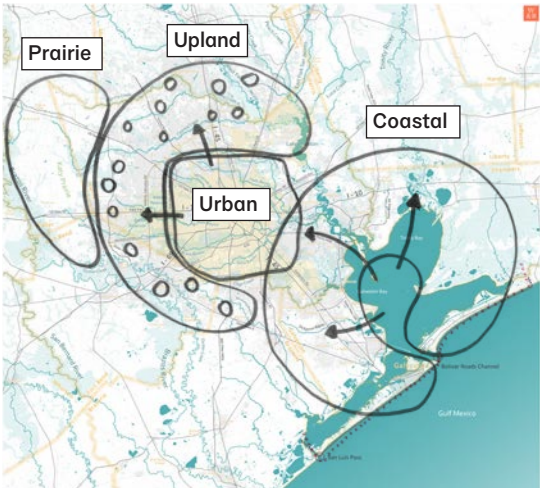
Surface and Systems

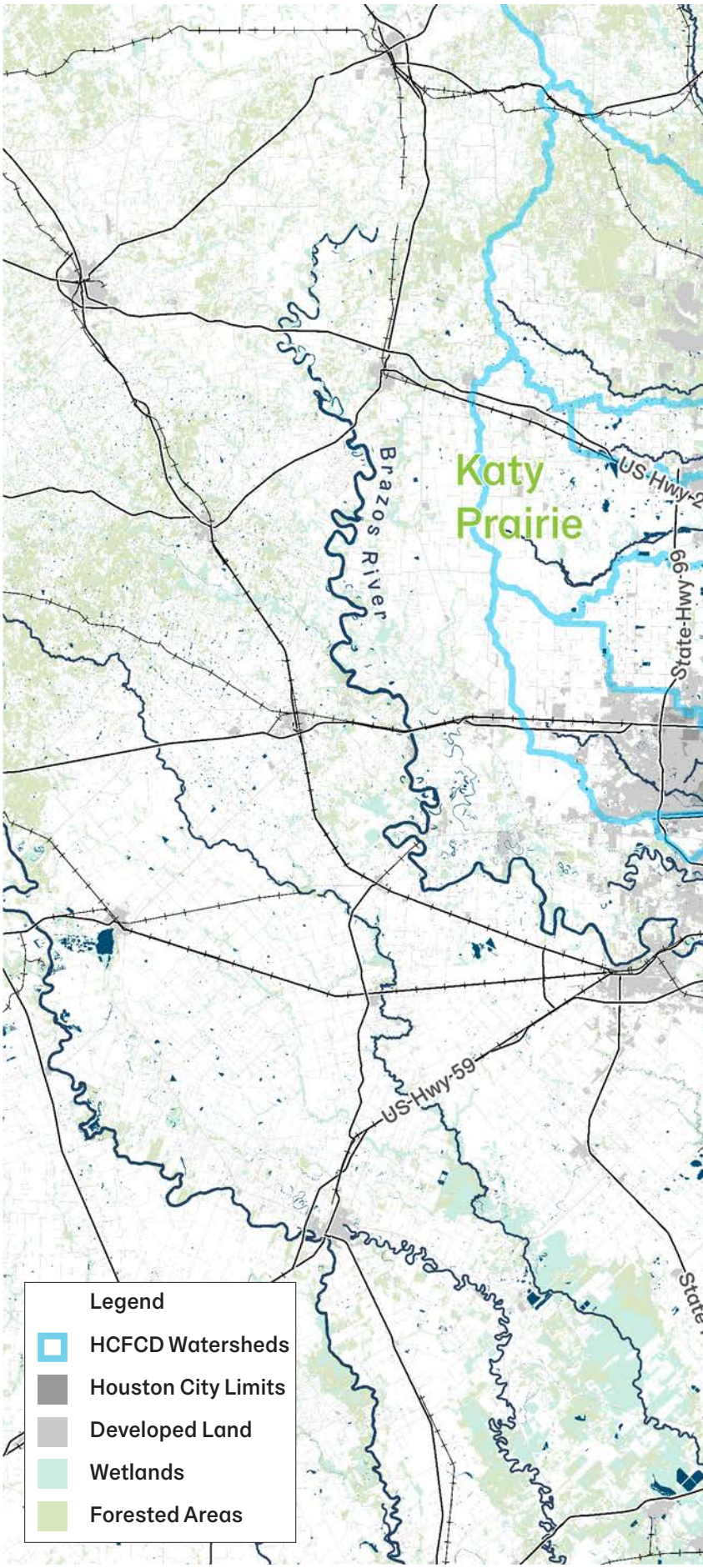
Systems Perspective

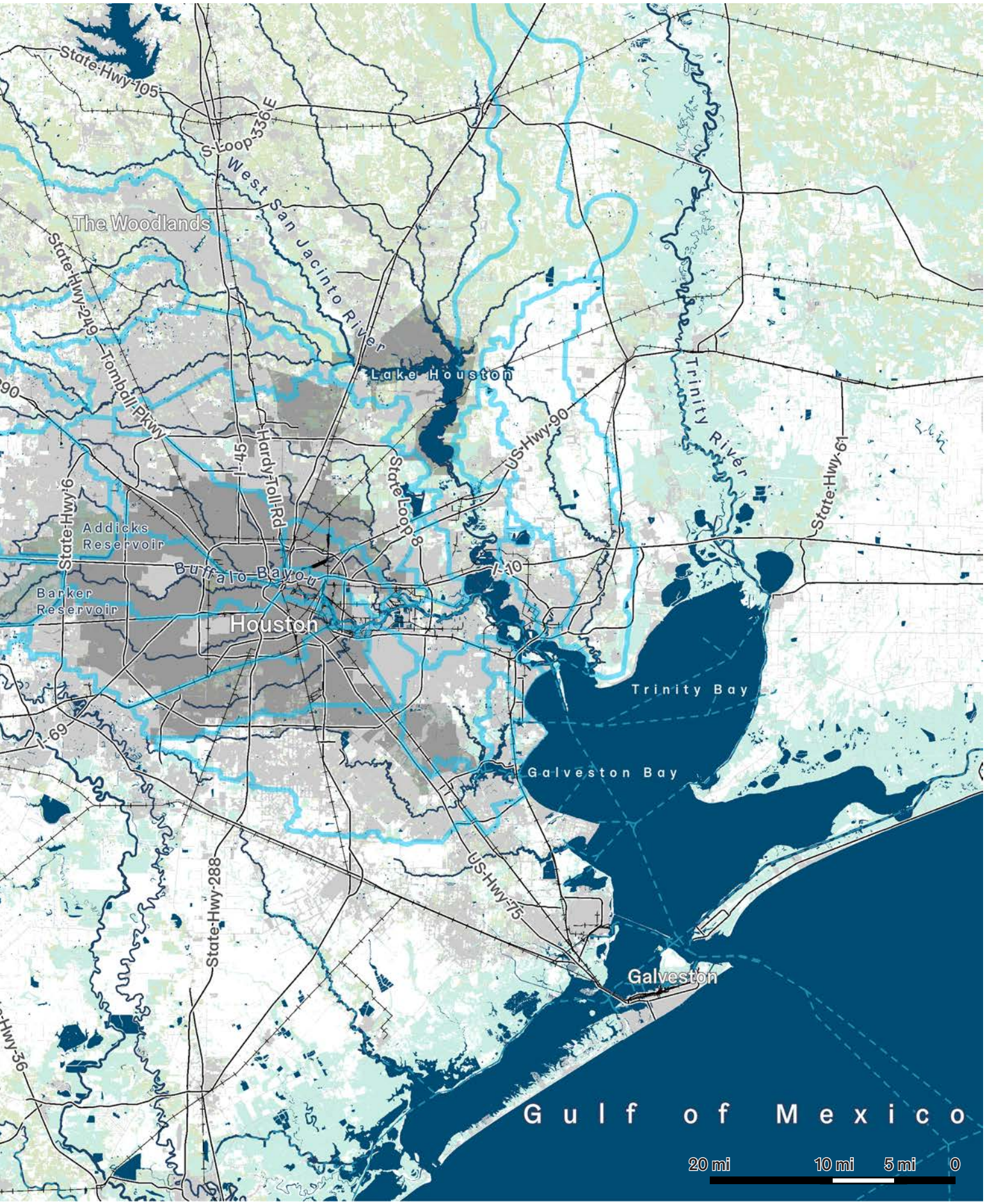
Houston is defined by a system of bayous and transportation corridors. Houston was built on rail lines and bayous and expanded by highways. The rail lines upon which the city of Houston was founded all converge at Buffalo Bayou. As it approaches the bay, Buffalo Bayou turns into a transportation corridor, the Ship Channel, Houston's gateway to the world. Twelve of Harris County's twenty two watersheds ultimately empty into the Houston Ship Channel. The intersections of infrastructure and water create both Houston's economic vitality as well as some of the city's greatest flood risk challenges. Roads and rail lines can constrain bayous and exacerbate flooding.

