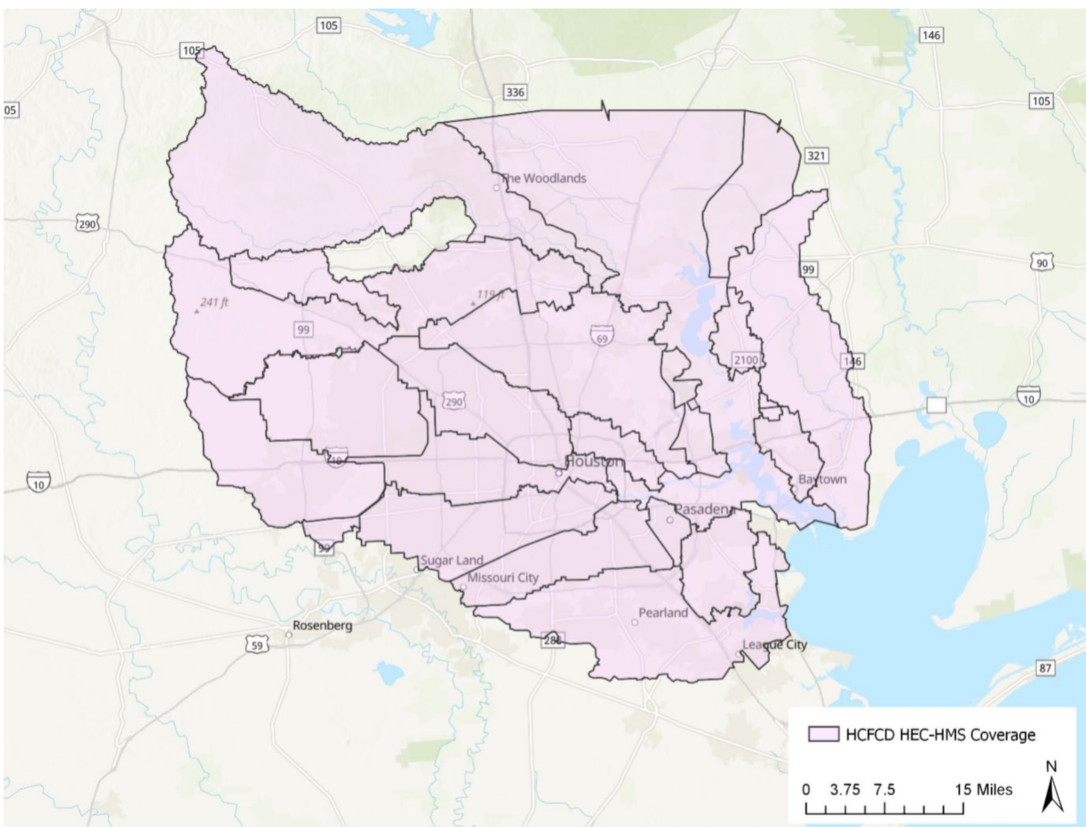


Figure 16: HCFCD Georeferenced HEC-HMS coverage

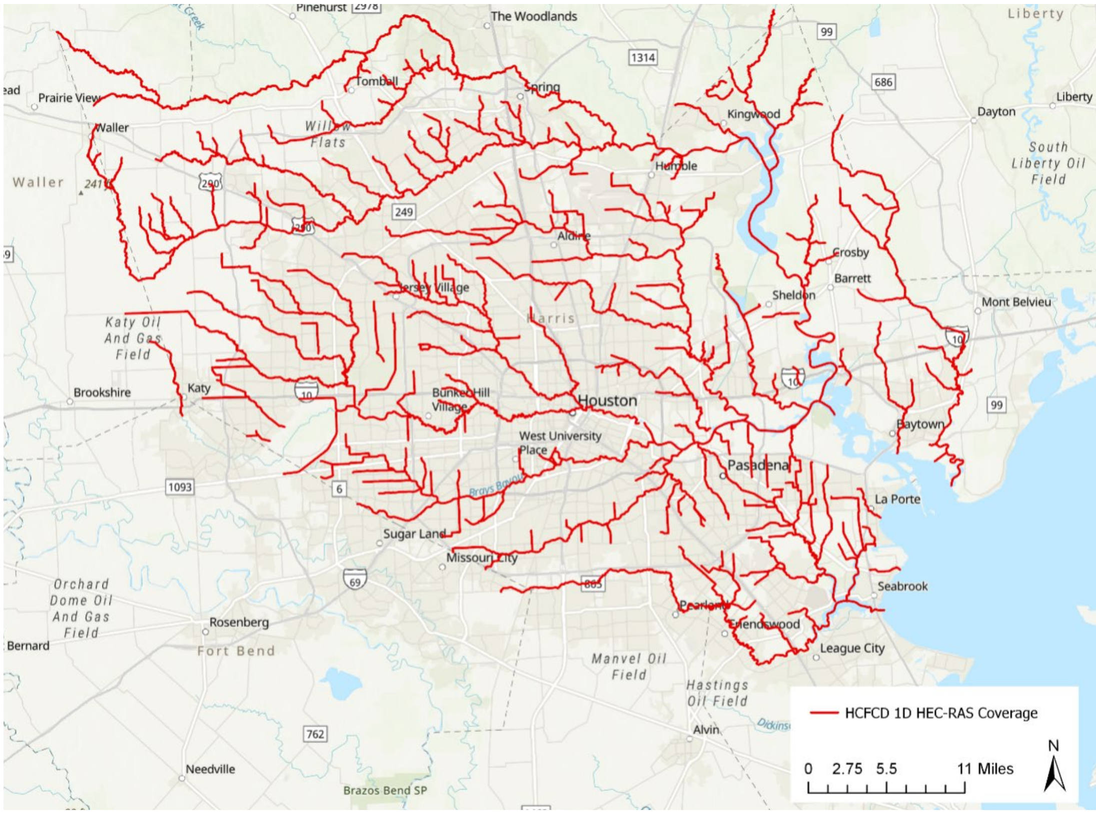


Figure 17: HCFCD Georeferenced HEC-RAS Model coverage

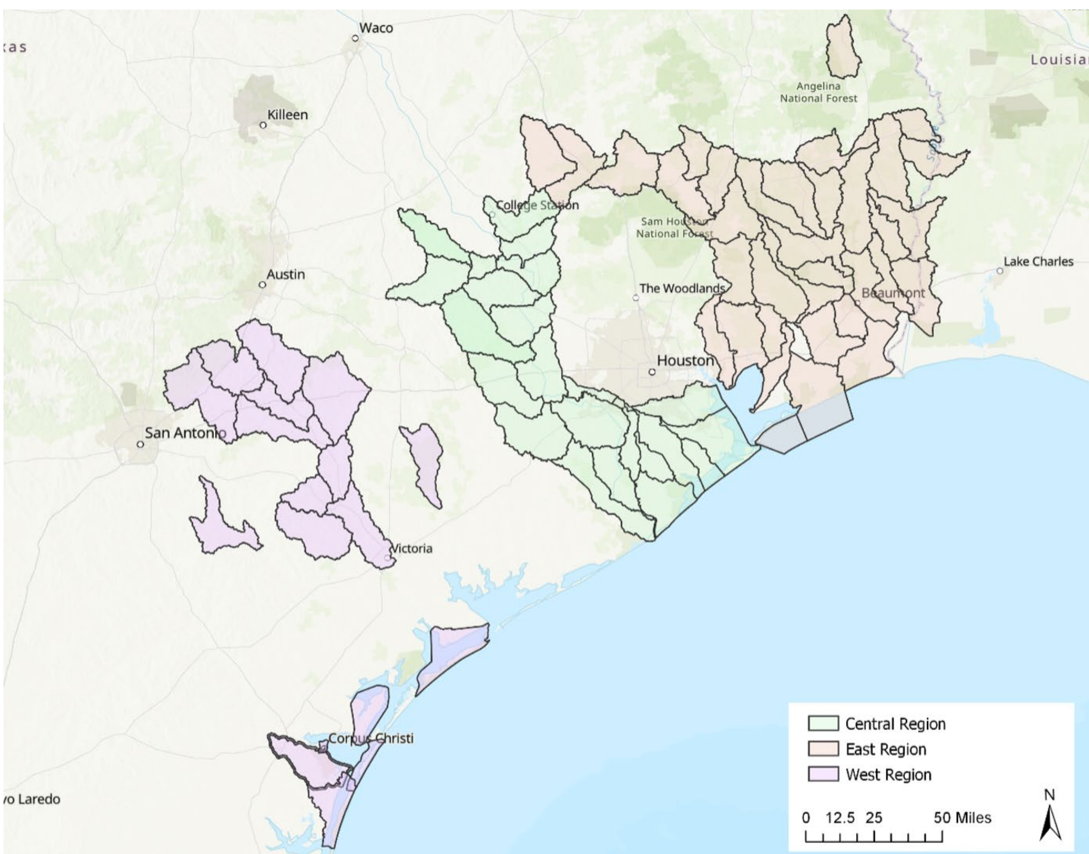


Figure 18: Planned GLO Combined River Basin Flood Studies Baseline Model coverage for Central, East, and West Regions

