

# The Sentinel City | A Multivalent Resiliency Plan for Houston, Texas

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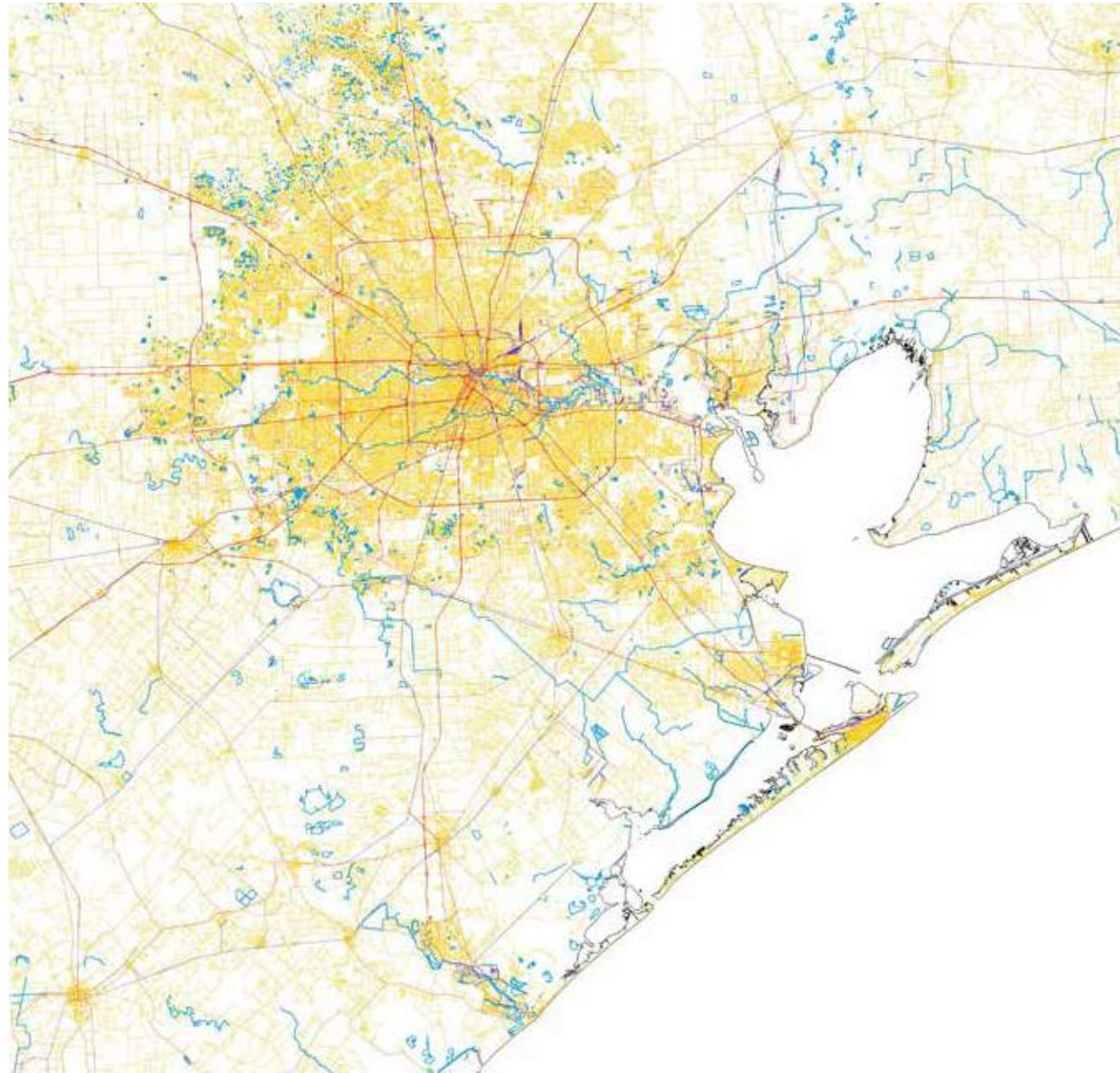
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The fabric of Houston, Texas  
By author, 2018

## Abstract

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Sentinel Cities are the first metropolises in the United States to exhibit signs of climate change-related stress. Each Sentinel has a unique set of problems to overcome. In Houston these are climate-augmented storms and sea level rise, which subject its residents to compound flood vulnerability from drastic rainfall and storm surge. Today, Houston is subject to several underlying systemic weaknesses inherited from the city's unchecked growth, which make the urban populace particularly vulnerable to flood events. The most acclaimed proposal to mitigate flood risk Houston is the "Ike Dike" Coastal Spine, a system of flood barriers and gates modeled after the 20<sup>th</sup> century Delta Works of Holland as precedent. Further interrogation of the Dutch model as precedent reveals deep differences between the Texas flood problem and that of the Netherlands, while also revealing aspects of the Delta Plan that Houston could emulate. A multivalent resiliency strategy for Houston can imitate these methods while also ensuring success in the distinct Texas social and political climate. This report explores a scheme called the String of Pearls, a strategy to incentivize sustainable growth in Houston while building emergency preparedness into the very fabric of the city.



**Dedication:**

This thesis is dedicated in three parts.

To my family and friends that have supported me in this process, especially Joey, who heard more about it than anyone, and Emma, with whom I spent the most late nights in coffee shops, and in whose presence half these pages were born.

To Simon and Edna, who for three years have been steadfast in their support of any urbanist confessions I dared share.

And to all the authors who inspired the premise of Sentinel Cities.

*“The world is changed. I feel it in the water. I feel it in the earth. I smell it in the air.”*

– J. R. R. Tolkien, 1954

*“Science fiction is not prescriptive; it is descriptive.”*

– Ursula K. LeGuin, 1969

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My brother and dad, who inadvertently redoubled my focus on this thesis by telling me to look for a job instead.

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## 1.o Methodology

This report was compiled through research, observation and design, each narrowing in scope to focus on Houston, Texas. First, research focused on climate change at the global scale, and how it manifests specifically for human life. The next step focused on the United States, and established the Sentinels of New York City, Norfolk, Miami, New Orleans, El Paso, Phoenix, San Diego, Los Vegas, San Francisco and Salt Lake City. Each Sentinel faces its own manifestations of climate stress, and the Sentinel City framework can be revisited in the future to address comprehensive American resiliency.

For this report, specificity was deemed necessary to make climate change appear actionable. Only half the country thinks climate change is harming Americans right now.<sup>1</sup> Climate change is perceived as a faraway fate, but the science-fiction-future gets closer every year. Policymakers and the public to which they are beholden must understand climate change as it manifests in their lives. There is an observed disconnect between the output of academics and the action it calls for. This can be credited to the visualization and language barrier between trained academics and the general populace. Part of this research focused on methods of data visualization to affect change.<sup>2</sup> This section concluded that accessibility, clarity, frequency, and interactivity of data visualization positively influence individual action to mitigate climate change.

From this point, research narrowed to focus on Houston, Texas and the underlying causes of its vulnerability. This included historical research of Houston’s formation and the nearby Galveston Island. The site-specific research looked forward as well as backward, and analyzed the proposed mitigation strategy called the Ike Dike. The Ike Dike was proposed in collaboration with faculty at the Delft Technology University in the Netherlands, and used the Deltawerken infrastructure as precedent.

A Plan II thesis grant was used to travel to the Netherlands to visit faculty at TU Delft and explore the Deltawerken in person.<sup>3</sup> Sources interviewed while in country include Nikki Brand, an editor of the 2015 publication *Delft Delta Design, Houston Galveston Bay Region, Texas, USA*<sup>4</sup> and the 2017 *Hurricane Harvey Report* produced by TU Delft, and Robbert Misdorp, editor and of the 2011 *Climate of Coastal Cooperation* and former

1 Nearly half of Americans (48%) think people in the United States are being harmed by global warming “right now.” The proportion who believe people are being harmed “right now” has increased by 16 percentage points since March 2015 and by nine points since our previous survey in March 2018.

Anthony Leiserowitz, *Climate Change in the American Mind*, Yale University, George Mason University, 2018, 3.

2 See Appendix A, for sources

3 See Appendix B, for travel route and grant proposal

4 See Appendix A, for more on this publication

Chief Engineer of the Rijkwaterstaat.<sup>5</sup> The input of these sources was augmented by direct observation of the Deltawerken and the educational buildings accompany them, including the Het Keringhuis, a visitor center near the Maeslantkering, and the Watersnoodmuseum, a museum dedicated to the 1953 Great North Sea Flood near Ouwkerk. The travel also allowed observation of the preserved history of Dutch water management at Kinderdijk, near Rotterdam. During this funded travel, observations were made through photography, notes and sketches.<sup>6</sup>

The travel to the Netherlands was complimented by independent travel to Houston, where the legacy of Hurricane Harvey was observed through photography, notes and sketches.<sup>7</sup> Sources interviewed while in Houston include Brent Nyquist, an architect at a local residential firm, and anecdotal accounts from Houston residents.

The research and observations informed the design phase. The design phase began as a regional spatial strategy and narrowed in scope to focus on pieces of the whole scheme, called the String of Pearls. The design was interrogated as both a physical and social scheme, and critiqued by a panel of School of Architecture faculty at a mid review, a progress checkpoint midway through the semester. The design was pursued at increasingly fractal scales, and visualized for this report.

The implications of this study are that design and organizational schemes can be used to further our progress toward a resilient Houston. This design vignette can be used to identify strengths and weaknesses of the proposed mitigation schemes to date. This methodology can be used to interrogate other coastal cities in America and around the world.

## 1.1 Introduction

Sentinel Cities are the first metropolises in the United States to exhibit signs of climate change related stress. This term was born while searching for a way to convey the power and the precipice inherent in these cities' futures – they are simultaneously instances of a wonder and warning. If our Sentinels accept their totemism and proactively mitigate climate change stress, they could serve as standards for other American metropolises and cities around the world. The Sentinels are America's chance to lead the world in resiliency planning, and the first city cast as in this role should be Houston, Texas.

Houston is a huge, coastal city with an economically and ethnically diverse population, which faces

<sup>6</sup> see Appendix B, for travel observations

<sup>7</sup> see Appendix B, for travel observations

climate-augmented tropical storms with increasing frequency. These storms are predicted to become larger, slower and more frequent as the world warms, and recent hurricanes have already demonstrated the severity of Houston's predicament in the public eye. Houston deserves the role of First Sentinel because of the enormity of its challenge and the capacity of its strength. The city has taken on disaster and survived, and it has the resources and resilience to do so in a more organized and equitable way.

Houston also has a reputation, of stubbornness, liberty and independence. The country knows that everything is bigger in Texas, and Houston illustrates this aphorism with pride. It is a Texas-sized city with a Texas-sized population – and Texas-sized problems. The city has an independent streak and cuts against the grain, and a track record of rejecting institutional mandates – for example, municipal zoning. Essentially, if it can happen in Houston, it can happen anywhere. The stage is set, the cast is chosen and the world is watching. Houston is uniquely suited to serve as the first example of equitable resiliency planning in America.

## 2.0 The Problem of Houston

Let's meet our cast. Houston, Texas is the largest city in the state in both population and metro area. Adjacent to Galveston Bay and perched on the Gulf of Mexico, Houston is the seat of Harris County and employs three million individuals in non-farm industries as of January 2019.<sup>8</sup> The city of Houston was founded in 1836 by the Allen brothers, two land speculators, who bought a league and a half of land at the confluence of the Buffalo and White Oak bayous.<sup>9</sup> The city was named in honor of President Sam Houston of the Republic of Texas, and even served briefly as the Republic's capital. Prior to the twentieth century, Houston established itself as a commercial and railroad hub for the cotton trade. In 1900-1901, several phenomena aligned to set Houston on its way to becoming the Houston – The Woodlands – Sugarland metropolitan statistical area it is today. The 1900 Galveston Hurricane and the Houston Ship Channel shifted commerce to the port of Houston. Not long after, the Texas oil boom contributed hugely to the city's industrial growth. Since then, that league and a half of land has grown into the most diverse metropolitan area in the country, served as base for the US space race, and is truly an industry capital of the world. Though the Port of Houston still ranks first in the U.S. in international waterborne tonnage, the city has evolved from a shipping town to an oil town to a global metropolis.

<sup>8</sup> Bureau of Labor Statistics, *Houston Area Employment – January 2019*, US Dept. of Labor, 2019, 1.

<sup>9</sup> Allan Turner, *At least the Allen brothers got it right on location*, Houston Chronicle, 2011, 1.

## 2.1 Houston as Sentinel

The Earth's rapidly changing climate is the most daunting problem facing our world today. Many cities in the United States are already facing the infrastructural failure brought on by climate-related stressors like extended drought, augmented storms, and sea level rise. Designers and governmental bodies alike are looking for precedents at home and abroad to help mitigate these and other issues. These cities stand sentinel at our coastlines and interiors alike, and if studied properly can be used as models for other American metropolises, both the developed and the developing world. One such Sentinel City is Houston, Texas; a metropolis known for its relative lack of codified development restrictions. The Houston-Galveston area is the first and most dire Sentinel to merit this type of interdisciplinary study because of its unique compound vulnerability.



Houston is the fourth most populous city in the United States, consistently one of the fastest growing metropolitan areas in the country, and one of the most racially and ethnically diverse American cities.<sup>10</sup> In 2014, population growth in Houston reached an all-time high, with 428 people moving to Houston every

<sup>10</sup> Daryan Jones, *Houston surpasses NYC and Chicago as most diverse city in America*, Crossroads Today, 2019.

24 hours.<sup>11</sup> For contrast, the Austin population boom between 2011 and 2017 averaged 152 new Austinites per day.<sup>12</sup> The Houston area is 37.8% Caucasian, 35.9% Hispanic, 17.2% black or African American, and 7.3% Asian American.<sup>13</sup> The city is home to seven universities, the largest medical complex in the world, the NASA Johnson Space Center and claims the title, Energy Capital of the World.<sup>14</sup> “Houston” was the first word spoken on the moon – *Houston, the Eagle has landed*.<sup>15</sup> Its famous lack of regulation and championing of privatization is the embodiment of the Texan, and, largely, American, low taxes low services model, with the exception of its monumental highway system. From the Gulf Freeway in 1948 to the 1980s multi-decade Sam Houston Tollway, Houston’s ambitious rings of freeways are evidence of the city’s rampant growth.<sup>16</sup> Its success as an urban model seems at once impossible and inevitable. Where else is the post-war exaltation of single-family home-ownership, car-ownership, the rise of a middle class on the tide of Fordism, better exemplified than in Houston? What similarly sized city survived the 2008 market crash as well as Houston?<sup>17</sup> The space race, the free market, capitalism and patriotism – the associations drawn from Houston are a roadmap of the American modern era. There is a mythology about the city that feels communal, collective, as if its trials and triumphs belong to us all – American ideals distilled into urban form. Its mythology may hinder Texans from accepting the reality of the situation – Houston, we have a problem.

## 2.2 Climate as Multiplier

For cities situated on the Gulf Coast, climate change manifests most direly in the increased frequency and intensity of tropical storms and sea level rise. The Intergovernmental Panel on Climate Change that met in September of this past year condensed findings into a summary for policymakers, a helpful simplification of complex and interrelated research. This document from the 2018 IPCC states with high confidence that we are on track for a global mean temperature rise of +2 degrees Celsius by 2100 compared to the 1960s-1990s average.<sup>18</sup> In 2018, global warming was recorded at +0.75degrees Celsius,<sup>19</sup> higher than the projections ac-

<sup>11</sup> Marcelino Benito, *By the numbers: Houston’s population boom*, KHOU11, 2018.

<sup>12</sup> John Egan, *Austin area population growth for 2019 among highest in U.S.*, CultureMap Austin, 2019.

<sup>13</sup> Statistical Atlas, *Race and Ethnicity in the Houston Metro Area*, 2018.

<sup>14</sup> City of Houston, official site.

<sup>15</sup> This is actually a contested statement, but the first word not relating to mechanical information or landing was indeed, Houston. Meghan Ashford-Grooms, *Rick Perry says first word spoken from moon was Houston*, politifact, 2011.

<sup>16</sup> BDug Begley, *Growing Houston demanded a bigger road system*, Houston Chronicle, 2016, 1.

<sup>17</sup> Loren Steffy, *Lack of zoning has paid off for Houston*, Houston Chronicle, 2008, 2.

<sup>18</sup> Intergovernmental Panel on Climate Change, *Summary for Policymakers*, Seoul, South Korea, September of 2018.

<sup>19</sup> National Centers for Environmental Information, National Oceanic and Atmospheric Administration, *Assessing the Global Climate in 2018*, 2018.

count for. Warming of this measure predicts increase in the rate of sea level rise by a factor of 1.5 from current understanding of glacial melt.<sup>20</sup> In summary, the Houston-Galveston will be subjected to more frequent and intense tropical storms and an increasingly changeable coastline due to our warming global climate. Between these two factors, the edge of Texas could look vastly different in the year 2100.

