



# Resiliency and Durability to Extreme Weather Pilot Study



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Houston-Galveston Area Council  
May 12, 2020

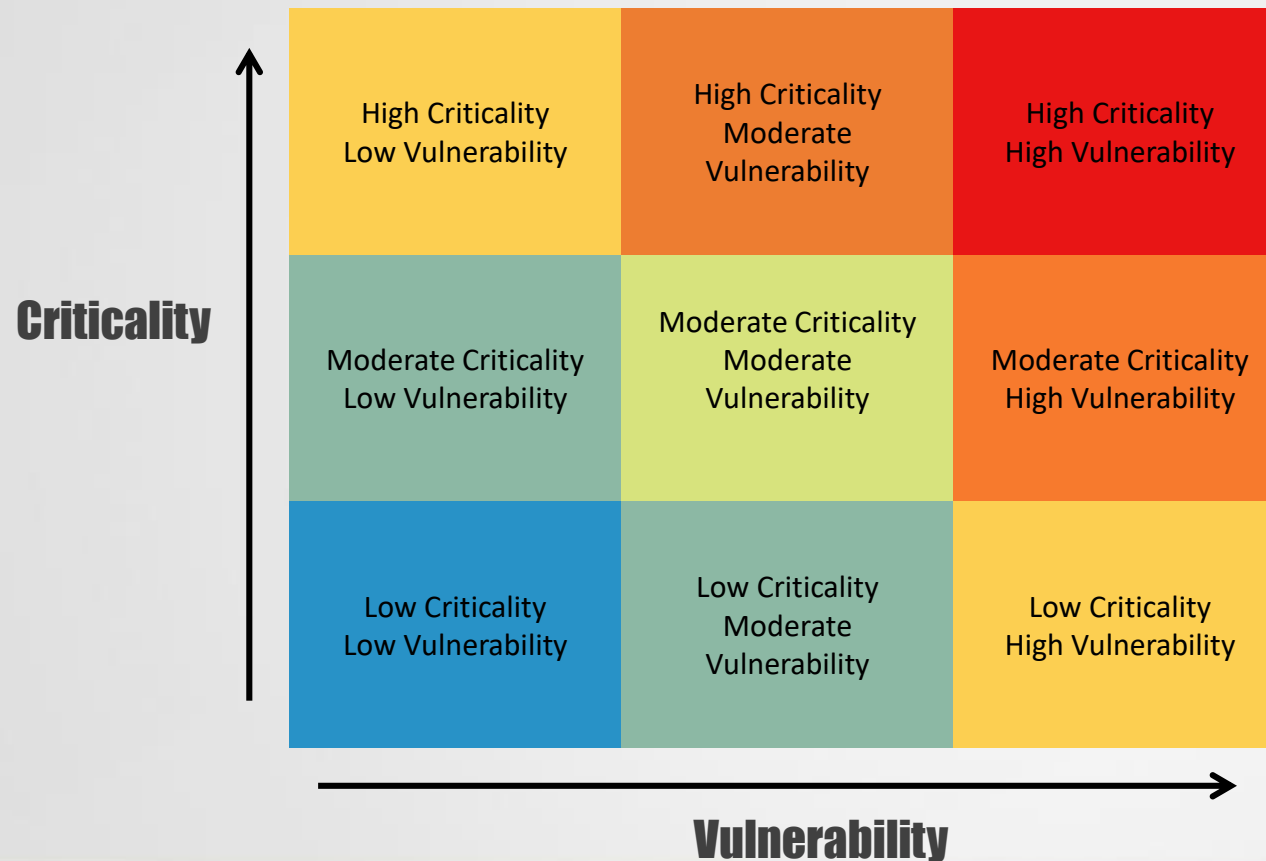


# Federal Highway Administration- Resilience Pilots

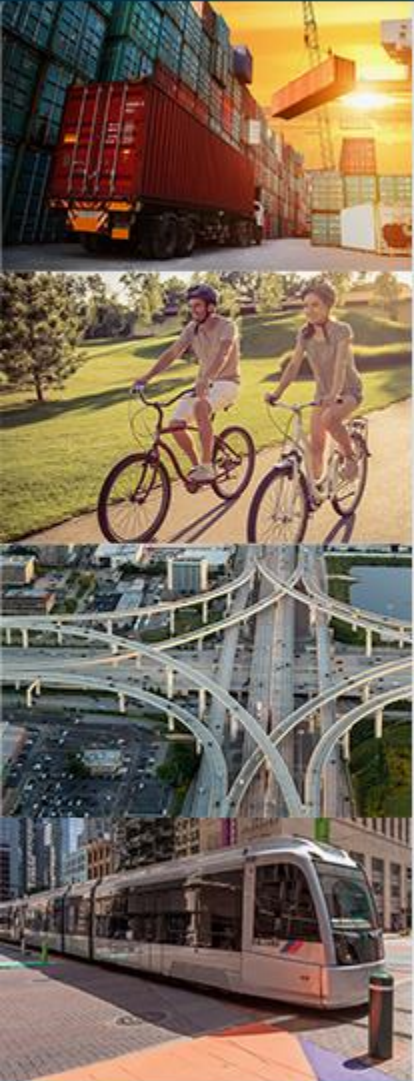


# Study Goals

- Measure Criticality and Vulnerability of Regional Transportation Assets to Extreme Weather Events



# Study Goals

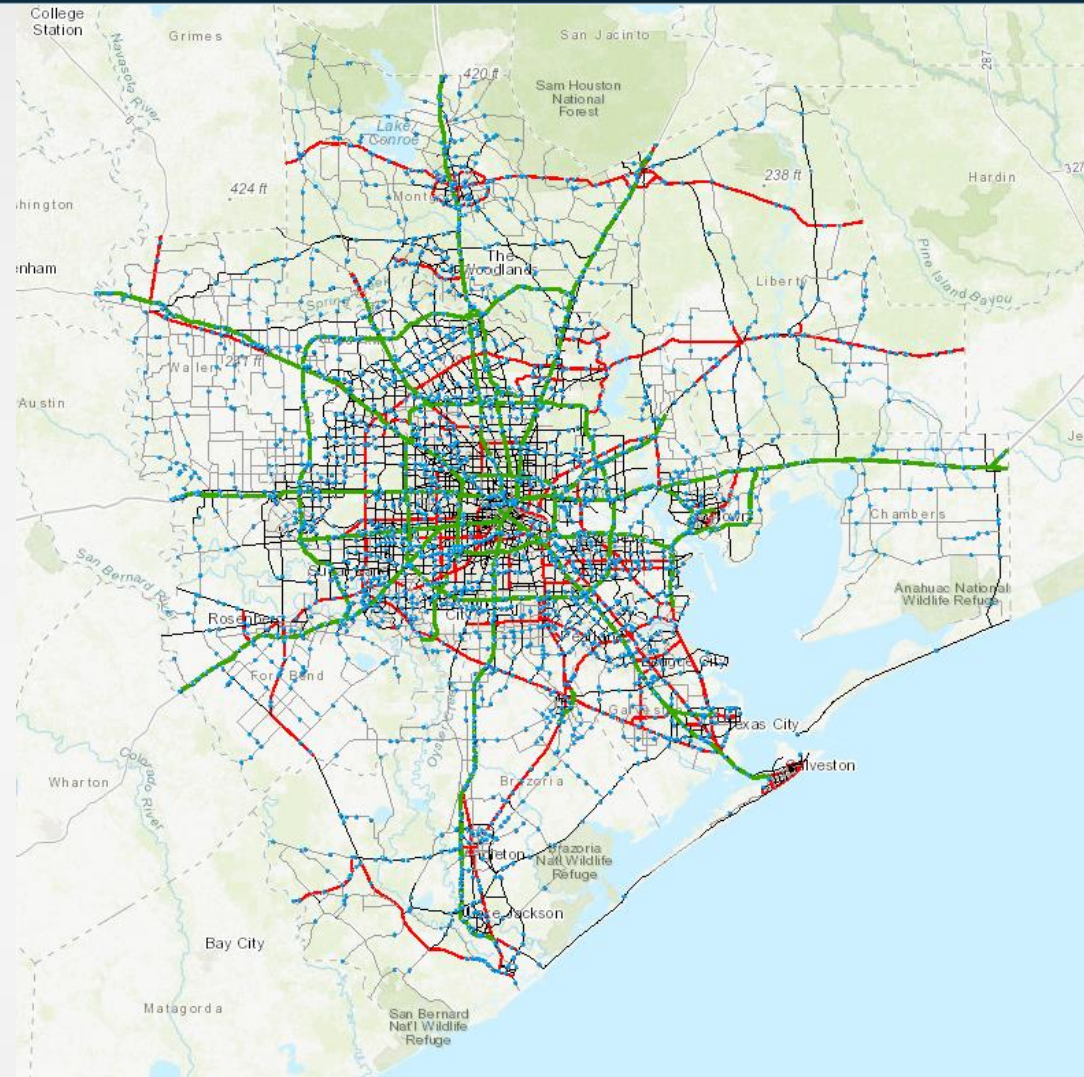


- Develop Adaptation Strategy Decision Tool that Provide Recommendations for a Resilient Transportation Infrastructure
- Update H-GAC publications and future project selection criteria



# Transportation Assets

- Freeways (83 segments)
- Major roads (7,696 segments)
  - major arterials
  - minor arterials
  - collectors
- Bridges (3,489) with waterway



**Bridges**

Bridges

- Waterway

**Functional Class**

Freeway Mainlanes

Major Streets

- Principal Arterial
- Minor Arterial
- Collector

# Scope, Climate/ Extreme Weather Threats

## FEMA Disaster Declarations

1967 - 2018



**13**

Floods



**11**

Severe Storms



**6**

Hurricanes



**3**

Fires



**2**

Coastal Storms



Work  
Group  
Feedback



**Extreme Weather  
Threats to Study:**

- 1) Inland Flooding
- 2) Coastal Flooding

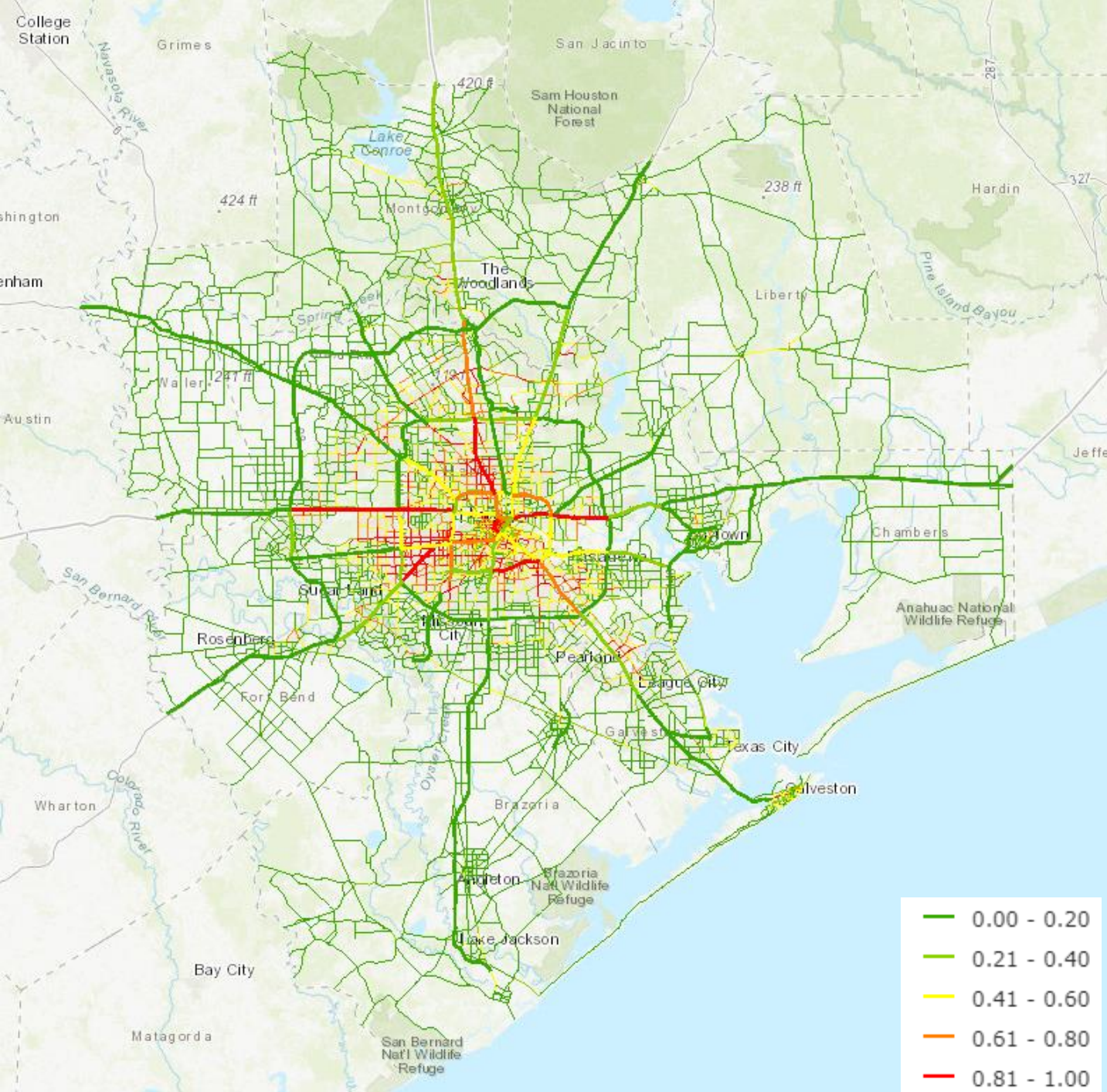
# Study Overview

- **Phase 1- Data Collection**
  - (Transportation Networks, Roads and Bridge Characteristics, Travel data, LiDAR data, Flood data)
- **Phase 2 – Criticality Assessment**
  - (measures the importance of road segments in the daily movement of people, goods and services)
- **Phase 3- Vulnerability Assessment**
  - (measures the exposure, sensitivity and adaptive capacity of road segments to flooding)
- **Phase 4- Criticality-Vulnerability Framework**
  - (combines results from criticality and vulnerability creates a C-V Matrix)
- **Phase 5-Economic Impact Analysis**
  - ( Measures the economic impact of disruption in a road network)
- **Phase 6- Adaptivity Strategy Decision Tool**
  - (provides strategies and recommendations in developing a resilient transportation infrastructure)

