

Hydrodynamic Simulation and Validation of Coastal Flooding in Galveston County, Texas to Identify Susceptible Roadway Networks

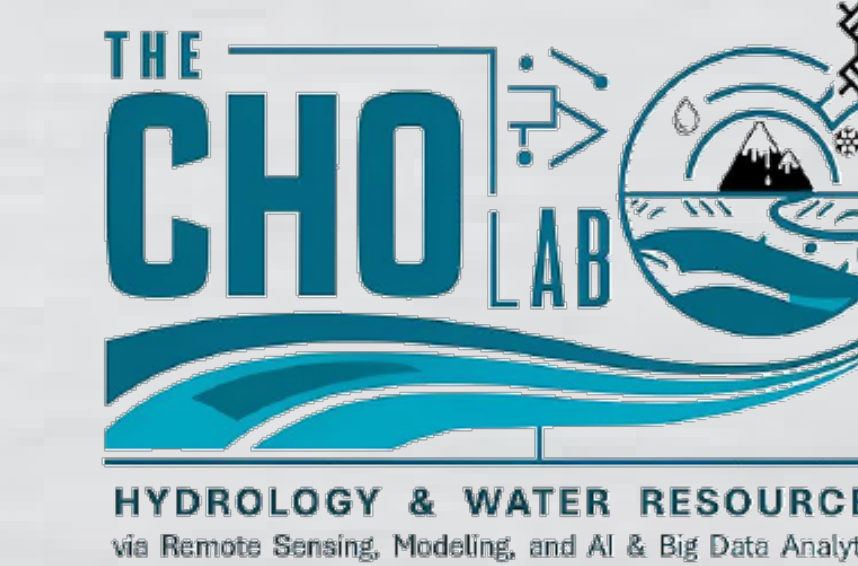
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Background

- Coastal areas face severe flood risks from sea level rise, storm surges, and hurricanes that can lead to catastrophic floods.
- These coastal floods are serious threat to the various infrastructures especially they can cause breakdown in transportation networks. Which can lead to system failures, loss of human lives and properties.
- Identifying vulnerable hotspots can save lives of people and their properties.



Source: NBC News

Research Questions

- How accurately can hydrodynamic model predict coastal flooding due to Hurricane Ike?
- What areas of Galveston County, TX can be inundated due to a 100-year return period event?
- Which road network segments of Galveston County are most susceptible to coastal flooding?

Study Area and Data

- Galveston County, TX.
- Surrounded by the Gulf of America (South) and Galveston Bay (North), it faces flooding risks from both directions.
- Extensive roadway networks.