Figure 3

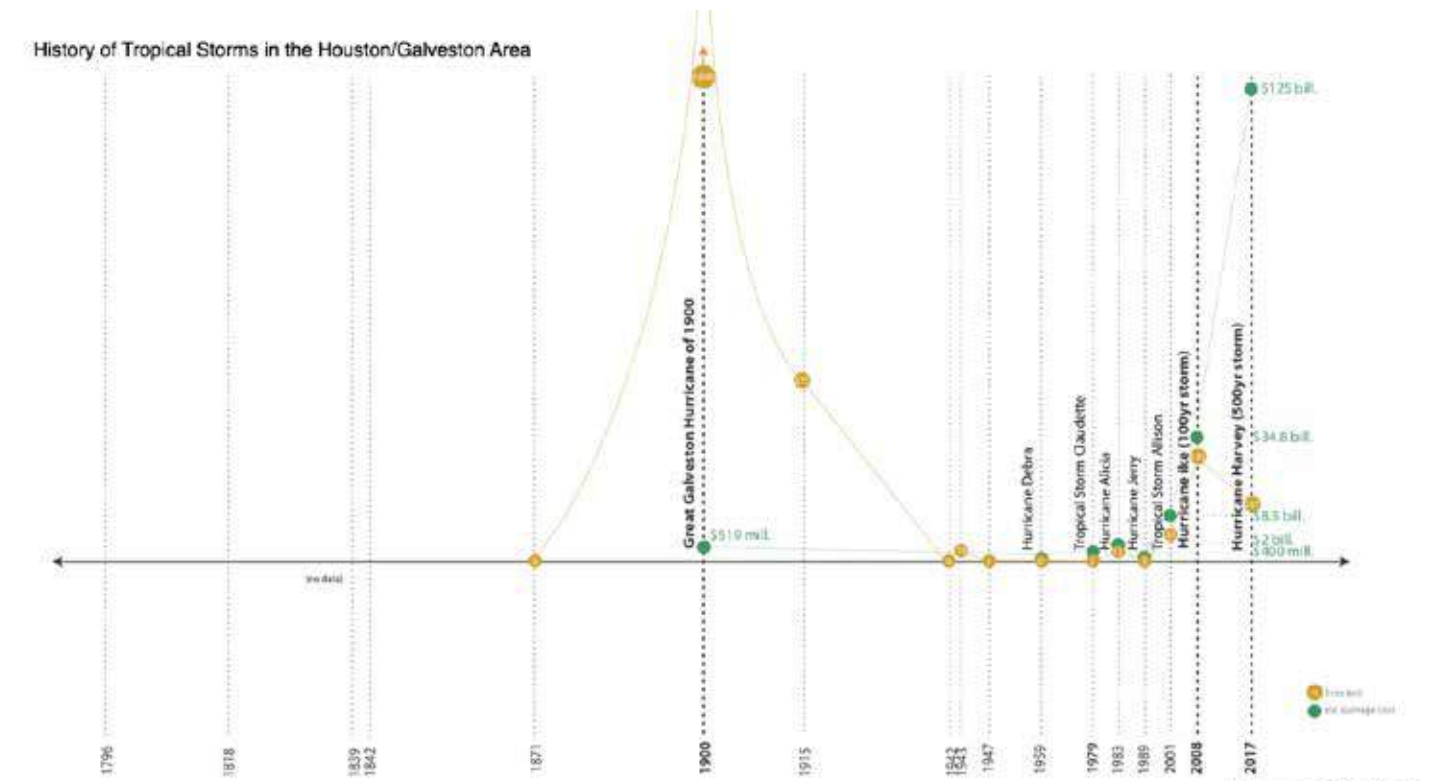
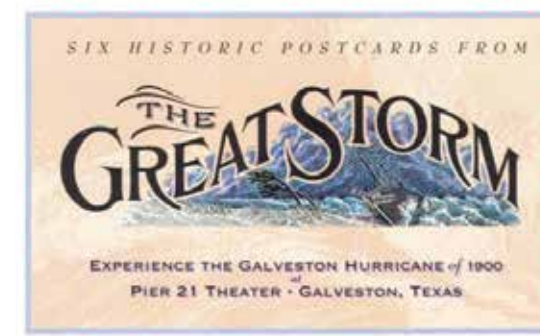


Figure 3 - History of tropical storms in Houston area

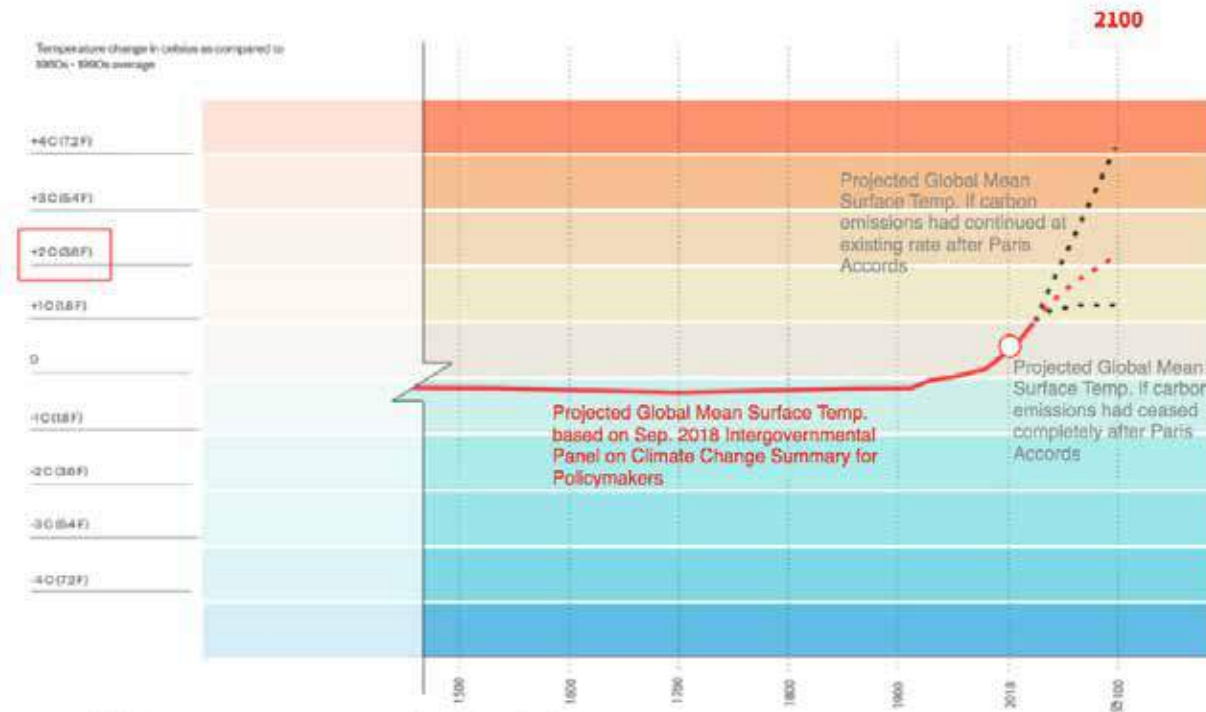
In response to the Great Storm, Galveston Island was put under martial law and then raised the entire island by an average of 12 feet with dredged sand. The 1900 storm also brought about the multi-year construction of the Galveston Seawall, a 17-foot high storm surge wall consequent of the island's newly raised elevation. The Seawall was completed in 1906 and then extended in 1916 along its southern edge, and now serves as a tourist attraction in the city's new essential industry. The Galveston Seawall is the longest built ocean edge condition in the United States.<sup>22</sup> While Hurricanes Allison and Ike have overwhelmed the Seawall, it still marks an important epoch of infrastructural improvement in the region, and demonstrates the resiliency of early Texans in the face of disaster.



Source: Roth, 2010



Source: Galveston Historical Archives, various



TU Delft (ND) Hurricane Harvey Report found that high temperatures of Gulf waters intensified Hurricane Harvey substantially in the final hours before landfall, strengthening into a C4 hurricane.

Figure 2 - Climate projections from IPCC 2018

The Houston area has a long shared history with tropical storms, but also a rich history of resilient response. Before hurricanes were named events, the Houston-Galveston area had already been hit by ten tropical storms (see Figure 3). The 1900 Galveston Hurricane, called simply the Great Storm by contemporaries, marked the end of the Golden Age of Galveston. The storm wiped out 85% of built structures on the island, and with eight thousand fatalities it remains the most disastrous weather event in the Northern Hemisphere.<sup>21</sup> This event combined with the construction of the Houston Ship Channel and the discovery of oil in the region, both in 1901, effectively marks the shift of commerce in the region from Galveston to Houston.

20 United Nations, *Global Sea Level Rise is Accelerating – Study*, UN Climate Change, Feb. 2018.

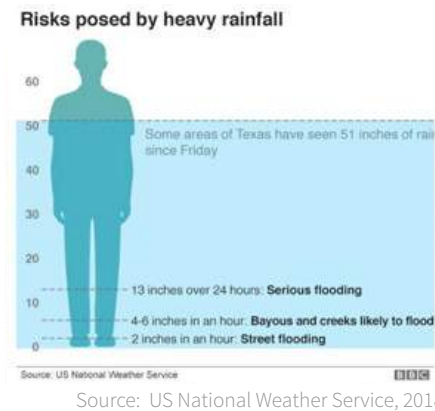
21 Galveston and Texas History Center, *1900 Storm*, 2017.

22 American Society of Civil Engineers, *Galveston Seawall and Grade Raising Project*, 2000.



## 2.3 Houston as Emergent

During the 21<sup>st</sup> century, more recent events illustrate Houston's unique vulnerability to all types of flood events. Seven named hurricanes and tropical storms have hit the Houston/Galveston area since 1959, and flash floods have become a common occurrence as well. Events like the Memorial Day Flood of 2015 and the Tax Day Flood of 2016 exhibit the weakness of the city's water management infrastructure even without the compounding factors of a tropical storm.<sup>23</sup> Any significant rainfall event, defined here as thirteen inches in twenty-four hours, over Houston easily makes the definitional shift from rainstorm to flash flood, shutting down entire areas of the city due to sheet flow<sup>24</sup> over paved area.



Reservoir. Source: Houston Chronicle, 2017

In 2017, Hurricane Harvey secured Houston's unenviable reputation as the one American city most severely affected by floods.<sup>25</sup> Much of this vulnerability can be attributed to the untethered sprawl of development to which Houston credits its success.<sup>26</sup> Unlike the top three most populous cities in the US, Houston has experienced its growth in suburban areas rather than the city center. This consistent demand for suburban development results in continuous spread of impervious over previously unpopulated areas. Increases in population density are positively correlated with increase in impervious cover, but this occurs in Houston without the eventual infrastructural payoff of high-density urban living. Instead, the city's free market responds enthusiastically to the demand for exurban growth, replacing Houston's natural conditions of minimally occupied coastal prairie with 10,062 square miles of on average 20% impervious cover.<sup>27</sup>

23 Jim Blackburn, *Houston a Year after Harvey*, Rice University Baker Institute, SSPEED Center, 2018, 3.

24 Flow that occurs overland in places where there are no defined channels, the flood water spreads out over a large area at a uniform depth. This also referred to as overland flow. Definition by National Oceanic and Atmospheric Administration.

25 Philip R. Berke, *Why is Houston so vulnerable to devastating floods?* BBC, 2017.

26 Id.

27 An estimation of PIMP is given by  $PIMP = 6.4J^{0.5}$  where J is the number of dwellings per hectare (Butler and Davies 2000). For Houston,  $J=3.7$  if 1 hectare = 2.47 acres. (see Appendix A, page X for units/acre).

## 2.4 Houston as Predisposed

Houston's rampant spread of impervious cover over its landmass is not the only factor that contributes to its vulnerability. Houston's natural conditions are inherently vulnerable to exacerbation by human intervention. The city center is perched on the edge of the Trinity and Galveston bays, separated from the Gulf of Mexico by the Galveston barrier islands. There are twenty-two major watersheds in Harris County, which condense and drain into four primary vectors, which release in turn into Galveston Bay. These are the Buffalo, the White Oak, the San Jacinto River and Clear Creek. Even if it were unedited by human hands, the confluence of these bodies means that their compound release into the Bay is a critical mechanism of the area's watershed network. The ebb and flow of this life-giving network is the natural heartbeat of the land, just as it's daily commuting population is its synthetic one. During tropical storms, that flow is impeded by a phenomenon called storm surge, the temporary rise of sea level in a localized area due to low atmospheric pressure of a storm system.<sup>28</sup> This can prevent the bayous from draining into the sea, and cause their water levels to exceed normal thresholds – and stay there. The result is temporary cessation of the area's natural water release – as if the heart has stopped pumping.

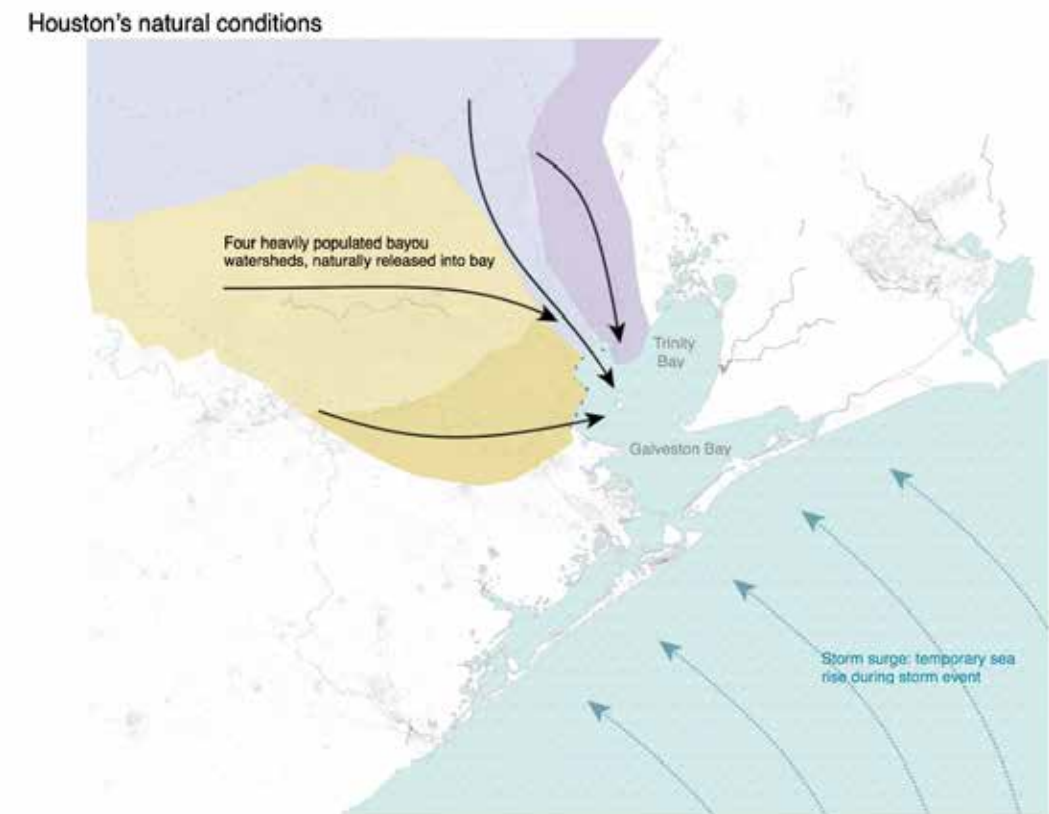


Figure 4 - Houston's compound flood vulnerability

28 Bas Jonkmon, Nikki Brand, Baukje Kothuis,

If the Houston area watersheds are akin to its circulatory system, its geological make up can be likened to a muscular framework – or lack thereof. The Houston area is predominately flat, not uncommon for a coastal city on the Gulf of Mexico. When combined with the bayou backlog, this means that a few inches of flooding can affect large swaths of flat land. It also means that the area is particularly vulnerable to the effects of land subsidence, the downward settling of land surface due to the movement of subsurface materials. This phenomenon can result from natural occurrences like limestone dissolution or earthquakes. It can also be caused by human interventions like fracking, mining, and the extraction of groundwater, oil or natural gas. You may not need to guess the scapegoat of Houston’s land subsidence. The musculature of Houston is depleted by the very vessel of its success – Texas Black Gold.<sup>29</sup>

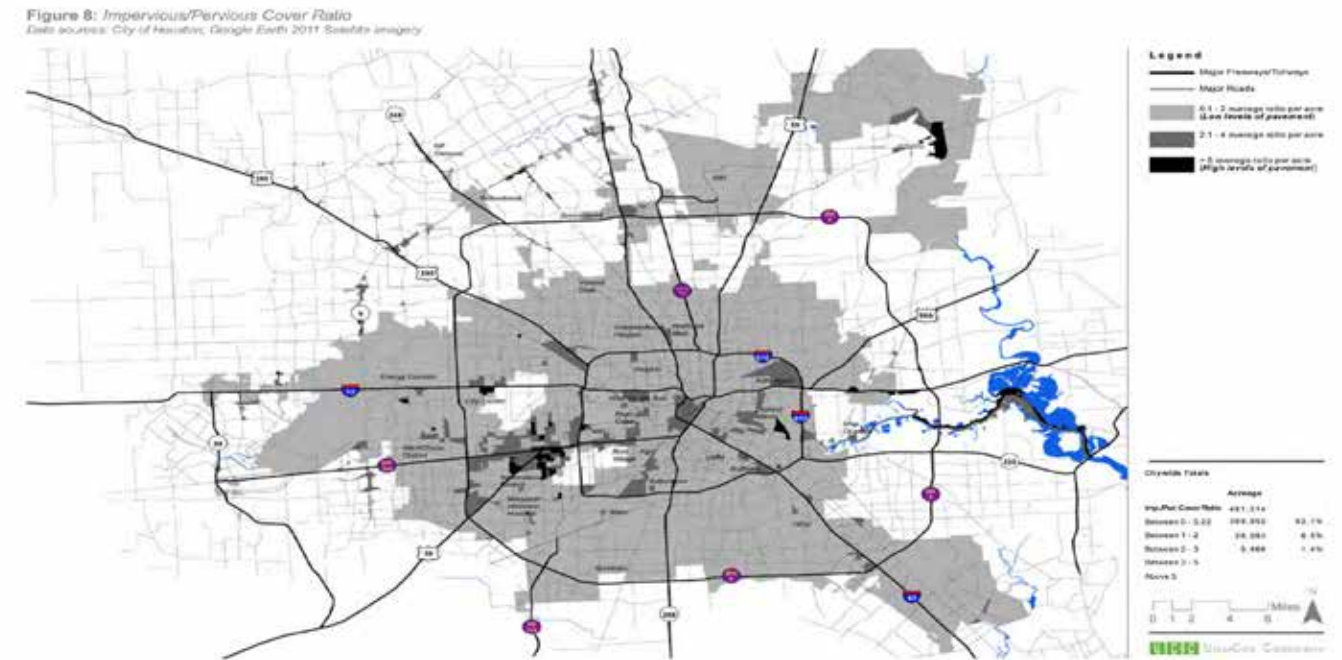
Lastly, we examine the integumentary system; the area’s skin. Houston’s soil quality is clay-like and largely non-absorptive. This relates to our skeletal system as well; with clay-like soils, there is a time lag associated with corrective land subsidence measures.<sup>30</sup> This means that any depression of clay-like soil is more permanent than with other soil types, and takes longer to restore to previous levels. These two factors create a bathtub effect when water falls on the Houston area, even without the compounding factor of storm surge. Even untouched by development, the 10,062 square miles we affectionately call the Houston-Woodlands-Sugarland Metropolitan Service Area would still be very susceptible to flooding. Alas, humanity has clumped into wonders of engineering and innovation we term “cities” – and Houston’s clumping resulted in many alterations of its natural systems. Given the gift of hindsight, there are several major areas that highlight the maleffects of human intervention in Houston. These can be outlined using our analogous body systems – albeit in reverse order.