# Criticality



# Criticality Assessment



- **Socio-economic importance (20%)**

- link to airport; link to port; service to activity population

- **Operational & usage importance (40%)**

- AADT; AADT-truck; transit ridership

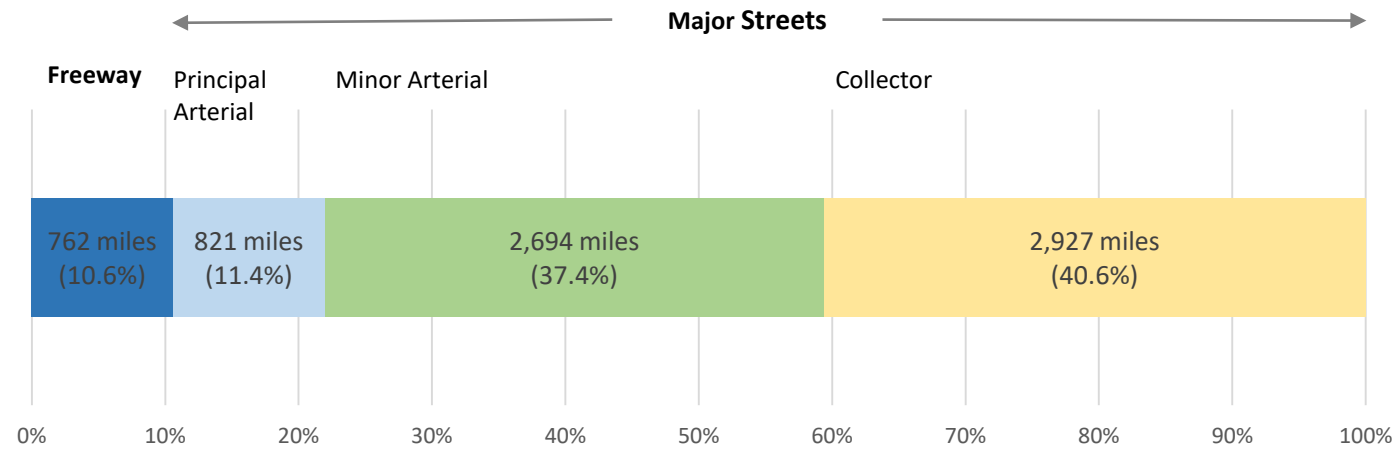
- **Health & safety importance (30%)**

- link to hospitals; link to fire stations; service to vulnerable population

- **Emergency response importance (10%)**

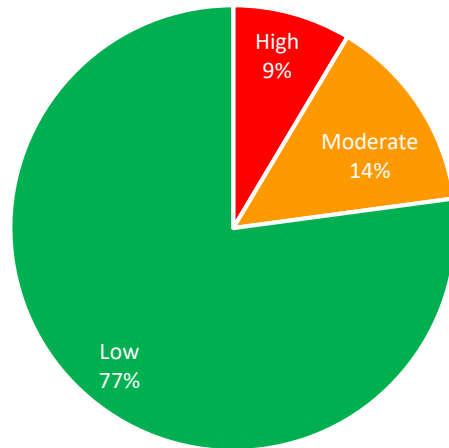
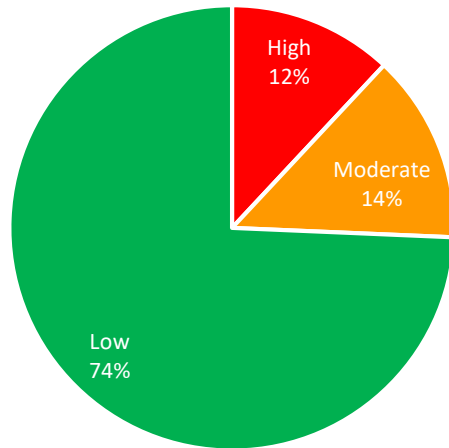
- evacuation route; link to shelters; link to EOCs; military access

Total 7,204 centerline miles

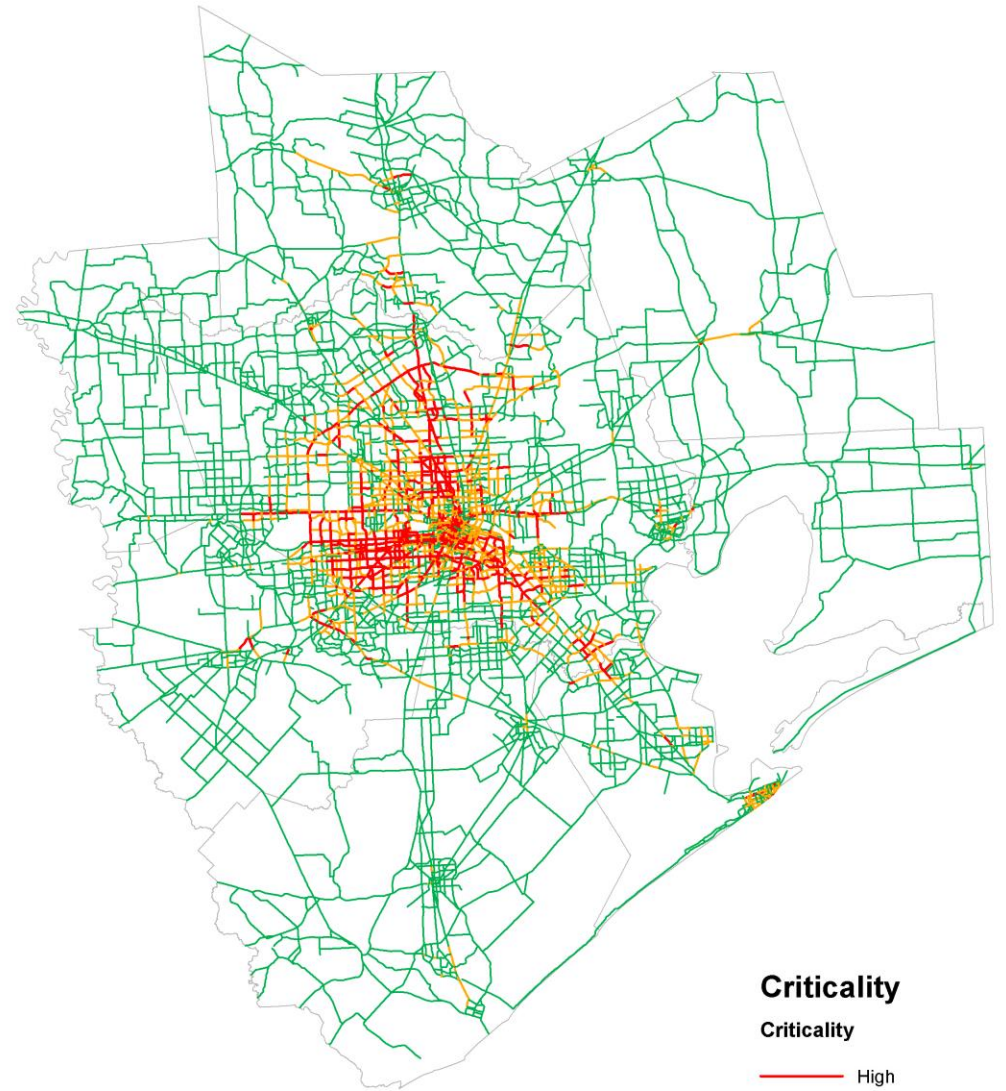


Freeways: 762 centerline miles (10.6%)

Major Streets: 6,442 centerline miles (89.4%)



# Criticality Assessment



0 5 10 20 Miles

## Criticality

- High
- Moderate
- Low

# Vulnerability





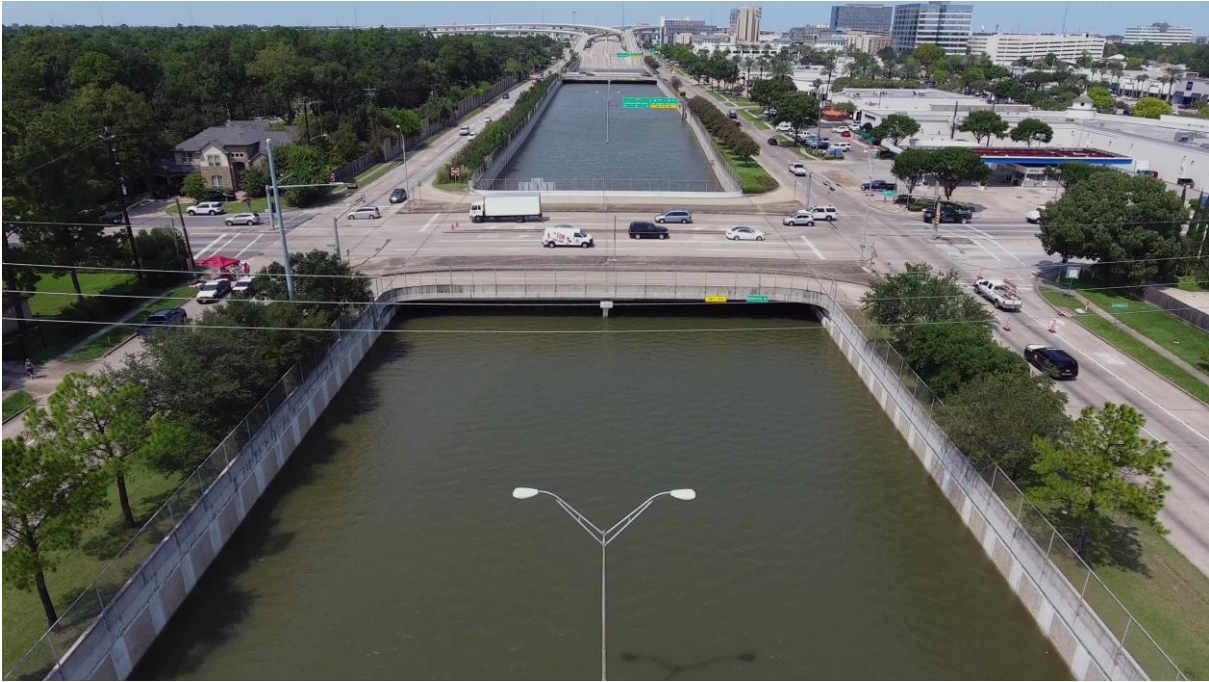
# Exposure Assessment: Harvey Flooding

## BW 8 at IH-10 South

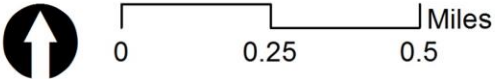
### Post Harvey Aerial Imagery (2017)

Flight Timeline

- Aug. 30, 2017 - Sept. 8, 2017



*BW 8 at Memorial Drive*





# Measuring Level of Exposure

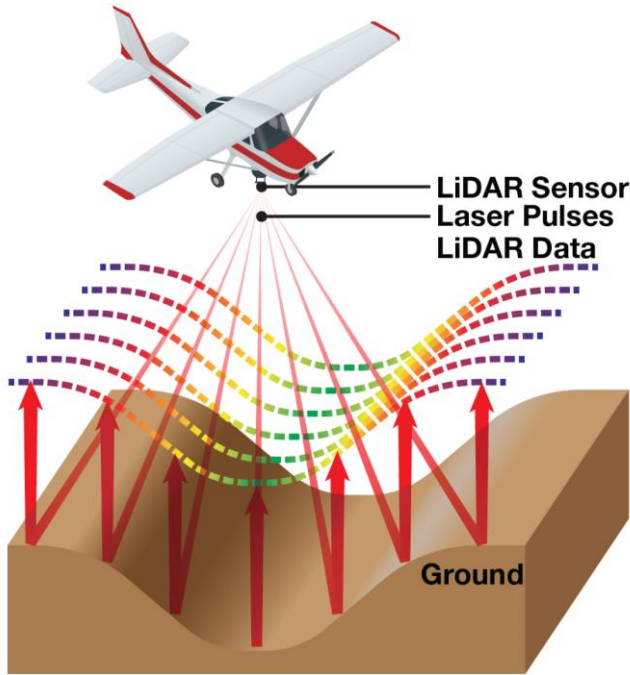
- Ground Elevation
- Surface Elevation (Roadways and Bridges)
- Water Depth

# Exposure Assessment: Harvey Flooding

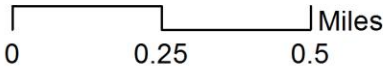
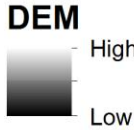
## BW 8 at IH-10 South

### Digital Elevation Model (DEM) from 2018 LiDAR

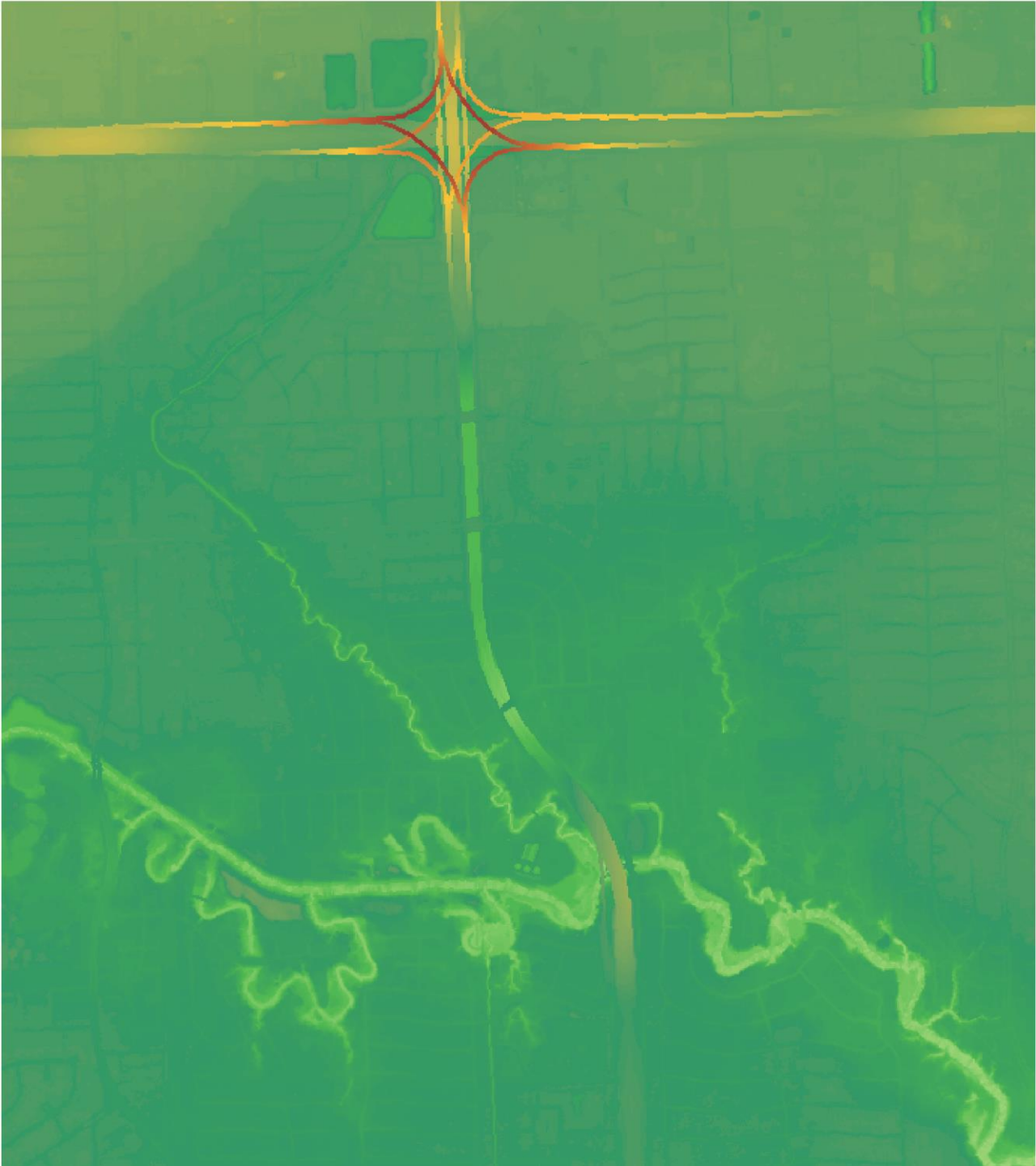
Digital Elevation Model (DEM) is a digital representation of a terrain's elevation data derived from 2018 LiDAR.