Houston contains a variety of landscapes that are all connected by bayous and transportation corridors. Water flows through bayous from prairies to the coast, and highways connect the urban core to the rapidly expanding suburban periphery. All of these landscapes and systems are interconnected; their challenges have upstream and downstream consequences. The flatness of Houston allows flooding in one bayou to impact another. Sea level rise, which threatens the coastal edge, also impacts upstream bayou conveyance. This causes backup and flooding, even at higher elevations. Developmental pressures in the upland periphery have the potential to create more runoff downstream. For any design solution to be successful in Houston, it must work for everything upstream and downstream.



Multiple Zones of the Houston Area




State Hwy 105
S Loop 336 E
West San Jacinto River
The Woodlands
State Hwy 249
Tomball Pkwy
Lake Houston
Trinity River
US Hwy 90
Hardy Toll Rd
I-45
State Loop 8
State Hwy 6
Addicks Reservoir
Buffalo Bayou
I-10
State Hwy 61
Barker Reservoir
Houston
Trinity Bay
I-69
Galveston Bay
US Hwy 75
State Hwy 288
Galveston
Gulf of Mexico
20 mi
10 mi
5 mi
0

Risk Levels

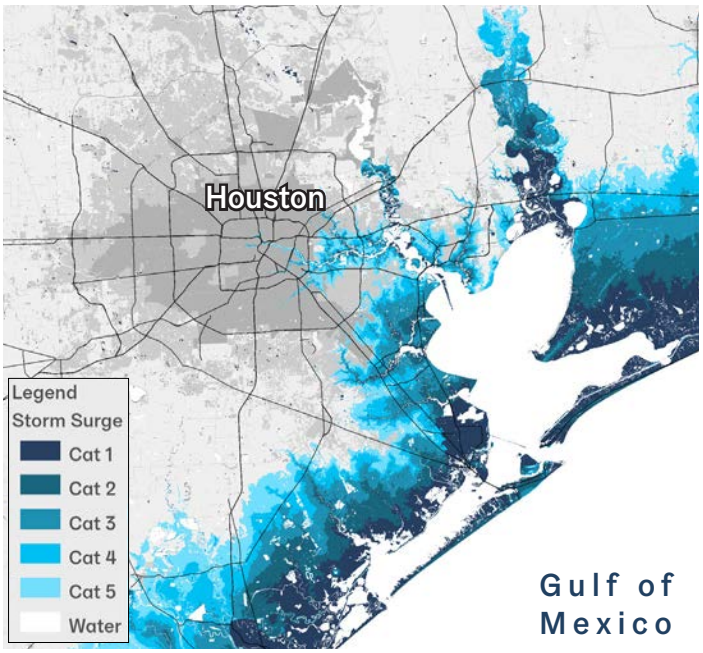
Gulf Coast Storms

Houston's economic vitality and its greatest source of risk comes from its connection to the Gulf of Mexico. Sitting on the western edge of what is known as hurricane alley, Houston receives at least one major storm almost every decade. Cyclones can impact both coastal areas and bayous upstream. Storm surge has both a direct impact for coastal areas, and an indirect impact for upstream bayous. Key port and industrial facilities along the Houston Ship Channel and Galveston Bay are threatened by storm surge and sea level rise. As an economic gateway to the U.S., Houston's vulnerability can have a nationwide impact.

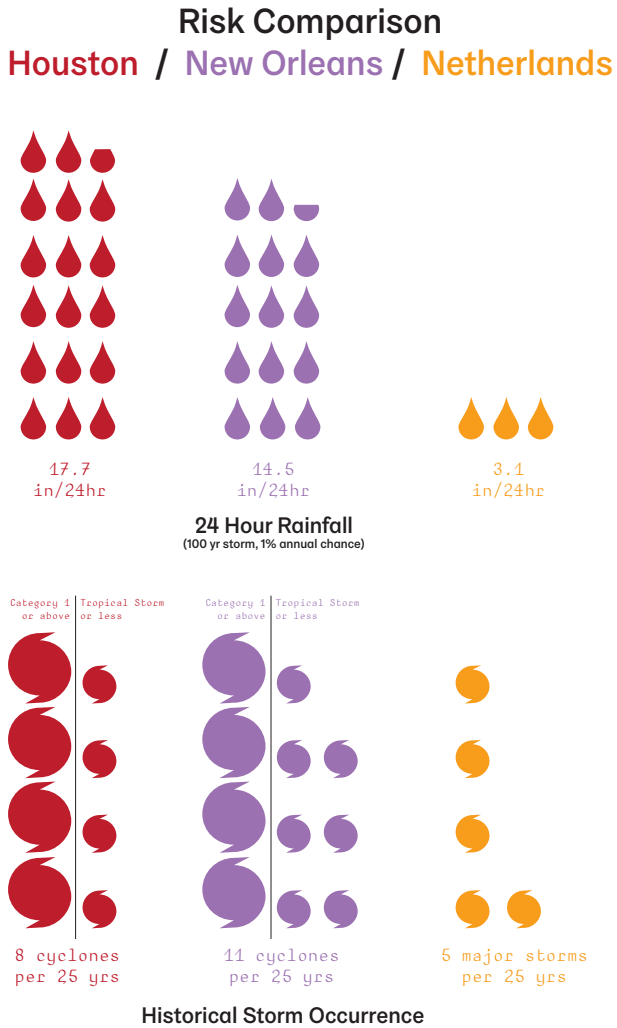
Storm surge will only worsen with sea level rise. Due to subsidence and other factors the rate of relative sea level rise in the Galveston Bay area is also significantly higher than the most of the United States. Sea level rise makes resilience a moving target. Immediate widespread action has the potential to ward off future risk.

Upstream bayous are also threatened by storm surge and sea level rise. Any increase in downstream water level slows the rate in which the bayous drain. The general flatness of Houston makes even slight increases in sea level have impacts far upstream. Coastal protection measures must similarly exist upstream and across multiple scales and sites.

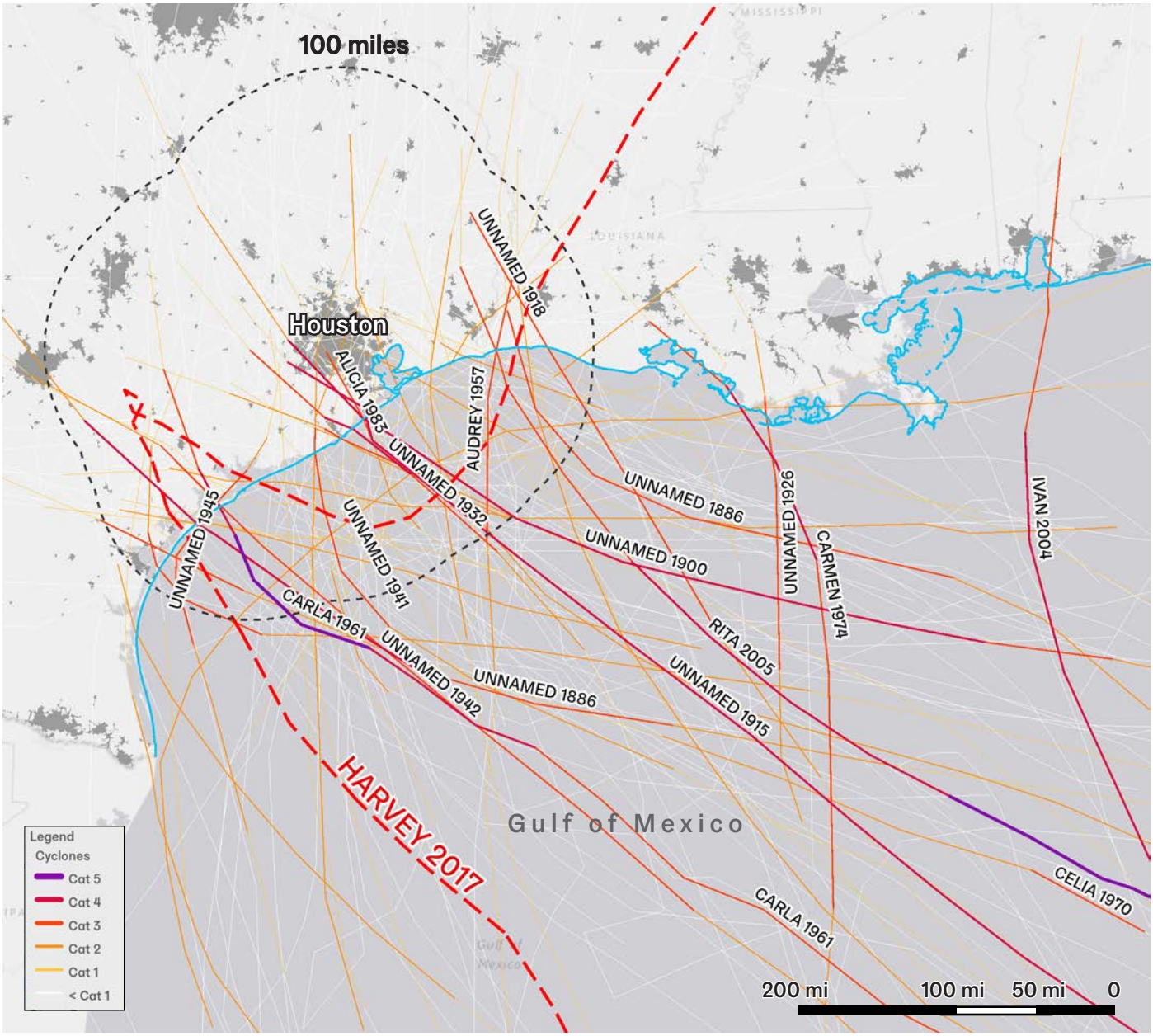
The risk to Houston's coast is multifaceted: storm surge risk is compounded by coastal erosion, wetland loss, and degraded water quality, and these factors impact the economic vitality of Houston and the character of Houston's coast. Currently Houston is considering multiple strategies for coastal protection including a storm surge barrier at the mouth of the Galveston Bay. Each facet of coastal risk must be addressed into the larger resilience strategy for Houston. Coastal protection must be matched with upstream flood mitigation efforts.