## 2.5 Houston as Body

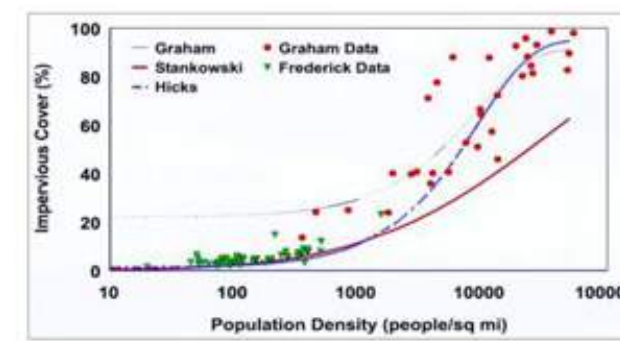
Let’s begin in reverse order with the integumentary – Houston’s thin skin of rapidly spreading impervious cover. Houston’s lack of zoning regulation is well advertised – “the Z-word,” locals call it.<sup>31</sup> Yet Houston is actually subject to other types of regulation. Some even argue that Houston is more restricted by its free market alternatives than is the average municipally zoned city.<sup>32</sup> Some posit that the spreading impervious

<sup>29</sup> John Harden, *For years, the Houston area has been losing ground*, Houston Chronicle, 2016, 1.  
<sup>30</sup> Kaveh Khorzah, *Land Subsidence Along the Texas Gulf Coast Due to Oil and Gas Withdrawal*, University of Texas at Austin, Master Thesis in Geological Sciences, 2000, pg 4.  
<sup>31</sup> Patrick J. Kiger, *The City with (Almost) No Limits*, Urban Land Institute, 2015, 3.  
<sup>32</sup> Michael Lewyn, *How Over-regulation Creates Sprawl (Even in a City Without Zoning)* GWU Law School, 2005, 1171.

cover, in the form of gated single-family sprawl and big-box retail, over increasing amounts of Houston’s skin is the product of the free market and should not be checked by government. In other cities, government does not face that tradition of opposition. Consider the urban growth boundary implemented in Portland, Oregon,<sup>33</sup> which promotes efficient use of land and public services inside the boundary while protecting the natural conditions beyond.



Source: HGAL Planning and Development Council, 2013



Source: Exum et al, 2005

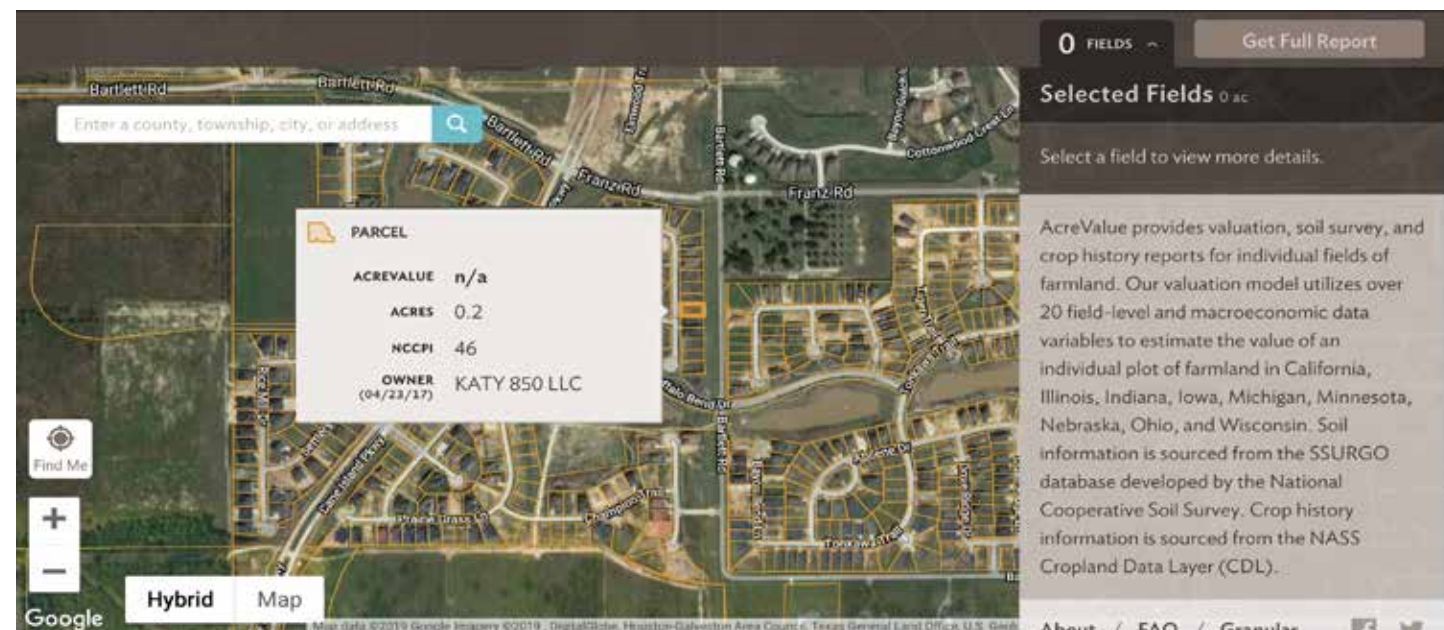


Source: Kinder Institute for Urban Research, 2017

<sup>33</sup> Oregon Metro, *Portland urban growth boundary*, 2018. See Appendix A for extended.

Municipal zoning was born in the early to mid 20th century, first passed in Los Angeles in 1908, and was mainly used to separate industrial from residential land usage. Zoning is an attempt to protect quality of life in human settlements, but the qualification of that term has evolved over time. The metrics of this ephemeral value evolved from simple land use adjacencies to building height restrictions to incentivization of social goals. In Houston, similar effects were achieved through private deed restrictions.<sup>34</sup> This realm of social goals, particularly environmental protection, is where we re-enter our integumentary metaphor.

Under traditional zoning, developers can be restricted from building in certain areas – for example, within the maximum flood pool of the Addicks and Barker Reservoirs. Under the reign of deed restriction regulation, landowners are only subject to the restrictions deeded by previous owners. This approach is heralded as a bottom-up alternative to the top-down perception of government imposed zoning. To stop the ever-expanding rings of suburban development in Houston, owners of undeveloped plats on Houston’s current edge would need to bar development on the site in perpetuity, even when subdivided in sale. A quick look at AcreValue.com reveals that in one square mile on highway 90 outside of Katy, plat owners includes such actors as; R & Y Interests, LLC; Bank of America, Katy 850 LLC, Major Investments, FST Realty and the Katie Prairie Conservancy.<sup>35</sup> Out of these, who is likely to forgo the profit of selling to a residential developer should the tide of suburban sprawl reach their doorsteps?



Source: by author from AcreValue, 2018

34 Patrick J. Kiger, *The City with (Almost) No Limits*, Urban Land Institute, 2015, 3.  
 35 See appendix A for visual and more on Katie Prairie Conservancy

This vignette illustrates the inherent flaw in relying on Houston’s so called “bottom-up” development rules – these are not decisions made by normal Texans for the betterment of their communities. Some of them may not even call Houston home – Katy 850 LLC is a Delaware based company.<sup>36</sup> Municipal zoning can protect the interests of real citizens against those of corporations when the two are at odds – the problem therein lies in attaining consensus that these are, in fact, at odds. Houston’s success has historically relied on the idea that they are not. The triumphs of the private sector are also those of the public at large. Inverting this narrative draws pushback from champions of the free market. Houston is unlikely to ever accept the private sector as wholly villainous – and it is not. Our hope lies in casting the free market as protagonist while establishing that preserving undeveloped land is a net positive for public health and safety. Houston’s corrective skincare regimen is, at minimum, to impede the spread of impervious cover and prevent further coastal prairie loss, and at maximum, to restore absorptive cover to large areas of land. Thus the integumentary system is restored, the spread of impervious cover kept at bay.

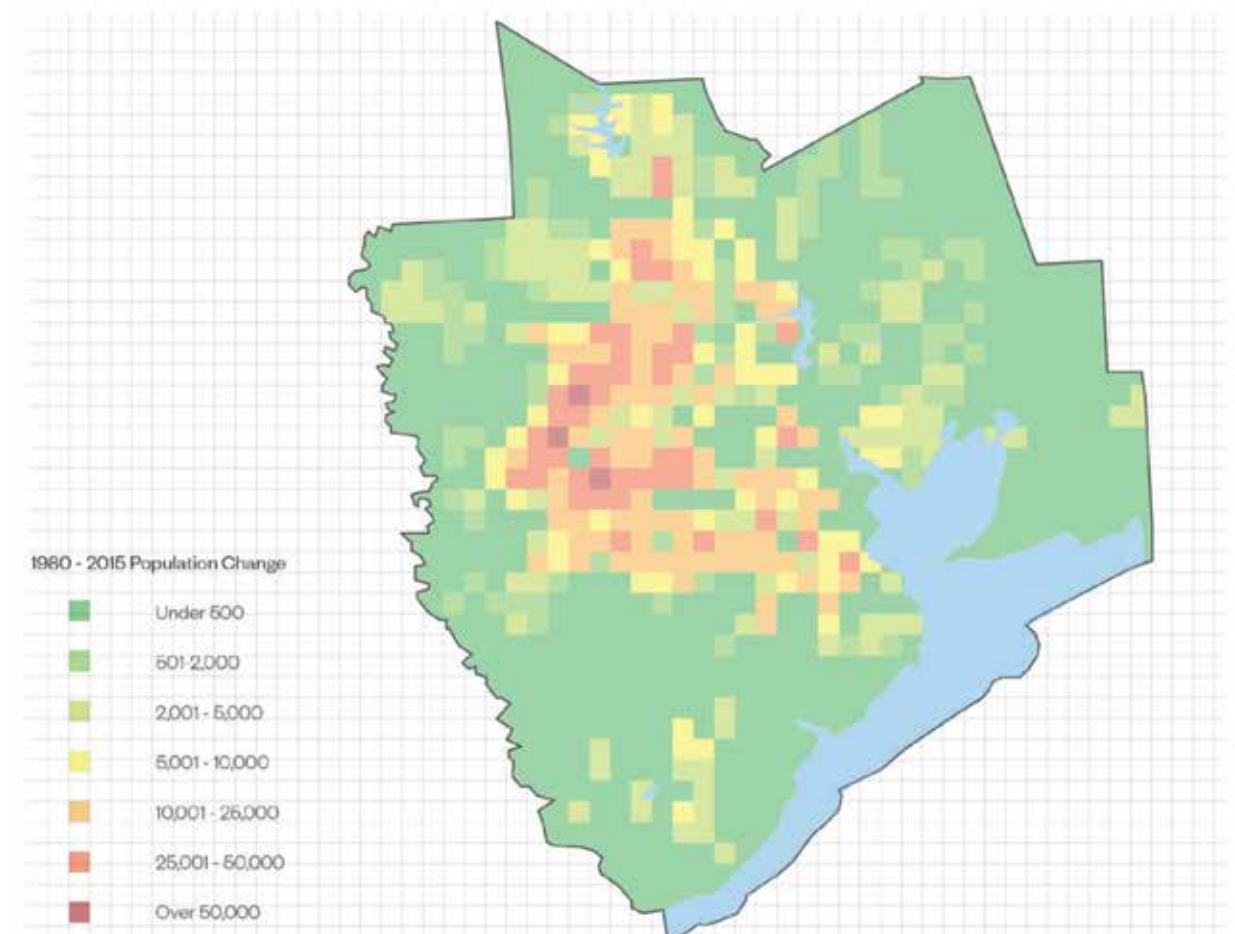
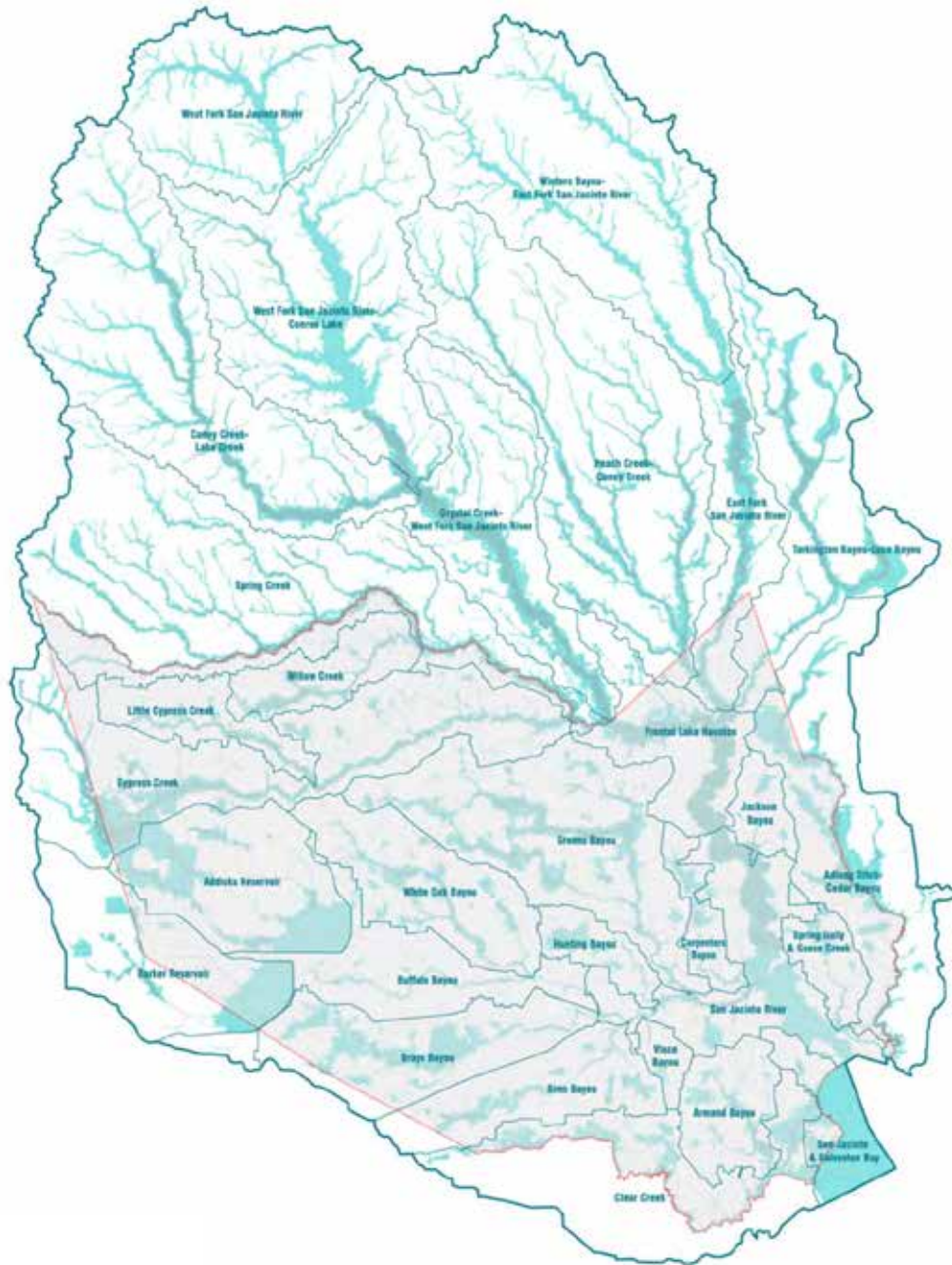


Figure 5 - Houston’s population growth abstracted

36 “Jurisdiction of Katy 850 LLC is DE.” - <https://companiestx.com/company/32049817425/katy-850-llc>



Source: Greater Houston Flood Mitigation Consortium, 2018

Second, we examine the treatment of its circulatory system – the bayous. The bayou is distinct from the river, identified by its slow-moving and often brackish waters. They are found in swampy, low-lying lands in coastal regions, and ocean tide may cause water flow to stop or even reverse. For decades before and after World War II, flood control engineers in Houston typically treated the bayou as a drainage ditch, straightening and paving its flat surfaces.<sup>37</sup> These efforts were intended to channel floodwaters toward the Gulf of Mexico as quickly as possible. The channelization of the bayous was undergone according to construction

<sup>37</sup> Jefferey Spivak, *The Bayou City: Reclaiming Houston's Signature Waterways*, Urban Land Institute, 2015.

standards of the US Army Core of Engineers.<sup>38</sup> The sectional difference between a natural bayou and a channelized one is very clear – speed over absorption, efficiency over enjoyment. The channelization is particularly susceptible to criticism when compared to the environmental and urban success of Fredrick Law Olmsted's Emerald Necklace approach to brackish river treatment in Boston – fifty years prior.



Source: Emerald Necklace Conservancy, 2018

Lastly, we examine the muscular system of Houston – the body mass of an increasingly complex organism. As previously stated, Houston is flat and subject to land subsidence due to human intervention. When material is taken out of the earth by human hands, the ground surface shifts to fill that void. In locations with clay like soil conditions, this settling of sediment is more plastic than elastic, meaning changes to surface level are slow-moving and largely permanent. In most cases, land subsidence is a result of groundwater depletion – but since the 1970s, Houston does not fall in that category, as its main water supply shifted surface water sources.<sup>39</sup> For this, the muscular system of Houston can be grateful. In place where land sinks at alarming rates, like in Jakarta,<sup>40</sup> there is a systemic failing of water resource management, meaning that citizens turn to illegal welling in order to meet current need. This particular problem is not a symptom of Houston; in fact the Houston area main water supply is surface water from the San Jacinto and Trinity watersheds, so the Evangeline and Chicot aquifers are actually more stable here than those in other Texas regions without surface water sources – San Antonio for example.<sup>41</sup> This shift to 86% surface water, 14% from the Evangeline and Chicot, was made in the mid 1970s, and was a smart move on the part of the public-private partnership that governs water supply. In Houston, water is not the primary resource we are pulling from the earth – our culprit is oil.

<sup>38</sup> *Id.*

<sup>39</sup> Drew Molly, *Drinking Water Operations*, Houston Public Works. Current.

<sup>40</sup> Amanda Ruggeri, *The Ambitious Plan to Stop the Ground from Sinking*, BBC, 2017.