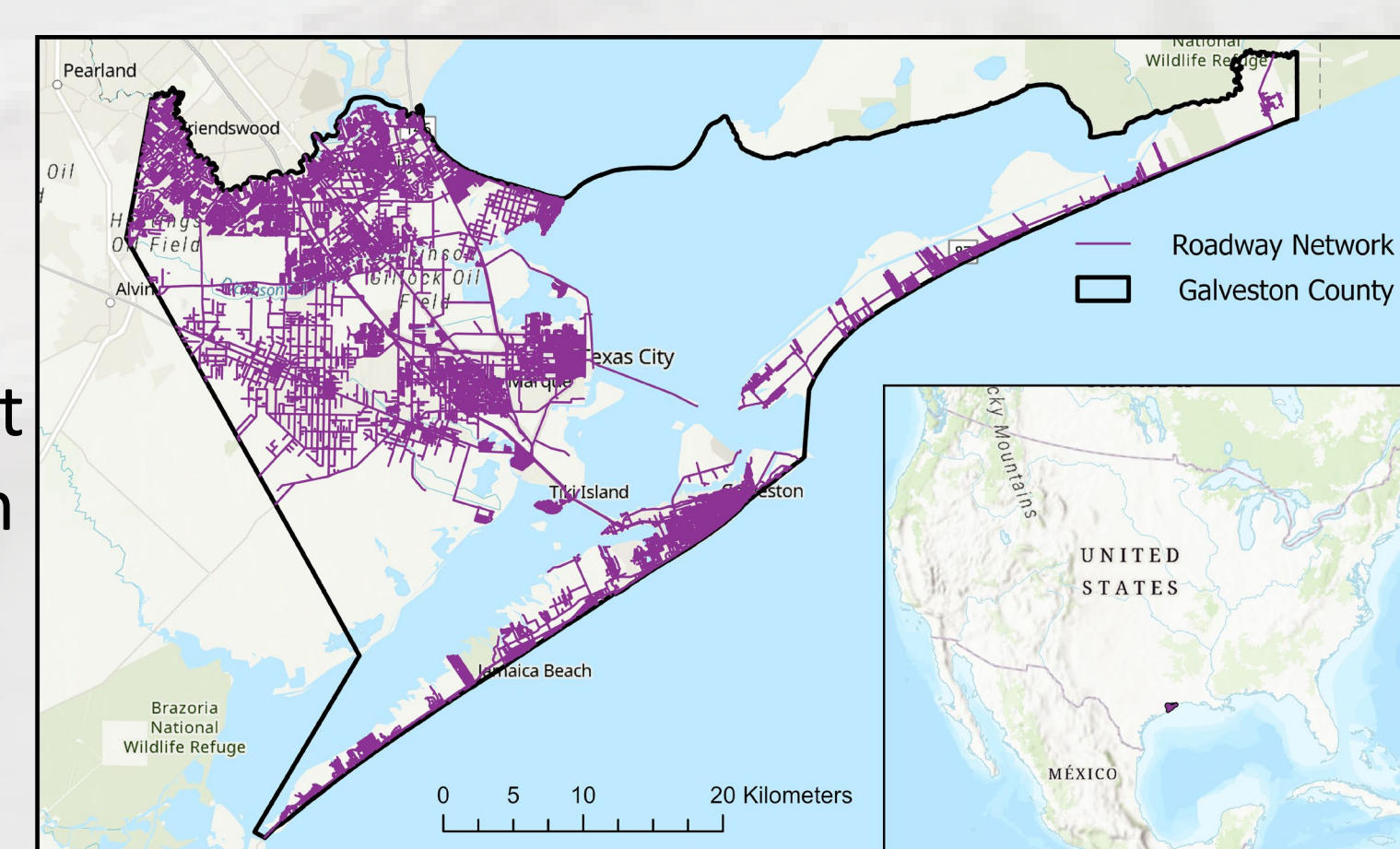


Fig. 1: Study Area

Table 1: Details of Data

Type	Data	Source	Spatial Resolution	Temporal Resolution	Data Collection Year	Remarks
Topographic Data	Projection File	Spatial Reference	NA	NA	NA	Input
	Digital Elevation Model (DEM)	USGS	3m	NA	2007	Input
Meteorological Data	Design Precipitation	NOAA ATLAS 14	NA	5minutes to 60days	NA	Input
	Historical Precipitation	NOAA NCEI	NA	Hourly	1946-1963 and 1993-2024	Auxiliary
Land Related Data	Land Use and Land Cover (LULC)	NLCD	30m	NA	2023	Input
	Soil Group	gSSURGO	NA	NA	2022	Auxiliary
	Impervious	NLCD	30m	NA	2023	Auxiliary
	CN	NLCD	NA	NA	NA	Input
	Manning's n	NLCD	NA	NA	NA	Input
Coastal Data	Sea Water Level	NOAA Tides and Currents	NA	Hourly	1904 to 2024	Input
GIS Files	City Boundary	City of Galveston Website	NA	NA	2022	Input
Flood Related Data	Depth	FEMA	NA	NA	2008	Validation
		HCFC	NA	NA	2009	Validation
Transportation Data	Roadway Inventory	TxDOT	NA	NA	2023	Input
Socio-economic Data	Socio-economic Variables	Smart Location Database	NA	NA	2021	Input

Methodology

- Hydrologic Engineering Center River Analysis System (HEC-RAS 6.6) and Hydrologic Modeling System (HEC-HMS 4.12) software were used along with ArcGIS Pro and Python.
- Design precipitation were calculated according to NOAA Atlas 14 and TxDOT guidelines.
- Excess rainfall were calculated using HEC-HMS.
- Loss Method: SCS Curve Number; Transform Method: SCS Unit Hydrograph; Graph Type: Delmarva (PRF 284).