#### Legend





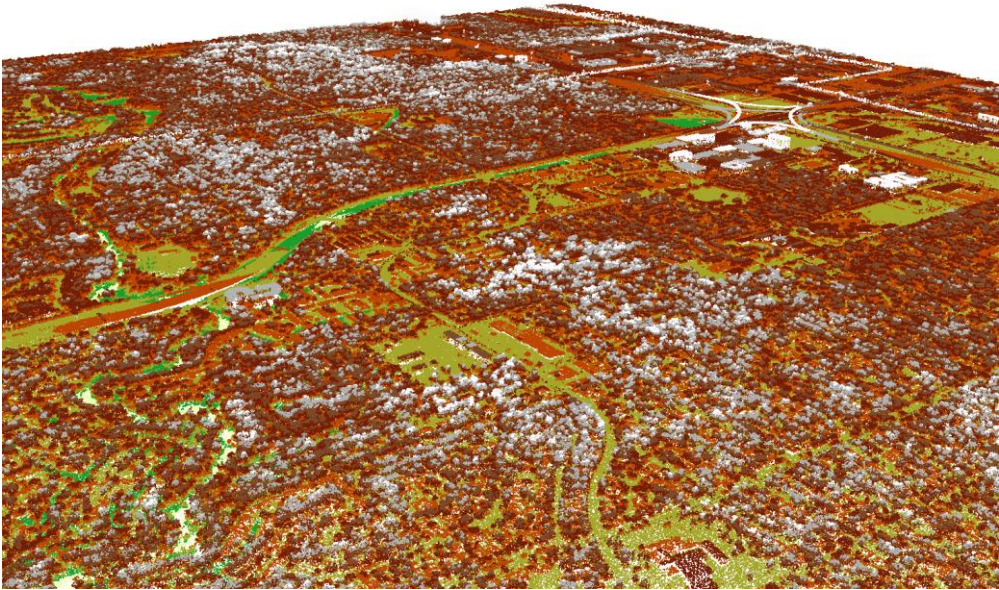


# Exposure Assessment: Harvey Flooding

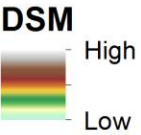
## BW 8 at IH-10 South

### Digital Surface Model (DSM) from 2018 LiDAR

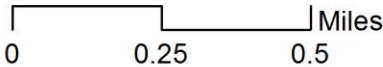
Digital Surface Model (DSM) represents the elevations of the reflective surfaces of **roadways** and **bridges** elevated above the ground.



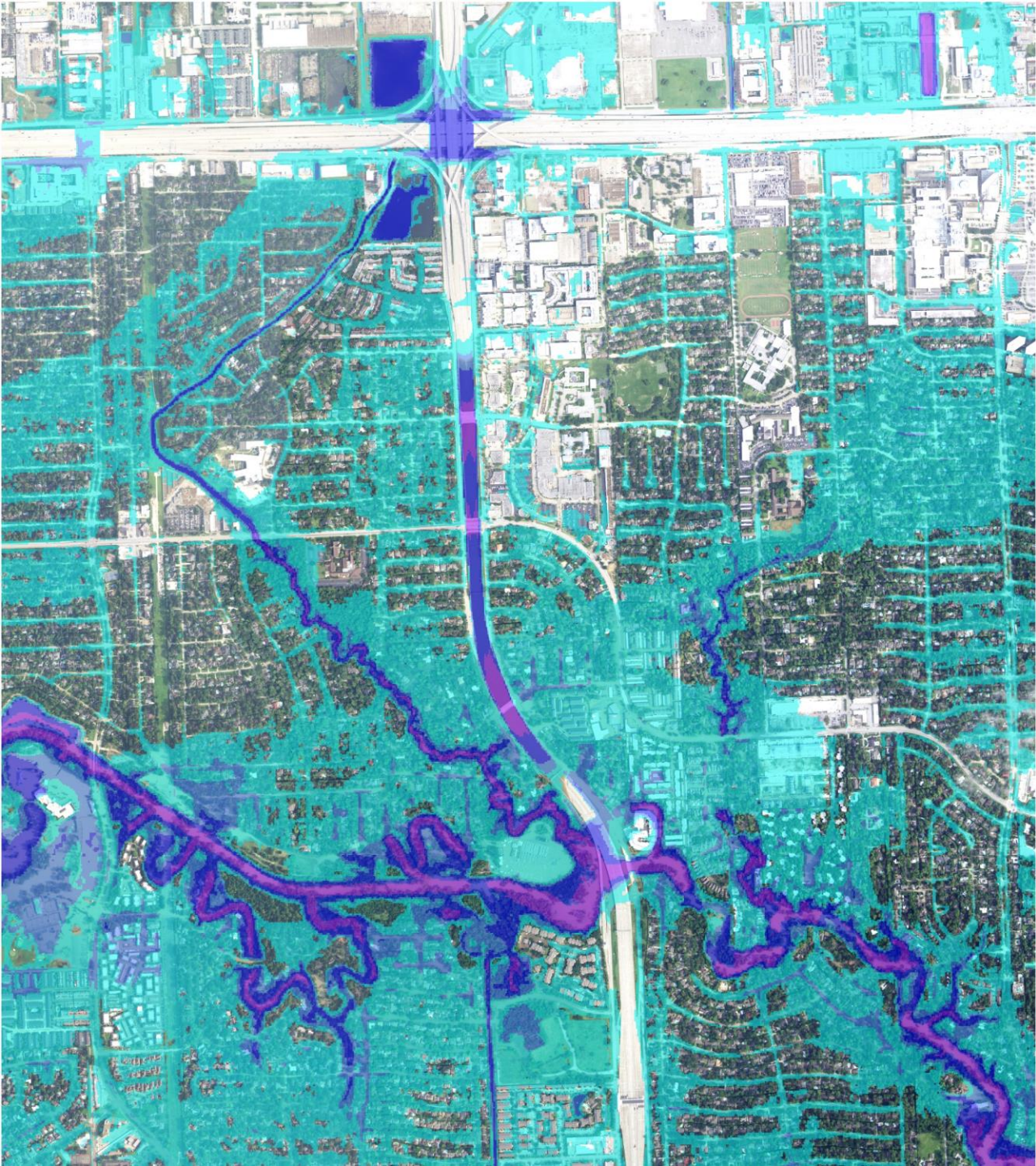
#### Legend



*LiDAR LAS image*







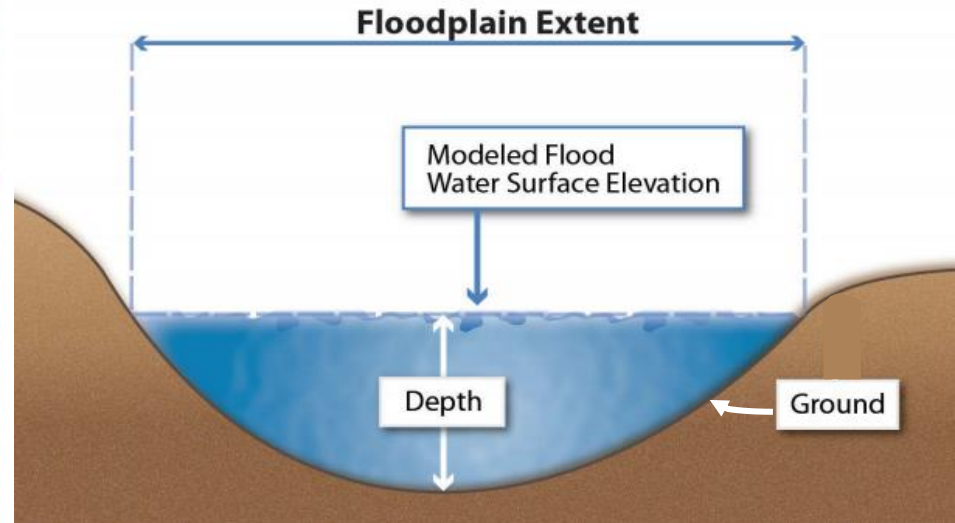
# Exposure Assessment: Harvey Flooding

## BW 8 at IH-10 South

### FEMA Harvey Flood Model (2017)

Water Depth Grid =

Modeled Flood Water Surface Elevation – Ground Elevation (DEM)



### Harvey Depth Grid

Feet

- 0 - 5
- 6 - 10
- 11 - 20
- 21 - 40
- 41 +



0 0.25 0.5 Miles



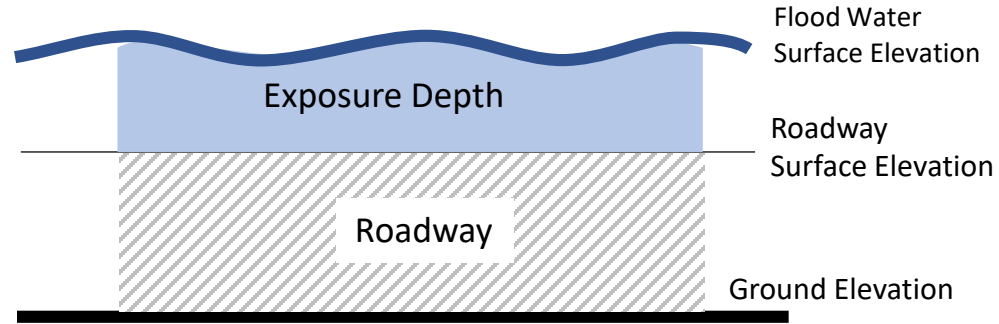


# Exposure Assessment: Harvey Flooding

## BW 8 at IH-10 South

### Exposure Depth Grid

Exposure Depth =  
 Flood Water Surface Elevation – Digital Roadway Surface Elevation



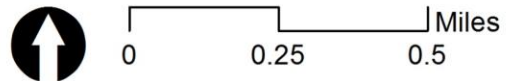
### Legend

#### Exposure Depth Grid

#### Exposure Level

- No exposure or low risk
- Medium-low risk
- Medium risk
- Medium-high risk
- High risk

Exposure Description	Exposure Level
Not exposed/ Less than 0 foot of flood water	No exposure or low risk
0 - 1 foot of flood water	Medium-low risk
1 - 2 feet of flood water	Medium risk
2 - 3 feet of flood water	Medium-high risk
More than 3 feet of flood water	High risk

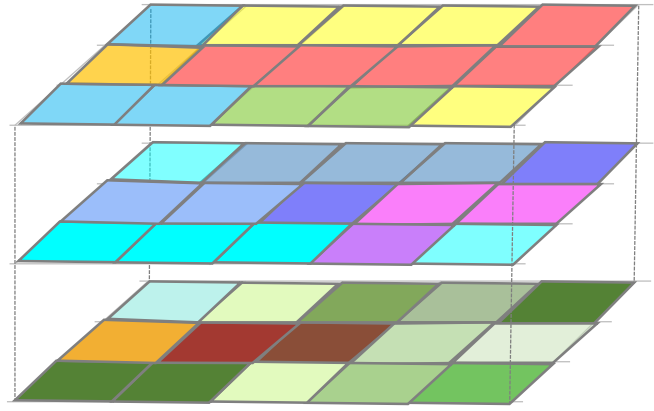
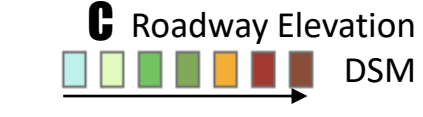
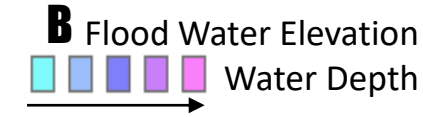
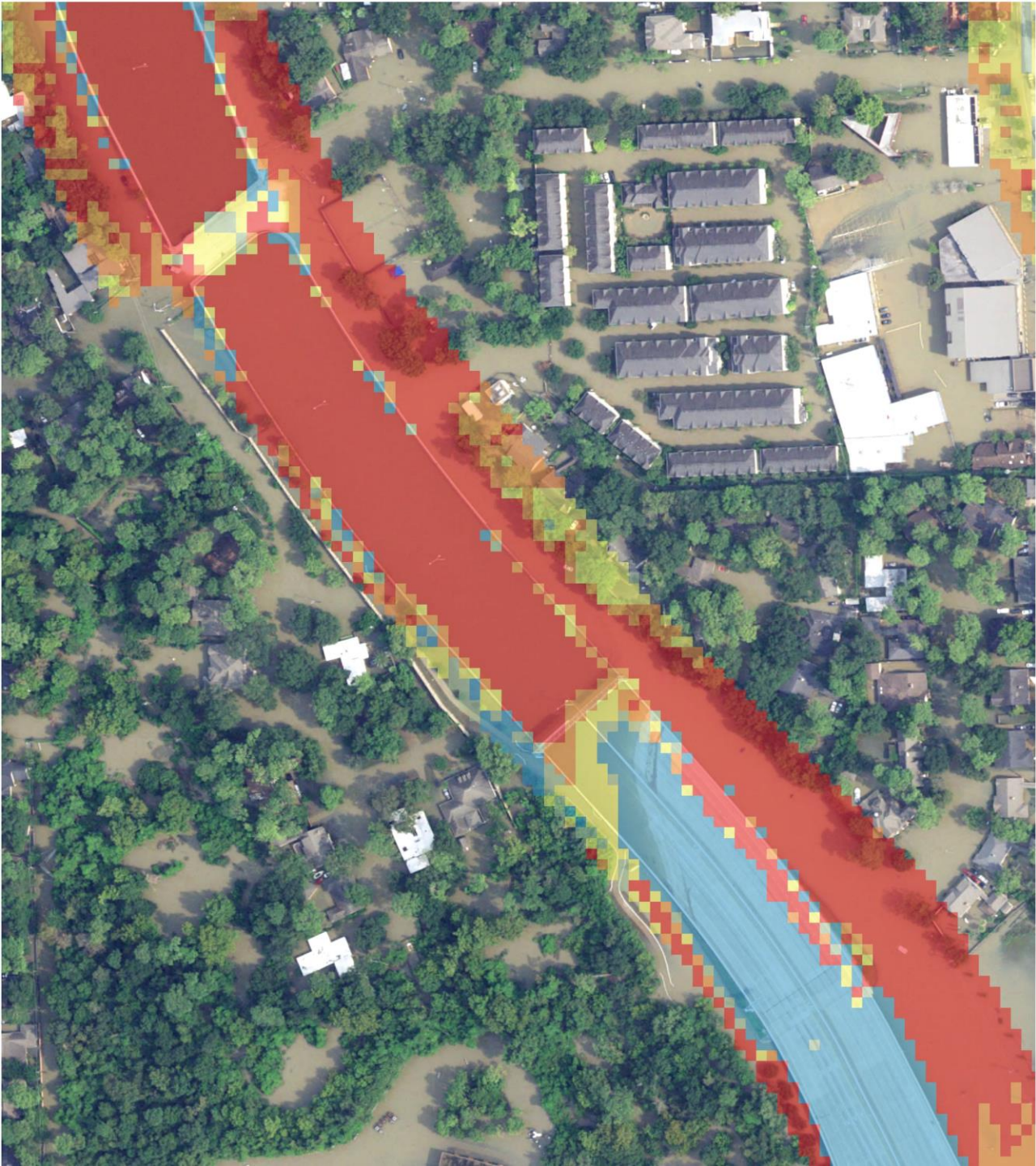




# Exposure Assessment: Harvey Flooding

## BW 8 at IH-10 South

### Exposure Depth Grid **A = B - C**



### Legend

#### Exposure Depth Grid

**Exposure Level**

Light Blue	No exposure or low risk
Light Green	Medium-low risk
Yellow	Medium risk
Orange	Medium-high risk
Red	High risk