<sup>41</sup> San Antonio Water System (SAWS) has been pursuing aquifer storage and recovery projects since 1998. [https://www.saws.org/Your\\_Water/WaterResources/Projects/](https://www.saws.org/Your_Water/WaterResources/Projects/)

The famous geyser at Spindletop struck both oil and the hearts of opportunists everywhere in Beaumont, 1901, just 80 miles from our host city.<sup>42</sup> Since its discovery, oil and gas have been removed from their subsurface homes at increasing rates.<sup>43</sup> The withdrawal of petroleum in the Houston has resulted in localized rates of subsidence that range from  $-0.27\text{m/yr}$  in Galveston to  $-0.53\text{m/yr}$  near Goose Creek, as studied from 1974-2000.<sup>44</sup> Although groundwater depletion has ceased due to its majority replacement with surface water sources in the 1970s, the clay-like soil shifts slowly and has not returned to equilibrium as of 2005.<sup>45</sup> This combined with the probable continuation of oil and gas production in the region ensure that land subsidence is a definite consideration of our muscular troubles, and is thus far ignored in relation to the petrochemical industry.<sup>46</sup>

The subsidence of our land musculature is highly localized in the cited study. The metrics cited refer to pockets of settling sediment, usually near salt deposits, where oil and gas have been extracted, and result in bowls of subsidence in the integumentary. This metric also interacts with general rates of sea level rise in the Gulf, resulting in increasingly complex metrics as perceived sea level rise is localized along the coast. Furthermore, according to projections used by the 2018 IPCC, regional relative sea level changes are likely dominated by specific natural variability to glacial melt via surface water mass redistribution, but will level out by the end of the century. This means we will soon see highly variable coastal sea rise in localized areas, but these trends will become consistent as water mass reaches global equilibrium as we near 2100. The Gulf Coast, and many other regions at low to mid latitudes are subject to rates of maximum rise. The Texas coastline is slated at  $.6\text{m}$ , or  $1.97\text{ft}$  of rise by 2100<sup>47</sup> if current rates adhere to projections. In the case of  $2\text{ft}$  of localized sea level rise, the shape of Texas and our host resemble the figures below.<sup>48</sup> The models used by the IPCC do not factor

localized land subsidence rates into their equation.<sup>49</sup> This variability communicates at least one certainty –

42 Texas Almanac, *History of Oil Discoveries in Texas*, Texas Almanac, 2014.

43 Kaveh Khorzah, *Land Subsidence Along the Texas Gulf Coast Due to Oil and Gas Withdrawal*, University of Texas at Austin, Master Thesis in Geological Sciences, 2000, 14.

44 Id., 59.

45 Presently in Harris and Galveston Counties, groundwater withdrawal has ceased in a majority of the study area. Petroleum production continues to occur and has caused measurable amounts of up to  $33.33\text{ mm y}^{-1}$  ( $1.31\text{ in y}^{-1}$ ). Two dominant causes of subsidence have been found in the region, oil and gas production and clay equilibration caused from previous groundwater withdrawal.

46 Subsidence will continue in the Harris-Galveston region as long as subsurface fluids are withdrawn at large rates. Presently, and gas production has been generally ignored as a cause of subsidence in the study area, even though oil and gas production has been occurring in the region for well over 70 years. Id., 83-84.

47 IPCC, 2018. Chapter 13 – Sea Level Rise.

48 Refer to Appendix A to see maximum rise of  $6\text{m}$  by Texas Climate News

49 Glacial isostatic adjustment (GIA), glaciers and ice-sheet surface mass balance (SMB) are taken into account. The models used are not specific enough to account for local land subsidence due to material extraction. The text refers to subsidence in terms of massive tectonic shift as accounted for by the GIA modeling, but land subsidence due to groundwater pumping is mentioned as a cause of localized diversion from regional projected rates of rise. 2018 Intergovernmental Panel on Climate Change, Chapter 13

we need flexibility in our waterways.

As qualified here, our host city is rapidly approaching multisystem failure due to the compound vulnerability of its natural conditions and subsequent human intervention. Houston's integumentary system can no longer compensate for the natural and manmade failings of its circulatory system. Its circulatory system has been channelized and made rigid, unable to respond organically to the increasing scale of climate-augmented storms and thus waterlogging its integumentary system. And the musculature of the region is depleting independently of Houston's mismanagement of water – due instead to its mismanagement of oil. Thus factors like sea level rise and storm surge are compounded by human intervention. Any scheme that addresses a city would no doubt value specificity, but the complexity of this bodily metaphor pales in comparison to the complexity of any truly holistic regional solution.

### 3.0 The Proposals for Houston

Were this thesis written for the purpose of denigrating human intervention in nature, its purpose would now be served. However, this is not a lesson in the abandonment of coastal cities, and Houston is not a city easily abandoned. Her perch on the precipice of catastrophe is the exact potential the Energy Capital of the World is uniquely poised to capture. Her engineering prowess, her grassroots-zoning substitute, and her employing power are all vessels with which Houston can become her own savior. Yet current schemes to mitigate flood vulnerability lack the holistic knowledge needed to navigate the natural and anthropological causes of the city's symptoms. Houston's multisystem failure requires both curative and palliative care as we negotiate a highly changeable edge condition.

The multitude of issues framed here, both natural and constructed, necessitate a multivalent resiliency plan that is both spatially and temporally scalable. Thus far our corrective efforts have been reactionary, due to lack of foresight, lack of resources or lack of interest. There are many proffered schemes that aim to mitigate the disastrous effects of tropical storms, but few have reached notoriety. The ones that do achieve visibility are stalled by lack of social or monetary support. Among such stalled solutions still cast as savior is the "Ike Dike" coastal spine, a proposal drafted by Texas and Dutch universities.

### 3.1 Ike Dike Coastal Spine

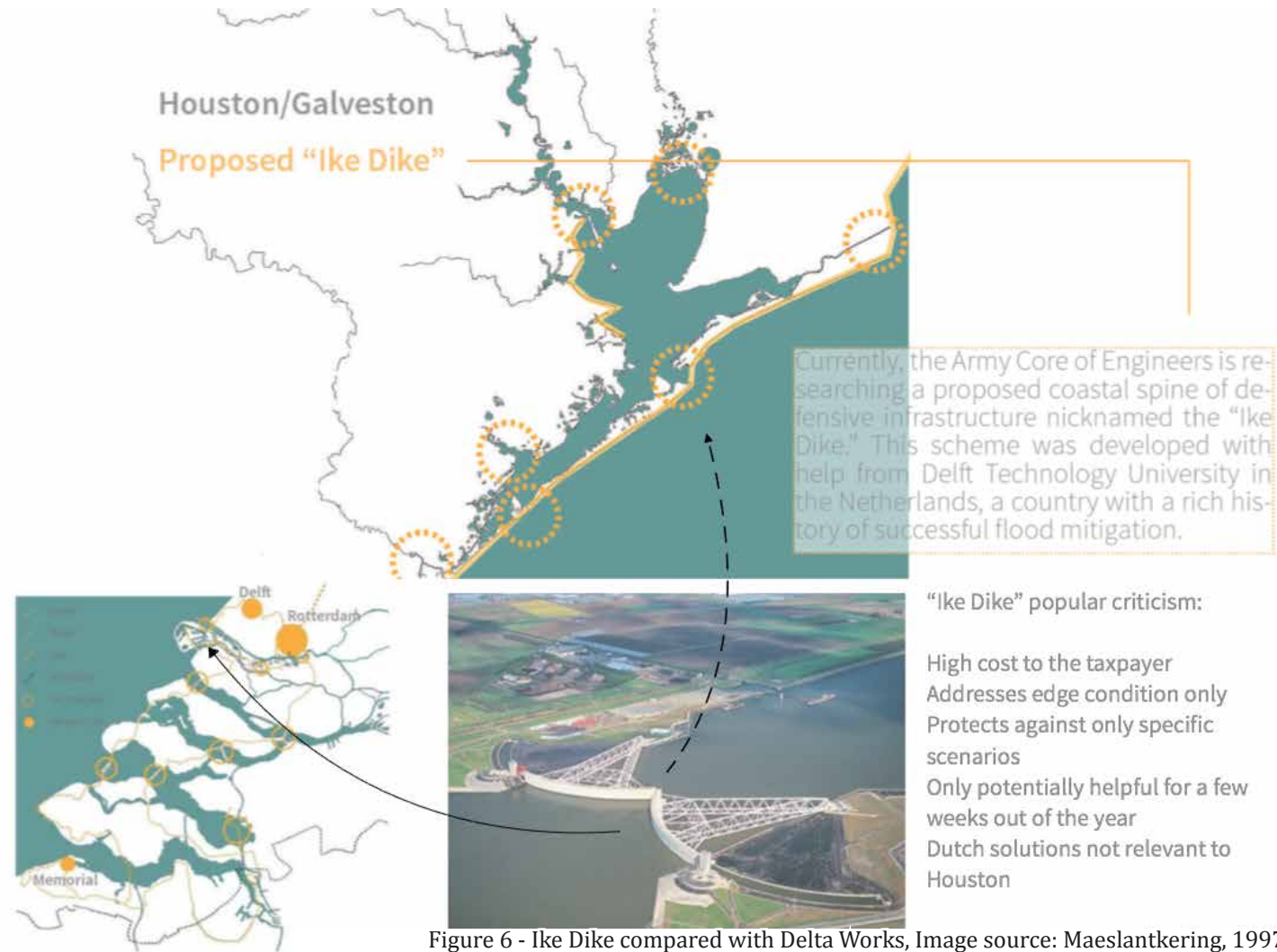


Figure 6 - Ike Dike compared with Delta Works, Image source: Maeslantkering, 1997

The proposed "Ike Dike"<sup>50</sup> is a system of floodgates and barriers modeled after the Netherlands' Deltawerken, or Delta Works, of South Holland and Zeeland. It was born after Hurricane Ike in 2008, its namesake, midwived by a marriage between Houston and Dutch universities.<sup>51</sup> TAMU Galveston and Rice University partnered with city organizations who then allied with Delft Technology University, an institution that has already offered its resources abroad from a country that makes a habit of doing so. The Netherlands has proffered its water-management knowledge to coastal regions around the world, including Southeast Asia and China.<sup>52</sup> The Deltawerken as precedent for the Ike Dike was subject to hefty criticism following the 2009-2011 refractory period – what we can call the period following a hurricane in which unification trumps criticism. After losing support post-refractory period, the proposal and its proponents faded from public eye.

50 The scheme, conceived by Bill Merrell over a decade ago, can be seen in more detail in Appendix A  
 51 Kothuis, Brand, Sebastian, Nillesen, Jonkman, *Delft Delta Design, Houston Galveston Bay Region, Texas, USA*, TU Delft, Delft University Publishers, 2015, 23.  
 52 Robbert Missdorp, *Climate of Coastal Cooperation*, Coastal and Marine EUC, 2011, 53-122.

Following Hurricane Harvey in 2017, the resurgence of demand brought the scheme back. The Ike Dike was revisited and fleshed out, and it is here that the proposal attempted to shed its nickname for the less heavily connoted coastal spine moniker – it is currently under review by the US Army Core of Engineers (USACE) for estimation purposes, but criticism has risen again as we leave Harvey further in the past. The critics' main grievances are as follows: too specific, too emergent and too expensive. And, after interrogating the Delta Works as precedent – they're not entirely wrong.

### 3.2 Holland as Precedent

There are similarities between our Houston situation and the Dutch example. A 20<sup>th</sup> century storm prompted both areas to implement infrastructural change after disastrous loss of life. Both peoples exhibit incredible resiliency in the face of disaster, and both are capable of incredible feats of engineering. However, the differences are much more numerous, and merit further interrogation of what, if any, characteristics of the Delta Works can or should be emulated in our host city.

The Deltawerken storm surge mitigation system was constructed in response to the devastating Great North Sea Flood that claimed 2,000 European lives, 1,800 of which were Dutch.<sup>53</sup> After this event, Scotland, England, Belgium and the Netherlands adopted storm surge mitigation efforts, as exemplified in the 1984 Thames Barrier of London and the Deltawerken that protect Holland and Belgium.

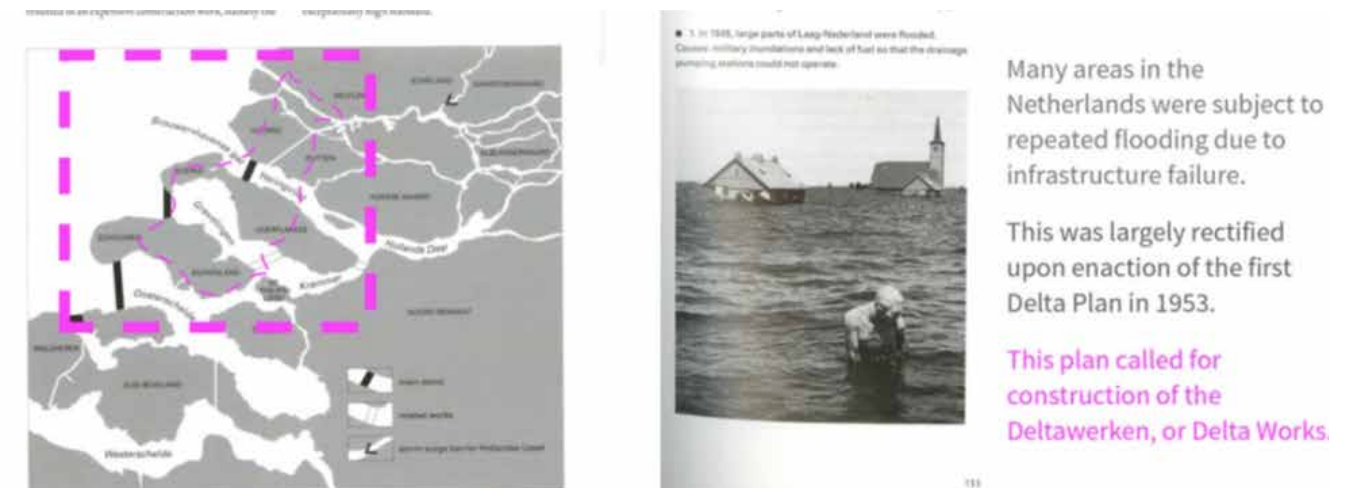


Figure 6 - Travel scope on map of Delta Works; flood image source: Van de Ven, 2011

53 At the Watersnoodmuseum, this event is memorialized inside huge caissons that were dropped near Ouwerkerk to repair the dike during the emergent 1953 situation. When outer dike rings were construction, the caissons became the museum, still rooted in sand from that day. See Appendix B for images.

In the Netherlands, the refractory period following the 1953 Waternoosdamp proved more actionable than our recent ones in Texas. This is in part due to the country's rich history of water management<sup>54</sup> and in part due to the size and accompanying dexterity of its government, two things that do not translate to Houston-Galveston megalopolis. The Delta Plan<sup>55</sup> was written and enacted, the first of three such plans outlining governmental response to flood risk. The first Delta Plan called for the immediate construction of surge barriers, and commandeered the resources needed to do so. The Plan also established the Delta Commission, an immensely powerful extra-governmental body that, anecdotally,<sup>56</sup> never had to question its funding or agency.

Upon the establishment of the Delta Plan, the Delta Commission began construction immediately on the fourteen dams, sluices, locks, gates and dikes that comprise the Deltawerken. In 1958, total construction costs were estimated at 3.3 billion guilder, or 4.3 billion USD, roughly 20% of the national GDP.<sup>57</sup> In 2012 the total costs were set at 13 billion USD,<sup>58</sup> majority financed by national budget and the discovery of natural gas in Holland. The crowning jewel of the Delta Works is the Maeslantkering, a huge storm surge barrier that protects the Nieuwe Waterweg from the North Sea. The gates are the largest manmade moveable object in the world, and rotate on a 10m ball joint, much like an arm or shoulder joint, to close when automatic closed loop sensors detect storm surge of +3m. The arced barrier face of each gate is 22m tall, providing protection for up to 3x that metric to allow flexibility of sea level rise.<sup>59</sup>



Source: Deltawerken, 2001

Figure 6 - Travel photos compiled

54 G.P. Van de Ven, *Man-made lowlands*, 1993, 7-117. In-depth look at the Netherlands water management history in epochs, from origin to 800, 800-1250, and 1250-1600.

55 Id., 237-286, *The Zuiderzee and the Delta Projects*.

56 Nikki Brand, TU Delft

57 J.C. Aerts, *Adaptation cost in the Netherlands: Climate Change and Flood Risk Management*, 2009. 34-36.

58 Id., 35.

59 Het Keringhuis, Maeslantkering Visitor Center, guided tour. Notes in Appendix B.

The second Delta Plan, nicknamed the Room for the Rivers project, was added to established Dutch flood cannon in 1995 and is ongoing. The Ruimte voor de Rivier plan addressed flood protection, master landscaping and environmental conditions in the areas surrounding the Netherlands' rivers.<sup>60</sup> This endeavor required relocation of many communities, but the process was incentivized by autonomy; if a community organized and moved voluntarily, it could ask a wish of the Delta Commission and be granted a new elementary school, new bridge or restoration of damaged public space. These were called "spatial quality projects."<sup>61</sup> It is important to note, however, that regardless of how voluntary relocation may have seemed, rural Dutch communities either could not or would not refuse their government buyouts.<sup>62</sup> As stated, the Delta Commission did not lack for authority or funding, thus buyouts exceeded market price and the Commission faced no interference from parliament or cabinet. This unified strength combined with the gathering mythology around the Delta Works over time ensured that though carrot was a great carrot, the stick loomed large behind.

The third Delta Plan of 2008 codifies climate change into policy. The Delta Commission, as led by politician Cees Veerman, advised in a public report that the Netherlands requires a massive new building program to strengthen the country's water defenses against the anticipated effects of what was then called global warming. The proposal included worst-case scenario evacuation methods and estimated pricing of protection against sea level rise in the North Sea, stating they must plan for a rise of 1.3m (4.3ft) by 2100 and 4m (13.1ft) by 2200.<sup>63</sup>

Since their full construction in 1997, the Delta Works have proved successful at preventing loss of property and life, but that is not their only gift to the public. There is also a sense of identity and pride built into these sites of historic water infrastructure.

The Deltawerken naturally acquire this mythological quality through an already established narrative –the social architecture of Dutch water infrastructure is written into its history. Twenty-six percent of the country is below sea level, and some 3,000 polders<sup>64</sup> reclaim that land from the sea. After all, *God created the Earth but the Dutch created Holland*.<sup>65</sup> Dikes, windmills and polders framed the first land management strategies in Dutch settlements, and pepper the country's military history as well. A dike is a vector of raised land

61 Id.

62 Id.

63 Id.

64 Van de Ven, Id., *History of water management*, origin to 800, 14.

65 Dutch saying, popular in Kinderdijk, Netherlands. Original author unknown.

that protects a polder, an area of low-lying land reclaimed from the sea, while a windmill pumps water from the polder area outside of the protective dike boundary using wind energy.<sup>66</sup> Dutch folk tales feature these human forms as narrative device.<sup>67</sup> The dike is at once mitigating and militant, managing and mythical, and a social cornerstone of the Dutch collective memory.

When visiting Kinderdijk, a UNESCO World Heritage Site famed for its beautiful, functioning, historic windmills, I was surprised by the presence of construction on a preserved site. The visitor center is reinvesting capital in itself alongside government funds to build a new learning center and pedestrian bridge to match its status. Signage reads, A New Entrance Worthy of a UNESCO World Heritage Site, Coming Soon! One of the windmills is preserved as a museum to tell the story of a traditional miller family's way of life.<sup>68</sup> The latticed blades were even used to signal familial or communal happenings – weddings, births, deaths. The windmill is a livable machine that spanned the programs of safety, housing and communications. In the Netherlands, water infrastructure at even its earliest examples avoided mono-functional intervention. Water infrastructure in Holland speaks histories, large and small.