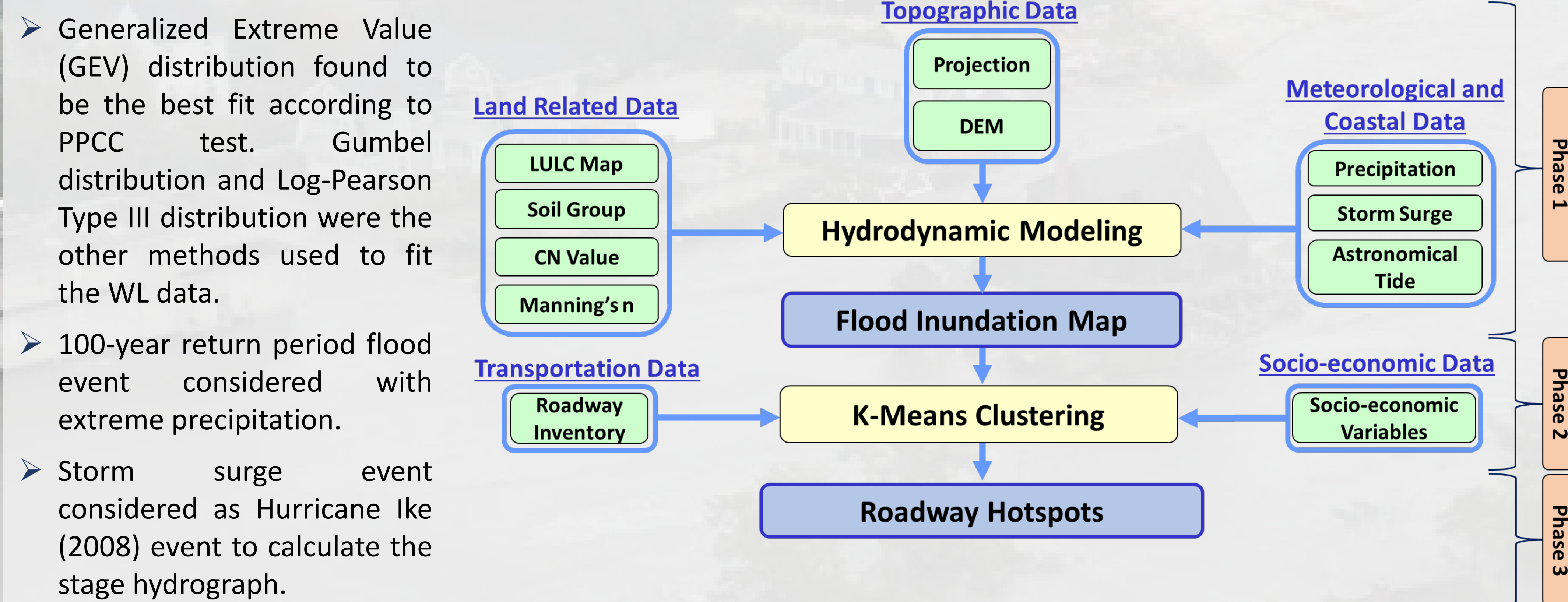


Fig. 2: Schematic Diagram for Flood Modelling and Susceptibility Analysis

- Combined flood depth, roadway attributes, and socio-economic indicators to form the vulnerability dataset.
- Normalized and directionally aligned all variables for consistent clustering.
- Performed K-means++ clustering on PCA-refined features to group road segments by vulnerability patterns.
- Identified hotspots: Classified segments into distinct risk clusters to highlight the most susceptible.

Result 1. Hurricane Ike Case Study

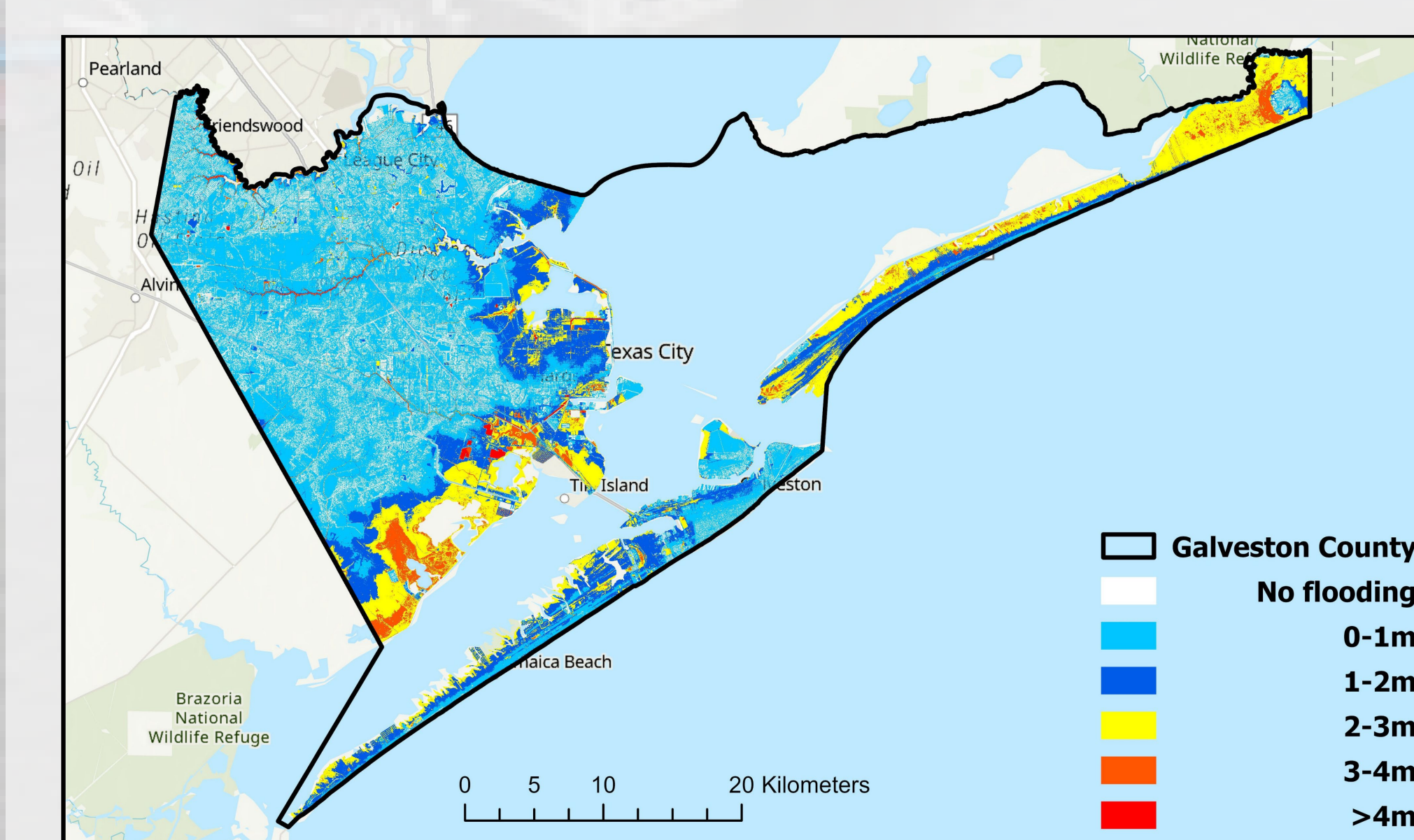


Fig. 3: Hurricane Ike Simulated Flood Map

- Hurricane Ike event was simulated, and a flood inundation map (Fig. 3) was developed.
- Resultant flood depths were compared (Fig. 4) with FEMA Mitigation Assessment Team Report values. Also, a performance metrics (Table 2) was created.