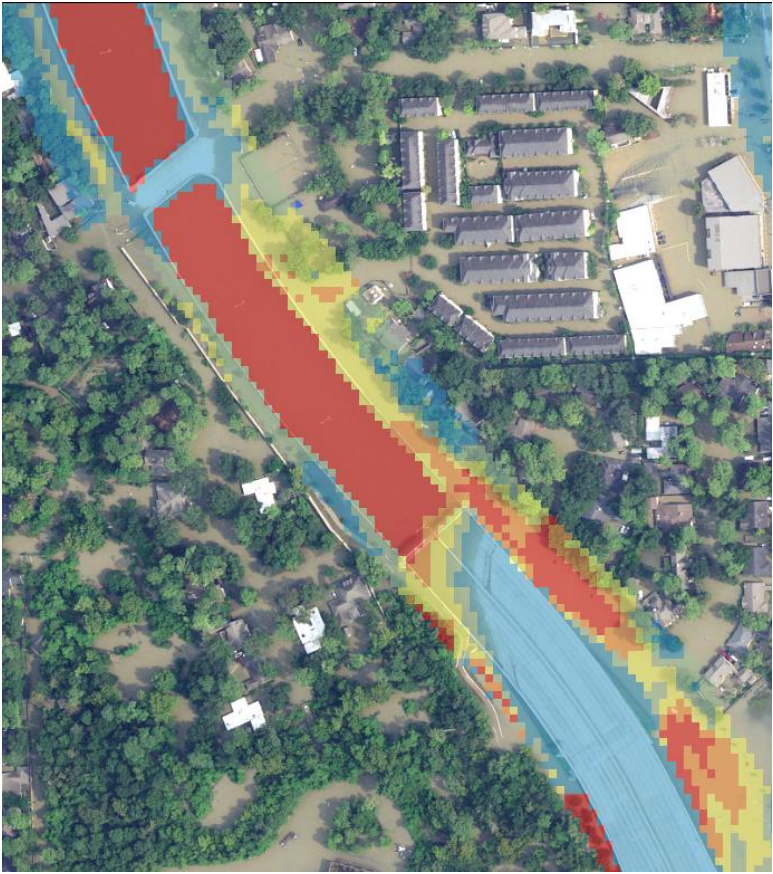
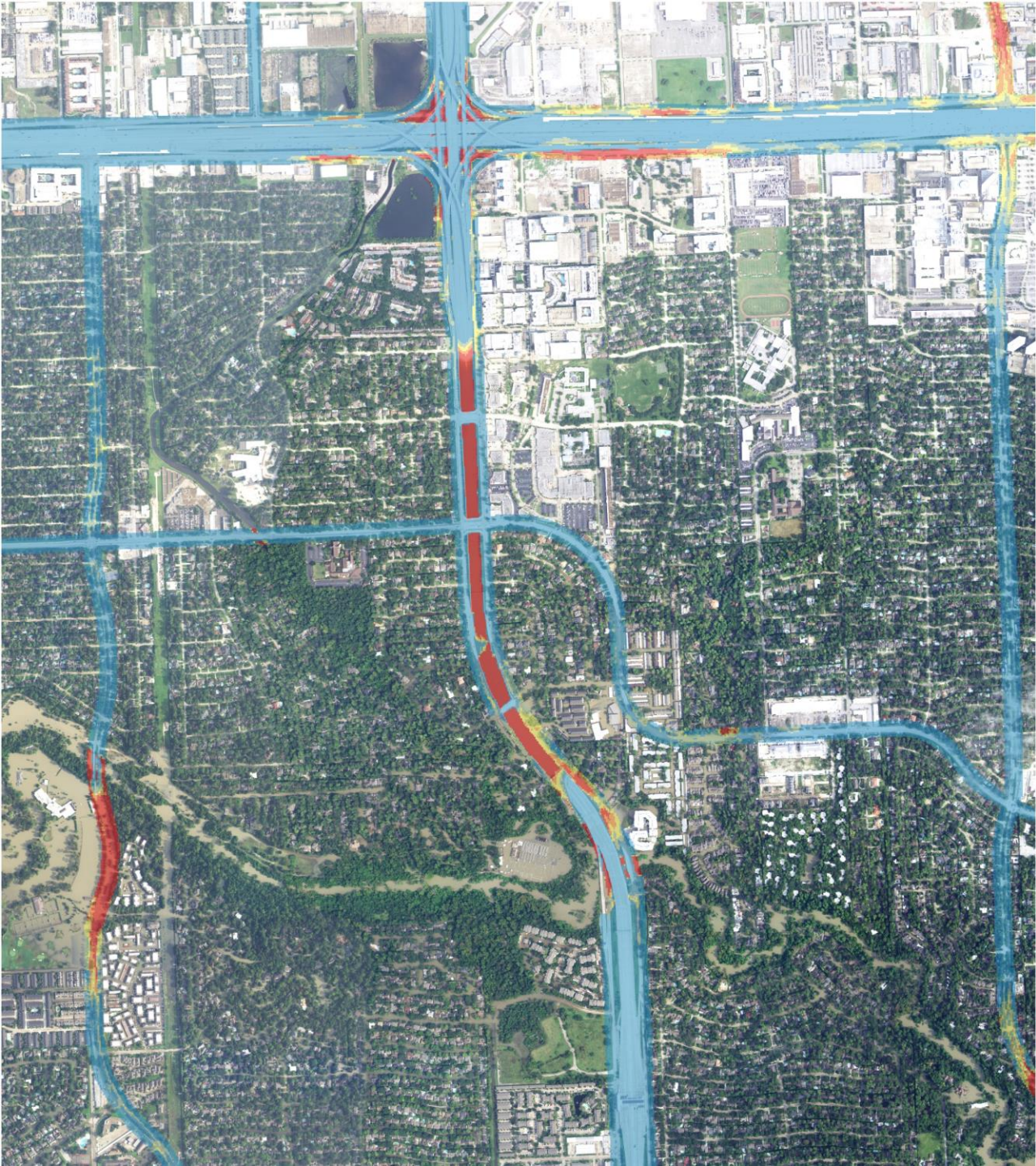
Exposure Description	Exposure Level
Not exposed/ Less than 0 foot of flood water	No exposure or low risk
0 - 1 foot of flood water	Medium-low risk
1 - 2 feet of flood water	Medium risk
2 - 3 feet of flood water	Medium-high risk
More than 3 feet of flood water	High risk





# Exposure Assessment: 500-Year Flooding

## BW 8 at IH-10 South

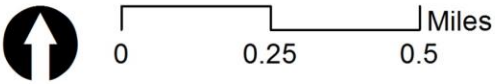


### Legend

#### Exposure Depth Grid

#### Exposure Level

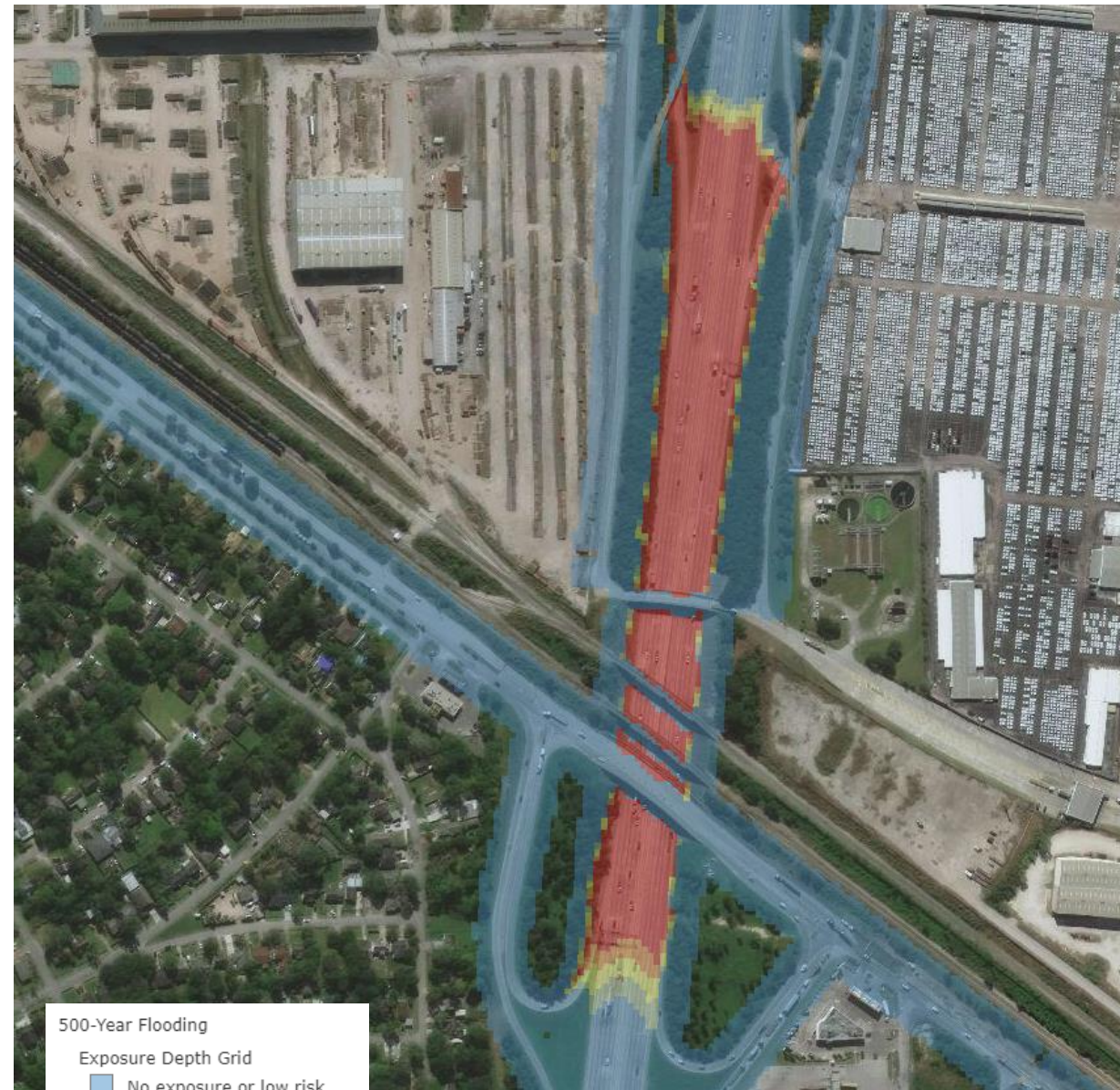
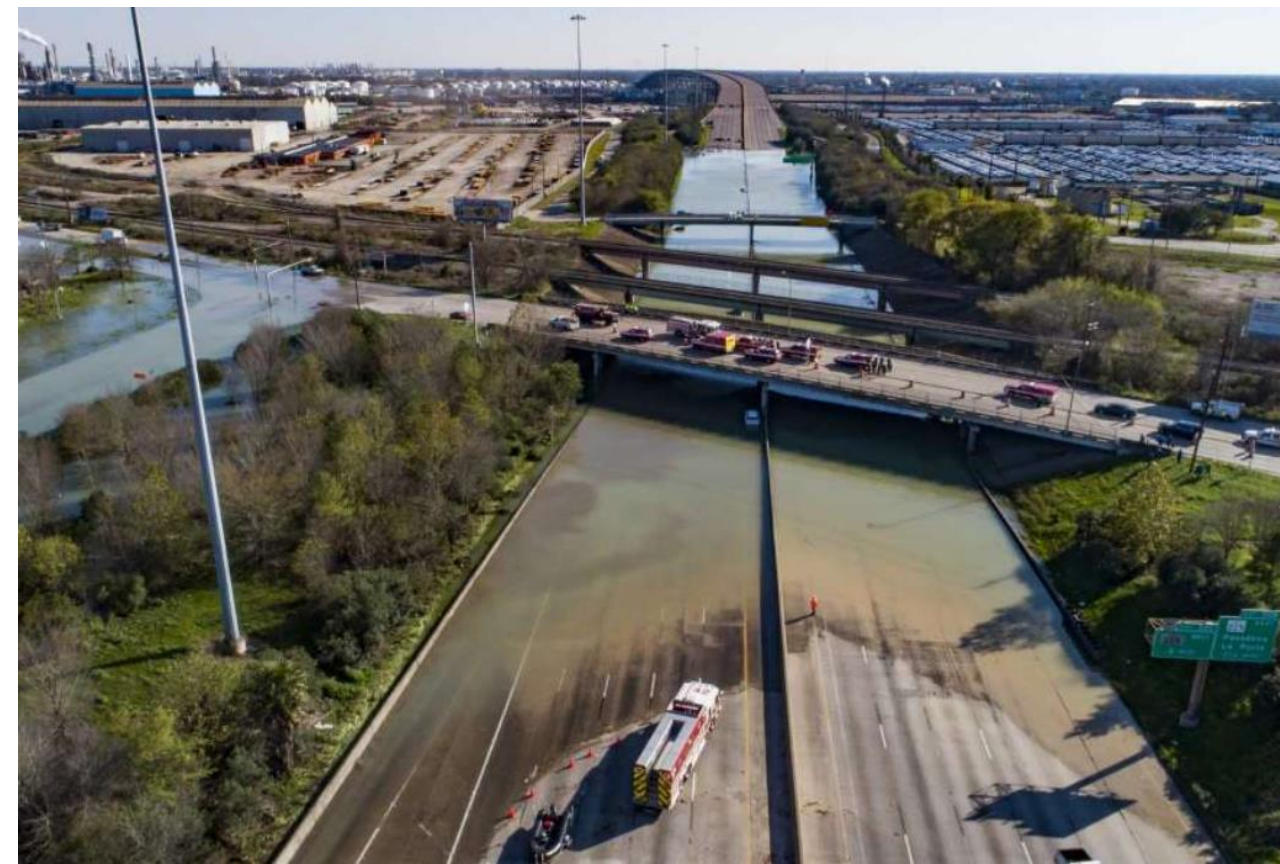
-  No exposure or low risk
-  Medium-low risk
-  Medium risk
-  Medium-high risk
-  High risk





28 Feb. 2020, Houston Chronicle

# Broken water line in east Houston disrupts city, forces boil order



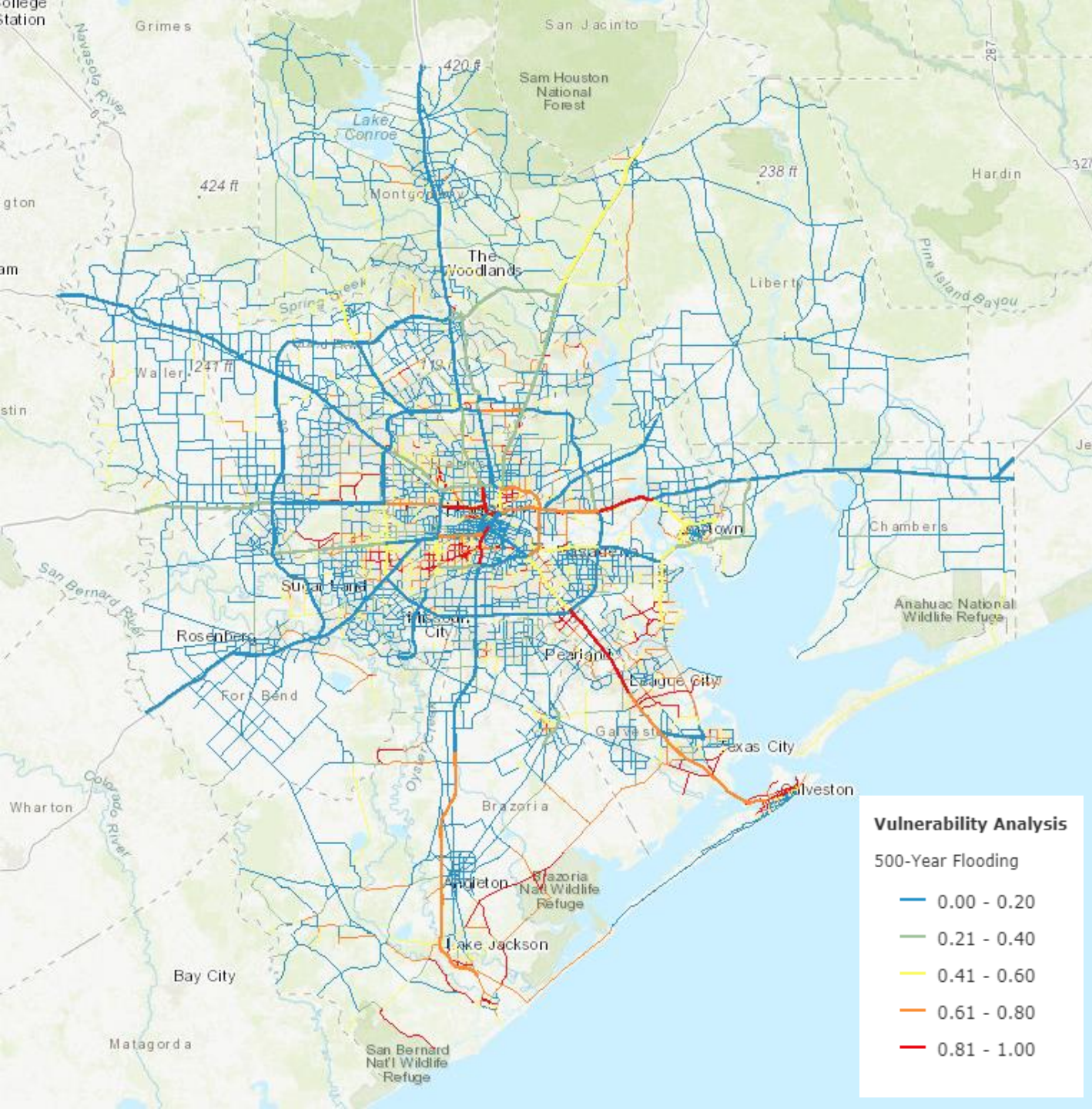
500-Year Flooding  
Exposure Depth Grid

- No exposure or low risk
- Medium-low risk
- Medium risk
- Medium-high risk
- High risk