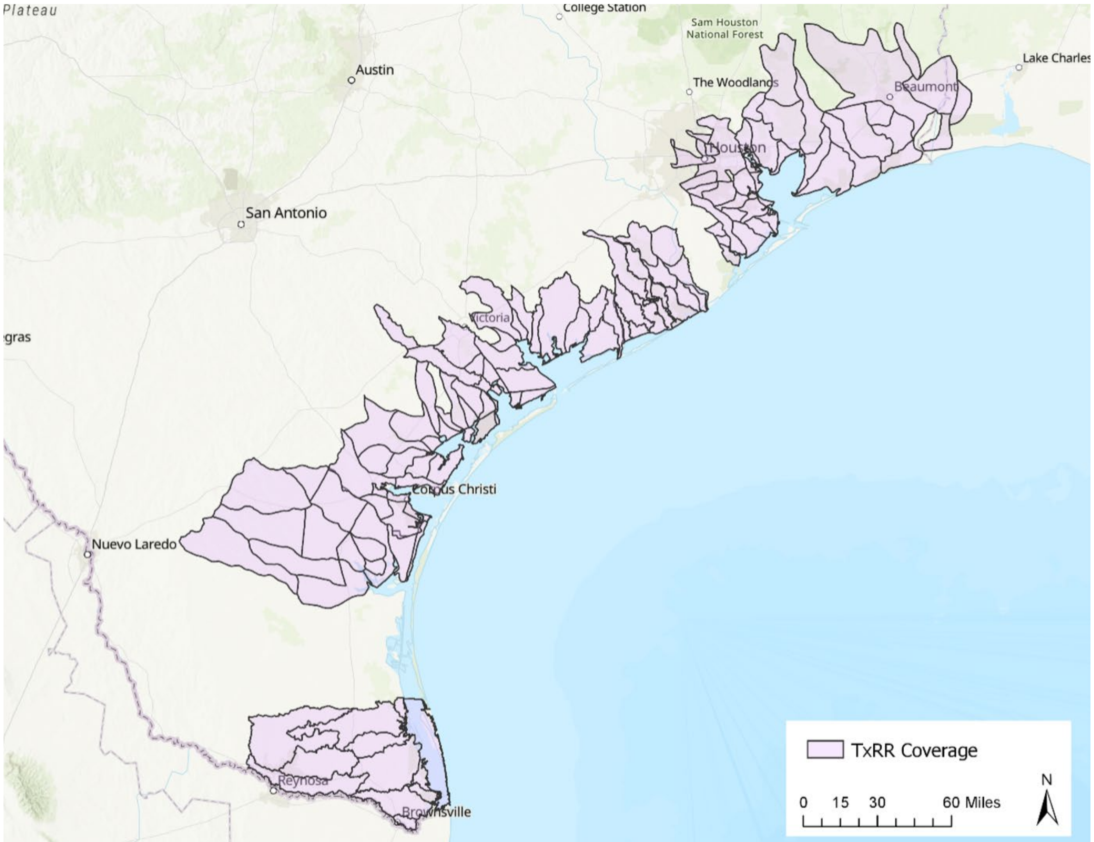


Figure 19: TWDB Georeferenced Texas Rainfall-Runoff Model coverage

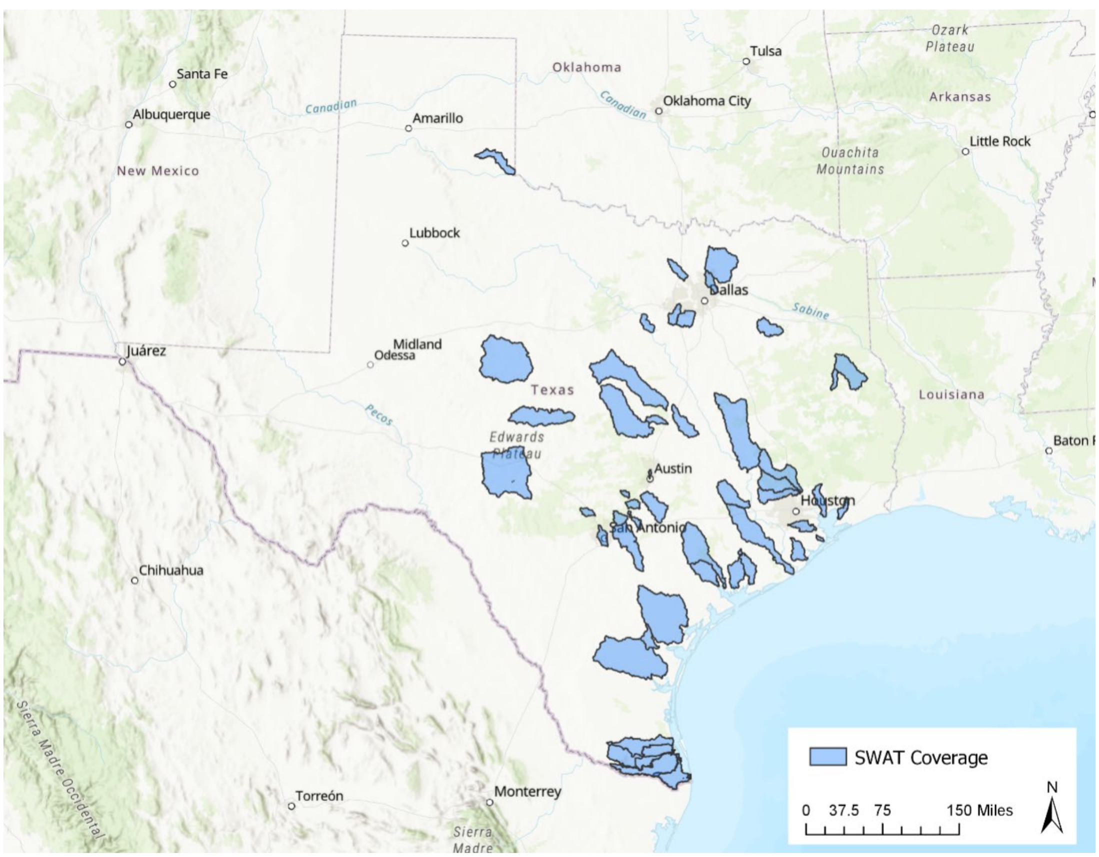


Figure 20: Texas A&M AgriLife Extension Georeferenced Storm Water Management Model coverage

4.8 Meteorological Models and Datasets

TIFF collected meteorological information with a slightly different format than other hydrologic, hydraulic, and coastal information. The meteorological information consists of models used to develop forecasts as well as datasets that have been modified and/or translated into a format digestible for hydrologic, hydraulic, and coastal modeling purposes (see Supporting Information 4-3). The models and datasets include forecast and/or historical information and range from statewide to global in coverage area.

4.9 Coastal Models

Coastal modeling leverages physical attributes and numerical methods to demonstrate and quantify coastal forcings and their consequences. These models simulate hydrodynamics, waves, and sediment transport along coasts and estuaries. Quantifying these forcings provides insight into their impacts associated with coastal inundation (i.e., storm surge), wave action, and/or geomorphological changes (e.g., beach erosion). These models can range in size from targeted locations along a shoreline to entire oceans depending on modeling effort needs. Brief descriptions of coastal hydrodynamic modeling software applied for coastal hydrodynamic modeling in the study region are noted in the Supporting Information 4-1.