Storm Surge

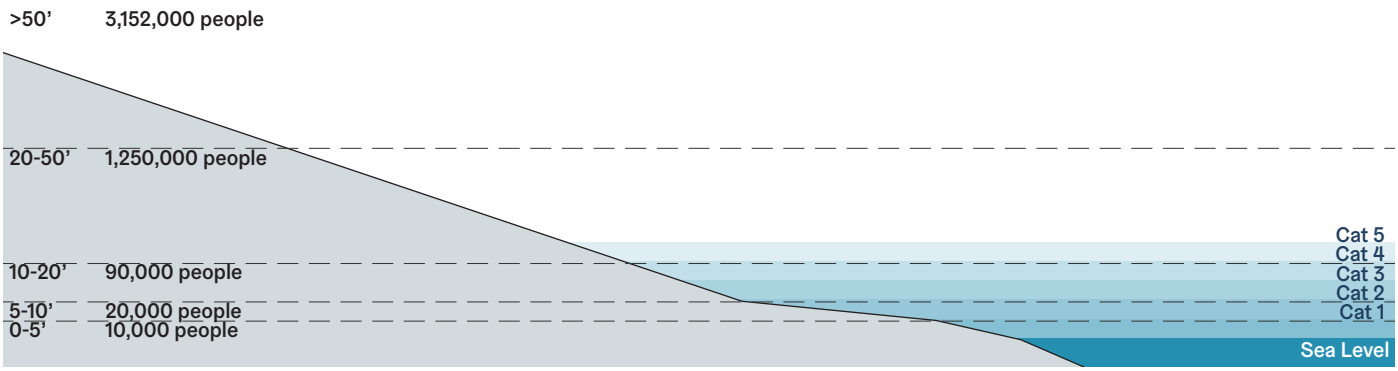


SOURCES
NOAA Atlas 14 https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=va
https://en.climate-data.org/europe/the-netherlands/north-holland/amsterdam-3330/#climate-graph
https://coast.noaa.gov/hurricanes/



Historic Cyclone Paths

Within 100 miles of Houston



Harris County Population Relative to Sea Level

Houston's topography slopes up gradually and steadily from the Galveston Bay. While a significant portion of residents are in direct risk from storm surge, most of Harris County's residents live over 50 feet above sea level.

Gulf Coast Rain

While wind and storm surge can damage property and exacerbate flood risk, the primary threat from hurricanes and tropical storms in Houston is precipitation. Even for Houstonians who live above sea level, tens of thousands of residents are inside bayou floodplains and even floodways. The Gulf Coast is one the wettest parts of the United States, and some of the most intense precipitation events occur around the Houston region. Even weaker tropical depressions can bring intense rainfall. Of the five most intense rain events along the Texan coast, four were classified as tropical storms or less, including Imelda in 2019. Intense rainfall is compounded by a relatively flat landscape, which creates wide floodplains and slow-moving bayous. Climate change is expected to accelerate the trend that Houston is already experiencing: heavy and intense precipitation. These storms are changing what is considered to be a 100-year or 1000-year design storm, used to assess risk and map floodplains. Because of these changes in weather and climate patterns, the boundaries of Houston's floodplains are expanding – and its resilience strategies must similarly expand.

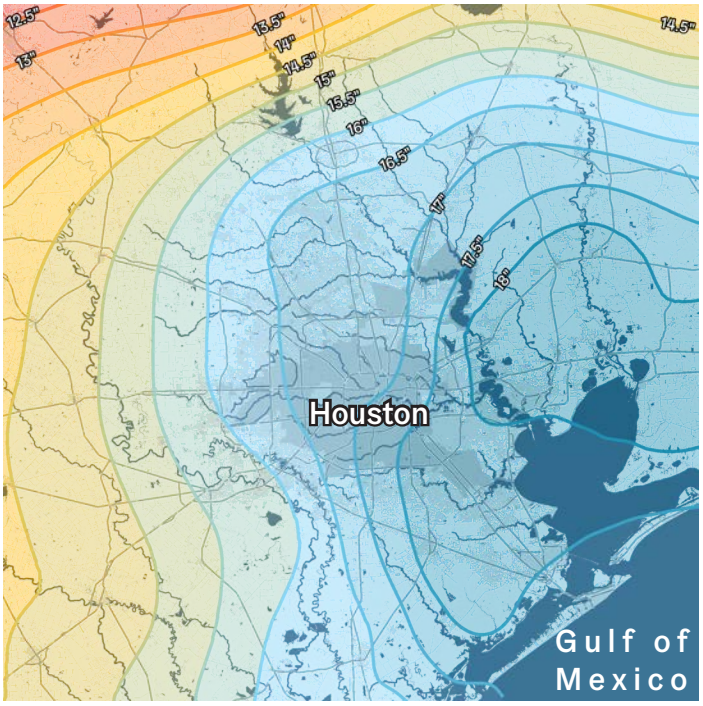
Stormwater Detention

The need for stormwater detention has always been present in Houston. The Addicks and Barker Reservoirs were built in the 1940's, designed to alleviate downstream flooding along Buffalo Bayou. After Hurricane Harvey in 2017, additional stormwater detention infrastructure has been planned or built. Along most of the major bayous of Houston, several massive detention basins have begun planning or construction. As precipitation data and floodplain maps are updated post Harvey, these new detention basins compensate for the new risk evaluation. While these new basins will store a tremendous amount of water, property within the floodplain will still remain at risk.