# Vulnerability Assessment VAST Tool

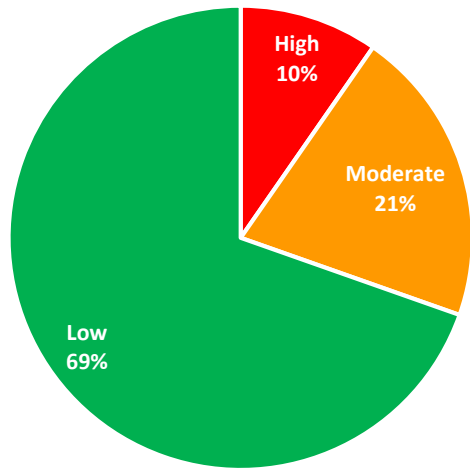
- **Exposure Assessment (70%)**
  - Flooding (100-year, 500-year, & Harvey)
  - Storm Surge (Hurricane Category 1 - 5 and Ike)
  - Sea-Level Rise (4 & 5 feet)
- **Sensitivity Assessment (20%)**
  - Bridge Age
  - Structural Evaluation
  - Channel Conditions
  - Scour Ratings
  - Pavement Condition
  - Past Closure
- **Adaptive Capacity Assessment (10%)**
  - Detour Length
  - Repair Cost



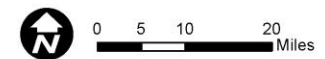
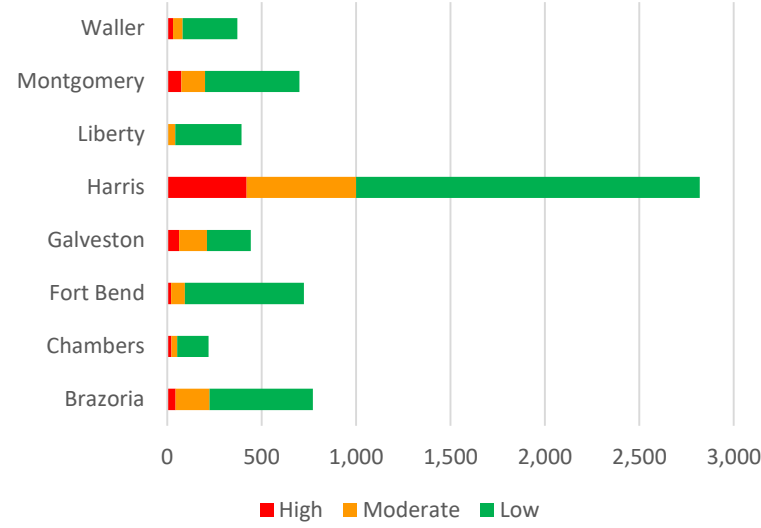
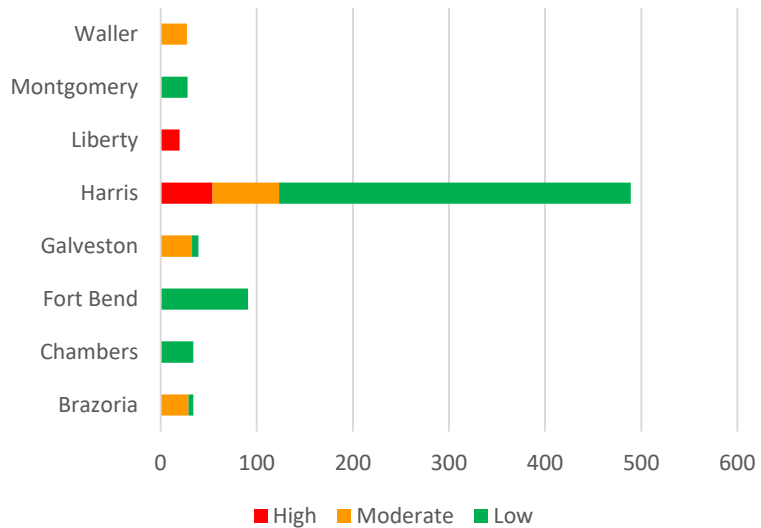
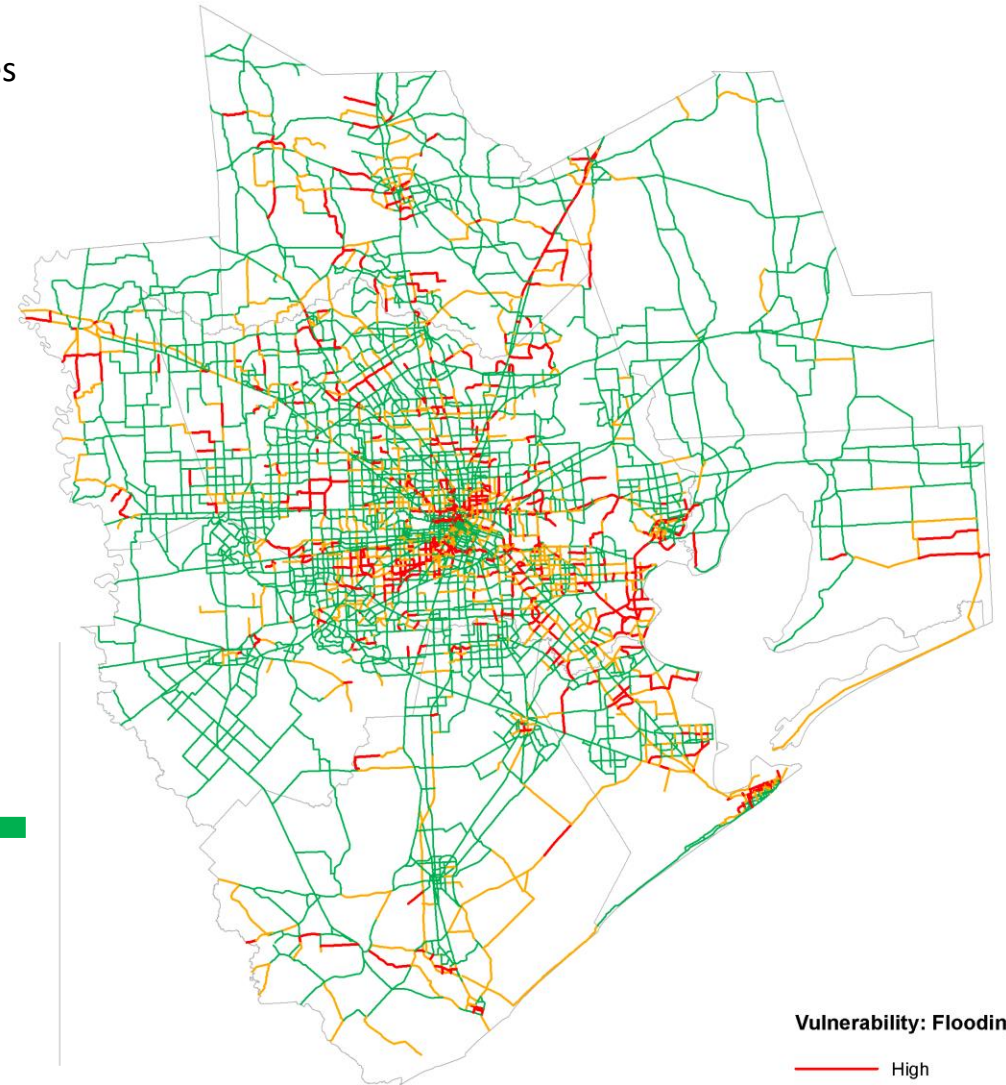
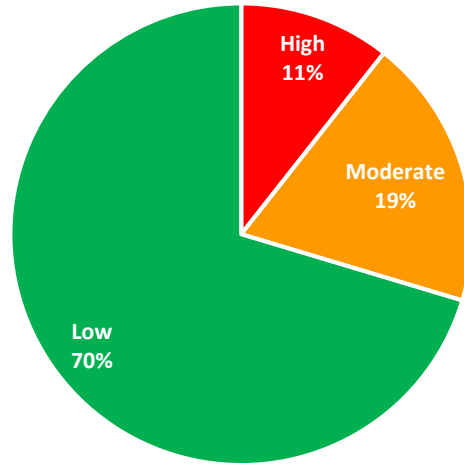
# Vulnerability Assessment

Vulnerability: Flooding (500-year flooding 50% + Harvey Flooding 50%)

Freeways: 762 centerline miles



Major Streets: 6,442 centerline miles



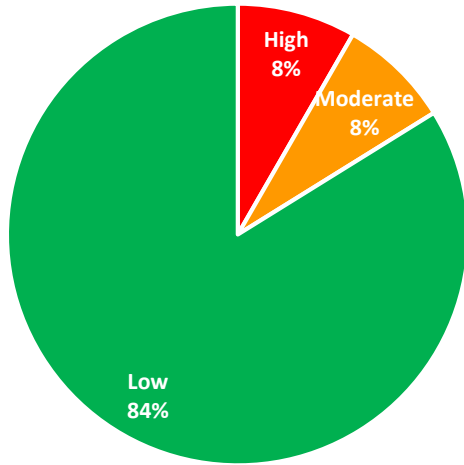
**Vulnerability: Flooding**  
 High  
 Moderate  
 Low



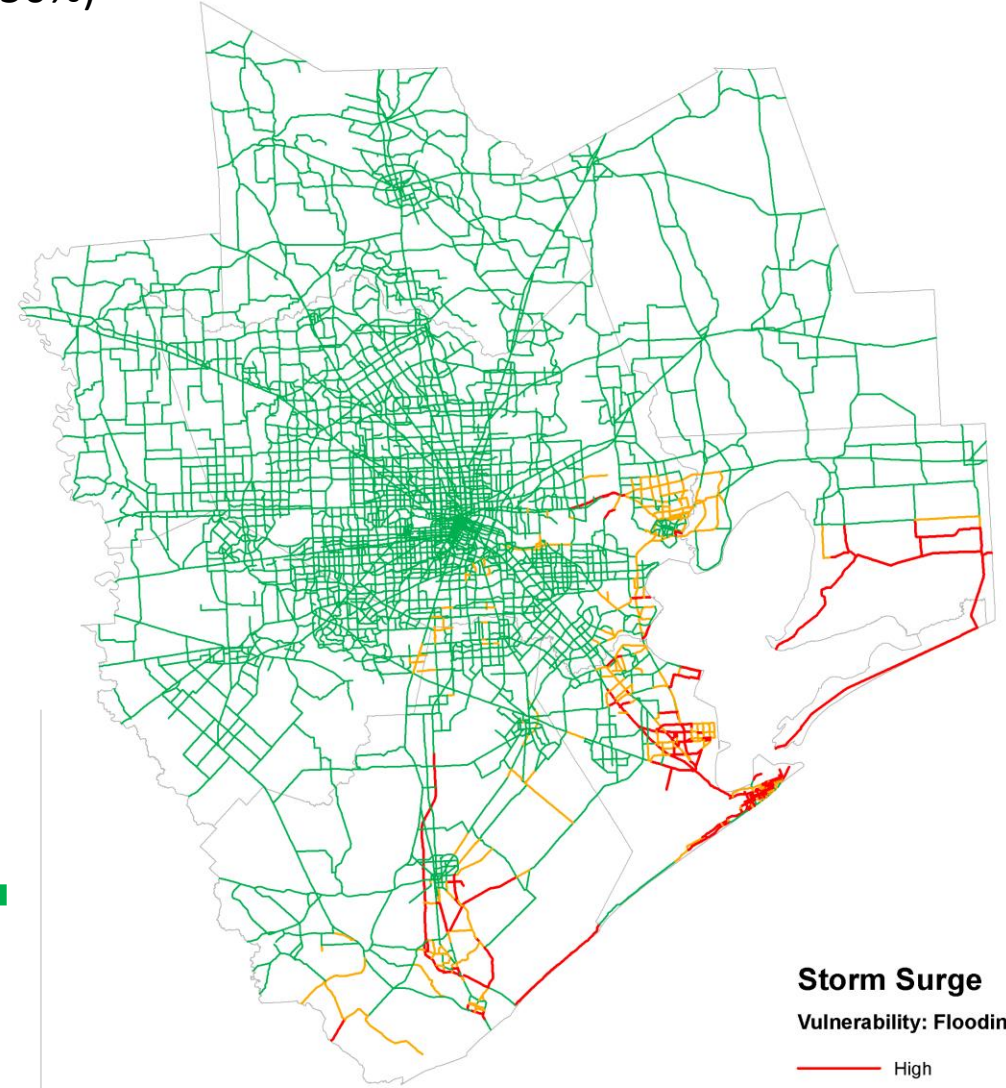
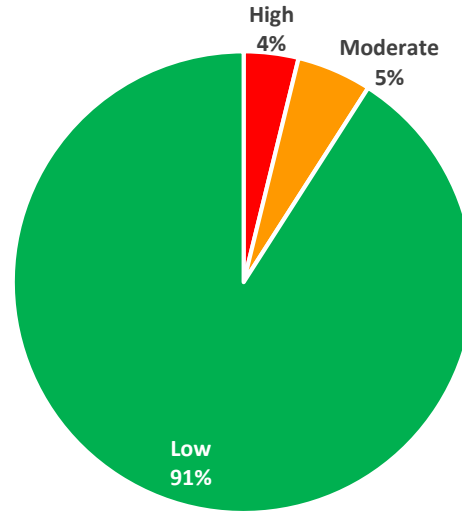
# Vulnerability Assessment