Figure 7 - Travel route with highlighted Works

The Delta Works themselves are a modern example of that same idea. The Works were constructed to shorten the Dutch coastline, decreasing the mileage vulnerable to storm surge and protecting the Low Countries farther inland. Though the primary purpose of the Works was to protect the perimeter, all are multifunctional pieces of infrastructure. Nine of the fourteen interventions act as road infrastructure while also damming the inner waters from the volatile North Sea.<sup>69</sup> The Haringvlietdam, completed in 1971, is a dam but also a flood barrier comprised of seventeen sluice gates, with a roadway atop them. Most dams also act as recreational zones with hike and bike trails, and educational material about wildlife in the area. The longest of the Works, the Oosterscheldekering, includes artificial island masses that now houses a water amusement park called the Deltapark Neeltje Jans. The park also educates the public about the Deltawerken and a panorama film of the 1953 North Sea Flood. Its attractions are mostly targeted for children, but the summertime weekly tours inside the inflatable surge barriers attract many dam enthusiasts. The Deltawerken themselves are multifunctional interventions, from the connections they provide through roadways to recreational and tourism uses.

Another factor present in the Delta Plan is the combined use of hard and soft infrastructures. The Oosterdam farther inland is a roadway and dam as well as an example of sand nourishment through “rainbow dredging,” a technique of dredging sand and augmenting landmass with the dredged material. Delta engineers capitalized on the underlying principle of coastal erosion, that on the leeward side of hard surface, land will erode and follow the tide. Using this idea, the sand nourishment is placed so that over the course of 20 years, its position will be adjusted and spread by tide to flow naturally into its best attenuation form. This technique is used on the Scheveningen beaches of The Hague as well, and Missdorp has worked to spread this technique to at-risk edges in many Southeast Asian cities.<sup>70</sup> Another example of Dutch soft infrastructure is preventative rather than retaliatory – the enforced development ban on the coastline. Eighty percent of the Dutch coastline is unbuilt,<sup>71</sup> to prevent that leeward coastal erosion and preserve the elasticity of the beaches as the country negotiates sea level rise in the coming decades.

The methods of the Deltawerken were not without criticism however – many environmental groups pushed back against the interruption of estuary ecosystems. Much of the soft infrastructure solutions cited resulted from environmental pushback. The separation of the fresh- and salt-water bodies resulted in interruption of tides, which in turn caused loss of floral and faunal life in the rivers. The interruption of flow also

66 Kinderdijk, signage. See Appendix B for more.

67 Example of Dutch dike mythology - Albertus Boli, *The Little Dutch Boy Who Saved Holland*, Young Readers. Boli's Fables for Children Who Are Too Old to Believe in Fables. Published 2009.

68 Kinderdijk, Windmill Museum. See Appendix B for notes.

69 “Delta Works,” Deltawerken, Official Site.

70 Robbert Misdroop, *Climate of Coastal Cooperation*, 2011. Asia and Island States, 53-122. Sand Nourishment – 164.

71 Id., 160.



caused sediment and sludge build-up in the rivers because of the loss of its natural outlet. Delta maintenance consequently dredges and clears impeded rivers to maintain water capacity and flow. The second and third Delta Plans considered environmental impact in more depth than did the first, and though the increased cost to the Delta program was significant, these environmental measures were received favorably.

Lastly, there are the accompanying programs that have sprung up around such monumental interventions. It is not only at UNESCO World Heritage sites that the Dutch celebrate their knowledge in glass and stone – there are three official visitor centers for the Delta Works, at the Maeslantkering, the Deltapark Neeltje Jans, and the Watersnoodmuseum dedicated to the 1953 North Sea Flood. The Keringhuis is the visitor center adjacent to the Maeslantkering, and it tells the history of the Delta Works and their legacy in the wider world. It also offers a walking tour in three languages of the huge gate itself, and hosts the huge public viewing and celebration of the gates every September when the Maeslantkering is tested before the rainy season.<sup>72</sup> The Deltapark is a great example of monetization of a new asset – the artificial islands – created by the Works, while also educating the public about their presence and longevity. The Watersnoodmuseum is a microcosm of a perceived larger phenomenon – the artistry and memorialization of the 1953 Flood throughout the low countries of South Holland and Zeeland. Below is an art map of each region paired with one such memorial, from a Watersnoodmuseum published collection<sup>73</sup> immortalizing the artists and their works that strove to memorialize the resiliency of the Dutch people and their heroism. This existing imagery of memory is an important ingredient of the mythology that surrounds and empowers the Delta Works.



Figure 8: Travel photos, Watersnoodmuseum interior

72 From Het Keringhuis, visitor center at Maeslantkering. See Appendix B.  
 73 Watersnoodmuseum, *het water | de storm | de stille*; *De Monumenten van de Watersnood 1953*, 2010 with supplement in 2016.



Figure 9 - 1953 Flood memorial with art map of Zeeland

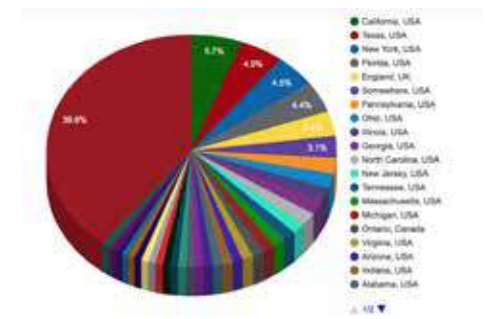
Source: de Monumenten de Watersnoodamp, 2011

### 3.3 Holland as Imitable

Now we can contrast these established methods of the Deltawerken to our host city half a world away. The Delta Commission was a unified, empowered authority with the resources to affect infrastructural megaprojects and enact buyout programs. Sea level rise and climate change are codified into Dutch policy. In contrast, in January of 2019 our president tweeted,<sup>74</sup>



Source: Twitter, captured 2018



Source: tweepsmap.com, captured 2018

74 “Be careful and try staying in your house. Large parts of the Country are suffering from tremendous amounts of snow and near record setting cold. Amazing how big this system is. Wouldn’t be bad to have a little of that good old fashioned Global Warming right now!” @realDonaldTrump, 2019.

The president's tweets alone are not indication of public opinion. Yet there are many people in the suburban rings of the Houston system that could be called the "Trump base."<sup>75</sup> There is major overlap between Houston area residents and Trump supporters, a population that we will eventually need to support any infrastructural program in Houston. Though lately there has been talk of the Republican Party "taking back climate change,"<sup>76</sup> it is counterproductive for the chief executive of these United States to harp the hoax harmonica each time a super snowstorm hits the Midwest – a phenomenon which climate change actually predicts hand in hand with sea level rise.<sup>77</sup> The result is a divided front in the fight against climate change. There are many people in Texas who follow the president on Twitter. There are not as many people in Texas who would know that ten days preceding said tweet, the Department of Defense released a 22-page report that details the 79 military installation vulnerabilities over the next 20 years due to the effects of climate change.<sup>78</sup> There is an appearances problem that severely limits the language with which we can discuss Houston's vulnerability, which in turn hinders any action taken to address it. Fear of a name increases fear of the thing itself<sup>79</sup> – and Houston, we are afraid.

We are not only crippled by the lack of transparent rhetoric concerning climate change on the Texas coast – the Texan model of low taxes, low services is directly at odds with the Deltawerken precedent. The most common criticism of the "Ike Dike" scheme is its cost to the taxpayer,<sup>80</sup> even when supplemented by federal dollars. Texans are distrustful of government funded anything – even disaster relief. Following Hurricane Harvey, the Volunteer Navy of truck-driving boat-owners were the heralded as heroes, while FEMA was indicated as culprit for its insurance flaws and inaccurate floodplains. Houstonians value the free market and individual liberty – the only way to massive infrastructural change in Texas is through public-private partnerships that bill at minimal cost to the taxpayer, an entirely different methodology than that used to erect the Delta Works.

The Room for the Rivers project as precedent is also inhibited by Houston's reluctance to accept government interference in land use – long established by its zoning substitutes. The voluntary Home Buyout

75 John Harden, *Houston-Area Maps Show Where Democrats, GOP are Gaining Votes*, Houston Chronicle, 2018.

76 Oliver Milman, *The young republicans breaking with their party over climate change, reclamation in sight*, The Guardian, Philadelphia, 2019.

77 IPCC, Summary for Policymakers, 2018, Chapter 13 – Sea Level Change, 1143.

78 Department of Defense, *Report on Effects of a Changing Climate to the Department of Defense*, Office of the Under Secretary of Defense for Acquisition and Sustainment. Cleared for Open Publication, Jan. 2019.

79 J.K. Rowling, *Harry Potter and the Philosopher's Stone*, 1997, 335.

80 Seamus McGraw, *Will Taxpayers Foot the Bill to Protect Oil Industry from Climate Change?* Climate Liability News, 2018.

plan has met with measured success,<sup>81</sup> but market rate buyouts for all volunteers far exceeds its funding.<sup>82</sup> Furthermore, once bought-out land belongs to the government, it leaves the market, effectively taking a private asset and replacing it with a public deficit. Managed retreat is an established strategy for flood mitigation – after all, a house demolished is a house that will never flood again. Yet in addition to the lack of sufficient funding for those that do wish to relocate, there are plenty of bayou-dwelling homeowners who would rather rebuild than relocate. Houstonians have built and chosen their communities, and are not in any hurry to leave them. Furthermore, the current flood insurance policies support rebuilding more than it does relocating,<sup>83</sup> which contributes to cyclical resident distress and displacement with each flood event. Anecdotally, the only residents who accepted took a buyout in the affluent micro-metropolis Hunters Creek Village along Buffalo Bayou are older residents who were considering relocating senior living facilities even before their home flooded during Harvey.<sup>84</sup> The remainder are rebuilding, elevating their homes the required 5.5ft in the 100-year floodplain.<sup>85</sup>

Another inhibitor to the plan is Houston's chosen patchwork policy of deed restrictions. For the kind of large-scale buyout necessary to widen and deepen the rivers like in the Dutch example, thousands of individual deeds would require legal scrutiny, and overturning common residential restrictions like prohibitive land use, material palettes or adjacent structures like maintenance sheds. Prohibitive land use restrictions could also be used to block the kind of "spatial quality projects" the Delta Plan used to incentive autonomy in the buyout process. The physical differences between Texas and Holland are equally as important as the socio-political ones. The dike and polder recipe of Dutch water management is enabled by its peaty ground quality – we have already discussed the drawbacks of Houston's clay-like integumentary system, and this is one more example. A second geological distinction is Galveston Island and the Bolivar Peninsula. The Delta Works were an effort to shorten the Dutch coastline through infrastructure – the vector along Galveston's seaward edge is already an efficient line with which we can separate the inland from the Atlantic. Thinking of the entire Galveston edge as a piece of Delta infrastructure is a jump in scale akin to that between a basketball and a marble.

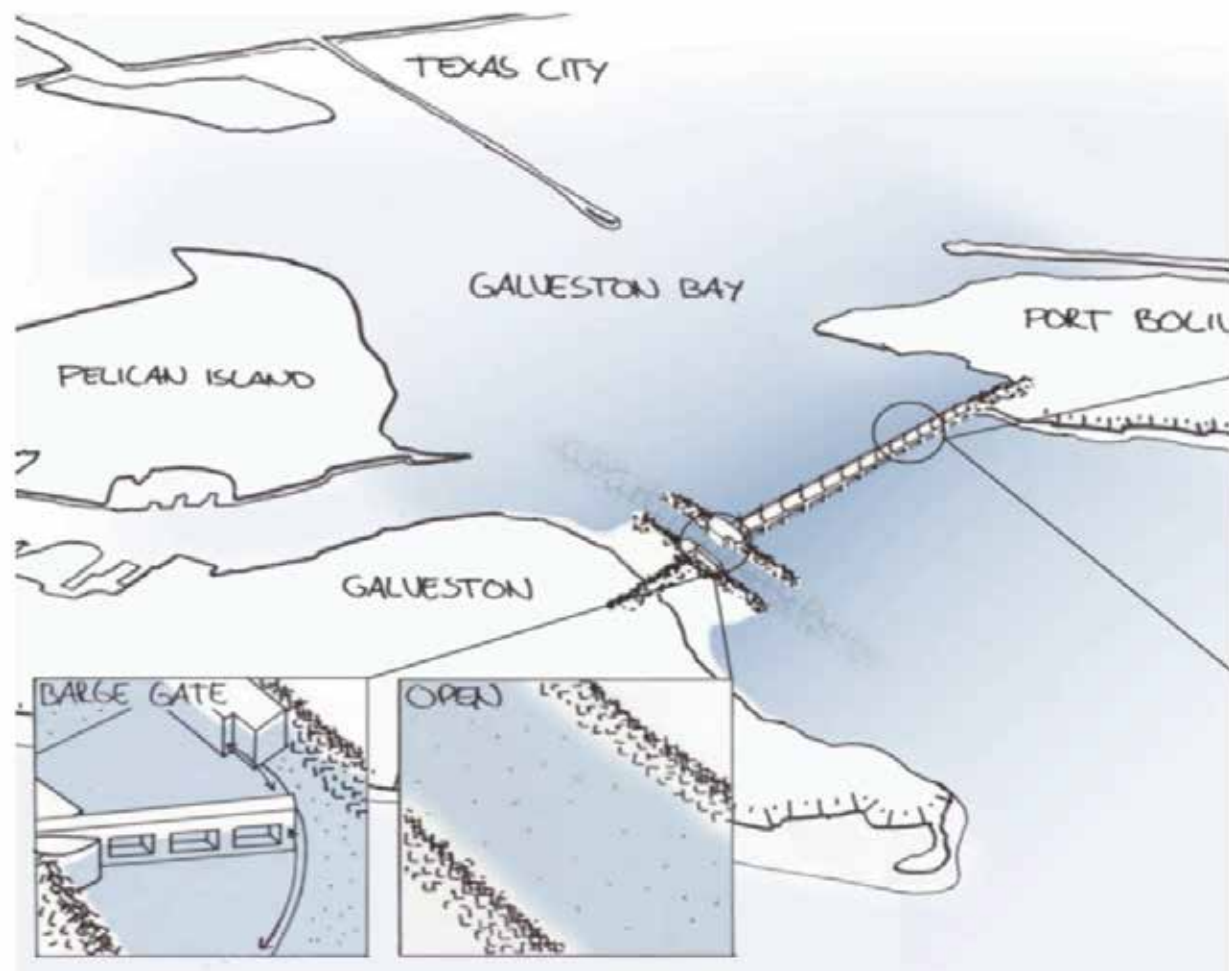
81 Harris County Flood Control District, *Latest Updates About Home Buyouts*, Home Buyout Program, updated May 1 2018. Houston Consortium, *Report*, pg 10. See Appendix A for more.

82 A.R. Siders, *Government-funded buyouts after disasters are slow and inequitable – here's how that could change*, The Conversation, Environment and Energy Section. 2018.

83 Jim Emerson, *What Private Mortgage Lenders Want You to Know About Flood Insurance in Texas* Amilenders, self-published, 2018.

84 Anecdotal from conversation with Hunter Creek residents and members of the Hunter Creek Neighborhood Association. See Appendix B for extended.

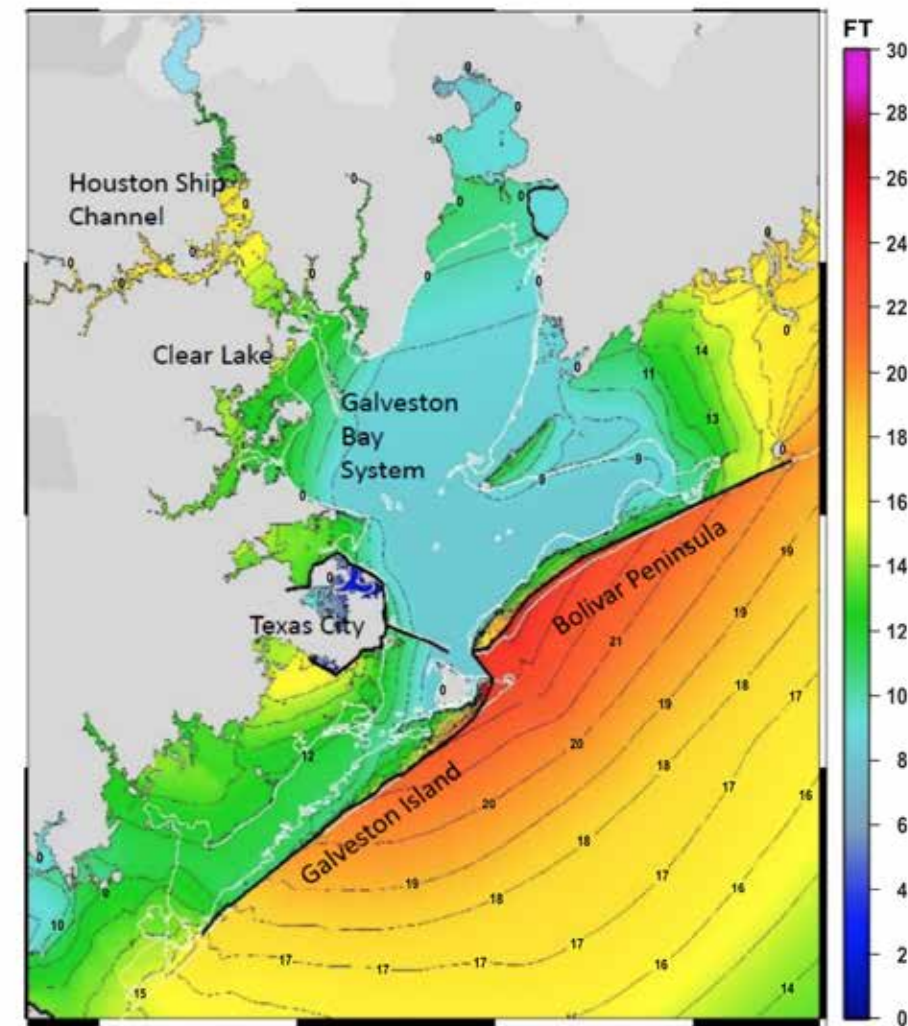
85 Anecdotal, from conversation with local architect. See Appendix B for extended.



Source: Nilleson, 2015

The premise of the Delta Works is to protect its edge from storm surge, but the surge in Holland is very different from that which Houston faces. We have established Houston's compound vulnerability to pluvial, fluvial and storm surge flooding. The Netherlands does not face hurricane level rainfall, especially those of Hurricane Harvey, the latest metric of disaster. The bayou flooding is not addressed in the Ike Dike coastal spine, which is primarily an edge consideration that protects from temporary sea rise. If constructed, the Ike Dike would allow the watersheds to drain into Galveston Bay, as the bay would remain at mostly normal levels.<sup>86</sup>

<sup>86</sup> Blackburn, *Houston a Year After Harvey*, Rice University and SSPEED Center, 2018, 49.