The coastal model coverage, shown in Figure 21 spans the major Texas bays but varies in complexity and purpose largely based on project needs at the time. Many coastal models are limited in inland extent since the detail within inland hydrologic/hydraulic models tend to lessen as the riverine environments approach the coast.

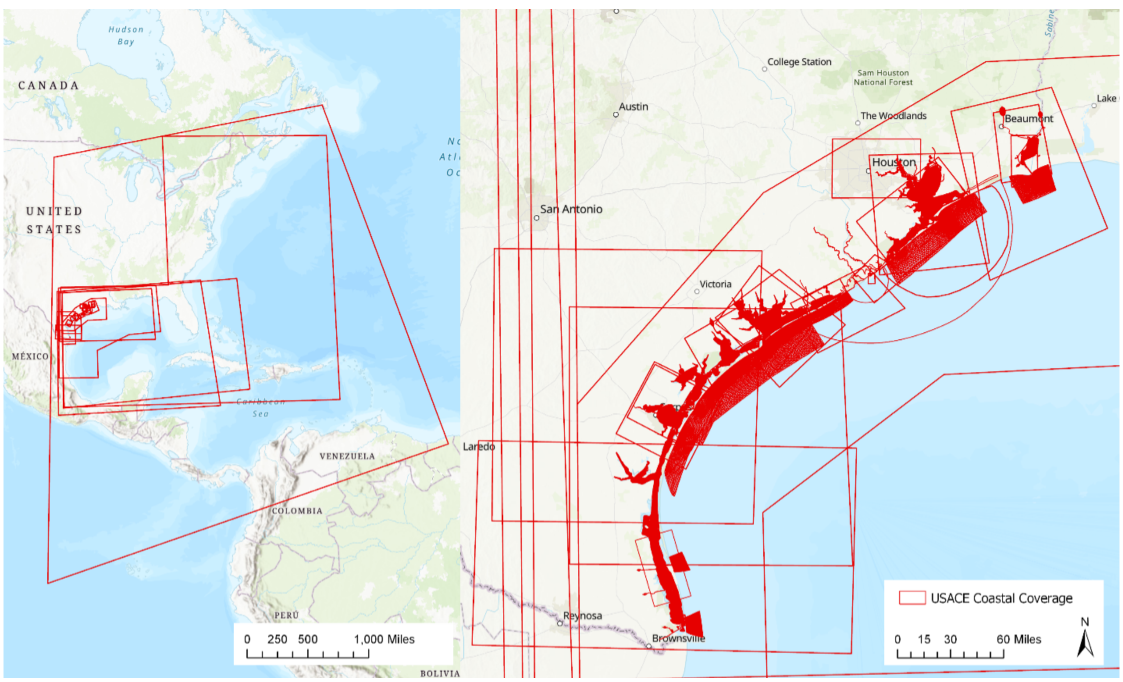


Figure 21: USACE Georeferenced Coastal Model coverage

4.10 Model Metadata Management and Dissemination

Once the model metadata was collected and categorized, TIFF coordinated with TDIS to compile and disseminate the inventoried information. Geodatabases containing shapefiles that were paired with their respective metadata were shared with TDIS. TDIS then leveraged the ArcGIS online platform to display the available model coverage areas and their associated metadata. TDIS staff used the Python programming language and geoprocessing tools to optimize the data for access in REST ArcGIS Enterprise services. These services

Hurricane Harvey flooding in Port Arthur, Texas © Sgt. Malcolm McClendon, U.S. Army National Guard

were then integrated with ESRI's Cloud-based ArcGIS.com infrastructure. Finally, using ESRI's app templating, TDIS integrated the map, the services and functionality for [model inventory viewer](https://arcg.is/0nm9L5) (Figure 22). The current model inventory effort includes 819 models as of December 2022 (TIFF Annual Report, Year One).