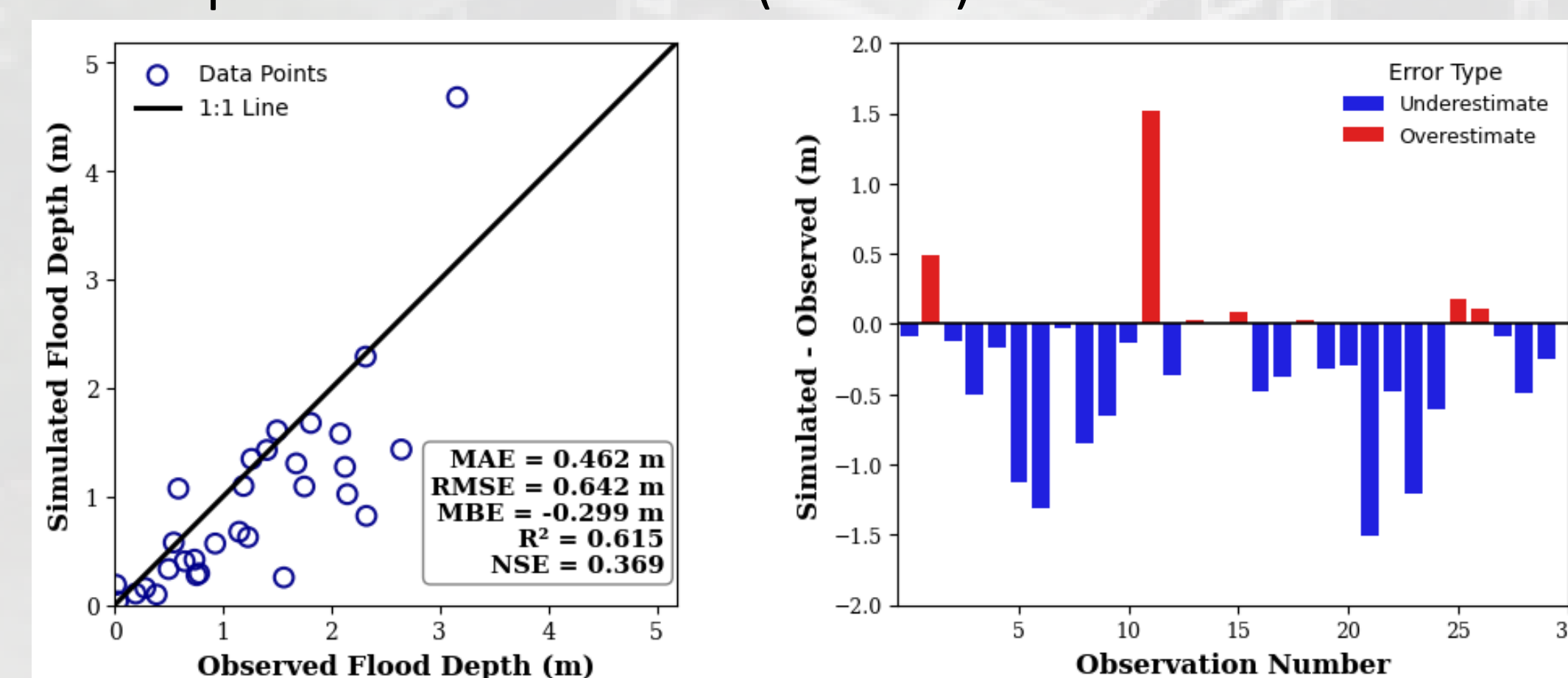


Fig. 4: Flood Depths Comparison

Table 2: Performance Metrics

Metric	Value	Metric	Value
MAE	0.46 m	NSE	0.37
MBE	-0.30 m	KGE	0.44
RMSE	0.64 m	R ²	0.62