Note: Modeled using the extent of coastal flooding from a small Category 4 storm coming ashore on the south end of Galveston Island.

Source: Dawson via Blackburn, 2018

But when subjugated to record rainfall events like Hurricane Harvey, a phenomenon predicted to increase in frequency, the areas adjacent to bayous still face flood vulnerability and immobility due to sheet flow between watersheds. Not only are there many social, political and physical differences between the Netherlands and Texas, the proposed Ike Dike scheme only addresses half of Houston's compound flood vulnerability. The storm surge focus of the scheme is leftover from its Dutch origins and its namesake – Hurricane Ike was primarily a storm surge event. Yet Houston is subject to more than just surge, and the criticism that the Dutch –inspired plan is too specific is founded in fact.

The Delta Works and consequent Delta Plans have saved the Netherlands. They have also affected a less quantifiable metric of social architecture that ensures their longevity and flexibility. In my time visiting

Holland, I came to know that level of physical and social architecture, which I believe, despite our differences, Houston can attain – in its own way.

We cannot simply copy engineering tactics used by European cities - if the answer were this simple, it would have been done long ago. The issues of citywide flood infrastructure are wrapped up with socio-economic ones, like government spending, renter's and flood insurance, and the social responsibility of planners, architects and municipal zoning bodies to protect citizens against the next disaster. What we can emulate is the multi-faceted approach the Netherlands has implemented, addressing both edge condition and internal drainage in a scheme that is spatially and temporally fractal.

Like any systemic method of infrastructure in the United States, water management can be used to disempower minority and low-income populations. Houston, with its socially and economically diverse citizenry, is uniquely positioned to serve as a model for equitable resiliency for other Sentinels throughout the country. Therefore any resiliency plan must look at the ways flood events affect the disproportionately vulnerable populations of Houston.

### 3.4 Houston's Compound Vulnerability

The first vulnerability Houston faces is almost universal among its inhabitants – the car commuter workforce. During Hurricane Harvey, Houston was transformed into an archipelago of physically isolated zones by the deadly combination of car dependency and flooded highways. Houston-area workers commute on average 24 miles daily,<sup>87</sup> and the standing water left behind by the storm and controlled levee release stalled the Houston workforce for ten days. Furthermore, gas prices in Texas increased by \$0.50/gallon following the decreased capacity of Houston refineries post Harvey by 3 million barrels per day, a metric that represents 16% of the nation's refining capacity.<sup>88</sup> In addition, as estimated 366,000 personal vehicles suffered damages due to Harvey, flooding the market with damaged vehicles in a city where car dependence is strong. Lastly, 54 of the reported 78 fatalities reported by September 1, 2017, were drownings, the majority of which occurred while driving into floodwaters or being swept away by current after exiting a vehicle.<sup>89</sup> Car culture and floodwaters are a deadly combination.

87 David Crossley, *The 3-hour commute? City Mobility Plan explained*, HoustonTomorrow, 2009.

88 TU Delft, *Hurricane Harvey Report; a fact-finding effort in the direct aftermath of Hurricane Harvey in the Greater Houston Region*, TU Delft, Rice University, TAMU Galveston, 2017, 50 – Indirect Damages

89 Id., 58 – Data Analysis

Houston's manmade vulnerabilities

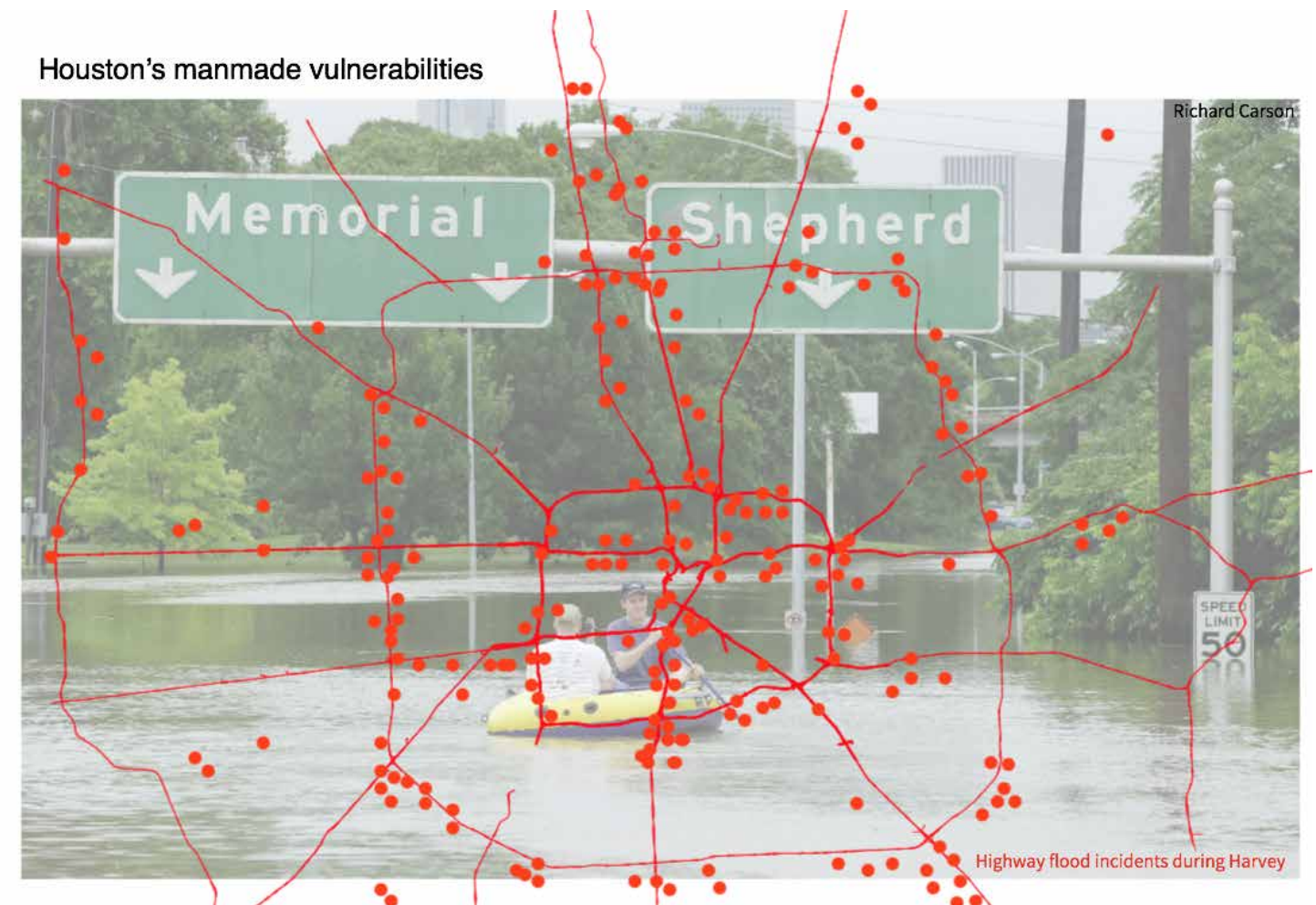


Figure 10: Highway flood incidents over photo by Houston Chronicle, 2017

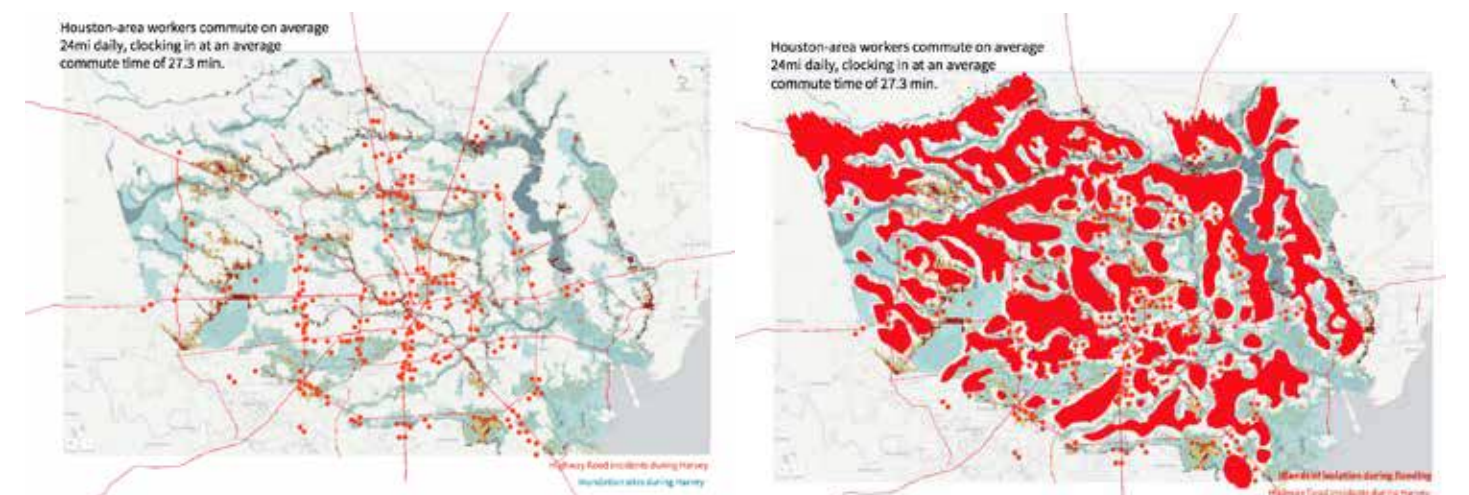


Figure 11: Houston as physically isolated islands during Harvey, over image by Kinder Institute of Urban Research, 2017

The second vulnerability Houstonians face is their environmental welfare, which relates directly to the disparity of income in the area. Harvey flooding severely compromised industrial facilities that manufacture plastics, chemicals and petrochemicals, and the contamination of these compromised industries is still being evaluated.<sup>90</sup> The Arkema facility in Crosby in particular was subject to explosions and high contamination.

90 Id., 49. Direct Damages.

tion, due to the degradation of temperature sensitive storage containers.<sup>91</sup> As of September 12, 2017, Hurricane Harvey caused an estimated 2,000 tons of chemical release into the standing waters near these facilities. The adjacency of low socio-economic neighborhoods to industrial land uses, and the resultant contaminants they release under pressure, is one more example of how urban vulnerability is linked to economic status. Vulnerability can be read spatially through land use and income levels, and any scheme that attempts to aid Houston should react accordingly.

The third level of vulnerability is the presence of language barriers in the city. Because of its massive employment force, Houston is a huge hub for immigration, and parts of the city have seen an enclave effect as ethnic groups gather together and form their new communities. This is not a stance on what Houston can or should do concerning non-English speakers in the workforce – merely an observation that these populations are also particularly vulnerable to misinformation and isolation during flood events. An estimated 44% of households in Harris County are non-English speaking households.<sup>92</sup> Thirty-three percent are Spanish-speaking households.<sup>93</sup> There are swaths of Houston where English is not the population’s first spoken language, and when this social barrier is compounded by the physical barriers of flooding we are looking at a very different Houston than the one we are used to seeing.

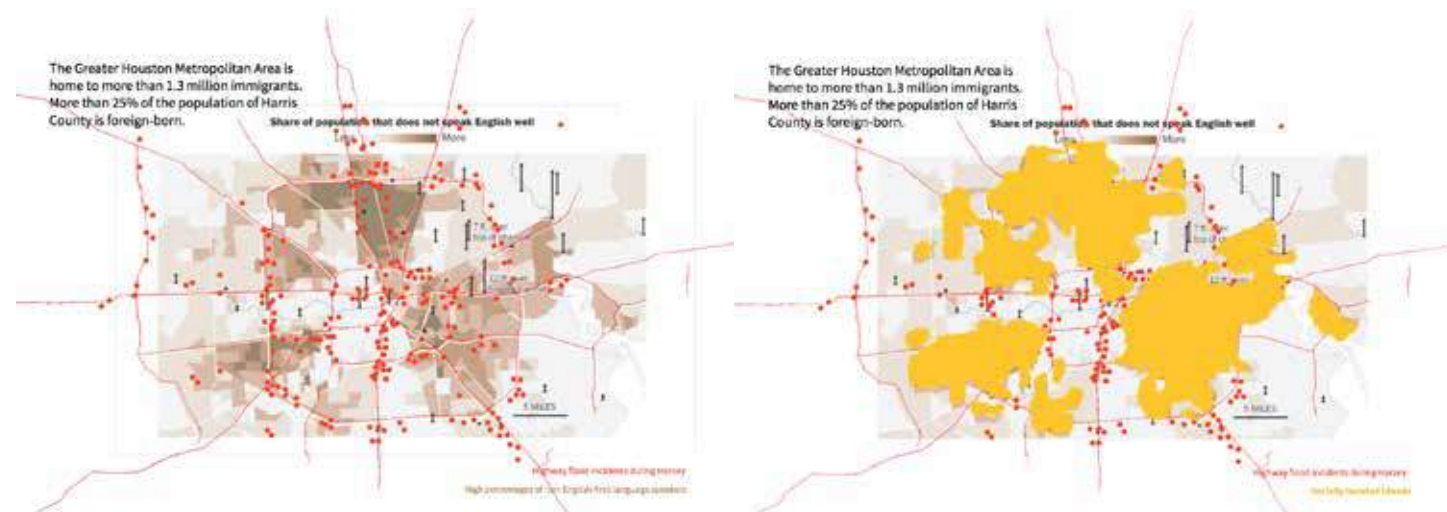


Figure 12: Houston as socially isolated islands during Harvey, over image by Washington Post, 2017

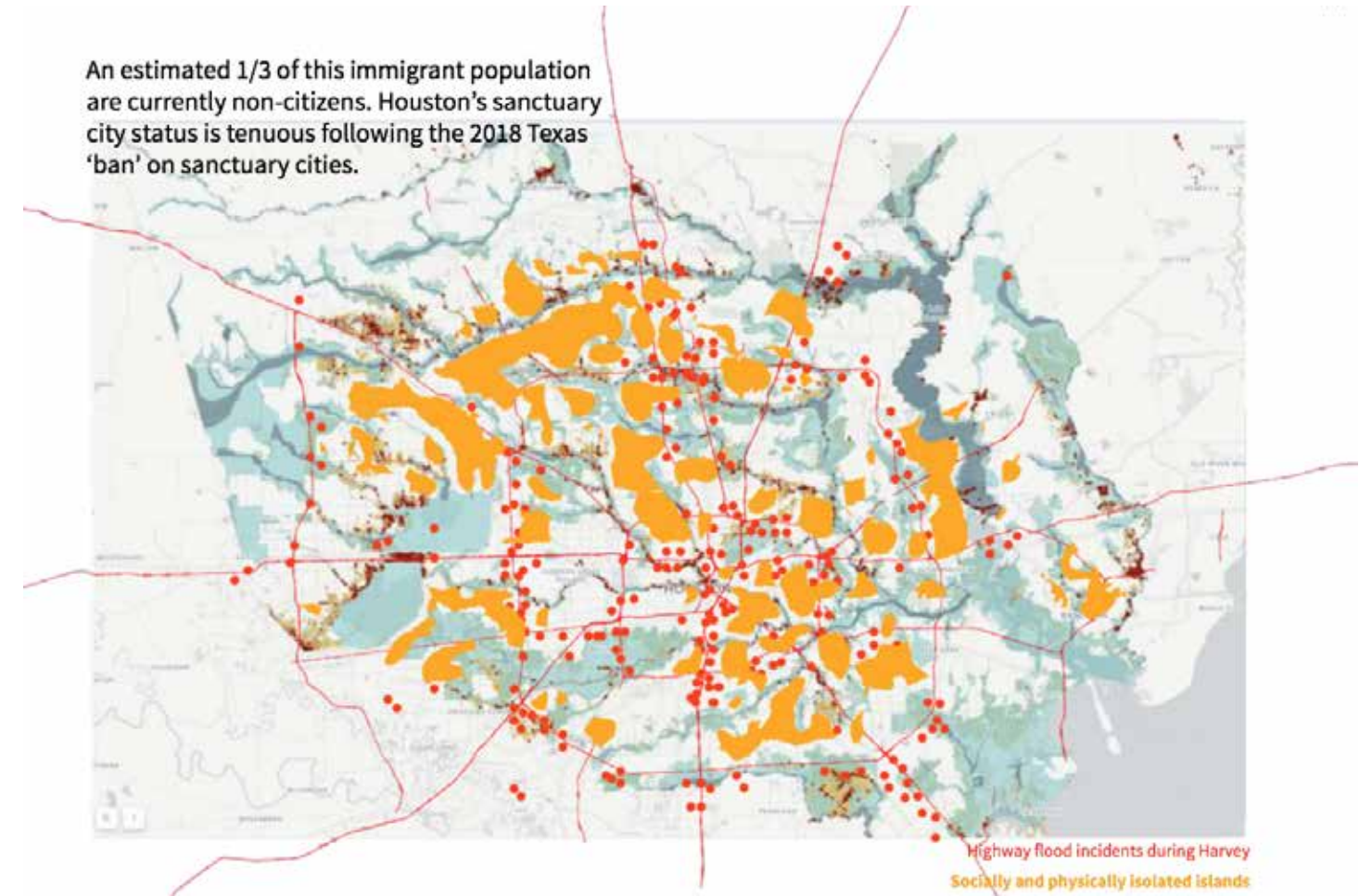


Figure 13: Houston as socially and physically isolated islands during Harvey

The fourth level of vulnerability is information shortage, before, during and after flood events. Many Harvey-flooded properties in Houston were not made sufficiently aware of their floodplain vulnerability, particularly the subdivisions built inside the flood well of the Addicks and Barker Reservoirs. Some homeowners say the flood risk was written in the fine print or not present at all in their contracts. A project by TAMU Galveston professor Sam Brody called Buyers BeWhere is a web tool allowing homeowners to find a risk assessment score for any plat in Harris and Galveston counties.<sup>94</sup> With tools like this one, academics are taking it upon themselves to take information and make it accessible to the public, because depending on the storm, any Houstonian can live in the floodplain.<sup>95</sup>

During flood events, information is distributed through radio, television, and social media, but during Harvey these methods did not prove effective. The two categories of vital response during Harvey were threat-driven response of the hurricane itself, and even-driven response, further hazards related to possible dam failure and sequential release.<sup>96</sup> Though Houston at large rightly determined any call for citywide evac-

91 Id., 50 – Indirect Damages, Environmental Damage.  
 92 US Census Bureau, *Limited English Speaking Households*, 2017.  
 93 Id.