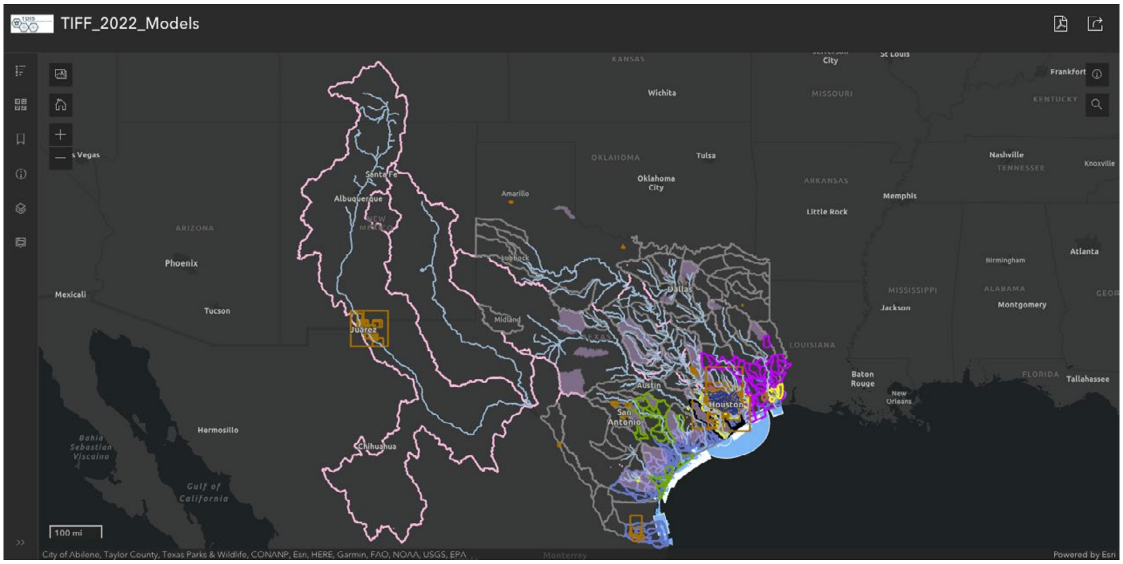


Figure 22: Draft TIFF Model inventory viewer (https://arcg.is/0nm9L5)

4.11 Challenges and Lessons Learned

The completeness and accuracy of the information collected during this task is that of a planning level of effort. While efforts were made to be comprehensive in the model inventory and associated metadata collection, there may be inaccuracies present. The extent of the completeness of each line of metadata was dependent upon what information existed and/or was made available at the time of collection. Some existing models were more robustly catalogued than others, and some did not have all relevant metadata available. It is important to note that the catalogued models are included for reference purposes and care should be taken when leveraging the existing information. This is particularly true when it comes to models developed for specific infrastructure implementation scenarios (i.e., not widely

Hurricane Harvey flooding in Port Arthur, Texas © Sgt. Malcolm McClendon, U.S. Army National Guard

applicable) or those that were created years ago and leverage outdated data inputs (e.g., outdated precipitation inputs, terrain, land cover data). This model metadata catalogue may be considered as a preliminary base level model information which can pave the way for future development of model repository for sharing with diverse stakeholders.

4.12 Suggestions

This initial model inventory provides base level model metadata information for hydrologic, hydraulic, meteorological, and coastal models. Although a significant number of model metadata sets were compiled for inland hydrologic, hydraulic, and meteorological models as part of this effort, metadata sets were compiled for a limited number of coastal models. Most of the compiled coastal models were developed for supporting different USACE projects in Texas. However, a significant number of coastal models were developed or are being developed by different universities for improving understanding of processes controlling coastal flood hazards. Other federal (e.g., NOAA and FEMA), state, county and local agencies also developed or are developing diverse coastal models for coastal flood hazard estimation in support of their respective program needs. Vendors of GLO's Combined Flood Studies and TWDB's RFPGs also compiled a very limited number of coastal models through their stakeholder engagement surveys. TIFF suggests the creation of comprehensive coastal model metadata collections for facilitating sharing of coastal models among Texas stakeholders and supporting improved understanding of coastal flood hazard estimation through leveraging existing models and datasets. TIFF also suggests periodic updates of the developed model inventory as more models become available. This living model inventory will prevent duplication of model development efforts as huge amounts of flooding analysis are being or will be performed to support a wide range of flood resiliency projects.

To facilitate model access and sharing with diverse stakeholders, TIFF suggests development of a comprehensive model management system including archiving and sharing of mode input and output files while taking the developed model inventory list as the test-case for development of a comprehensive model management system. Once the model management system is developed, it needs to be made available not only for sharing archived models, but also providing opportunity to the model developer for uploading their new models for wide disseminations. TIFF also suggests future investigation of how the developed models—which vary in resolutions, accuracy, and other factors—can be leveraged and integrated for improved understanding of flood risk in the study region.

Texas A&M University helping stakeholders plan for future flood risk © FEMA

5 Component 4 – Planning and Outreach

Component 4 ensures that end-users' flood planning and mitigation needs are incorporated into the data and modeling frameworks and the findings from various efforts are well communicated. A close collaboration among TIFF, CHARM, RFPGs, Combined Flood Studies is required to achieve such a goal.

TIFF will also support expansion and improvement of flood planning in Texas by incorporating the new findings into the existing planning tools or recommending the creation of new tools. Finally, TIFF will work to balance and communicate between project-based and regional planning scale solutions. TIFF will perform each of the following subtasks in collaboration with the TATs:

- Establish a Planning and Outreach TAT to support Component 4
- Coordinate with the RFPGs and stakeholders to identify flood planning and mitigation scenarios consistent with regional flood planning efforts, beginning by establishing a working relationship with RFPGs or their coastal liaisons to identify TIFF end-users
- Develop and implement a comprehensive outreach plan to engage regional planning groups and other stakeholders regarding flood planning and mitigation efforts
- Annually reassess user needs regarding flood planning and mitigation efforts and requirements and provide the results by updating the comprehensive outreach plan and preparing an annual progress report
- Support the development of flood communications and educational materials
- Investigate the opportunities to balance and communicate between project-based and regional planning scale solutions
- Perform a literature review on planning tools and develop list of data modeling needs for planning tools
- Evaluate and provide feedback on the initial inventory of planning datasets (e.g., parcel data, structure characteristics, first-floor elevation, building codes, demographics, etc.) provided by the GLO Combined Flood Study Groups
- Make recommendations pertinent to flood planning and outreach/communication to GLO as they arise

5.1 Comprehensive Outreach Plan - Year One

The goal of TIFF is to deliver products that improve the resiliency response of Texans impacted by coastal flooding. The TIFF comprehensive outreach plan seeks to gather perspectives from two primary groups of TIFF product end-users, technical and non-technical, to create useful and reliable guidelines, standards, recommendations, and related products. This plan describes how the SC will leverage existing outreach programs to reach the non-technical general public and establish relationships with technical end-users to address their unique challenges.

TIFF is committed to developing useful and reliable products that can be employed across flood-impacted communities in Texas. To build a foundation of trust within these communities, the SC will utilize an inclusive bottom-up approach to gather information on end-user needs, leverage collaboration with experts, avoid redundancy with similar flood-focused projects, and follow a sound scientific approach in the development of all guidelines, recommendations, and related TIFF products.

5.1.1 Building Trust as a Reliable Source of Information

Establishing TIFF as a trusted source of recommendations, guidelines, and standards for coastal flood risk planning and mitigation is key to the success of the TIFF. As TIFF seeks to improve the resiliency of Texans in the path of compound flooding, TIFF must deliver accurate and reliable information based on sound science for effective planning. There are five key elements needed to build a foundation of trust that will be explored in detail herein (Figure 23). The suggested guidelines, model recommendations, and educational materials provided by TIFF will be a collaborative effort using input from technical experts, stakeholders, and impacted communities.