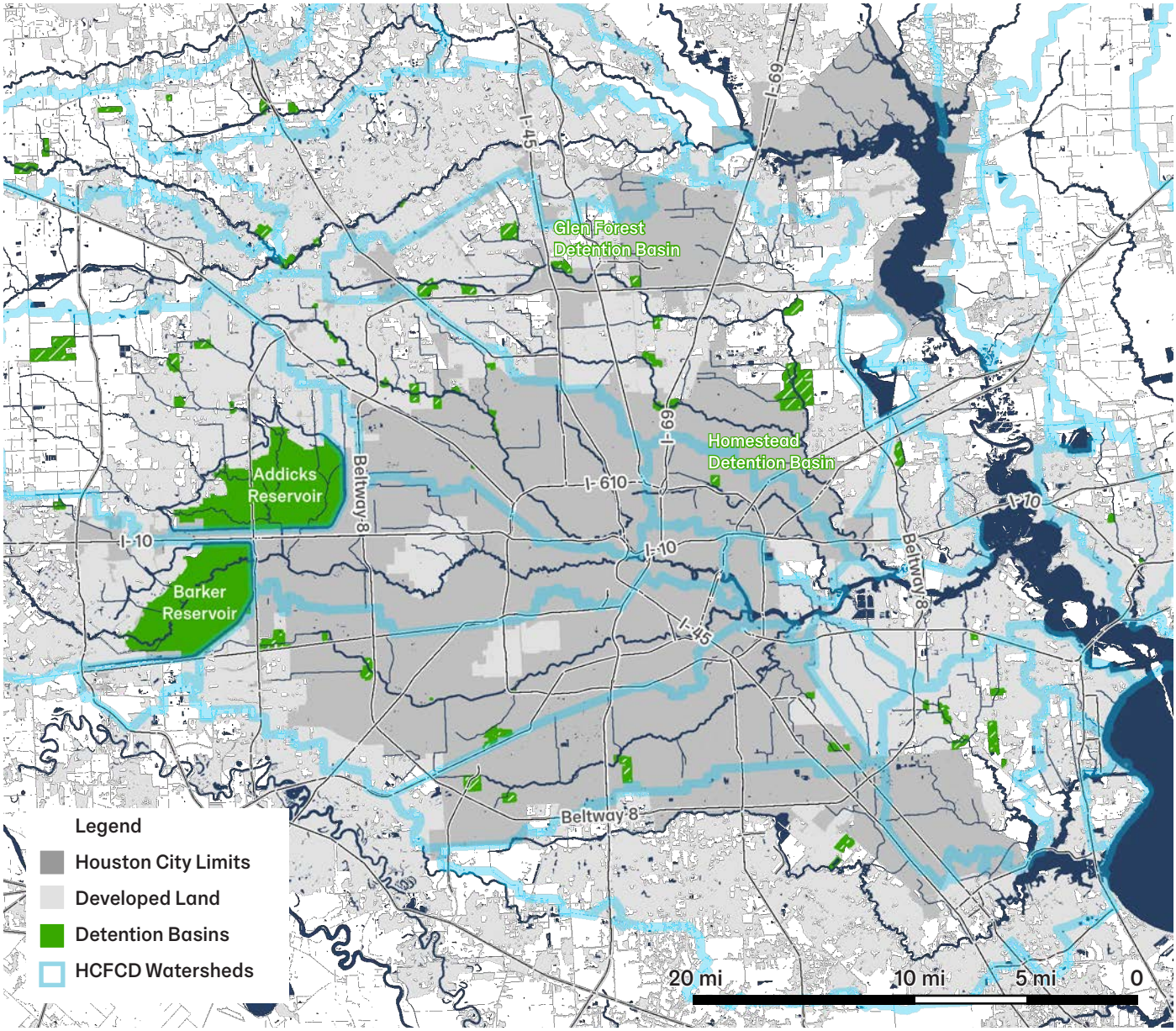
The rapid outward expansion of Houston makes finding space for large scale water storage difficult in some parts of the city. Locations to built infrastructure at the scale of Addicks or Barker Reservoirs are limited, particularly when environmental impacts are factored. The US Army Corps is considering the construction of a third reservoir past Addicks and Barker but its usefulness may be limited due to its location at the top of the watershed. The Greens Bayou watershed still has large parcels of land that are undeveloped and opportunities for water detention. Space to store water becomes more limited closer to downtown. In Houston's urban core, detention must be achieved through other means.

Glen Forest Detention Basin
Greens Bayou has seen some of the most substantial detention basin construction post-Harvey.

Homestead Detention Basin Kashmere Gardens



24 hour 100 year (1%) Precipitation Event
The greater Houston area receives some of the most intense precipitation events in the US. Study areas are the red outlines.



Reservoirs and Detention Basins

Addicks and Barker were some of the largest and earliest detention basins built in the Houston Region. Since Hurricane Harvey, the HCFCD has begun the planning and construction of around 70 additional detention basins throughout Harris County.

Houston Precipitation Event Classifications

	2-Year 50% Chance	5-Year 20% Chance	10-Year 10% Chance	25-Year 4% Chance	50-Year 2% Chance	100-Year 1% Chance	500-Year 0.2% Chance
1 hr	2.23 in	2.77 in	3.23 in	3.86 in	4.33 in	4.85 in	6.38 in
24 hrs	5.12 in	6.94 in	8.75 in	11.6 in	14.1 in	17 in	25.5 in
4 days	6.89 in	9.41 in	11.9 in	15.8 in	19.3 in	23.2 in	32.9 in

Harvey 24 hrs
16.07 in*

Harvey 4 days
30.87 in*

Precipitation events for from sourced from the NOAA Atlas 14
**Harvey rain data sourced from the NOAA rain gauge at Houston Intercontinental Airport*

Challenges

Growth and Flood Risk

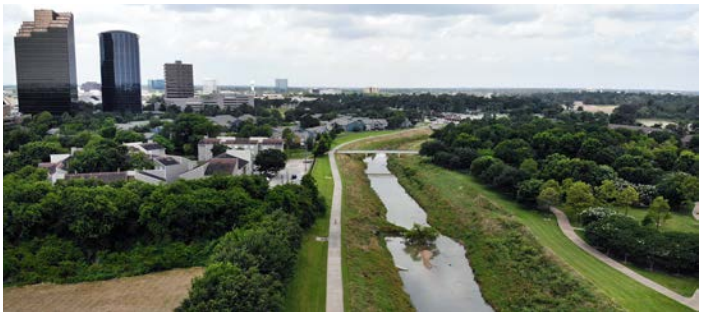
Approximately seven million people live in the Greater Houston area, with the majority living outside of the city boundary. The region has added approximately three million people from 2000 to 2019, nearly doubling in size. Most of that growth and development has occurred outside of the city of Houston, often in unincorporated areas. The rapid pace of development makes flood risk adaptation a moving target. Development in the floodplain, and without adequate stormwater management, leads to increased risk and more runoff downstream. Homes that were previously safe can easily become at risk with any increase in upland runoff. Without adequate standards for development, downstream adaptation becomes necessary. Historic neighborhoods are often the most at risk.

The downstream impacts of upstream development necessitate multi-scalar design solutions. At the largest scale, Houston is a patchwork of jurisdictional bodies. This means that collaboration is part of a strategy to manage development in Houston. At the home and neighborhood scales, a lack of zoning based policy tools means that Houston has to find alternative sources to promote better development practices. Retrofits and adaptations can be a form of growth from within, especially in areas that do not have large spaces for water storage. If development that is insensitive to water continues upstream and in flood prone areas, and retrofitting efforts are avoided or delayed, today's risky neighborhoods become tomorrow's buyouts.

Potential of Water

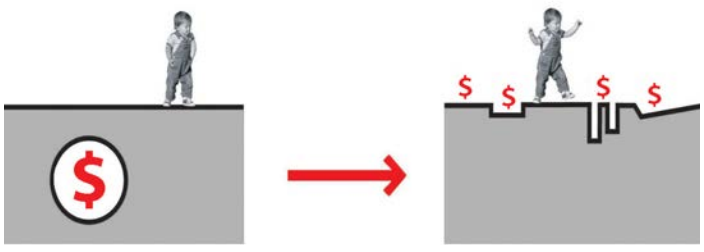
Shifting land use patterns to become responsive to water provides opportunities in addition to mitigating risk. Water has the potential to provide recreational amenities and create a sense of place. Too often in Houston, neighborhoods are disconnected from the bayous in their own backyards. The revitalization of portions of Buffalo Bayou created a new type of vibrant park space while encouraging nearby redevelopment and investment. Each of Houston's bayous, each running through unique neighborhoods, can provide a unique public experience. The Bayou City's identity is in its bayous.