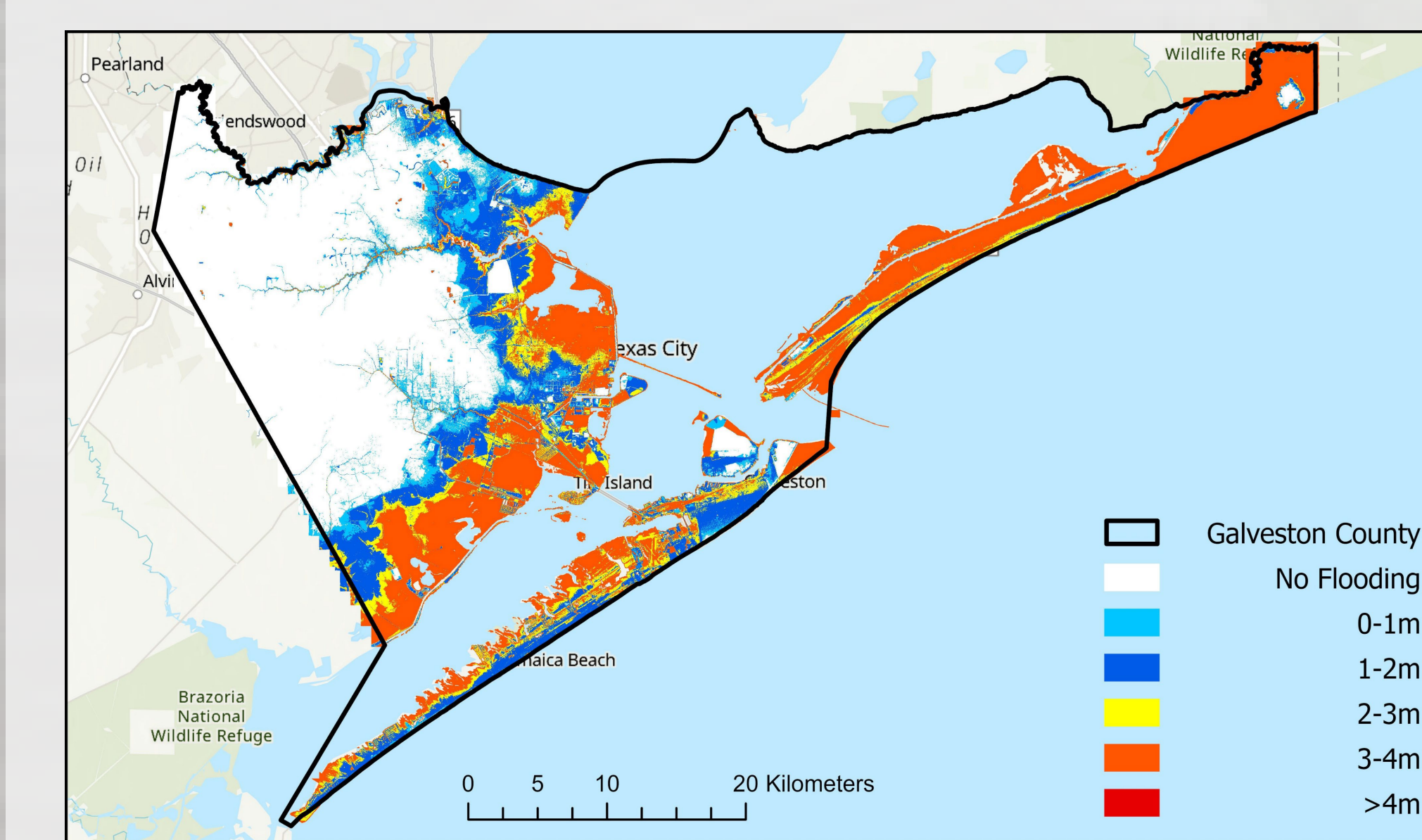


Fig. 5: HCFC Hurricane Ike Flood Map

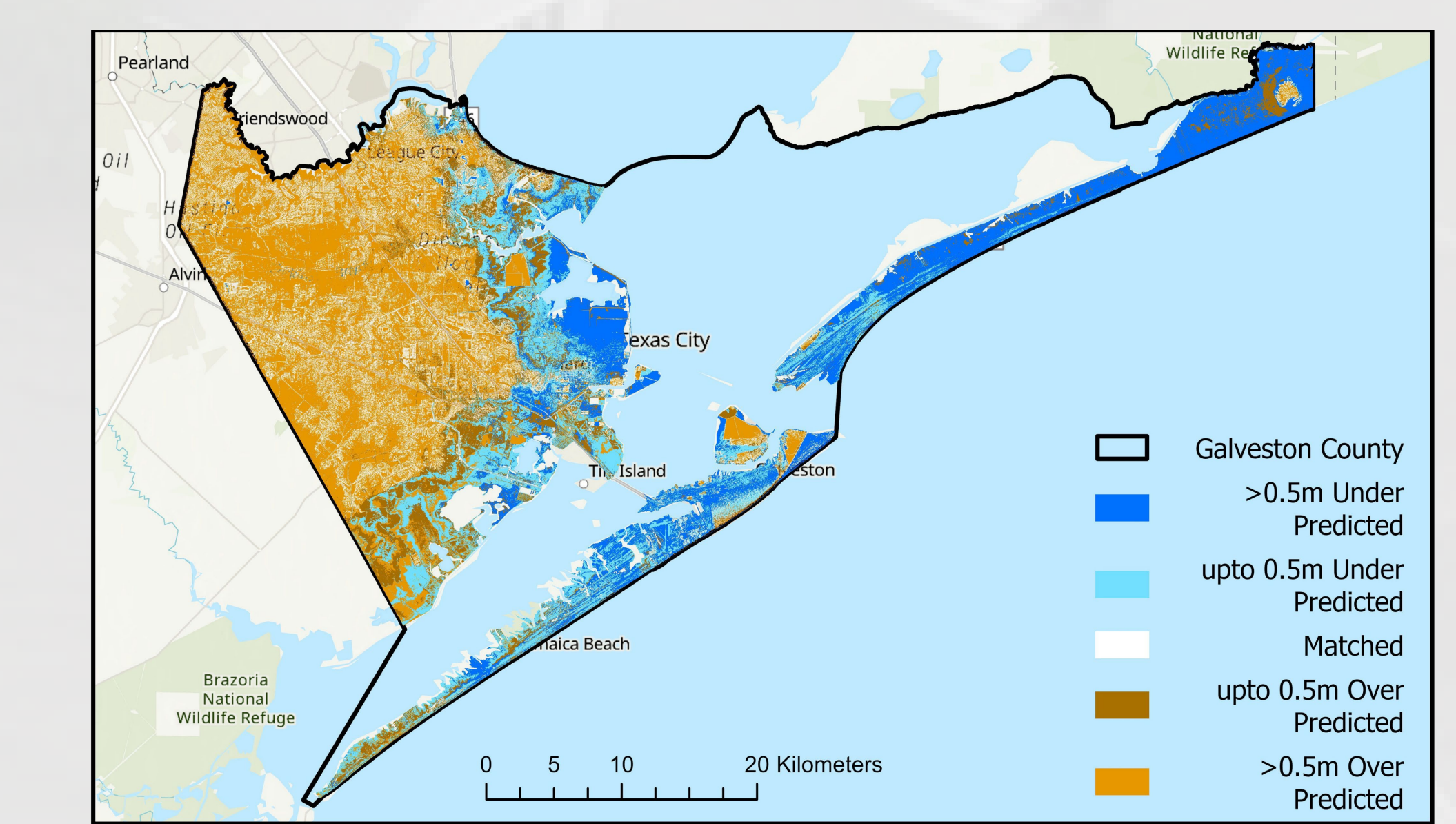


Fig. 6: Simulated and Observed Flood Depth Comparison

Result 2. 100-Year Design Flood Map

- The highest depths concentrated along the coastline and low-lying urban areas.
- Depths exceeding 2m occur primarily in southern Galveston Island and near major bay-facing corridors.
- Moderate flooding (1–2m) extends inland along drainage pathways and developed neighborhoods.
- Shallow flooding (0–1m) is distributed throughout much of the county.