The TIFF guidelines, recommendations, or suggestions for data collection and modeling are not intended for use in a regulatory framework but are intended to support voluntary comprehensive planning. The measure of success for TIFF is defined by the adoption and use of its standards and guidelines by communities to plan for and mitigate the risk of compound flooding.

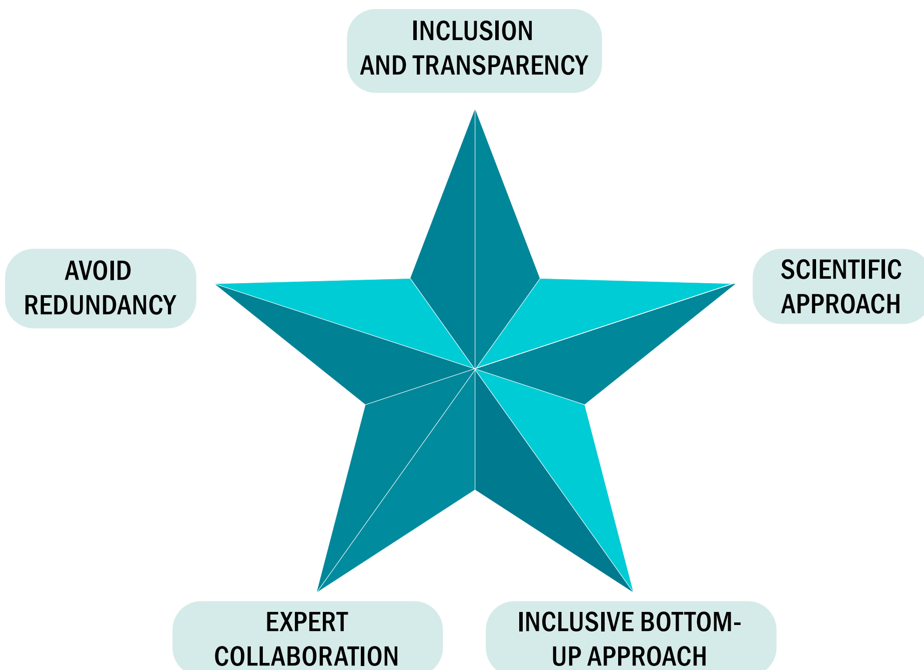


Figure 23: The TIFF star shows the five major elements of trust for building a reliable brand among the Framework's end-users

5.1.1.1 EXPERT COLLABORATION

The SC seeks to collaborate with experts in the field of coastal flooding to leverage key knowledge and expertise. Feedback on end-user needs and collaboration with experts across many disciplines will ensure valued and relevant TIFF products. The TAT members (96 people among the four components, as described in Section 1.1.3.3) are well-known experts in various aspects of coastal flooding including data monitoring, new monitoring technologies, data management and visualization, modeling, planning, and outreach. TIFF will interact with technical end-users through interactive meeting opportunities and other direct forms of communication (e.g., surveys, workgroups, emails, etc.). Figure 1 lays out the general execution approach used by TIFF to execute all TIFF project efforts and shows where in the process the TATs will be consulted for feedback. The ultimate goal for TIFF is the pioneering of a new collaborative effort to address compound flooding impacts in Texas and establishing the TIFF project as a benchmark for future efforts in this field.

The state and federal agencies that support the TIFF efforts are recognized leaders in flood science, planning, and mitigation. The TIFF project is funded through GLO, where several successful programs are already in place to improve the livelihood and success of Texans recovering from natural disasters. Likewise, TWDB stewards several successful community programs to provide assistance to those impacted by flood and storm related effects. Both partner federal agencies (USACE and USGS) are recognized leaders for their expert contributions to modeling and data collection science. These agencies both have a strong history of partnering with state agencies such as GLO and TWDB to improve the safety and lives of the communities they serve.

5.1.1.2 INCLUSIVE BOTTOM-UP APPROACH

It is well-established that the engagement of end-users in the creation of any new product or idea will lead to a higher likelihood of the use of new products once they are available to a community at large. The early engagement and inclusion of the end-users in development of project deliverables is one way to build trust among technical and non-technical end-user groups. TIFF seeks to connect with non-technical end-users through leveraged assistance from existing agency programs already engaged with these communities on similar topics.

Once perspectives are collected, then the process of creating solutions in the form of guidelines and recommendations to meet end-user needs can progress. Moreover, the SC is working closely with researchers from the school of communication at the University of Texas at Austin, who are working on a research project funded by TWDB to conduct surveys and interviews to gather information on how potential end-users could benefit from TIFF products.

Communities and individuals that could benefit directly from the guidelines and model recommendations made by TIFF, such as those living in areas where compound flooding may be a concern, will be able to provide feedback on their needs and concerns for local areas through established agency programs, as discussed in more detail in Section 5.1.2.

5.1.1.3 SCIENTIFIC APPROACH, INCLUSION, AND TRANSPARENCY

Expert collaboration in all four components of the TIFF planning project will help ensure that the guidelines, recommendations, and all related TIFF products are created through a holistic scientific approach. As mentioned earlier, the SC is comprised of individuals and agencies that have made valuable contributions to the field of flood science and are committed to using a sound scientific approach to develop recommendations that will be useful to end-users. To further these efforts the SC members, collaborate with technical experts in the field of flood science beyond the TIFF associated agencies. It is the belief of all the SC members that a logical scientific approach must be behind any of the TIFF recommendations in order for these recommendations to prove useful to, and become trusted by, all potential TIFF end-users.

To create a useful product, it is imperative to first understand the needs of those end-users that will use the product in future applications. To this end, the SC looks to include input at all possible end-user levels (through direct and indirect outreach) and to consider feedback on the needs of both technical and non-technical end-users in the development of TIFF guidelines, recommendations, and related products. Going forward, TIFF project efforts will focus on gathering these perspectives directly from technical end-users and indirectly from non-technical end-users through interactive opportunities and established programs. Inclusion of the perspectives and needs of these end-users will assure that the generated TIFF products from this project are useful, helpful, and trusted by the communities they are intended to assist.

The SC believes in keeping TIFF project activities transparent and open to anyone with interest in flood planning and mitigation. To achieve this, the SC will make final products

Texas A&M University's Texas Community Watershed Partners hosting a CHARM workshop in Galveston County. © Texas A&M University

available to the public and post project updates on the website. Furthermore, all data gathered or collected (if any) by the TIFF planning project will be shared with the public through TDIS.

5.1.1.4 AVOID REDUNDANCY

In addition to assuring that all TIFF guidelines and recommendations are created via a sound scientific process with expert collaboration, TIFF is committed to avoiding redundancy and duplicative efforts. Through an extensive effort to communicate with project managers across Texas on planned and ongoing flood related data and model driven projects, TIFF cataloged many important projects related to flood preparedness in Texas (refer to Section 1.2). By recognizing and cataloging so many flood-related efforts already in place across the state, TIFF may help avoid project duplication efforts statewide and provide end-users with a helpful comprehensive project overview. Avoiding redundancy is a key component of creating useful and relevant TIFF products.