94 See Appendix C for web tools  
 95 Anecdotal - phrase from local Houston residential architect  
 96 Hurricane Harvey Report. Id., 63 – Evacuation

uation would cause more problems than it would solve, some smaller cities still called for mandatory evacuation, including Bay City and Sugarland. This is an example of threat-driven response, and on the small scale of these examples, worked quite well. Event-driven response includes the alert that the Addicks and Barker Reservoirs would undergo controlled release to save the infrastructure from massive failure. Residents along the Buffalo Bayou were warned the day before that controlled release would occur in the night, and were advised to gather belongings and evacuate at sunup. The Addicks release was slated to start at 2am, with Barker releasing 24 hours later, but was moved up to 12:31am, and word was sent out via tweet.<sup>97</sup>



Source: Twitter, captured 2018



Reservoir release during Harvey, source: ProPublica, 2017

During these turbulent events, many unofficial platforms attempted to help spread information. In one example, Waffle House updated Twitter with location closures that were used to pseudo-analyze the worst flooded areas.<sup>98</sup> Other more sinister and sensationalist misinformation was spread via social media platforms like Facebook and Twitter.<sup>99</sup> These tools served as multipliers for both accurate and inaccurate updates, resulting in general confusion during the continued flooding as conflicting information spread across the internet.

Even after the Hurricane Harvey exited stage right, residents remain unclear whether their damages are actionable. The federally funded buyout program is encumbered by legalese, and residents must negotiate applying to the program before they can even graduate to benefiting from it. As we fast approach another hurricane season, many Houstonians are still displaced or rebuilding from the last one. Lastly, there is inaccessibility to the information we do have concerning how individuals can prepare for flood events. The City of Houston added a 43 page document to its emergency preparedness cite in 2016.<sup>100</sup> The document contains, on the last page, instructions for ordering the document in other languages.<sup>101</sup> Smaller local bodies have taken on the onus of disaster preparedness, with upcoming Hurricane Town Hall meetings during the summer of 2019.<sup>102</sup>

97 “COE Releases on Addicks and Barker Reservoirs has started,” @JeffLindner1, Aug. 28 2017.

98 Id., 65, Emergency Response

99 Id., 76, Communication: the effects of ‘Fake News’

100 See Appendix C for online material for emergency preparedness.

101 See Appendix A for reference

102 See Appendix C for scheduled town halls for Houston resiliency

Any plan to mitigate flood risk in Houston must address these vulnerabilities. The immobility, isolation and information deficit are all necessary levels of social architecture that exceed the capabilities of the Ike Dike spine proposal. Any plan must also emulate the multi-functional intervention of the Delta Plan, employing both hard and soft mitigation tactics to plan for the future. Any plan must also address the underlying causes of Houston’s manmade vulnerability, reversing past measures where possible and preventing their spread everywhere else. Lastly, this plan must be spatially and temporally fractal, scalable to the individual, the neighborhood, and the region, on the right-now timeline, the 2050 timeline, and the 2100 hundred timeline. What Houston needs, is a String of Pearls.

### Long term, multifunctional infrastructure

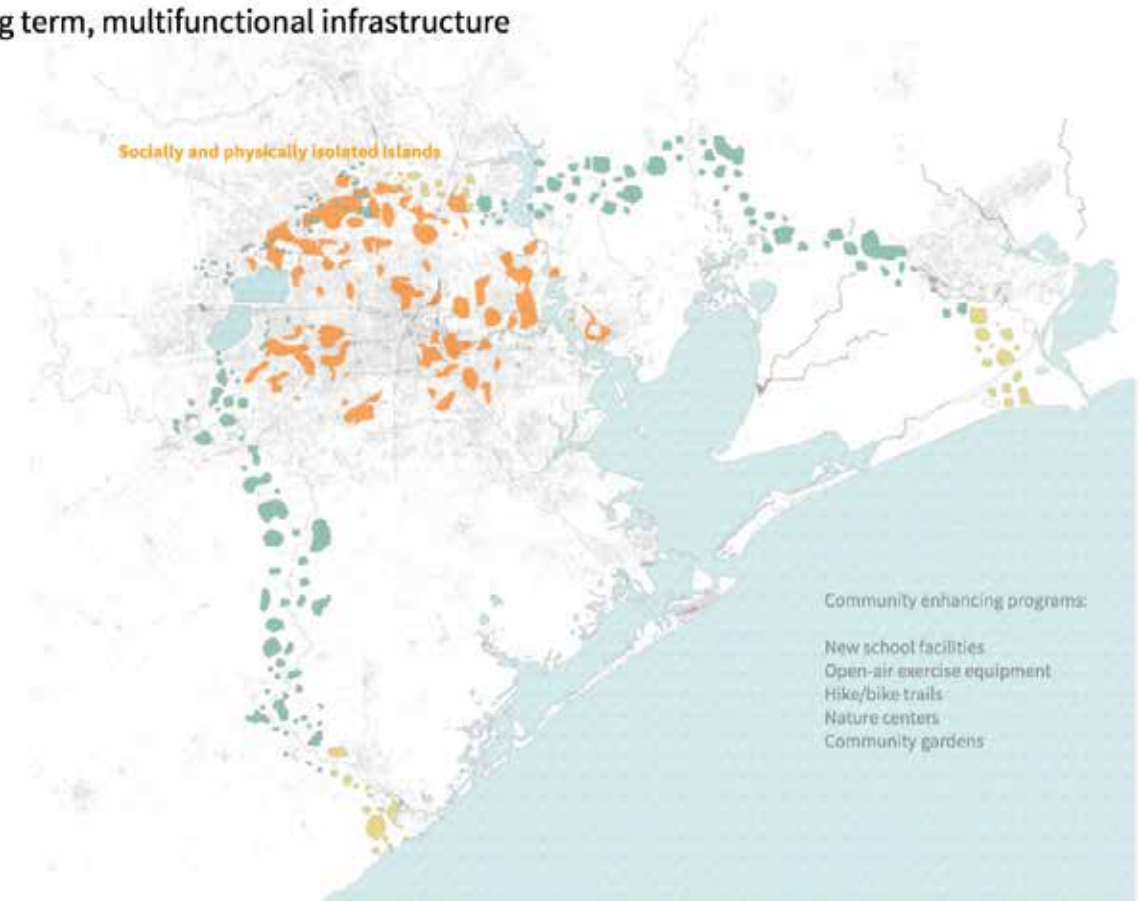
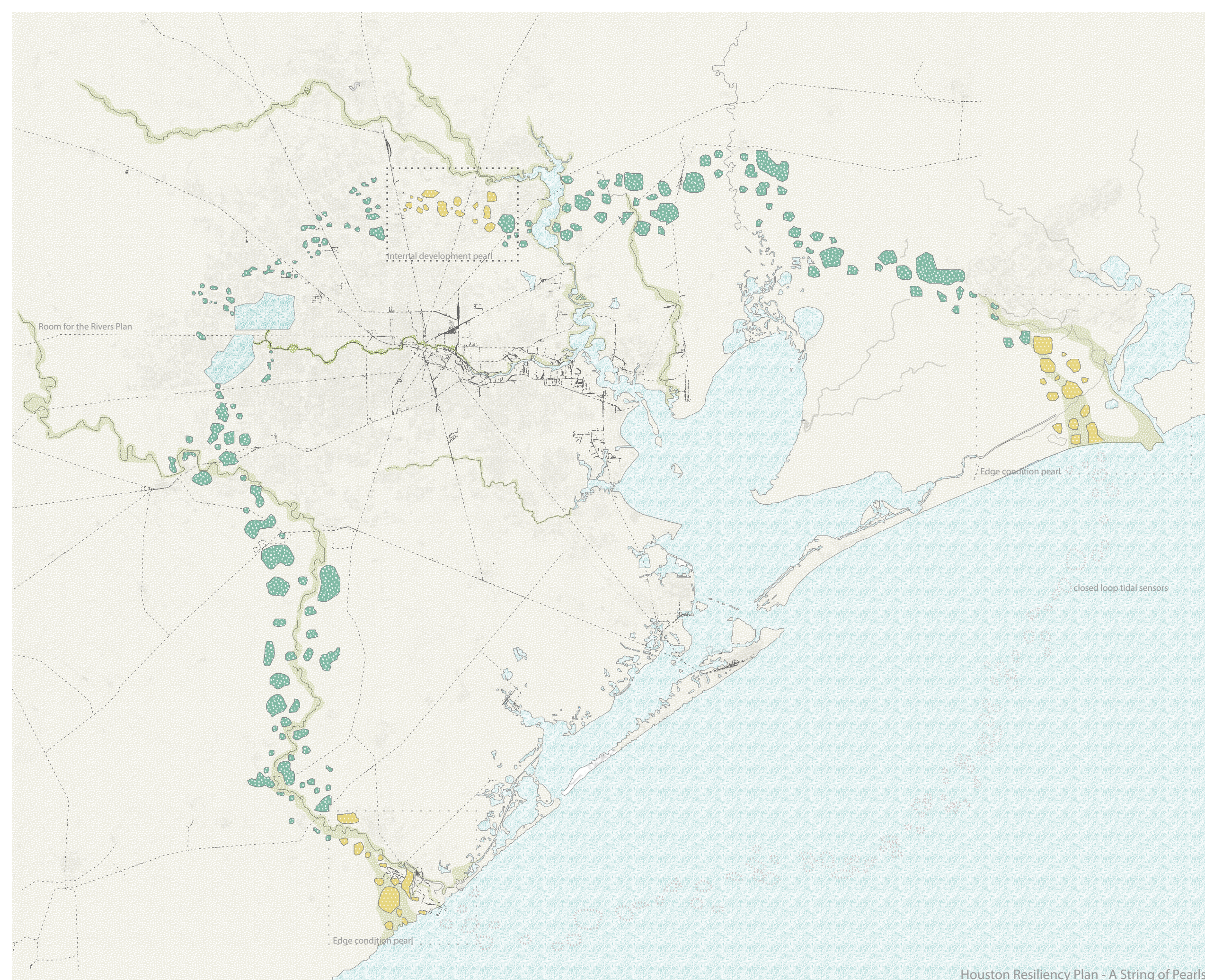
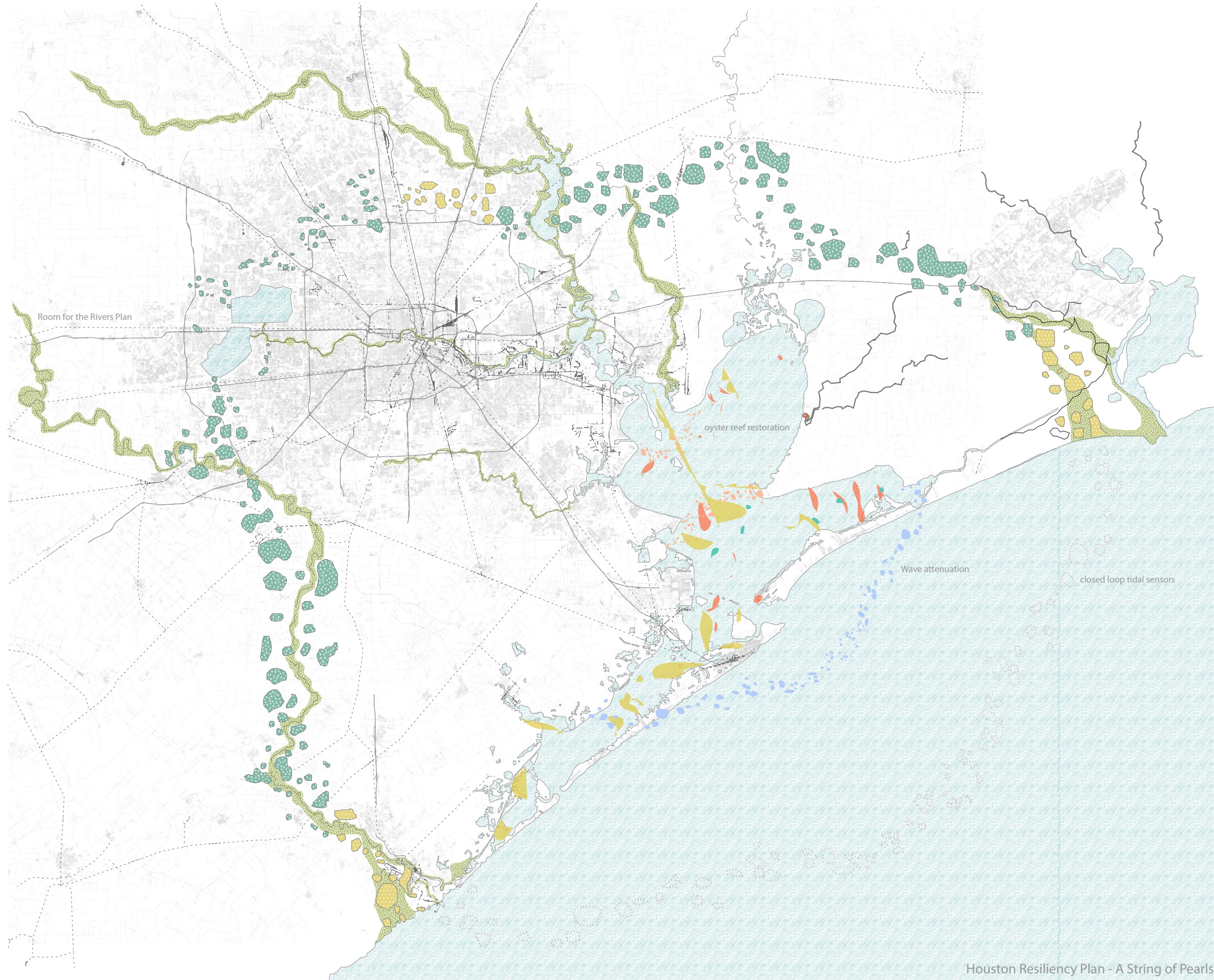


Figure 14: String of Pearls intersects with physically and socially isolated islands



The String of Pearls is a chain of sustainable development pods centered around retention reservoirs that function as recreational space at all other times. This image is both representational and metaphorical, meaning that each Pearl increases in tangibility as the study zooms further inward. The highlighted Pearls show the first areas that merit the next step of interrogation. The Pearls are low-impact developments with minimal impervious cover.

Figure 15: The String of Pearls



The String of Pearls also incorporates soft infrastructure into its spatial planning. Here you can see oyster restoration projects in pink, with past and present oyster reefs in green and yellow. The Deltawerken used natural mitigation efforts like sand nourishment and wave attenuation as contingency plans that will adapt to their changing climate. The Pearls scheme must also use soft infrastructure planning like oyster seeding to give Houston longevity and natural resiliency.

Figure 16: The String of Pearls - soft infrastructure



## 4.0 Houston as a String of Pearls

The String of Pearls is a multivalent resiliency strategy for Houston, Texas, with three thematic categories - the Pearls, the Bayous, and the Archipelago. The scheme is a fractal solution that can be implemented at many scales, and aims to mitigate Houston's compound vulnerability through physical and social planning. The Pearls relieve the pressure on the overburden bayou watersheds and divert excess flow outside of the normal release zone. The system is multi-functional, emulating the Delta Work's usefulness during and beyond the rainy season. The Pearls can be implemented as Houston's main mitigation strategy or as a complimentary system to the proposed Coastal Spine. The Pearls also have natural relationship with many parts of Houston, not solely the city's edge, and can serve as catalyst for the zones of the city we have identified as the most vulnerable during flood events.

### 4.1 The Pearls

The String of Pearls is a chain of pro-development pods centered around detainment reservoirs to relieve the pressure on the overburdened bayou system. The String of Pearls catches and stores water during rainfall events, and releases it outside of the highly vulnerable Galveston Bay, effectively circumventing the compound flood zone of central Houston along the Ship Channel. They augment a modified version of the Ike Dike proposal, filling its gaps in scope. The Pearls are public-private partnerships facilitated by extra-governmental bodies like Central Houston, a corporation that develops place-making urbanism in the city's downtown.<sup>103</sup> Partnerships that imitate this corporation will be formed for each of the Pearl zones, combing local input, design skillsets, and public and private funding to craft place-makers in each neighborhood that benefit the communities around them.

The String of Pearls accepts that any scheme that is anti-development will not succeed in Houston. Because of this, each Pearl is a site-specific example of sustainable development, a car-less neighborhood situated along existing commercial rail lines with new schools, single and multi family homes, small businesses and recreational zones that can act as reservoirs during storm events. Free from car-dependency, the Pearls minimize impervious cover while maximizing walkability and passively healthy living. Each green space reserved as emergency reservoir space will enforce minimal development, with only educational visitor

<sup>103</sup> See Appendix C for local Houston companies working on sustainable urbanism

centers and public bathrooms built on site. The commuter needs are satisfied by Shell sponsored electrical transit pods, which pop on and off the existing rail lines to bring residents into the downtown during peak commuter hours. The student population is ferried laterally by School Trolleys, the sustainable evolution of the school bus, where students can get tutoring help and healthy breakfast on the way to class.

The new school system is a series of Big Energy-sponsored elementary, middle and high schools, which employ technology and sustainability-savvy faculty to teach the Green Curriculum. The Green Curriculum augments the Texas standard requirements while also rooting education in the past, present and future of the anthropocene. The Green Curriculum at the high school level guarantees top 15% graduates admission into the top environmental studies, sustainable engineering, and environmental law programs at public universities throughout the state, including the University of Texas and Texas A&M sister school systems as well as city universities. The Green Curriculum also incorporate energy internship into the curriculum, allowing upperclassmen to spend part of their school day gaining valuable insight at their sponsoring Energy Company. For students that don't pursue college education, each Energy Company partner guarantees admittance to an affiliate technical or trade school focused on alternative energy production, a direct link to future employment in the Energy Capital of the World.

The String of Pearls is a long-term plan, and can be likened to the Delta Works in their scope. But unlike the Deltawerken, the Pearls strive to help Texans out of preexisting vulnerabilities associated with low-income neighborhoods – education and employment. The new home construction will help fund the other public programs present in the Pearls, the private partnership with energy giants will help communities prosper while the corporations gain positive public image and a future employment force of well-educated graduate and skilled tradesmen. Yet this construction process will take time, an estimated 50-70 years from initial planning to completion, even in a city with Houston's impressive development resume. To truly implement an effective plan, intermediate steps must be taken.