1 Increasingly severe and frequent flooding from intense rainfall

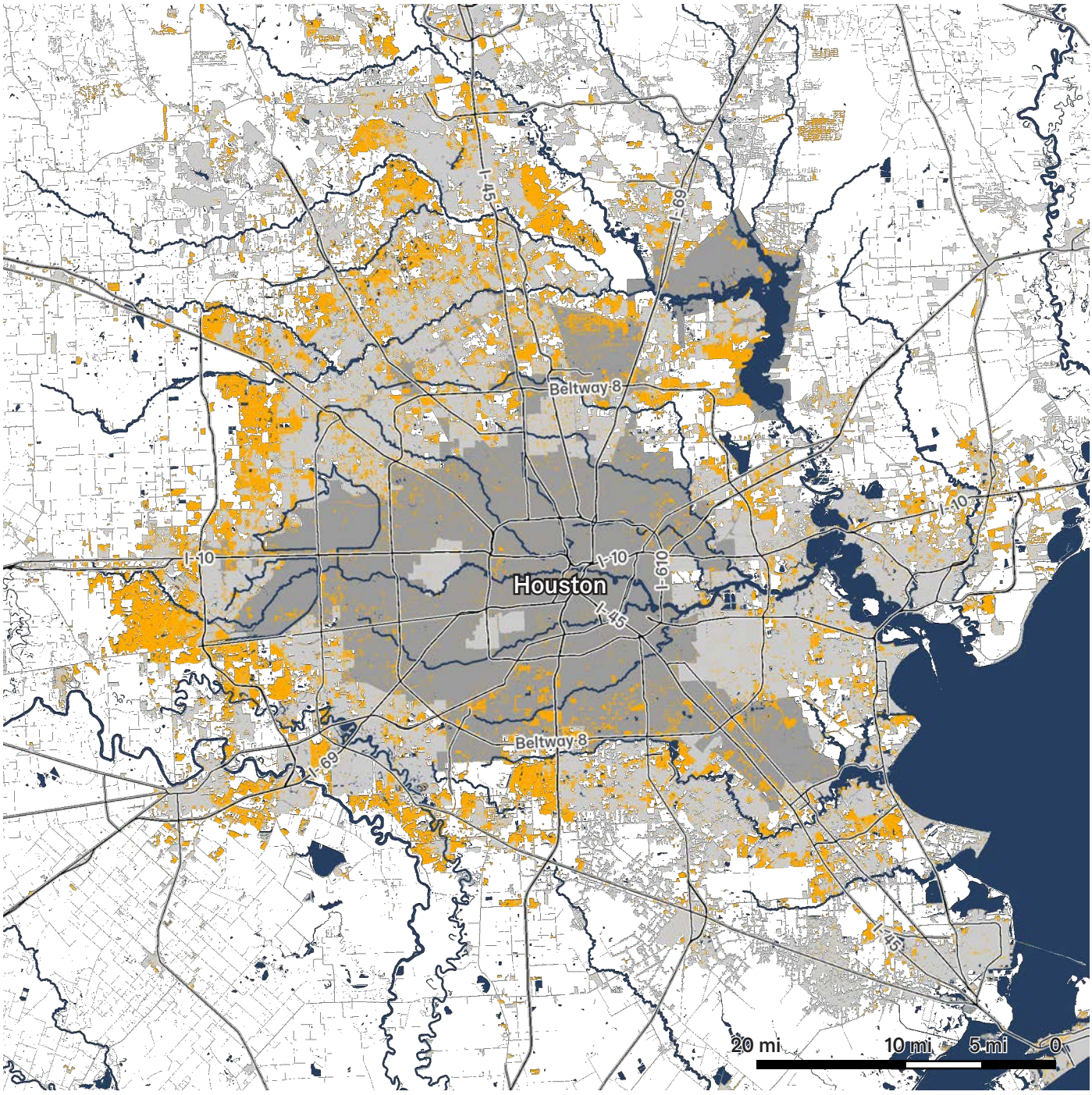


2 Development pressure in low-lying, risky, and ecologically sensitive areas

3 Unrealized potential of water as an urban and recreational amenity



Same-Cost Approaches to Water Challenges
Narrowly defined projects may succeed on narrow evaluation, but risk missing greater value.
Image credit: Urbanisten



New Development, 2001 - 2016
Most new development has taken place outside of the Houston city limits.

Legend

- Houston City Limits
- Developed Land
- New Development 2001-2016

Soils and Ecology

Coastal Prairie

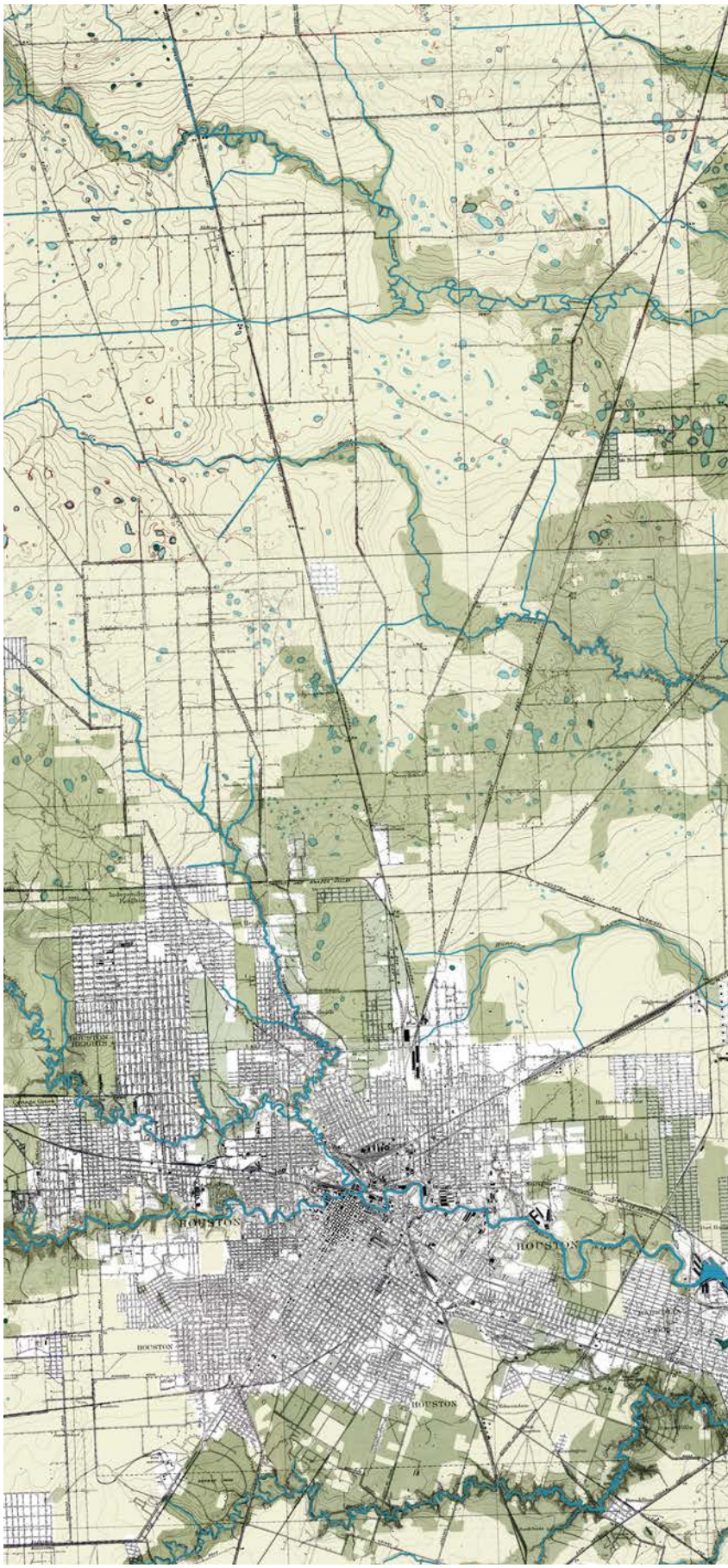
Houston sits on what was once a vast coastal grassland. The same flatness that shapes Houston's floodplain today created the historic landscape of the past. The bayous that run through present day Houston originally meandered across the prairie. Over time, wind eroded traces of those bayou paths into a subtle topography of pimple mounds and prairie potholes. Slight changes in elevation kept some areas dry while other areas turned into wetlands and lakes. The original grasslands of the Texas coast were speckled with pockets of water, each a different microcosm.

As modern development pressure built over the prairie and channelized the bayous, oxbows and prairie potholes became floodways and floodplains. Without the grasslands the underlying clay soil is largely impervious. Stormwater runoff cannot infiltrate into the ground. Accelerated runoff quickly turns into flooding.

Katy Prairie

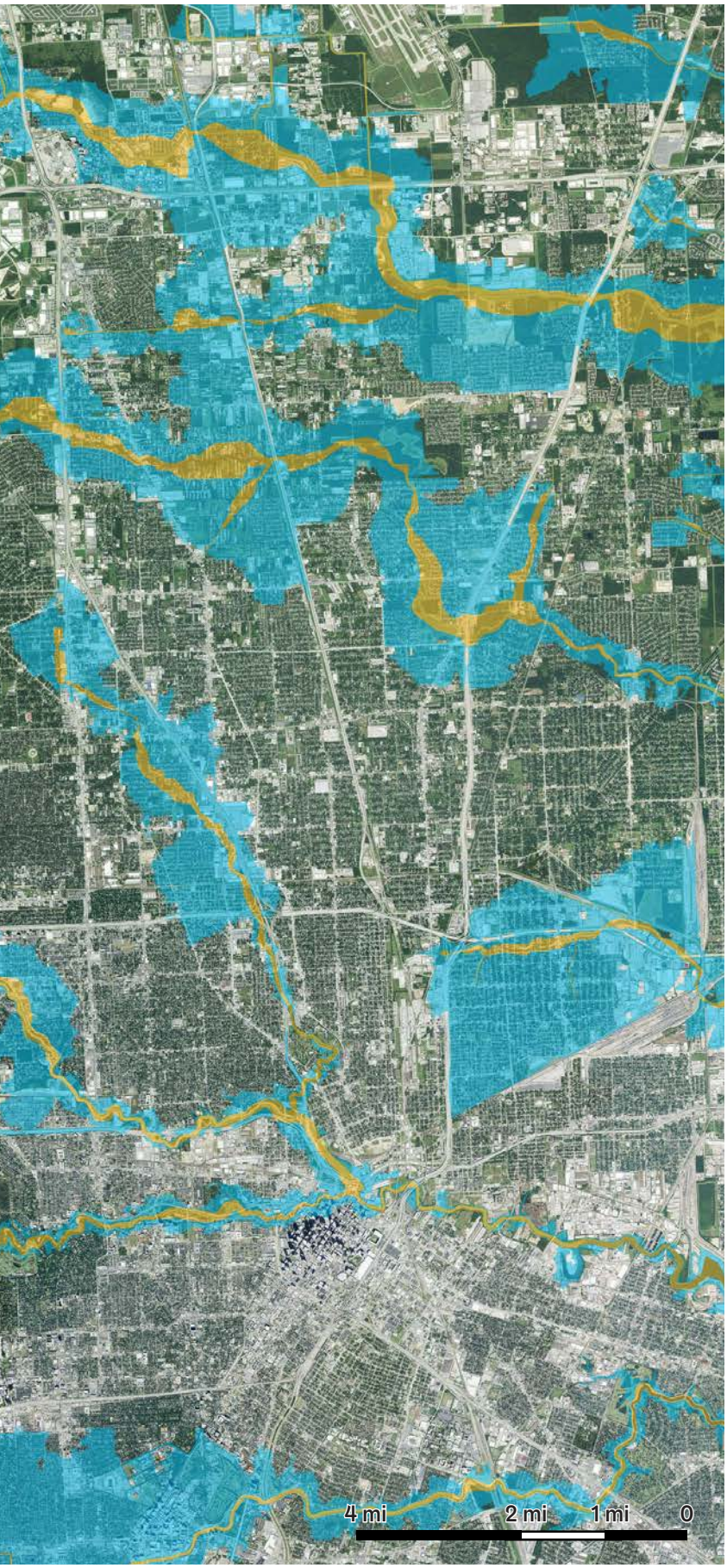
The Katy Prairie conservation areas are some of the last preserved western gulf grassland ecosystems.