The efforts put forth by the TIFF project to provide a holistic view of all related flood science work efforts in the state is novel in its approach and function. The benefits of having a comprehensive database where project information can be added and updated as needed will be evident in the funds and man-hours saved as redundancy is avoided from duplicative efforts. It is the intention of the SC to make this database available through methods that will be further developed. The existence of a comprehensive database to reference flood science projects that are currently ongoing or completed will significantly improve efforts to avoid project redundancy.

Individual members of the SC participate in various meetings to update stakeholders on TIFF progress, as well as to inform the SC on the progress of other projects. The Texas Flood Organizing Group, Galveston Bay Council, Southeast Texas Flood Coordination Study, and GLO Combined Flood Studies could be named as a few of these meetings.

5.1.2 Outreach Plan and TIFF End-Users

TIFF is a continuously evolving planning project designed to generate products responsive to end-user needs including a final report with recommendations to improve planning tools for coastal flooding and its associated risks. A non-biased, scientific approach is prioritized to ensure reliability of TIFF products in the communities they are designed to help. TIFF potential products can be categorized into three groups: 1) recommendations for new projects (e.g., need for data acquisition and model generation); 2) technical guidelines for planning tools, modeling frameworks, data management and visualization, and new monitoring technologies; and 3) information on coastal flooding for general public. The target end-users for the first two products are different from the latter; thus, the TIFF outreach efforts will focus on reaching two basic groups of end-users. Those with a more technical background will be considered as 'technical end-users', while those that may lack that technical background but would still greatly benefit from the TIFF guidelines and recommendations will be referred to as 'non-technical' end-users. Every possible effort will go into collecting information and feedback on the needs of these two end-user groups to generate TIFF products. Figure 24 shows a simple version of a communication path between groups of technical and non-technical end-users that the SC will employ to gather this information.

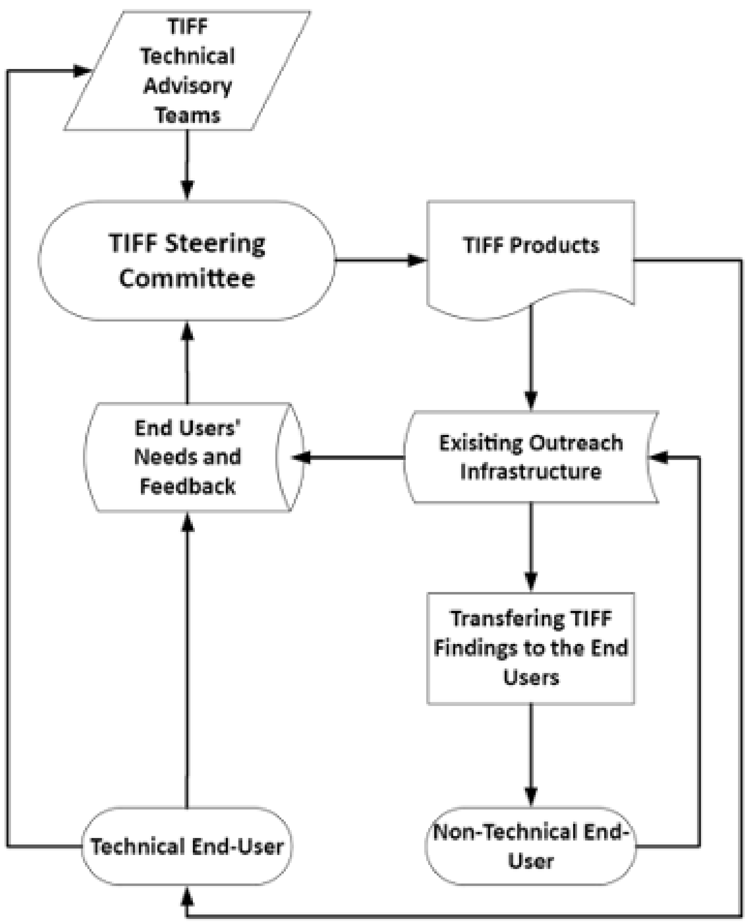


Figure 24: Simplified communication feedback loop between technical and non-technical end-users and the SC to produce useful TIFF products

5.1.2.1 TECHNICAL END-USERS

A direct outreach approach will be used to build a relationship with the TIFF technical end-users and exchange information with them. This group is primarily represented by members of the TATs which include experts from federal, state, and academic agencies.

Technical end-users also include the RFPGs established by TWDB, their coastal liaisons, the consulting engineering firms who support the RFPGs as well as the GLO's Combined Flood Studies, and TDIS. Such inclusion guarantees the information exchange between the TIFF, technical end-users, and the stakeholders of these major planning efforts. Finally, a direct relationship will be formed between the TIFF and Texas Coastal Resiliency Master Plan (TCRMP) project.

5.1.2.2 NON-TECHNICAL END-USERS

End-users engaged in the creation and development of any policy, product or guideline are more likely to use or follow those guidelines or products once they are available to a community at large. The early engagement of the end-users in development of project goals and deliverables is one way to build trust among technical and non-technical end-user groups. TIFF seeks to achieve this bottom-up inclusiveness of non-technical end-users through leveraged assistance from existing agency programs already engaged with these communities on similar topics.

An indirect approach will be applied to exchange information with the non-technical end-users (general public) via the existing initiatives and programs such as the efforts conducted by CHARM, RFPGs, and TWDB's Community Assistance Program. TIFF will leverage the existing relationships among the aforementioned programs and the communities they serve to a) get feedback on community needs; b) transfer TIFF products to the communities; and c) educate the communities on coastal flooding. Figure 25 shows a more detailed communication path with a breakout view of the different groups making up both the technical and non-technical end-users' groups. The TIFF outreach plan will be refined and become more focused as the initial TIFF efforts progress over the next three years with updated plans providing more details on these relationships as they develop.

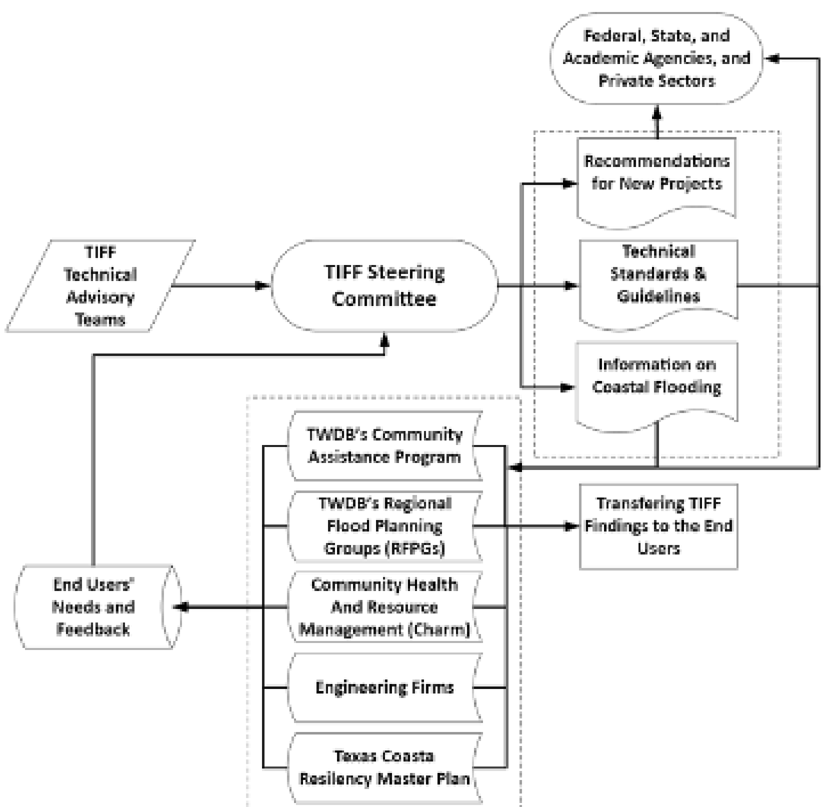


Figure 25: A detailed break out of the communication loop between TIFF and technical and non-technical end-users with these groups defined from Figure 24