## Vulnerability: Storm Surge (Category 4 Storm Surge 50% + Ike Storm Surge 50%)

Freeways: 762 centerline miles



Major Streets: 6,442 centerline miles



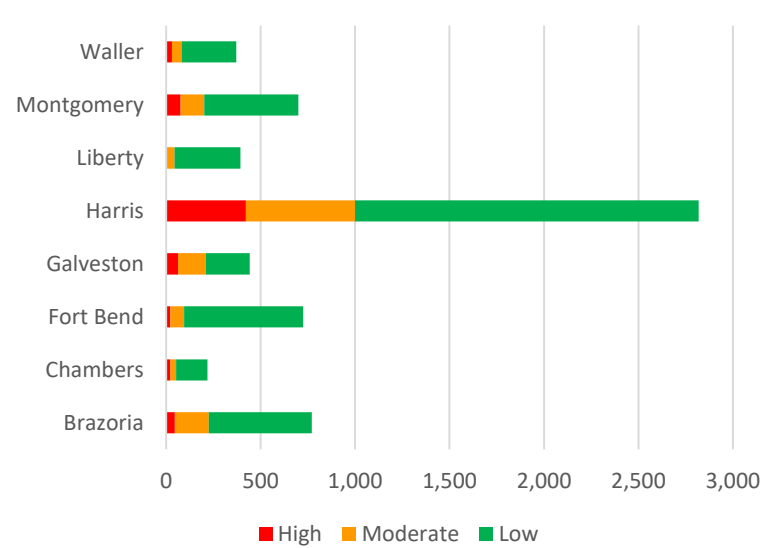
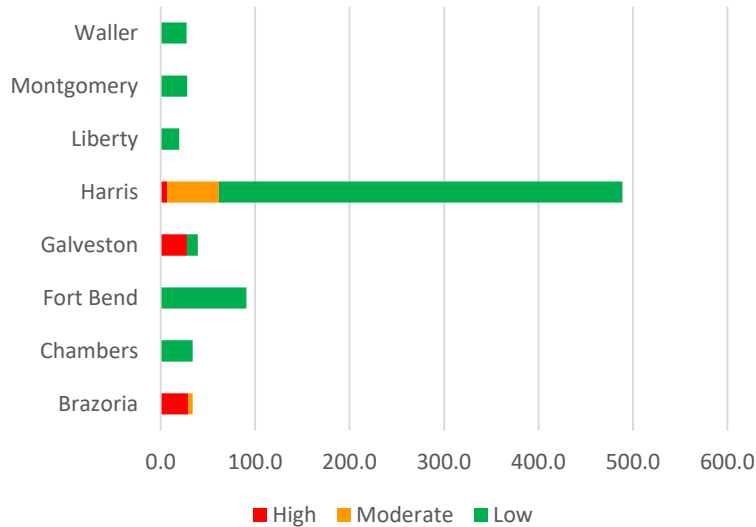
### Storm Surge

#### Vulnerability: Flooding

- High
- Moderate
- Low



0 5 10 20 Miles

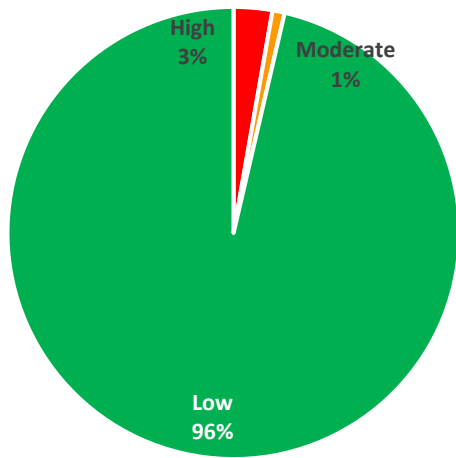




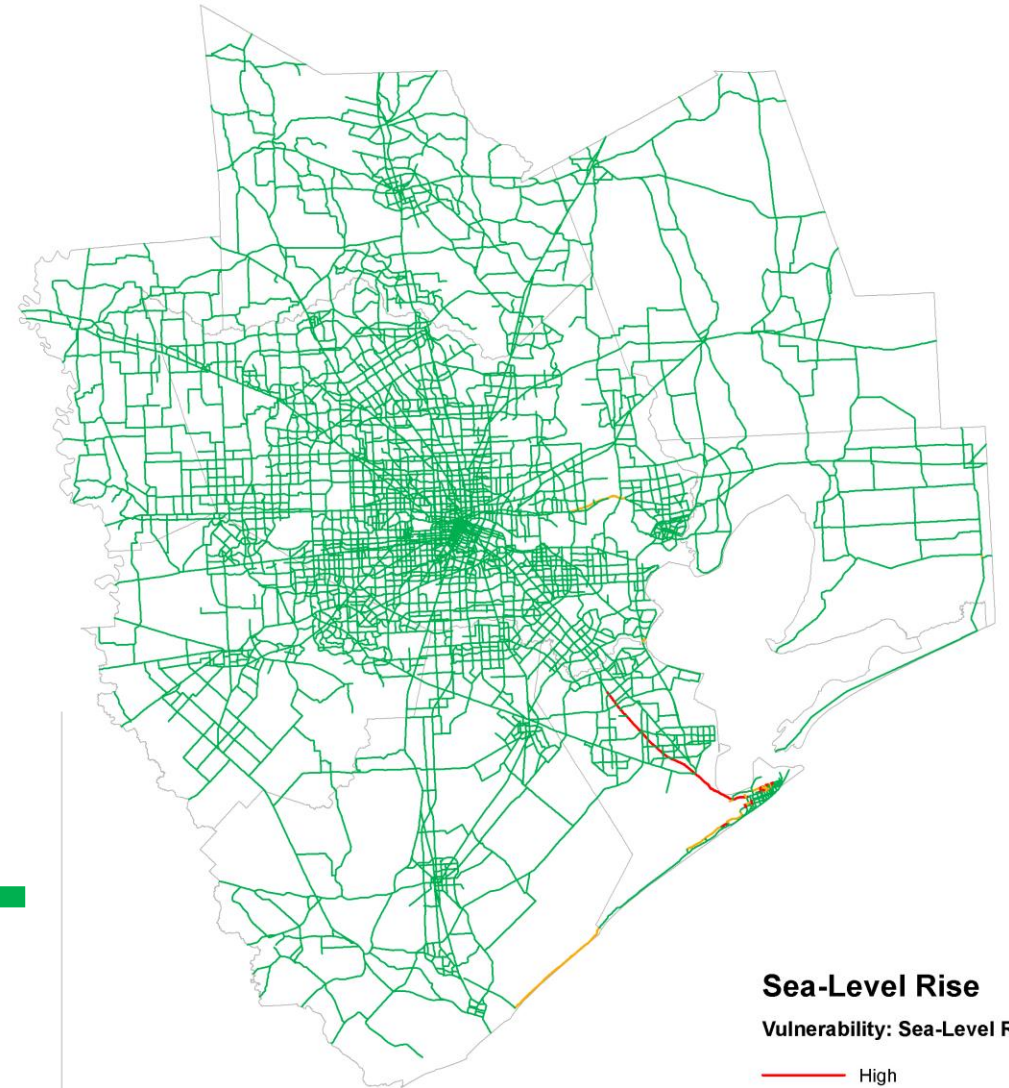
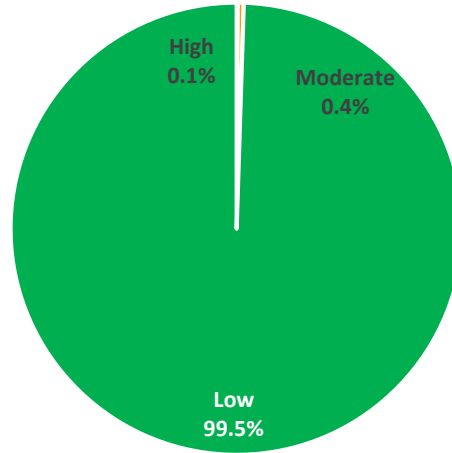
# Vulnerability Assessment

## Vulnerability: Sea-Level Rise (5-ft Sea-Level Rise 100%)

Freeways: 762 centerline miles



Major Streets: 6,442 centerline miles



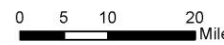
### Sea-Level Rise

Vulnerability: Sea-Level Rise

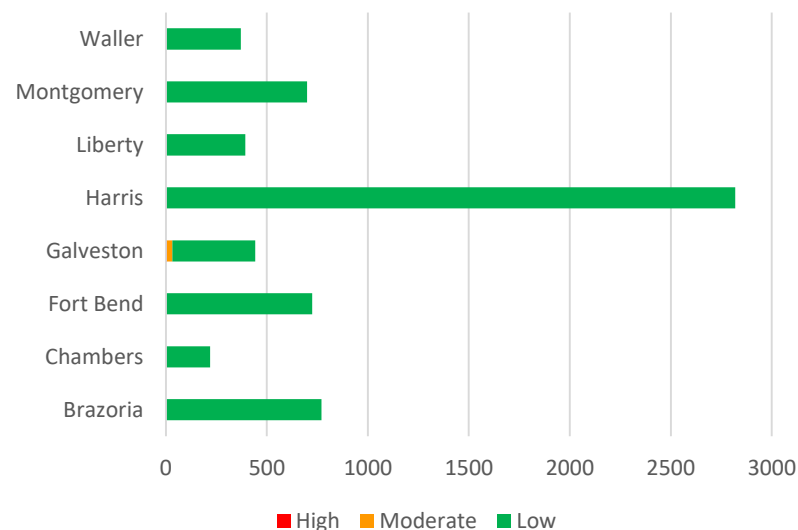
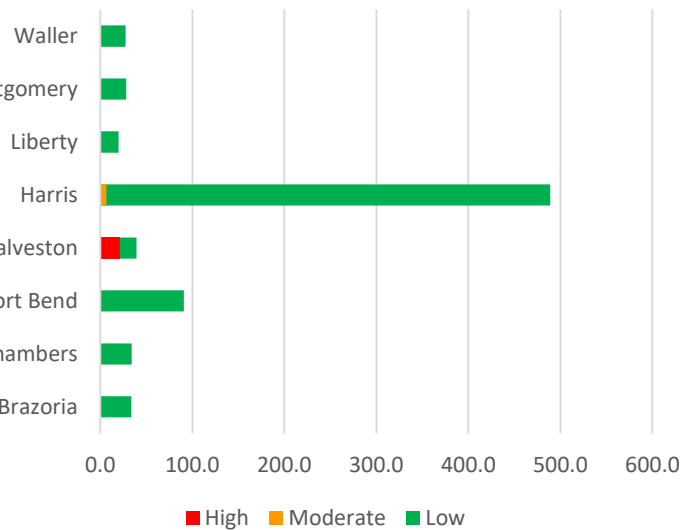
High

Moderate

Low



Miles



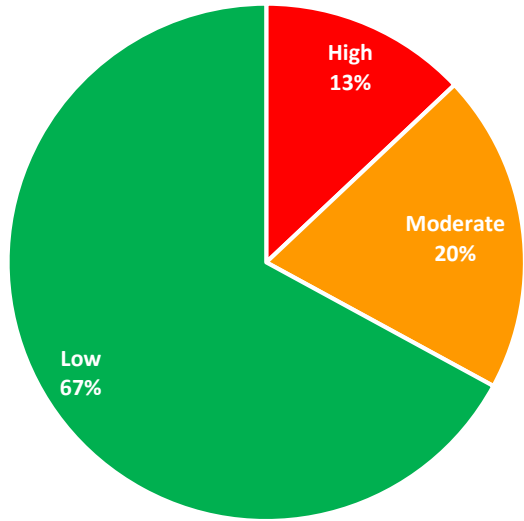
High Moderate Low

High Moderate Low

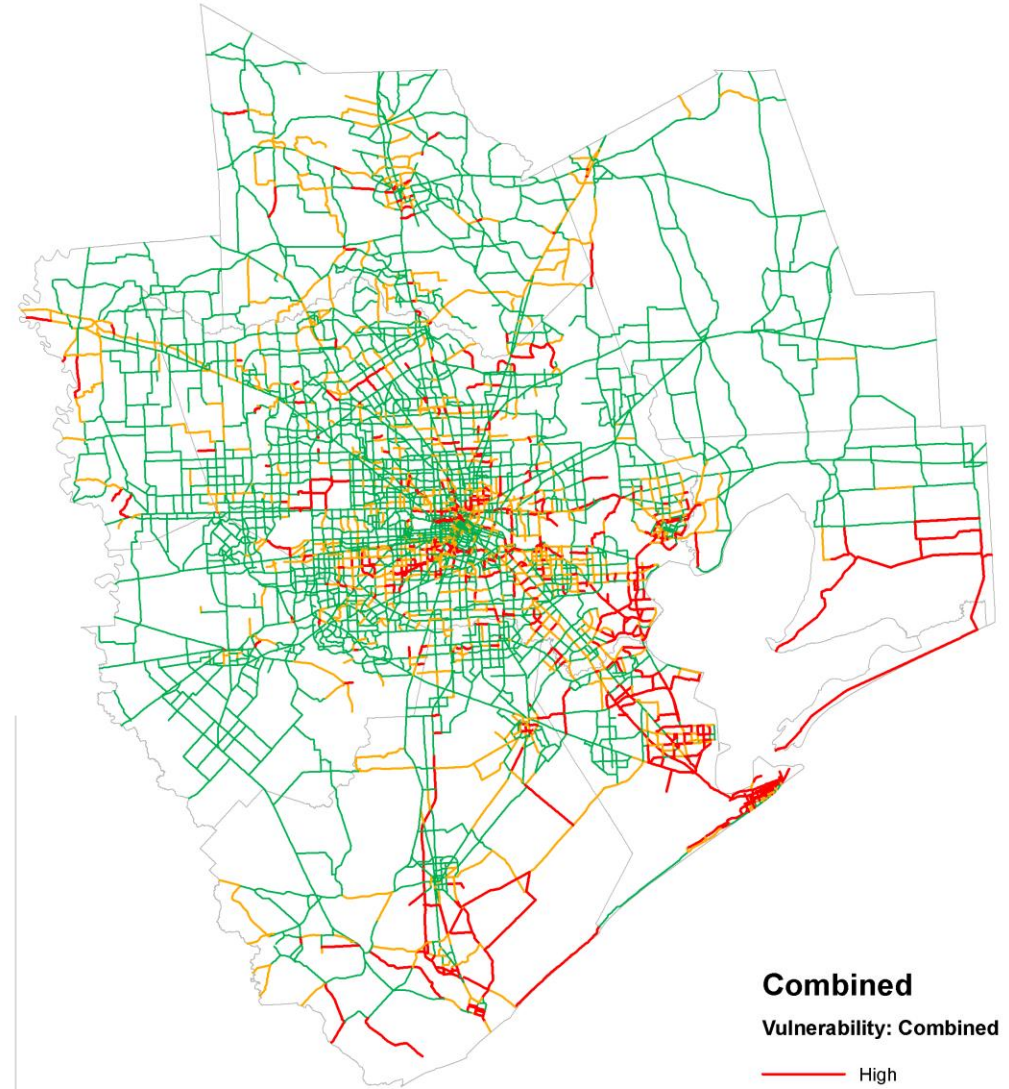
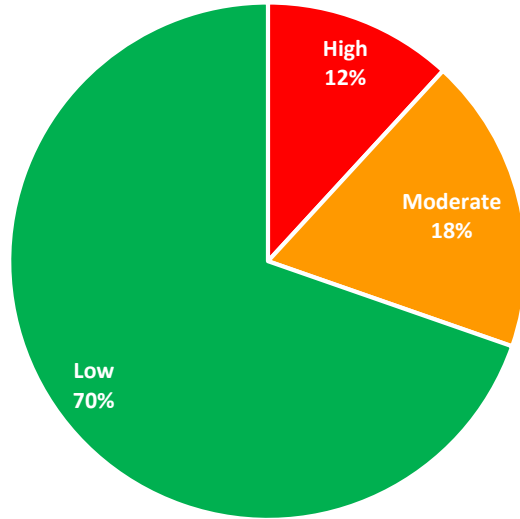
# Vulnerability Assessment

Vulnerability: Combined (Flooding 50% + Storm Surge 35% + Sea-Level Rise 15%)