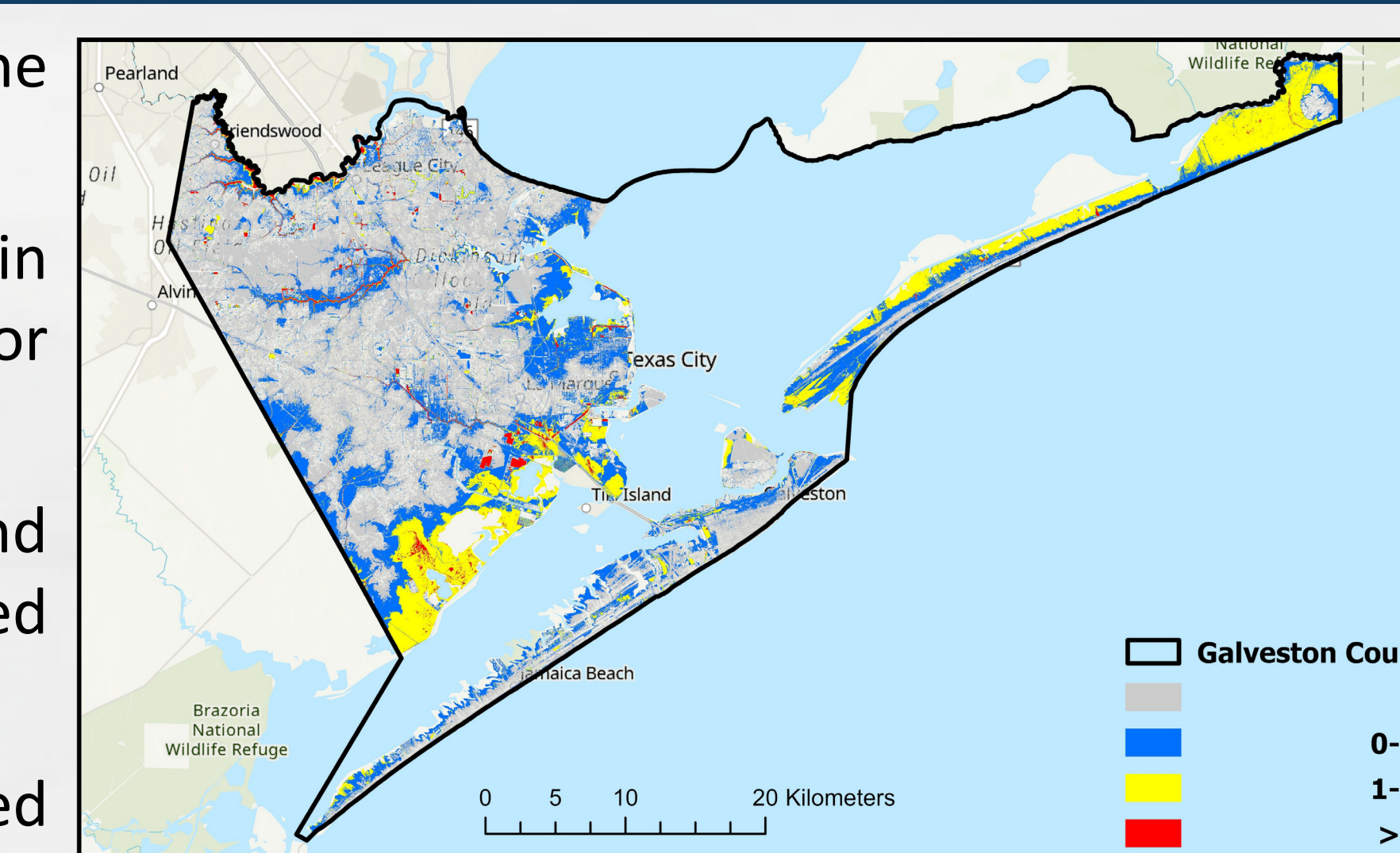


Fig. 7: 100-year Return Period Flood Depth Scenario

Result 3. Roadway Hotspots

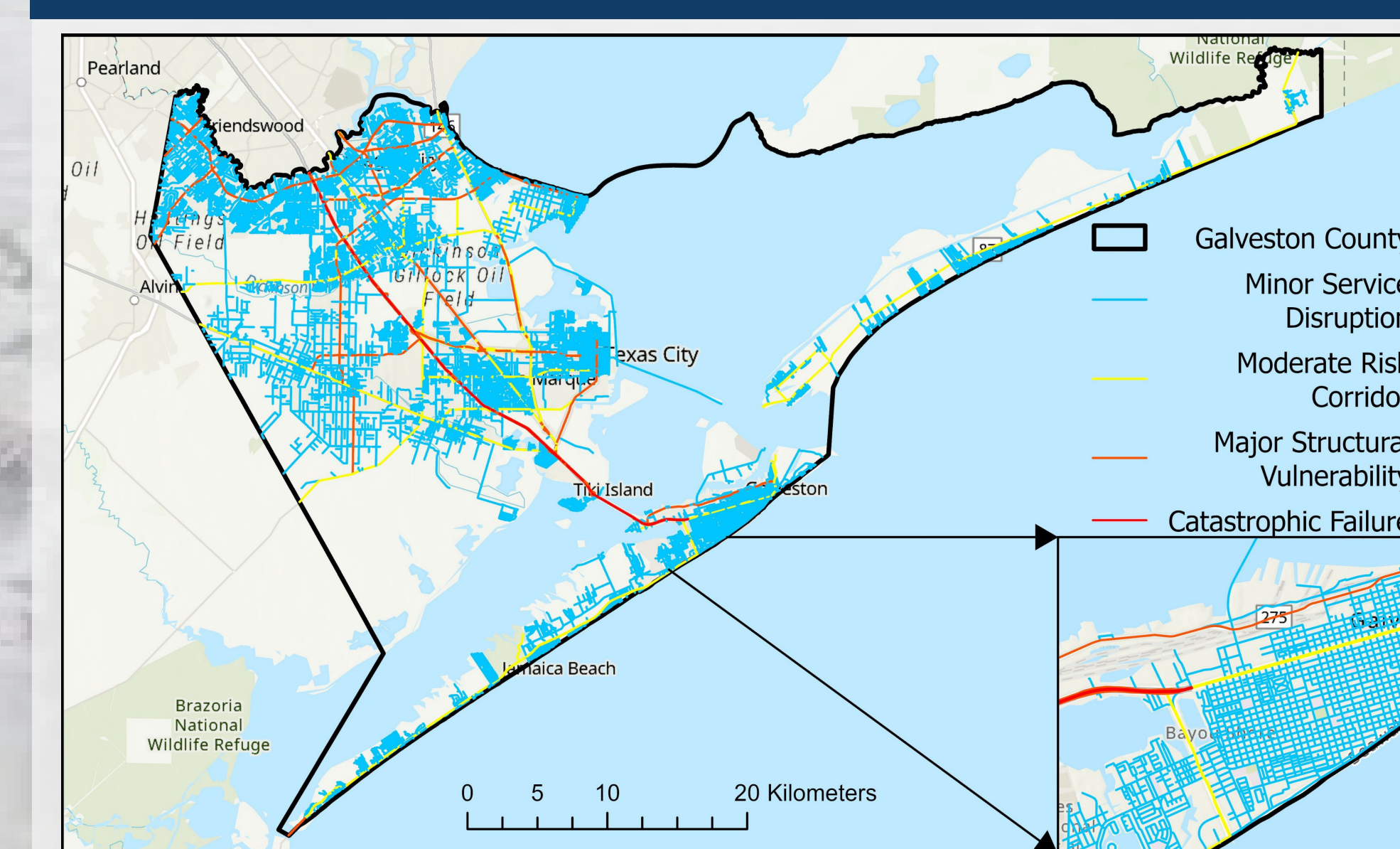


Fig. 8: Roadway Hotspots

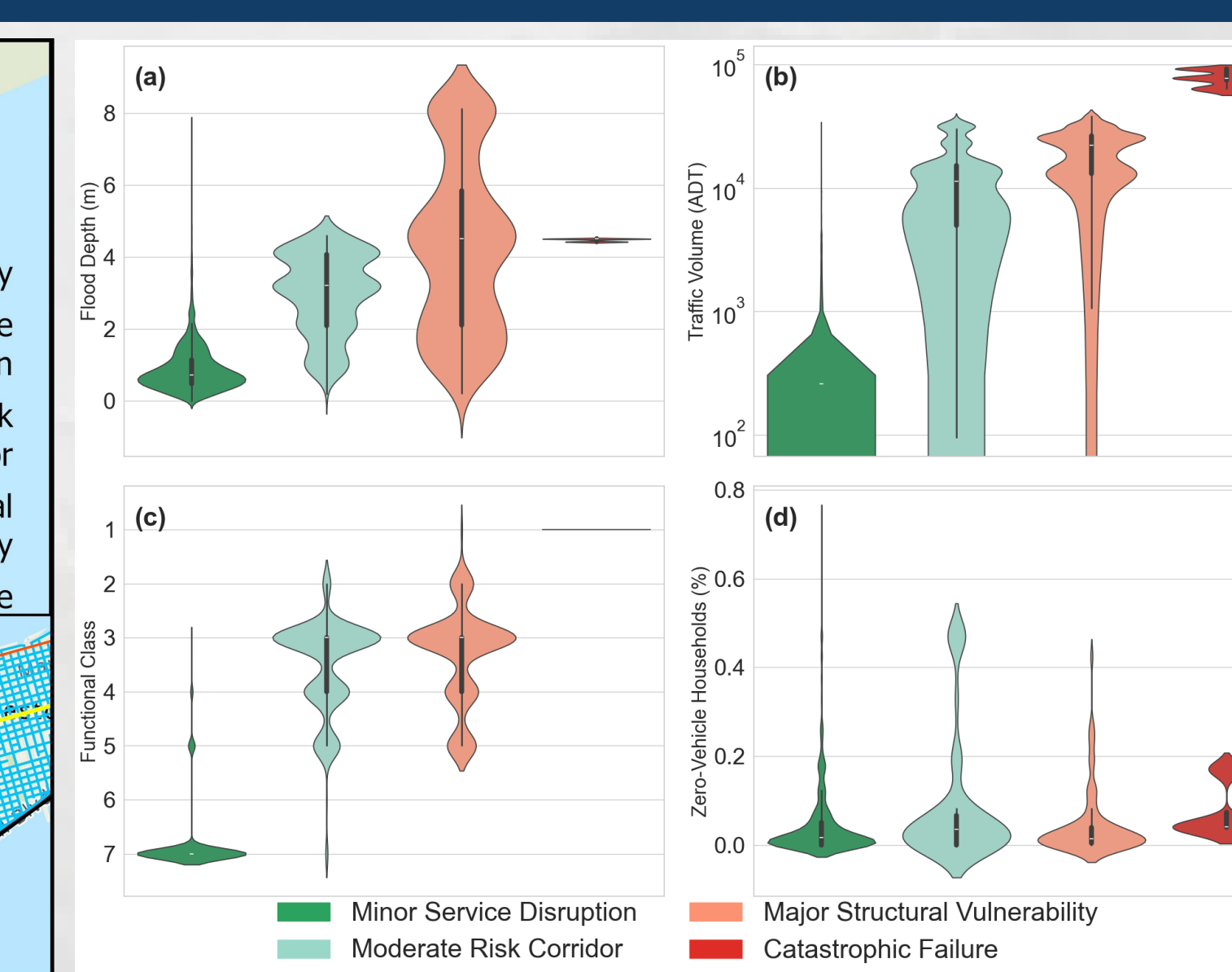


Fig. 9: Key Distributions for the Clusters

- Segments exposed to >1–2 m or >2 m flooding predominantly fall into the Major Structural Vulnerability and Catastrophic Failure classes, especially along major roadways.
- Inland areas with shallower flood depths (0–1 m) correspond mainly to Minor Service Disruption and Moderate Risk Corridor clusters, reflecting lower physical damage potential but possible localized disruptions.
- The violin plots show how key indicators—flood depth, AADT, functional class, and zero-vehicle households—vary across these four vulnerability categories.

Conclusion

- The simulated flood depths differ from the observed depths by 0.46 m and the model explains 62% of the variability in observed flood depth.
- MBE value is -0.30 m indicates the model underestimates the flood depth by 0.30 m on an average, which is also confirmed by the comparison with HCFC inundation map.
- The clustering reveals four distinct vulnerability regimes across Galveston County, driven jointly by flood depth, roadway importance, traffic demand, and neighborhood socioeconomics.
- Higher-risk corridors align with major traffic routes and deeper inundation, indicating system-level mobility disruption rather than isolated flooding.

Future Work

- The study will be extended do comparisons with Hurricane Harvey (2017) event.
- The developed flood map will be incorporated with traffic simulation to find out the susceptible roads due to traffic disruption.

References

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