5.1.3 Leveraging Existing Efforts and Building Relationships

5.1.3.1 CHARM

CHARM is a Community Health and Resource Management mapping application developed by Texas A&M AgriLife. It gives local officials, stakeholders, and citizens the power to map and analyze community solutions with real-time feedback. With several technology updates to the existing software, the CHARM platform will be brought online for use by the communities. GLO's Community Development and Revitalization program will also fund multi-day technical training sessions to further build planning competence at the local level. When integrated with the disaster database project, this enhancement could provide local communities with the information, tools, and technical expertise to make informed planning decisions. This planning study collects and presents the necessary data to "inform both the state and local communities of possible solutions that plan for and create a more resilient landscape in the state of Texas."

The SC met with CHARM leadership to discuss the opportunity for TIFF to work with CHARM to reach non-technical end-users. The meeting yielded a consensus between the efforts to work together to seek community needs and feedback, and to disseminate TIFF guidelines and related products.

5.1.3.2 TWDB COMMUNITY ASSISTANCE PROGRAM

The Community Assistance Program team at TWDB helps educate communities and provides information and guidelines, such as workshops, resources, and trainings, necessary for participating in the National Flood Insurance Program and Community Rating System (CRS) programs. By participating in the CRS program, communities can earn a discount for flood insurance premiums based upon the activities that reduce the risk of flooding within the community.

The SC champion for outreach met with TWDB Community Assistance Program staff to discuss a coordinated effort to reach the non-technical end-user groups. Both parties agreed to work together to communicate community needs and to share information produced through TIFF. As a result of this collaboration, tasks in a new contract between TWDB and the School of Communication at the University of Texas at Austin were designed to build a foundation for future TIFF needs.

5.1.3.3 RFPGS

In the wake of historic flooding in Texas, the 86th Texas Legislature (2019) passed legislation to create Texas' first-ever regional and state flood planning process and provide funding for investments in flood science and mapping efforts to support plan development. The legislature created a state flood planning framework and charged TWDB with creating flood planning regions based on river basins and administering the required, ongoing work of flood planning. This effort is aimed at better managing flood risk to reduce loss of life and property from flooding. Additionally, the legislature created a new flood financial assistance fund and charged TWDB with administering the fund. The Flood Infrastructure Fund, as approved by Texas voters in November 2019, will be used to finance flood-related projects.

The overarching goal of regional flood planning, and the comprehensive state flood plan that will rely on the plans created by these regional groups, is to protect against loss of life and property from flooding. At the October 1, 2020 Board meeting, TWDB designated the initial voting members of the 15 RFPGs; each regional flood planning group will be responsible for developing a regional flood plan by January 2023. Based on the regional flood plans, TWDB will prepare and adopt the Texas' first-ever state flood plan and present it to the Texas Legislature in September 2024. TWDB will provide grant funds to planning groups, enabling them to hire technical consultants to perform much of the work necessary


Aerial photo of Galveston Texas © Eric, Adobe Stock

to develop the regional flood plans. Regional flood plans are required to be based on the best available science, data, models, and flood risk mapping. TWDB hosts a region-specific webpage for each planning group that contains a general description of the region, the list of counties that lie within the regional boundary, and meeting updates. To view a region of interest, visit https://www.twdb.texas.gov/flood/planning/regions/index.asp.

The SC met virtually (via Zoom) with the designated coastal liaisons from the RFPGs on Wednesday, September 1, 2021 to discuss their specific needs and discover ways to leverage our respective activities (see Section 1.3.2 for more details). The meeting successfully opened a dialogue between the RFPG coastal liaisons and TIFF. The liaisons identified and discussed many important issues that will be considered during the development of the TIFF deliverables. The coastal liaisons also expressed their willingness to be informed on TIFF milestones and to continue providing feedback to the TIFF.

5.1.3.4 TEXAS COASTAL RESILIENCY MASTER PLAN

The TCRMP provides a framework for community, socio-economic, ecologic and infrastructure protection from both short-term, direct (e.g., flooding, storm surge) and long-term, gradual impacts (e.g., erosion, habitat loss) of coastal hazards. The goal of this plan is to restore, enhance, and protect the state's coastal natural resources. The plan contains a list of projects identified and vetted by Technical Advisory Committees from across the state. Such projects will help to identify and enhance opportunities to improve the resilience of the Texas coast and its natural environment to coastal hazards. Furthermore, the TCRMP provides valuable data and information used by decision-makers to protect against and recover from natural disasters. Finally, the TCRMP prioritizes critical projects with regards to recovery from storms and natural disasters that could be eligible to receive funding from a multitude of funding sources.

The SC met with GLO to discover effective ways to leverage coastal planning efforts. TIFF gained a better understanding of TCRMP Technical Advisory Committees and their targeted


Aerial photo of Galveston Texas © Eric, Adobe Stock

audience. Through a vital information exchange, a significant opportunity was identified to leverage and optimize coordination efforts with coastal stakeholders and decision-makers. The discussion led to TCRMP recognition of TIFF as an example of cross-agency collaboration to grow key knowledge and experience in planning for resilience to coastal flood hazards. Next steps will be to further develop this collaboration.

5.1.3.5 ENGINEERING FIRMS

The TWDB RFPG's and GLO's Combined Flood Study groups are working closely with engineering firms throughout the state. Both efforts rely on engineering expertise to assist with plan and policy development related to flood mitigation. The SC considers these engineering firms to be among the technical end-users of future TIFF products and is seeking to gain insight on their needs and perspectives of the flood planning challenges they face. In doing so, TIFF hopes to provide useful recommendations and information to these engineering firms for informing future planning cycles.

The SC is working with the Meadows Center Facilitation Team to facilitate an interactive meeting with this group of engineering firms set for 2023 with a goal of identifying information and planning tools that will be useful to these engineering firms in future phases of current state funded projects.

5.2 Future Efforts

As TIFF outreach efforts continue, the Outreach Champion, (TWDB) together with the SC, will focus on further identification of end-users and building relationships with the people, programs, and agencies mentioned in this report. In subsequent reports, updates describing ongoing outreach activities will be provided. The next steps include identifying ways to leverage existing outreach programs to indirectly reach non-technical end-users and gather feedback on the specific needs of technical end-users.