Freeways: 762 centerline miles



Major Streets: 6,442 centerline miles

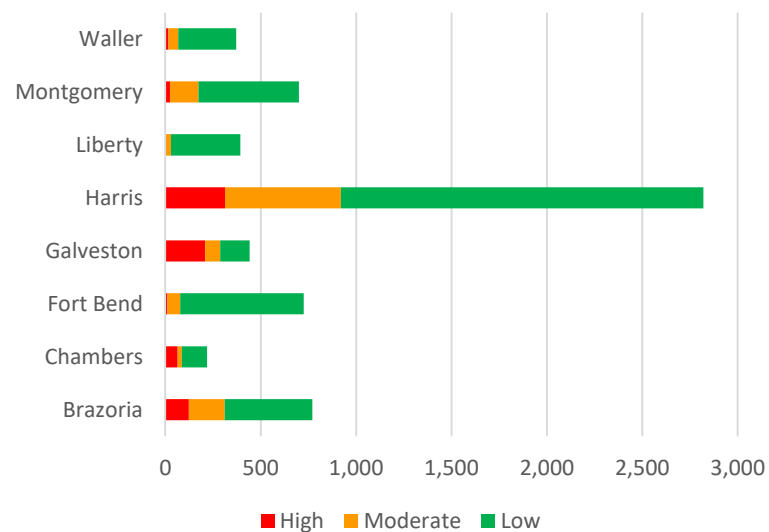
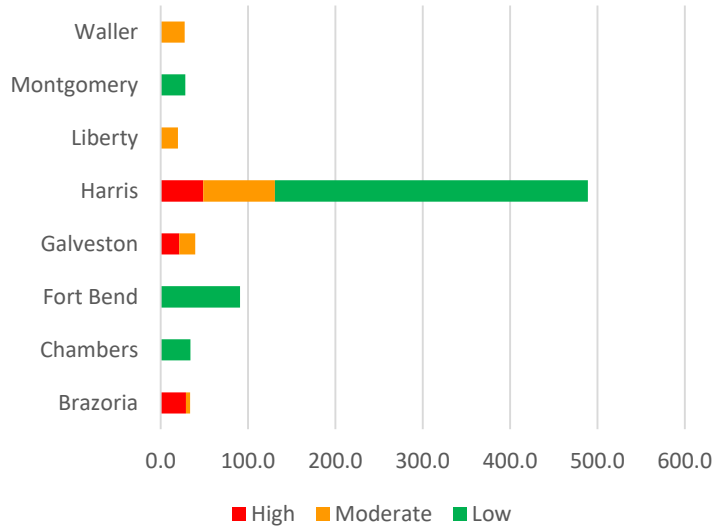


**Combined Vulnerability: Combined**

- High
- Moderate
- Low



0 5 10 20 Miles

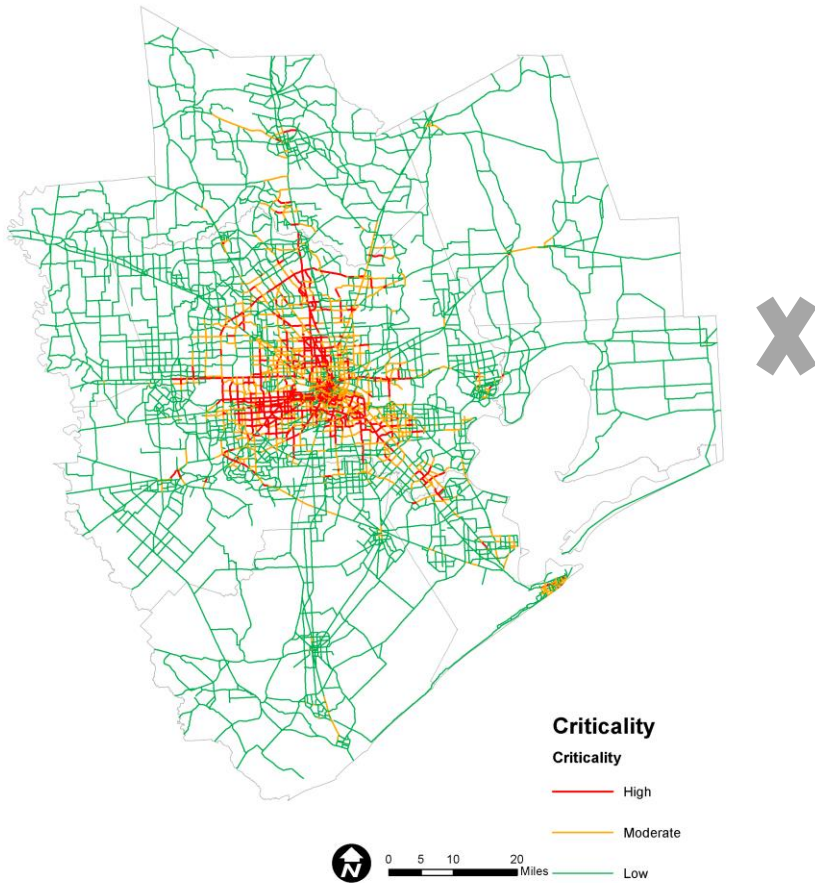




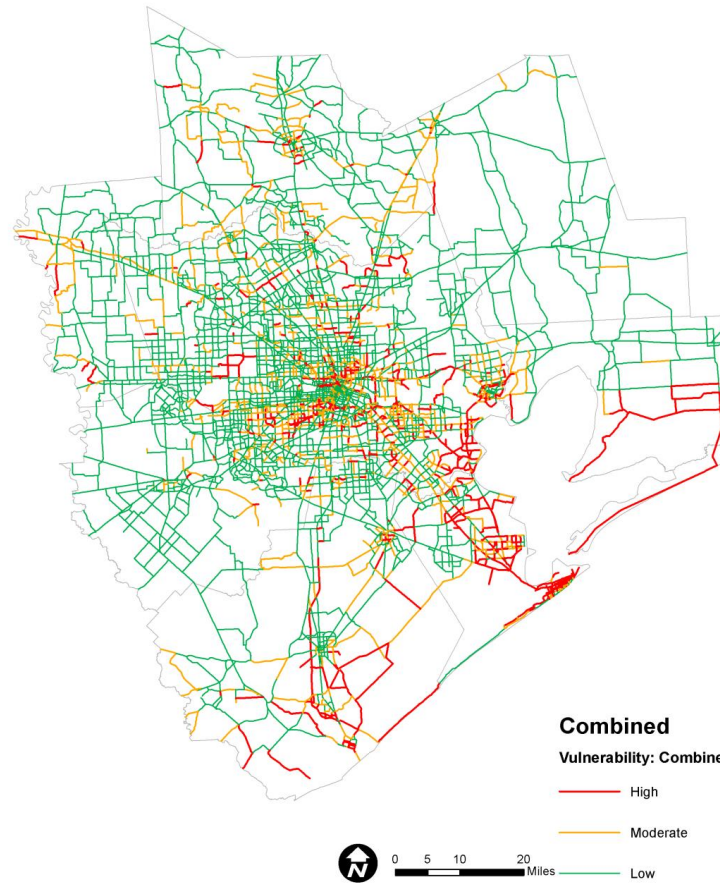
# Criticality-Vulnerability Matrix

# Vulnerability – Criticality Matrix

Criticality (3 types)



Vulnerability (3 types)



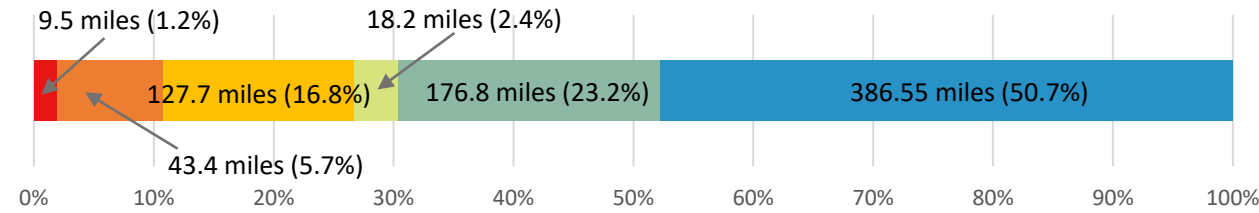
Criticality-Vulnerability Matrix (9 types)

High Criticality Low Vulnerability	High Criticality Moderate Vulnerability	High Criticality High Vulnerability
Moderate Criticality Low Vulnerability	Moderate Criticality Moderate Vulnerability	Moderate Criticality High Vulnerability
Low Criticality Low Vulnerability	Low Criticality Moderate Vulnerability	Low Criticality High Vulnerability



# Vulnerability – Criticality Matrix

Freeways: 762 centerline miles

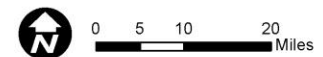
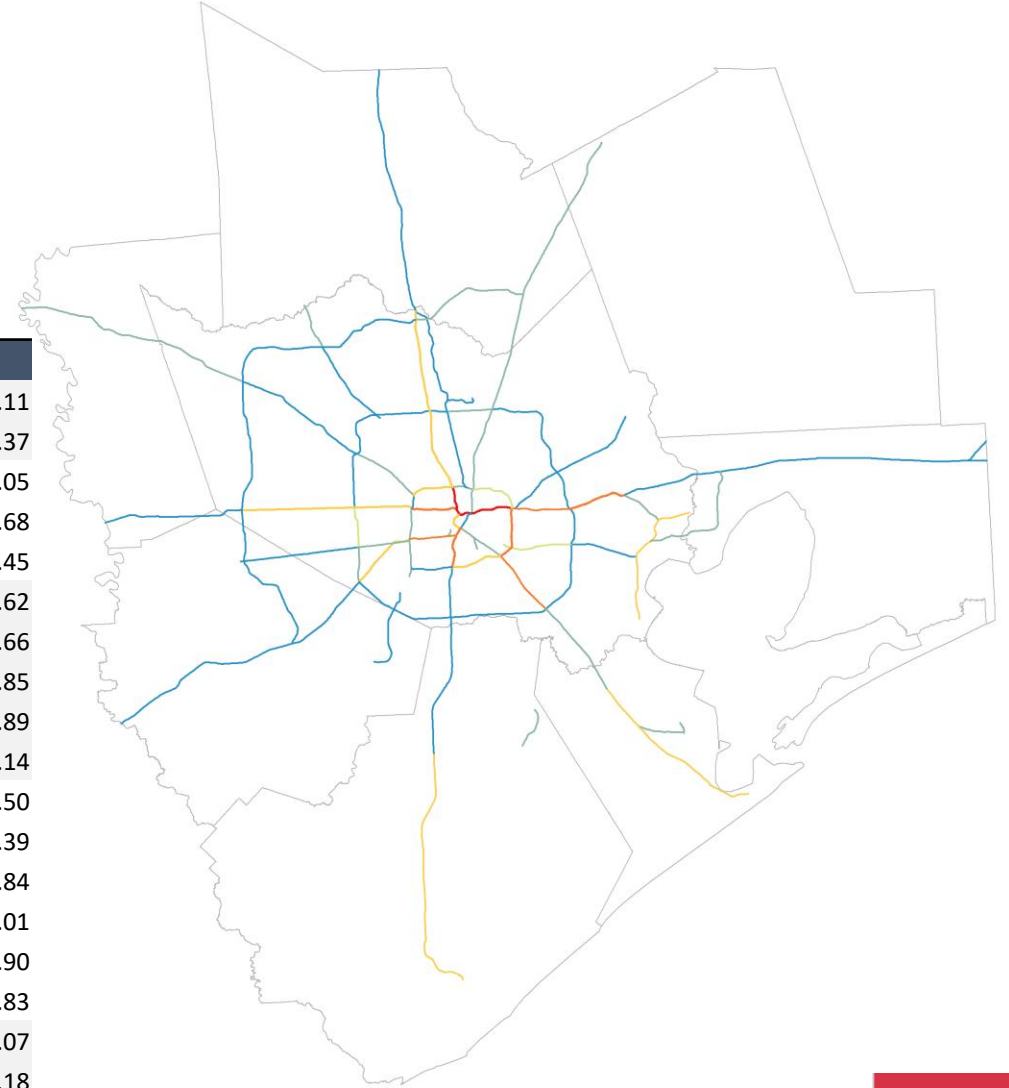


## Matrix Summary

Matrix	Miles	%
Total	762.2	100.0%
High Criticality - High Vulnerability	9.5	1.2%
Moderate Criticality - High Vulnerability	23.2	3.0%
High Criticality - Moderate Vulnerability	20.2	2.6%
Low Criticality - High Vulnerability	66.2	8.7%
High Criticality - Low Vulnerability	61.5	8.1%
Moderate Criticality - Moderate Vulnerability	18.3	2.4%
Low Criticality - Moderate Vulnerability	113.7	14.9%
Moderate Criticality - Low Vulnerability	63.1	8.3%
Low Criticality - Low Vulnerability	386.5	50.7%

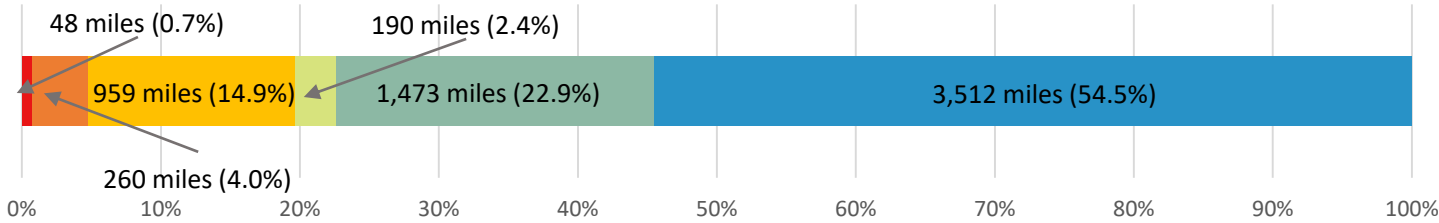
## Freeways Details (excerpt)

Matrix	Name	Miles
High Criticality – High Vulnerability	I-45	3.11
	IH 10 E	6.37
High Criticality -Moderate Vulnerability	GULF FWY/IH 45	8.05
	IH 10 E	6.68
	IH 69	5.45
	IH 10 E	6.62
	IH 10 W	5.66
Moderate Criticality -High Vulnerability	IH 69	0.85
	SOUTH FWY/SH 288	3.89
	SOUTH LOOP E	6.14
High Criticality – Low Vulnerability	IH 10 W	19.50
	IH 45	2.39
	IH 69	7.84
	NORTH FWY/IH 45	21.01
	NORTH LOOP	4.90
	SOUTH LOOP E	5.83
	GULF FWY/IH 45	21.07
Low Criticality – High Vulnerability	SH 146	16.18
	SH 288	28.94