photo credit: By Katy Prairie Conservancy - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=5100822



1922

Credit: USGS, colorized Waggonner and Ball



2016
Credit: USDA NAIP

Prairie Floodplain

Slight changes in elevation have a similar impact on the floodplain today, shaped by nearly imperceptible changes in topography. Highway and railroad berms can impound water or cause it to back up, thus widening floodplains. Structures built on the remnant paths of old bayous are almost always in the floodway or floodplain. By understanding the historic coastal prairie that Houston was built on, we gain insight into today's flood risk. The floodplains of the city are the result of the prairie landscape and its systems, even if the prairie is gone.

Hunting Bayou
The recently constructed wetland shelves along hunting bayou resemble the past ecological condition.

Legend:

Floodplain

Floodway

Drainage and Infrastructure Networks

Houston is defined by its bayous and highways. These two networks are both vital to the city of Houston: a network of bayous drain the city, and modern transportation infrastructure created the city's economic vitality, which supports its continued expansion. Flood risk in Houston often arises when these two networks collide.

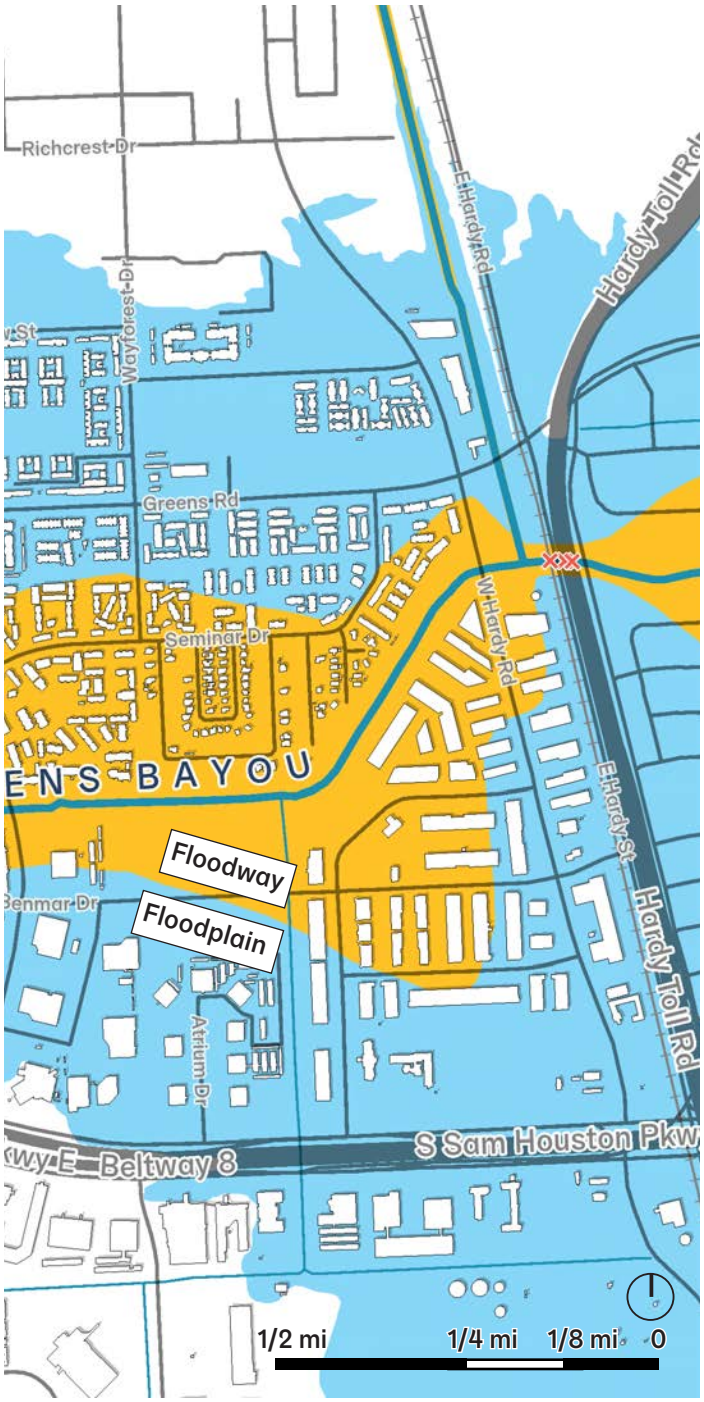
Bottlenecks and Floodways

Intersections between water and infrastructure networks often create bottlenecks in conveyance paths; water has limited ability to pass through a constricted space. Some of the starkest examples of this result from intersections between historic bayous and historic rail lines. Most of these bayou crossings were built well before Houston expanded around them, so flood risk would only become apparent later as those areas developed. Historic rail lines are often characterized by low bridges and small berms. These constrict floodwater and cause floodways and floodplains to expand along the rail corridor.

Wide floodways put people at the most risk. The floodway is defined by FEMA as the channel in which a waterway needs to convey stormwater downstream. Floodways typically have the most developmental restrictions. Legacy homes that find themselves within the floodway as flood insurance rate maps become updated are often most at risk. They deal with both moving water during flood events, and a limited or prohibited ability to rebuild. Constricted and enlarged floodways create problems in both land use/occupation and water conveyance.