6 TIFF Recommendations

6.1 Recommendation #1: Quality Assurance and Integration of Historical TCOON Data

Project Name: Texas Coastal Ocean Observation Network (TCOON) Enhancements
Scope: Integration of historical TCOON datasets into NOAA's operational database.
Schedule: 3 years
Estimated Budget: $1,325,000
Implementation Agency: NOAA
Estimated CBR: 16
Explanation of Benefits: Significantly increase accuracy of coastal flood modeling and forecasting.

See Supporting Information 6-1 for more information.

6.1.1 Attached Letter to the Texas General Land Office

August 09, 2022

Attn: Tyler Payne, PMP, Project Manager - Community Development & Revitalization, GLO

Dear Mr. Payne:

I am pleased to submit a recommendation provided by the Steering Committee of the Texas Integrated Flooding Framework (TIFF) planning project. The TIFF Steering Committee recommends investment in the quality control and quality assurance of the historical TCOON datasets not currently incorporated in the official National Oceanic & Atmospheric Administration (NOAA)'s Center for Operational Oceanographic Products and Services (CO-OPS) database. To achieve this goal, NOAA's CO-OPS will utilize an innovative data processing and metadata evaluation approach to review 5,400 station months of water level data through their quality control and assurance process. The project is envisioned to take three years to complete and cost approximately $1.352M. The $1.352M upfront cost estimated for this project has a potential significant return on investment not just by intrinsic value of the data, but more importantly by decreasing the uncertainty of water level data in the coastal zone, which will lead to a better understanding of sea level rise analysis, coastal flooding analysis, and thereby, support in planning and design of flood risk management and coastal storm risk management projects. The key benefits of this project are as follows:

- Benefit/Cost Ratio = 16
- Deliver quality-controlled time series of water level data for an extended period of record.
- Update and improve foundational reference products like tidal datums and long-term sea-level trends that underpin coastal mapping and flood hazard assessment. Extending the five-year data series data to 25 years or more will significantly reduce the uncertainty of the various products supported and will provide the confidence level (> 95%) that users need.
- Expand the Inundation Dashboard for the Texas coastline by providing more integrated data on coastal flooding, including real-time alerts, and historic coastal inundation tracked through flood thresholds at the gage locations.

Please contact me at (512) 936-0844 or amin.kiaghadi@twdb.texas.gov if you have any questions or need additional information regarding this recommendation.

Respectfully,

Amin Kiaghadi, Ph.D., P.E.
TIFF Project Manager
Texas Water Development Board

6.2 Recommendation #2: Priority Areas along the Texas Coast for Bathymetry Data Acquisition

Project Name: Priority Areas along the Texas coast for Bathymetry Data Acquisition
Scope: Collecting bathymetry data in areas with a high priority need to enhance the performance of various modeling efforts
Schedule: Varies
Estimated Budget: Varies depending on water type, size of project, and the data collection methodology
Potential implementation Agency: TWDB, NOAA, USGS, and others (varies)
Explanation of Benefits: Significantly increase accuracy of coastal flood modeling and forecasting.

See Supporting Information 6-2 for more information.

6.2.1 Attached Letter to the Texas General Land Office

October 11, 2022

Attn: Shonda Mace, Manager - Community Development & Revitalization, GLO

Dear Ms. Mace,

I am pleased to submit a recommendation provided by the Steering Committee of the Texas Integrated Flooding Framework (TIFF) planning project. The TIFF Steering Committee recommends bathymetry data acquisition for 20 identified high priority areas along Texas coast, including shallow bays, rivers, and deep channels. This recommendation was based on a gap analysis which identified areas where bathymetric data are not available, or the existing data are more than 20 years old. Moreover, the TIFF Steering Committee utilized insights from Technical Advisory Team (TAT) members and other experts to identify the highest priority areas for bathymetric data needs along the Texas coast. The TIFF recommendation for priority areas considers only the feedback from survey participants; thus, is limited with respect to representing a broad stakeholder community. The cost of bathymetry acquisition depends on the type of waterbody, size of project, and method of collection. Considering the fact that bathymetric data is one of the most important datasets for coastal modeling, having recent and high accuracy bathymetric data will significantly increase the accuracy of coastal flood modeling and forecasting. This curated list for the highest priority areas in need of bathymetry data is intended to guide decisions for data collection in context of limited funding resources.

Please contact me at (512) 936-0844 or amin.kiaghadi@twdb.texas.gov if you have any questions or need additional information regarding this recommendation.

Respectfully,

Amin Kiaghadi, Ph.D., P.E.
TIFF Project Manager
Texas Water Development Board

7 List of References

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8 Supporting Documents

8.1 Section One

- **Supporting Information 1-1:** TAT Kick Off Invitation
- **Supporting Information 1-2:** TIFF Technical Advisory Team Rosters
- **Supporting Information 1-3:** Ongoing Statewide Flood Projects
- **Supporting Information 1-4:** TIFF TAT Kick Off Meeting Agenda
- **Supporting Information 1-5:** TIFF Kick Off Meeting Participant List
- **Supporting Information 1-6:** TAT Kick Off Meeting Notes
- **Supporting Information 1-7:** TAT Kick Off Meeting Follow Up Email
- **Supporting Information 1-8:** Coastal Liaisons Meeting Agenda
- **Supporting Information 1-9:** Coastal Liaisons Meeting Invitation
- **Supporting Information 1-10:** Coastal Liaisons of the RFPGs Meeting – Participants List
- **Supporting Information 1-11:** Coastal Liaisons of the RFPGs Meeting Notes
- **Supporting Information 1-12:** Component 1 TAT Meeting 1 Summary
- **Supporting Information 1-13:** Component 1 TAT Data Classification Survey Results
- **Supporting Information 1-14:** Component 2 TAT Meeting 1 Summary
- **Supporting Information 1-15:** Component 3 TAT Meeting 1 Summary
- **Supporting Information 1-16:** Component 4 TAT Meeting 1 Summary

8.2 Section Two

- **Supporting Information 2-1:** TIFF TAT Kick Off Meeting Agenda
- **Supporting Information 2-2:** TIFF Data Classification Workshop Summary
- **Supporting Information 2-3:** Bathymetry Workshop Materials
- **Supporting Information 2-4:** Bathymetry Suggestions Survey
- **Supporting Information 2-5:** Subsidence Workshop Materials

8.3 Section Three

- **Supporting Information 3-1:** Coastal User Interfaces Inventory
- **Supporting Information 3-2:** Existing Coastal User Interfaces

8.4 Section Four

- **Supporting Information 4-1:** Model Inventory Metadata Tables
- **Supporting Information 4-2:** Description of the Modeling Software
- **Supporting Information 4-3:** Model Inventory Meteorological Metadata Tables

8.5 Section Six

- **Supporting Information 6-1:** TIFF Recommendation #1: Quality Assurance and Integration of Historical TCOON Data
- **Supporting Information 6-2:** TIFF Recommendation #2: Priority Areas along the Texas Coast for Bathymetry Data Acquisition