# Vulnerability – Criticality Matrix

Major Streets: 6,442 centerline miles

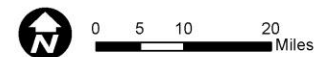
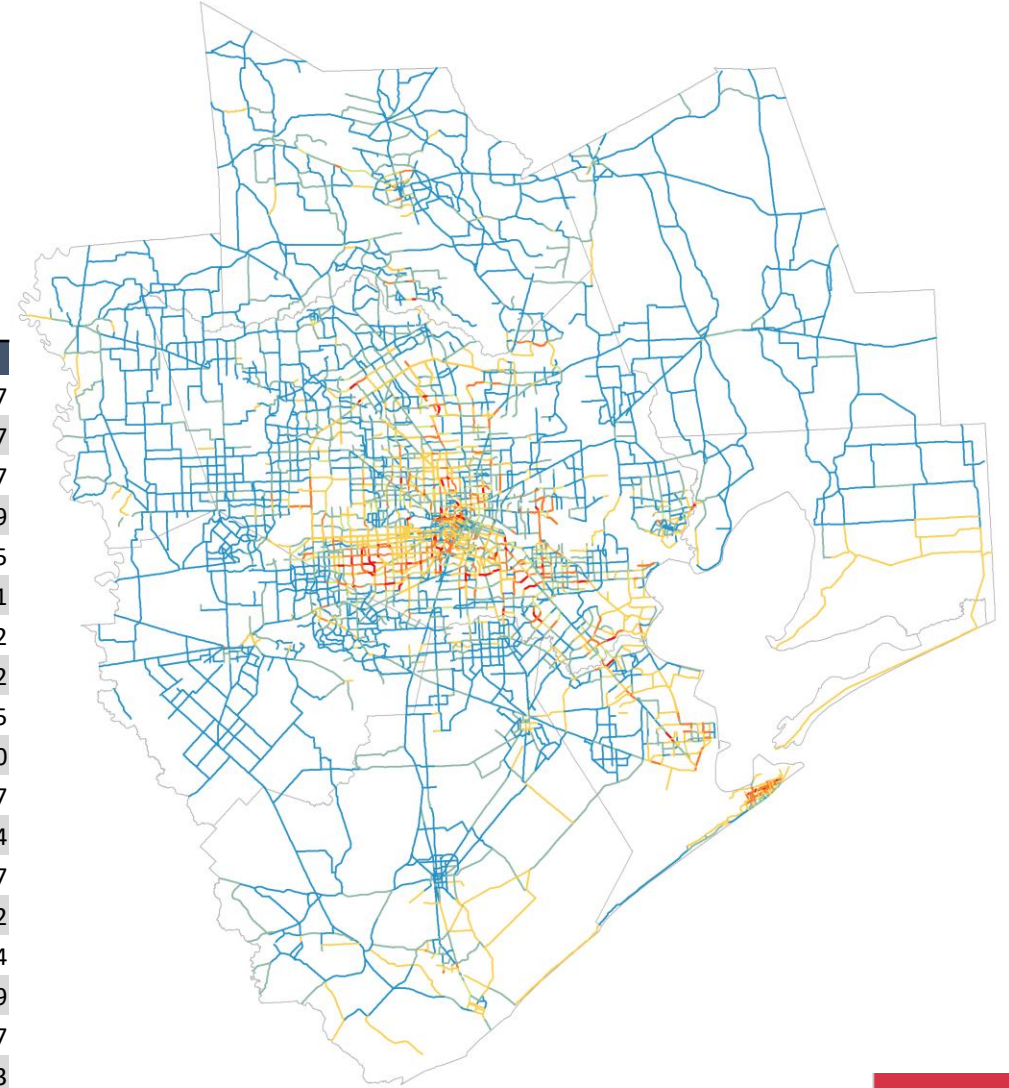


## Matrix Summary

Matrix	Miles	%
Total	6,442.0	100.0%
High Criticality - High Vulnerability	48	0.7%
Moderate Criticality - High Vulnerability	119	1.9%
High Criticality - Moderate Vulnerability	140	2.2%
Low Criticality - High Vulnerability	595	9.2%
High Criticality - Low Vulnerability	364	5.7%
Moderate Criticality - Moderate Vulnerability	191	3.0%
Low Criticality - Moderate Vulnerability	861	13.4%
Moderate Criticality - Low Vulnerability	611	9.5%
Low Criticality - Low Vulnerability	3,512	54.5%

## Principal Arterials Details (excerpt)

Matrix	Name	Miles
High Criticality - High Vulnerability	BROADWAY (Galveston)	2.617
	SH 3	1.537
	BROADWAY (Houston)	0.777
	COLLEGE	1.199
	CULLEN	0.735
	FAIRMONT PKWY	1.021
	FEDERAL	0.462
	FM 1960	0.142
	KIRBY DR	0.635
	LOCKWOOD DR	0.620
	MEMORIAL DR	0.637
	MONROE	0.134
	NASA RD 1	1.237
	OLD SPANISH TRAIL	0.102
	SH 35	0.794
	SH 146/LOOP 201	0.239
	SHAVER	0.437
SPENCER HWY	0.463	
LOOP 336	0.119	





# Economic Impact Analysis

# Economic Impact Analysis

**Scenario 5: US 59**



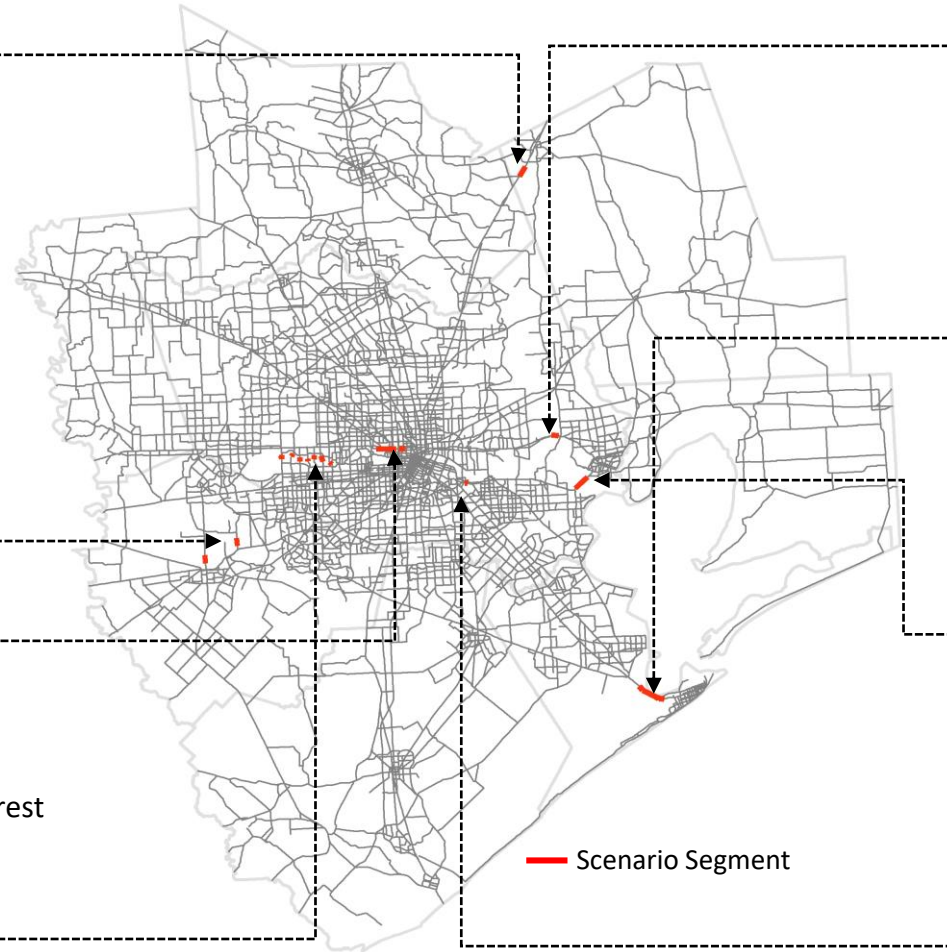
**Scenario 6: FM 723 & FM 359**



**Scenario 7: IH 10**



**Scenario 8: North-South Connectors along Buffalo Bayou between Memorial Dr and Briar Forest**



**Scenario 1: IH 10 San Jacinto Bridge**



**Scenario 2: Gulf Freeway Galveston Causeway**



**Scenario 3: SH 146 Fred Hartman Bridge**

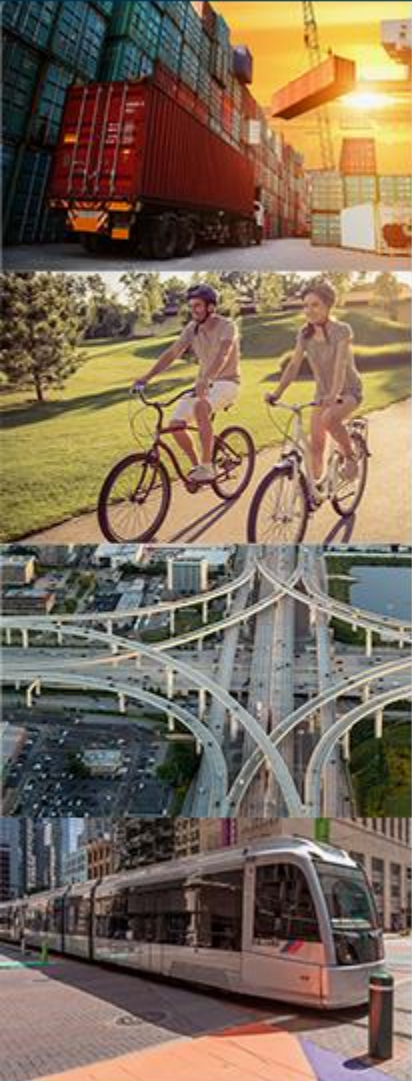


**Scenario 4: SH 225/Lawndale St.**





# Economic Impact Analysis

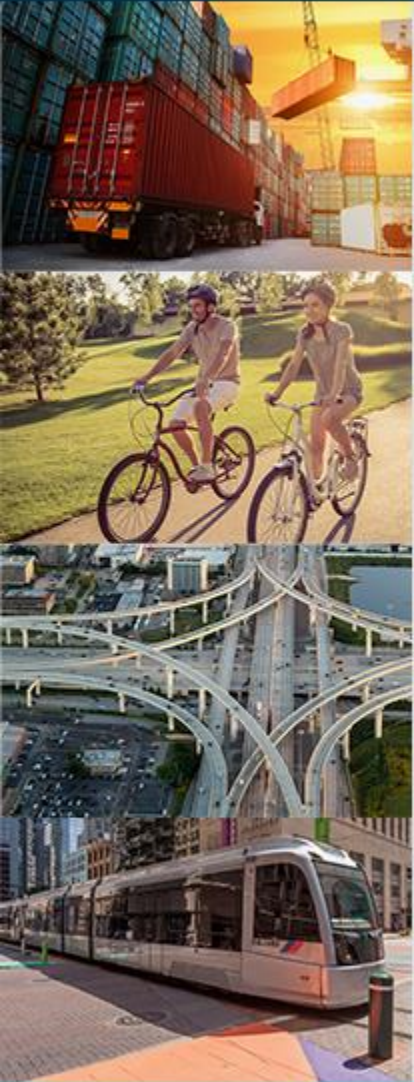


GDP Loss (Million of Fixed Dollars in 2020) by Scenarios

Scenario	Description	Annual	Month	Week	Day
<b>Scenario 1</b>	IH 10 San Jacinto Bridge	206.9	17.2	4.0	0.6
<b>Scenario 2</b>	Gulf Freeway Galveston Causeway	599.2	49.9	11.5	1.7
<b>Scenario 3</b>	SH 146 Fred Hartman Bridge	205.6	17.1	4.0	0.6
<b>Scenario 4</b>	SH 225/Lawndale St.	191.5	16.0	3.7	0.5
<b>Scenario 5</b>	US 59	182.5	15.2	3.5	0.5
<b>Scenario 6</b>	FM 723 & FM 359	173.6	14.5	3.3	0.5
<b>Scenario 7</b>	IH 10	215.3	17.9	4.1	0.6
<b>Scenario 8</b>	North-South Connecters along Buffalo Bayou between Memorial Dr and Briar Forest	494.8	41.2	9.5	1.4
<b>Scenario 1+3+4</b>		431.0	35.9	8.3	1.2
<b>Scenario 1-8</b>		1,407.5	117.3	27.1	4.0

Source- H-GAC Travel Demand Data and REMI Transight

# How can one utilize the data from this study?



- Road Segment Elevation Data
- Criticality of Road Segment based on individual criteria
- Location Specific Exposure Depth
- Network Redundancy (Detour Length)
- Project Prioritization



# Resilience Tools

### Resilience Street Profile

**CONTROL PANEL**

Functional Classification (select item/s)

Freeway Minor Arterial Collector

Principal Arterial

Street Name

None

Overall Criticality (0-1)

Vulnerability (Low-Moderate-High)

None

Combined Matrix

None

Select a street segment to display resilience profile on the map using selection tool

**STREET NAME: HARDY TOLL ROAD**

1 of 7364

**STREET INFORMATION**

Street ID: FsigID\_10  
 FHWA Classification: Freeway  
 Center-line Mile: 13.09  
 Network Redundancy: 1.20

**CRITICALITY**

Criticality Score : Low  
 Detailed Scores (0-4):

- Linkage to airport: 3
- Linkage to port: 0
- Access to activity population: 0
- AADT: 0
- AADT-Truck: 0
- Transit Ridership: 0
- Linkage to hospital: 0
- Linkage to fire station: 0
- Access to vulnerable population: 0
- Evacuation Route: 0
- Linkage to shelter: 0
- Linkage to emergency operation: 0
- Military access: 0

**VULNERABILITY**

Vulnerability Score (Floodng) : Low  
 Vulnerability Score (Storm Surge) : Low  
 Vulnerability Score (Sea-Level Rise) : Low

Detailed Scores:

- 500-Year Flood: Moderate
- Harvey: Low
- CAT1 Storm Surge: Low
- CAT2 Storm Surge: Low
- CAT3 Storm Surge: Low
- CAT4 Storm Surge: Low
- CAT5 Storm Surge: Low
- Ike Storm Surge: Low
- 4-ft Sea-Level Rise: Low
- 5-ft Sea-Level Rise: Low

**MATRIX**

Criticality Overall (Low-Moderate-High): Low  
 Vulnerability Overall (Low-Moderate-High): Low

Overall Matrix: Low Criticality - Low Vulnerability

What is Matrix?

High Criticality Low Vulnerability	High Criticality Moderate Vulnerability	High Criticality High Vulnerability
Moderate Criticality Low Vulnerability	Moderate Criticality Moderate Vulnerability	Moderate Criticality High Vulnerability
Low Criticality Low Vulnerability	Low Criticality Moderate Vulnerability	Low Criticality High Vulnerability

**Regional Resilience Data** HGAC

Find address or place

Map controls: Zoom in/out, Home, Full Screen, Layers, etc.

Scale: 1:97,588 30,659 Degrees

Map data: Esri, HERE, Garmin, FNO, USGS, NSA, EPA, etc.

# Acknowledgements

- H-GAC Staff
- Texas Transportation Institute
- TxDOT Houston District
- Federal Highway Administration
- Harris County Flood Control District
- Rice University SSPEED Center
- Regional Stakeholders



# Contact and Links

## Resilience Tool

<https://datalab.h-gac.com/resilience/>

## Contact Information

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# Bridge Exposure

## Bridge Exposure Classification Criteria

Exposure Description	Exposure Category	Exposure Score
Water level 6+ feet below bridge deck	Not exposed/low risk	0
Water level 4-6 feet below bridge deck	Medium-low risk	1
Water level 2-4 feet below bridge deck	Medium risk	2
Water level within 2 feet below bridge deck	Medium-high risk	3
Water level above bridge deck	High risk	4



# Vulnerability Assessment: Bridges



## Bridge Vulnerability Detail

Bridge ID	121020050801222
Feature Intersect	SAN JACINTO RIVER
Name	IH 10 WB
Year Built	1971
Operational Status	Open
Type Service Under Bridge	Waterway
Waterway	Bridge deck and roadway approaches above flood water elevations (high water).
Exposure: 100YR	Medium risk of exposure
Exposure: 500YR	Medium risk of exposure
Exposure: Harvey	Medium risk of exposure
Exposure: Category 1	Low risk of exposure
Exposure: Category 2	Medium risk of exposure
Exposure: Category 3	Medium-high risk of exposure
Exposure: Category 4	Medium-high risk of exposure
Exposure: Category 5	Medium-high risk of exposure
Exposure: Ike	Medium risk of exposure

Bridge Sections from LiDAR data

Regional Collaboration • Transportation Planning • Multimodal Mobility