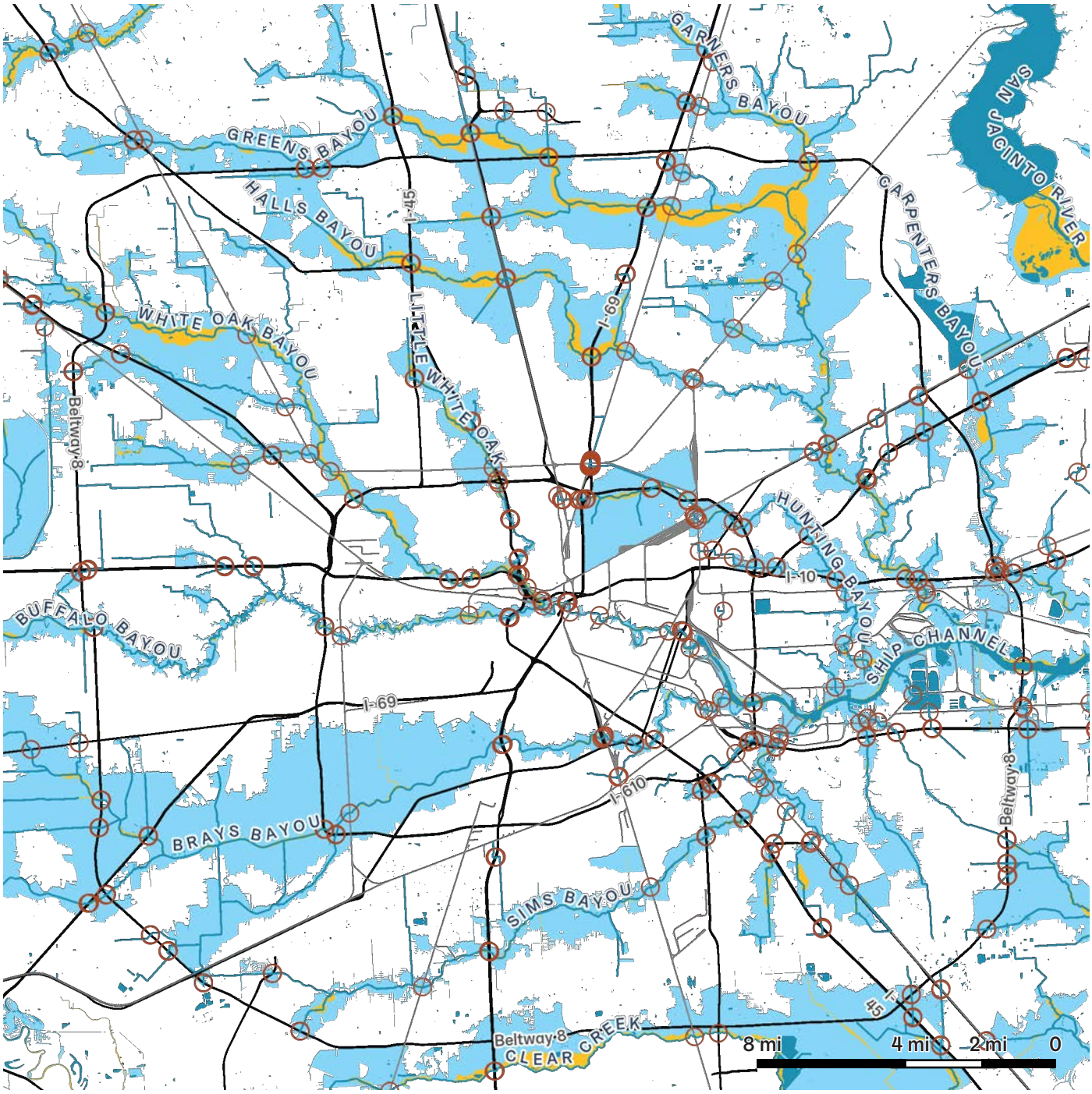
Resolving conveyance issues creates a difficult dilemma. To alleviate any upstream constriction, downstream will have to receive more stormwater. The balancing act of improving conveyance without creating downstream flooding requires a watershed scale level of planning.

Resolving occupation within a floodway is difficult as well. Property buyouts can take time and leave neighborhoods fragmented. Situations are more difficult for renters, who lack the same buyout options as property owners. A concerted housing effort is needed to give relocated residents affordable alternatives. Buyout properties cannot merely be demolished; residents must be able to buy or lease comparable housing in safe areas.



Development in the Floodplain and Floodway

In Greenspoint, a significant amount of buildings and infrastructure were constructed within the floodplain and the floodway of Greens Bayou.



Network Intersections

Intersections between the bayou and transportation networks often amplify flood risk in Houston.

Legend

- Floodplain
- Floodway
- Network Intersection Point

Street and Transit Networks

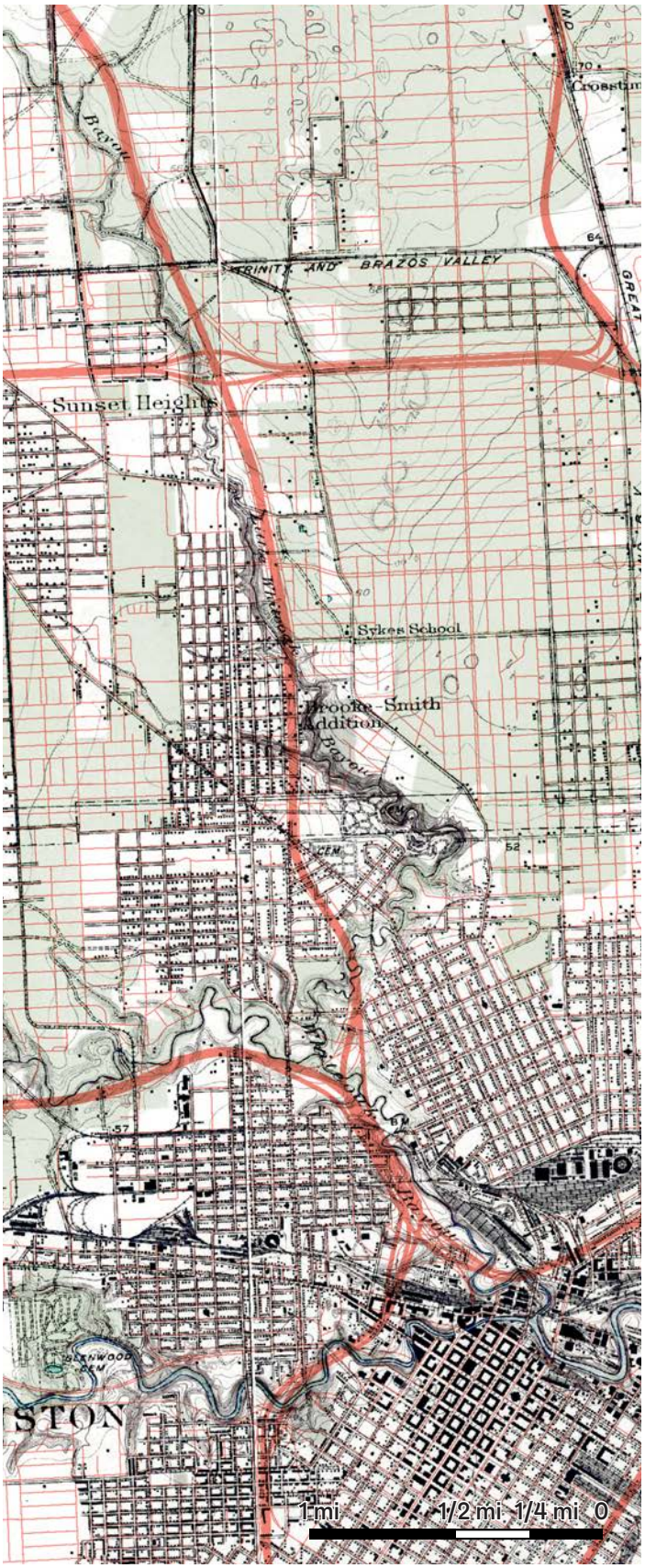
Houston is built on a historic street grid that the highway system expanded over time. Houston's historic neighborhoods were built around established corridors; the highway system was not. Large highways cleave through neighborhoods and the historic street grid. Expansion created disconnection, particularly in the three focus areas. As the city grid grew its adherence to the historic grid diminished. This resulted in the prevalent patterns of suburban subdivisions farther away from the urban cores.

Transportation Expansion

The constantly expanding highway system presents opportunities, as renovation allows for redesign. For example, existing bottlenecks or other problems in the drainage system can be addressed. Culverts can be daylighted and re-naturalized, and constrictions can be alleviated. As public transit becomes more available, opportunities to create safe egress corridors for access and evacuation are more feasible. Neighborhoods can be reoriented around historic street corridors. Expansion also provides the opportunity to resolve problematic intersections. Conversely, expansion of the transportation systems also has the potential to exacerbate flooding.

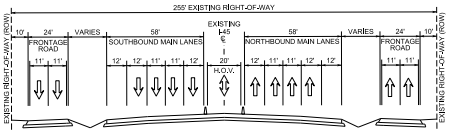
Interceptor Streets

Streets and other paved areas contribute a significant portion of the city's runoff. For the denser parts of Houston, streets are also the largest swath of space in the public right of way. Between those two factors there is a tremendous opportunity to transform streets from contributors of runoff to vital pieces of detention infrastructure. Creating "interceptor streets" at key junctures around Houston can mitigate the cascade of runoff entering the drainage system. These interceptors streets can be aligned with historic, commercial, and public transit corridors, to provide multiple public amenities in addition to flood risk reduction.

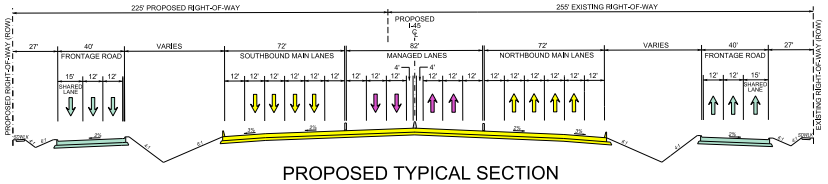


Highways and City Streets

Above: The highway system, shown in orange, disrupts Houston's historic city street grid, dividing neighborhoods and creating boundaries.
Map: USGS
Colorized by Waggonner and Ball



EXISTING TYPICAL SECTION
AIRLINE DRIVE TO SHEPHERD DRIVE



PROPOSED TYPICAL SECTION
AIRLINE DRIVE TO SHEPHERD DRIVE

Existing and Proposed Road Section

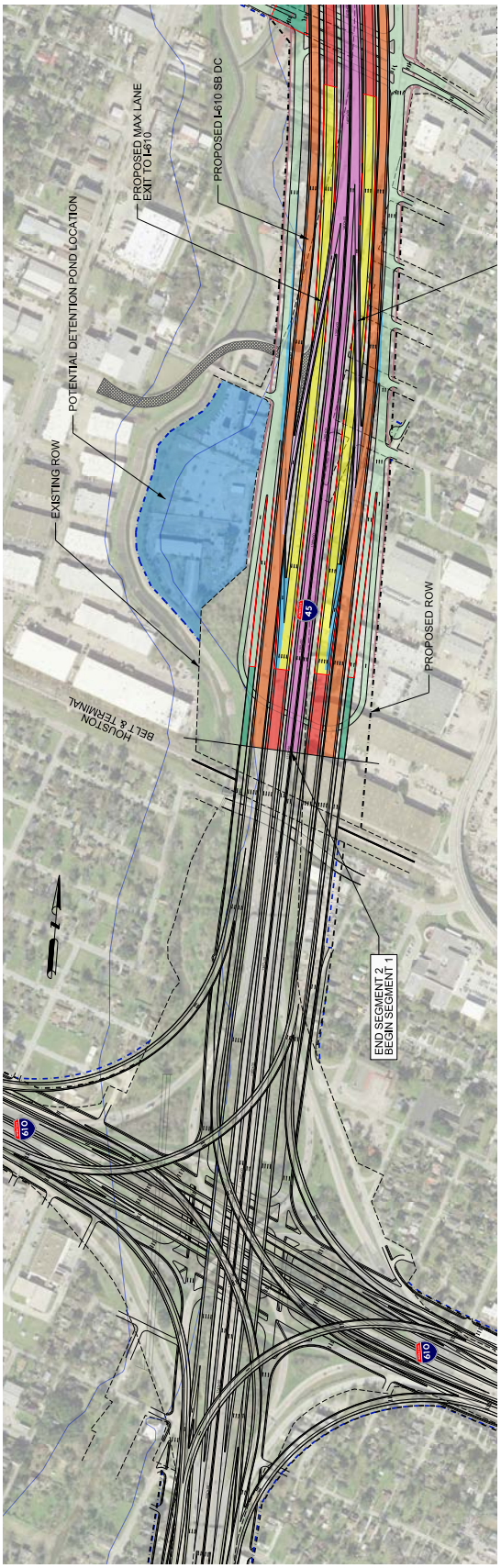
The North Houston Highway Improvement Project I-45 Expansion will nearly double the width of the highway. All of the expansion is on the west side of the existing highway.

I-45 Crossing at Greens Bayou

Bridge crossings can alter the flow and limit the water storage capacity of bayous.

Interceptor Street Example

The above street is constructed out of pervious material and sits on top of gravel with underground detention cells, and bioswales flanking both sides.



North Houston Highway Improvement Project

Top and Above: The existing highway is planned to increase capacity by adding several driving lanes and frontage roads on either side, which will push into adjacent neighborhoods. *Credit: TXDOT*

Land Use and Development

Unraveling Houston

Discerning land use rationale, or lack thereof, is critical in Houston. The lack of zoning makes eclectic land use patterns commonplace. A myriad of sources can shape the city form: historic corridors, patchworks of jurisdictions and reinvestment zones, and ever-expanding transportation networks. Without zoning, the toolkit for shaping development must take a corresponding myriad of forms.

Crossing Jurisdictions

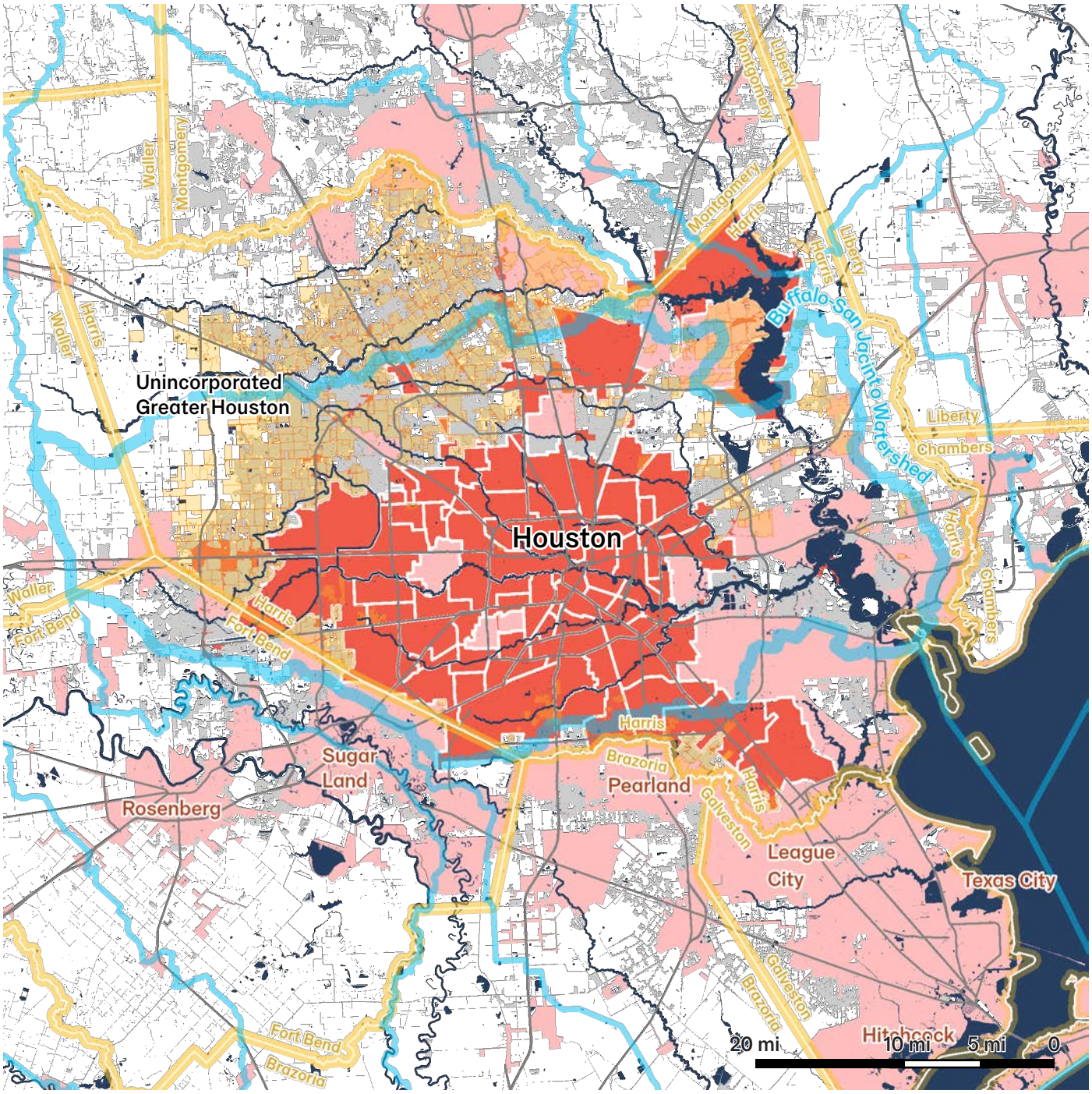
Greater Houston includes eight counties, with over 100 cities total, and approximately two million people living in unincorporated areas. Since 2000, Greater Houston has added approximately three million residents, while the City of Houston has limited its annexation efforts. As the Greater Houston area expands, the multitude of jurisdictions expands with it.

Where areas are divided by political boundaries, they are connected through watersheds. For example, Buffalo Bayou spans across three counties, multiple municipalities, and dozens of utility districts. In unincorporated parts of Greater Houston, over 370 municipal utility districts (MUDs) define stormwater infrastructure. For solutions to work across the entire watershed, collaboration is essential.

Historic Corridors
Example of historic multi-modal transit along Texas avenue networks that supported the growth of the city.
Credit: University of Houston Digital Library, Historic Houston Photographs

Land Use Patterns
Houston is characterized by eclectic land use patterns.

Land Use Patterns
In Houston neighborhoods, a wide range of land use and building types exist in close proximity, or even within the same parcel



Political Boundaries

Houston (dark red) is split up into 88 super-neighborhoods. Most of Houston is located within Harris County (orange line), although a significant number of Harris County residents live in unincorporated space. Much of greater Houston's unincorporated space is within municipal utility districts, or MUDs (light orange).

Legend

- Houston
- Other Municipalities
- Unincorporated
- Municipal Utility Districts (MUDs)
- County
- HUC-8 Watersheds