### 4.2 The Bayous

The String of Pearls is augmented by Buyout the Bayou, a plan to gradually subtract development from the edges of our bayous to allow for their widening and deepening. The buyouts are facilitate by the existing Harris County Flood District buyout program, but once acquired the land is ceded to the EPA for re-naturalization of the bayou section. A staff of ten full time employees is assigned to each bayou to facilitate the application process, as well as mediate between neighborhood associations and the EPA when the bayou

widening comes into effect.<sup>104</sup> The return of the bayous to natural state will be accompanied by running trails, pedestrian bridges and rain gardens to naturally clean water and provide more beautiful views for residents who opt to stay. The 21<sup>st</sup> century will see cities rise and fall by the use of their urban waterfronts. The Bayou City has tremendous place-making potential now underutilized in its internal water's edges, and the time is ripe for a rise in the city's perceived livability. This plan allows for flexibility in bayou capacity to allow for the estimated sea level rise in the area by 2100. This process is expected to take 30 years to complete, but it is encouraging that it has already started. This initiative can also feed into the existing Houston Bayou Greenways Concept by Bayou Greenways 2020, referenced below.<sup>105</sup>



Source, Houston Parks Board, 2016

If more land is acquired than the EPA deems necessary to expand bayou capacity, local artists can work with residents to memorialize the heroic actions of the Volunteer Navy during Hurricane Harvey. To date there are 100 proposed improvements among the 22 watersheds of the Bayou City<sup>106</sup> - these can be populated by the local artist projects. The new art map of the Houston bayous, like its precursor in Holland, will add an imagery of memory that the residents deserve, commemorating their loss and their strength.

<sup>104</sup> This is modeled after a collaborative approach to flooding in North Carolina, where the state worked with communities affected by Hurricane Fran of 1996 to explore available options. In some cases, entire communities opted to relocate together. Referenced in Consortium, 11.

<sup>105</sup> Referenced in Blackburn, 44. Image courtesy of Houston Parks Board.

<sup>106</sup> Id., 43.

### 4.3 The Archipelago

Additionally, the Archipelago is a possible system of social programs that arms the physically isolated islands depicted in figure # to protect and react to flood events. Each island is a Flood Village, with a board of volunteers and local leaders who will be trained to disseminate information and aid to their respective constituents through social media. The Village leadership will be equally representative of the varying income brackets that comprise the affected Village area, and distribute information in every language representative of the Village populace. Each island Village will be outfitted with emergency response services housed in existing unused buildings, and will designate a school or community center with the capacity to serve as home base. Food, water and clothing will be kept at the home base, and will serve as the town hall for each Flood Island prior to hurricane season so that residents are familiar with the location. The town hall venues will hold meetings with their flood constituents bi-monthly, and form emergency response volunteers that are familiar with sandbag protocol and can aid families in flood-proofing their homes. Residents will be informed which Flood Village they will have access to during flood events, and will be encouraged to participate in Island planning measures prior to disaster events. This plan can be enacted immediately, using social media and neighborhood leadership to ensure Village Leadership is trusted to receive and interpret citywide information.

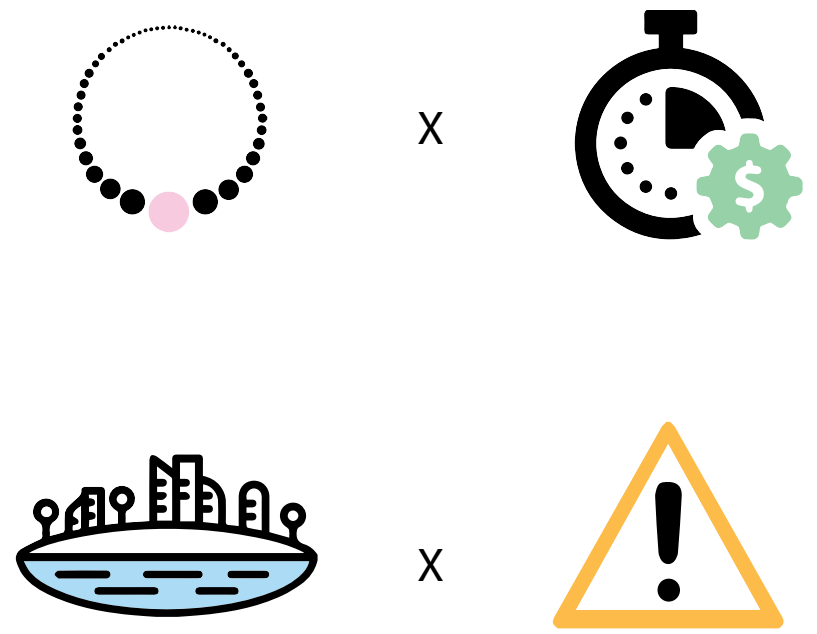
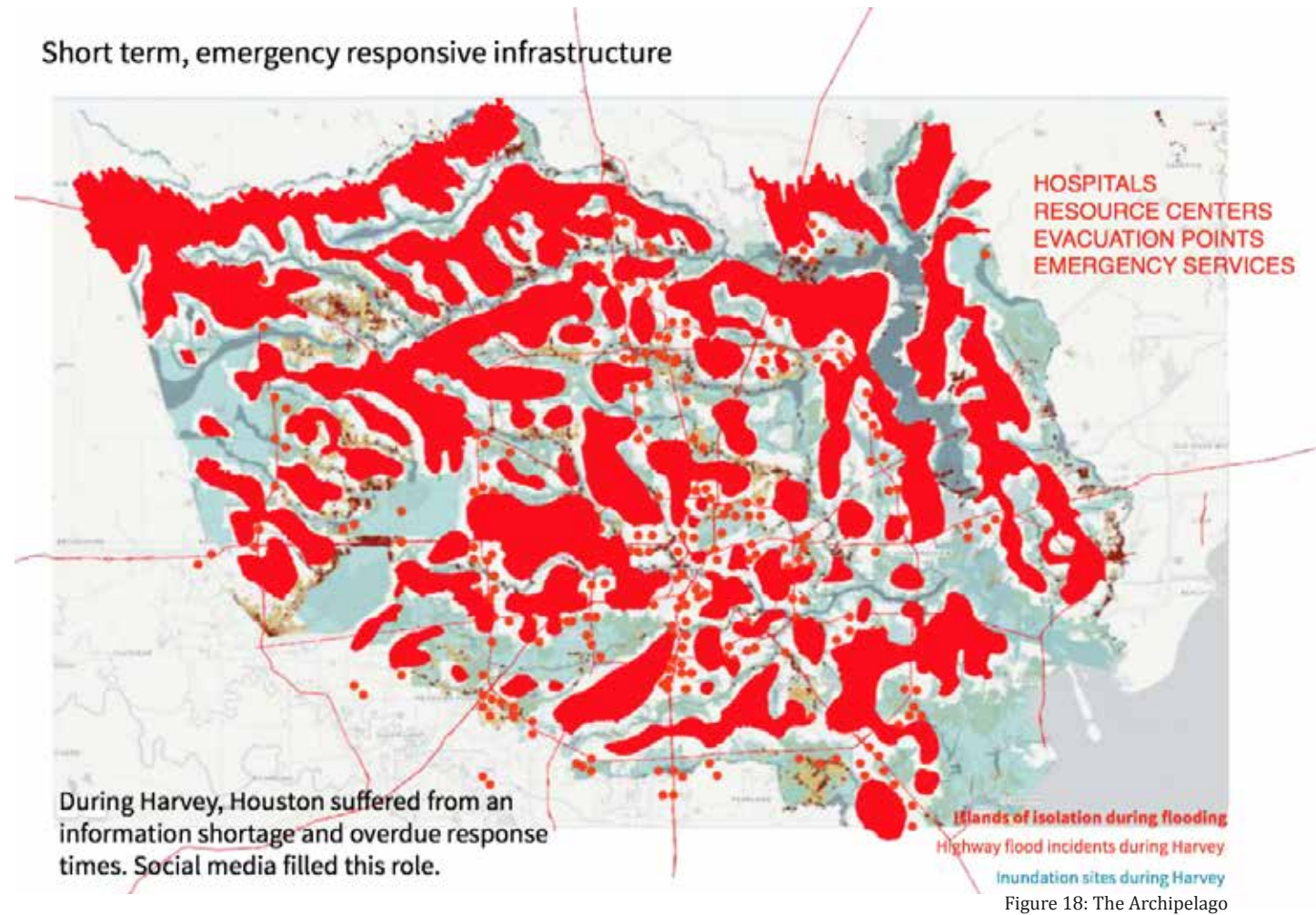


Figure 19: graphic for temporal scale of projects

## Short term, emergency responsive infrastructure



The multivalent resiliency plan contained herein is tripartite – the Pearls, the Bayous, and the Archipelago. Each piece is fractal in the scales of space and time. Each piece accounts for the social needs of the affected areas. Each piece intends to decrease the vulnerability of the Houston populace regardless of income or immigration status.

This String of Pearls is an opportunity to craft physical and social infrastructure that can protect against worst-case scenarios, but also act as productive pieces of the city outside the rainy season. With the wealth disparity present in Houston, the disproportionate burden these issues and their infrastructural solutions will place at the feet of our most vulnerable populations is a powerful precedent to set for other American resiliency plans. Careful assessment of the Dutch precedent is a useful method to interrogate our own needs specific to Texas. Combined with an approach informed by the city's history, demographics, and economic power could set the tone for other Sentinels in the American South. The penultimate goal of this thesis is translation: from data to visualization, from private knowledge to public knowledge, and from victim to victor. Together, we can build a better Texas – and it starts in Houston, our Sentinel City.

## 5.0 Conclusion

This report has demonstrated through research, observation and design the compound vulnerability and its proposed mitigation in Houston, Texas. The city is a complex organism that faces multisystem failure from the compounding effects of human intervention on a natural environment already predisposed to flooding. Both historical and recent events lead us to treat Houston, Texas as the direst Sentinel City, but the metropolis also has a great capacity to serve as a model for other urban resiliency plans. Any scheme that is proposed to aid Houston must treat the underlying causes of the rampant flooding as well as its symptoms.

The proposed Ike Dike Coastal Spine is the foremost among Houston-area resiliency schemes, but it does not attempt curative methods of addressing Houston's predisposition to flooding. Further study of its main precedent, the Deltawerken of the Netherlands, reveals deep differences in methodology between the two schema. However, Houston can still learn from the Dutch precedent, particularly its social architecture that complements and empowers the physical. Using these ideas, the String of Pearls is a strategy that employs spatial and social programming to set a sustainable example for development in Houston. Through the addition of development Pearls and subtraction along the bayous, the String of Pearls outlines a future that Houston is perfectly positioned to attain. The Pearls strategy also initiates its tripartite measures in order of immediacy, with the organization of the Archipelago as emergent programming, in a kind of soft phasing. The String of Pearls aims to act on different scales of space and time. The schema both critiqued and proposed herein can be applied to other Sentinel Cities in the United States, the first metropolises in the country to exhibit signs of climate change related stress, and around the world.

The main limitation of this report is the lack of community outreach. One of the central narratives of the String of Pearls infrastructure is resident involvement. If taken further, this report would work with Houston communities in the Archipelago targeted zones to craft holistic models of the social programs described. Cities of the 21<sup>st</sup> century will rise and fall by the way they handle urban water, and the extent to which they allow their public to drive that negotiation. Houston is uniquely suited to lead the charge into our science fiction future of climate-augmented storms and sea level rise. The city's founding, formation, growth and prestige are her armament – the future of American resiliency is her inheritance. It is the hope of this report that the Houston of 2100 is a stronger, more equitable and sustainable Sentinel City.

The stage is set, the cast is chosen and the world is watching – Houston, what will you become?



## 6.0 Author Biography

Dana Moore is a native Texan, born in San Antonio. In her five years at UT, Dana was honored by the Dedman Distinguished Scholarship and pursued her dual degree Bachelor of Architecture and Bachelor of Arts in Plan II Honors. Dana spent her time biking to Alaska, traipsing across Europe with sketchbook in hand, and gaining work experience in Austin, Boston and New York City. Dana was fortunate to receive a Plan II travel grant to visit faculty at Deft Technology University and see the Deltawerken firsthand in the Netherlands. After graduation, Dana will return to New York City to pursue various employment opportunities. She hopes to continue the union of science fiction and architecture in all her future endeavors.

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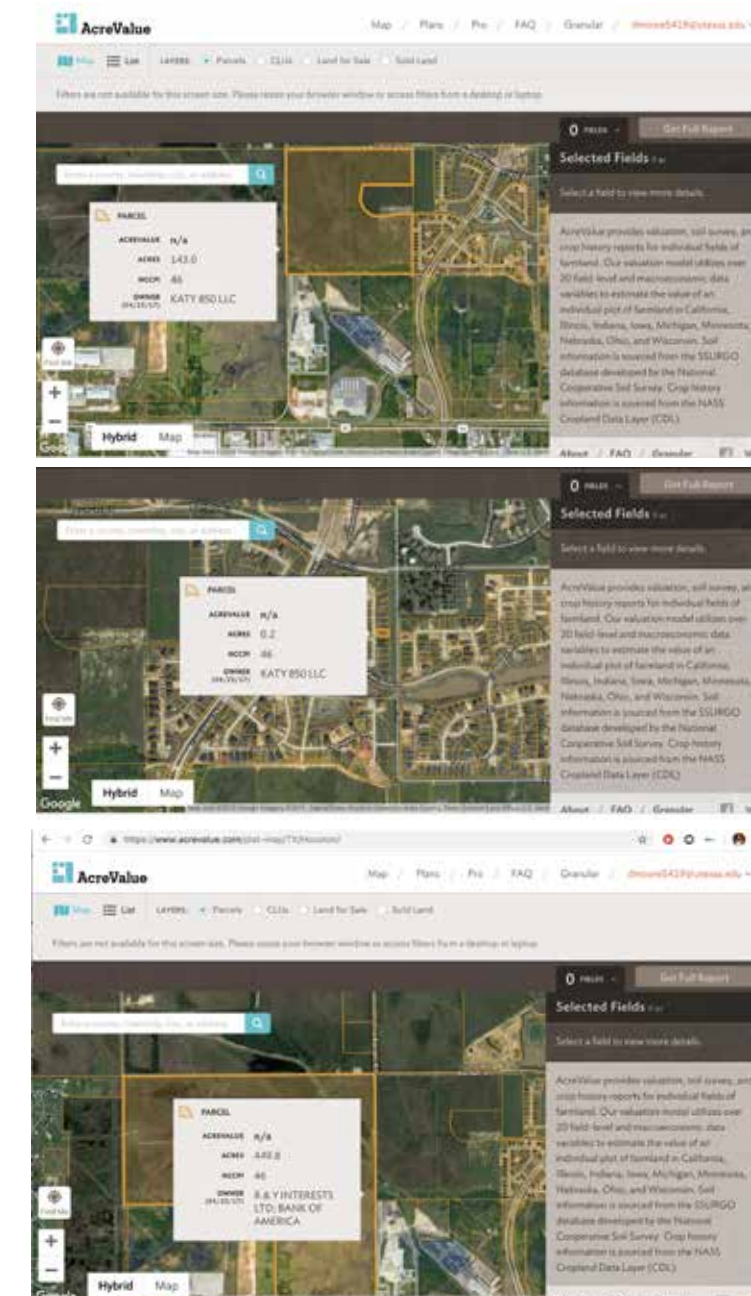
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## 8.0 Appendices

The appendices A and B hold extended imagery from sources and from travel documentation. They are included here in alphabetical order by topic. Appendix C contains web tools and useful online sources for how to get involved with Houston's flood mitigation journey.

### Appendix A - Extended Source Imagery

AcreValue.com



Source, AcreValue.com

Noord-Holland  
**AMSTERDAM**  
Binnen het getroffen gebied

**plek** Stadhuis, entreehal  
Normaal Amsterdams Peil

**kunstenaar** Louis van Gaasteren (1922) en Kees van der Veer (1948)

**object** reliëf met dwarsdoorsnede van Nederland en drie waterkolommen




**maten** lengte van het reliëf 25 meter

**materiaal** zandsteen, donkergrijs arduin, glas en aluminium

**onthulling** bij de opening van het stadhuis op 18 mei 1988

**eigenaar** Stichting Normaal Amsterdams Peil

**details** Uit de kelderruimte waar de NAP-paal staat, stijgen drie waterkolommen op. Twee daarvan geven de actuele waterhoogte bij IJmuiden en Vlissingen aan. De derde kolom geeft de bijzonder hoge waterstand van de watersnoodramp in 1953 weer. Het water kwam toen 4,53 meter boven NAP, 2,46 meter hoger dan normaal.

38 39



Zeeiland  
**OUWERKERK**  
Schouwen-Duiveland

**plek** Watersnoodmuseum  
Weg van de Buitenlandse Piers 5

**maten** 20 x 60 x 20 meter per caisson

**materiaal** vier betonnen Phoenix caissons  
Gebruikt door Rijkswaterstaat in 1953 om het gat in de dijk bij Ouwkerk mee te dichten.

**details** Deze caissons werden overgebracht uit Engeland waar ze oorspronkelijk bedoeld waren om te gebruiken bij de invasie in Normandië in juni 1944. Op 6 november 1953 werd onder grote (ook Koninklijke) belangstelling het laatste gat in de Zeeuwse dijken gedicht. Jarenlang lagen de caissons er ongebruikt en verlaten bij totdat in 2001 vooral door de inzet van Ria Geluk in één caisson het begin werd gemaakt voor het Watersnoodmuseum. In 2003 kreeg het museum het predicaat Nationaal Monument en in 2009 volgde de opening van alle vier de caissons.

Delfts blauw bord uit de collectie van het museum.

6 7

Noord-Brabant  
**FIJNAART/HEIJNINGEN**  
gemeente Moerdijk

**plek** Hoge Heijningsedijk

**kunstenaar** H.J. (Henk) Elerme (1895-1968)

**maten** 240 x 70 x 90 cm  
op heuvel van basaltkeien van 8 x 5 m

**materiaal** kalkzandsteen uit Eindhoven (FC)

**opdracht** gemeente

**onthulling** 1 februari 1955

**details** Na de vorming van de gemeente Moerdijk is besloten ook de slachtoffers uit de oude gemeenten Willemstad, Klundert en Zevenbergen bij dit monument te herdenken. Op 1 februari 2003 is de naamplaat van zwart gepolijst graniet in een roestvrijstalen frame onthuld, waarop de namen staan van 103 slachtoffers. In 2008 is het beeld voor een grondige restauratie tijdelijk van zijn sokkel gehaald.





136 137

Zuid-Holland  
**NIEUWERKERK A/D IJSEL**  
rest van Zuid-Holland

**plek** Schielands Hoge Zeedijk  
tussen Ouderkerk en Nieuwerkerk a/d IJssel,  
bekend als de Groenendijk

**kunstenaar** Roel Bendijk (1937)



**titel** Dijkwerker met zandzakken op deel van boortwand

**maten** 145 x 240 x 110 cm

**materiaal** beton  
vloer van basaltblokken, 12 x 5 m

**opdracht** Hoogheeremadschap van Schieland

**onthulling** 12 oktober 1988 door schipper Arie Evegroen van de Twee gebroeders.

258 259





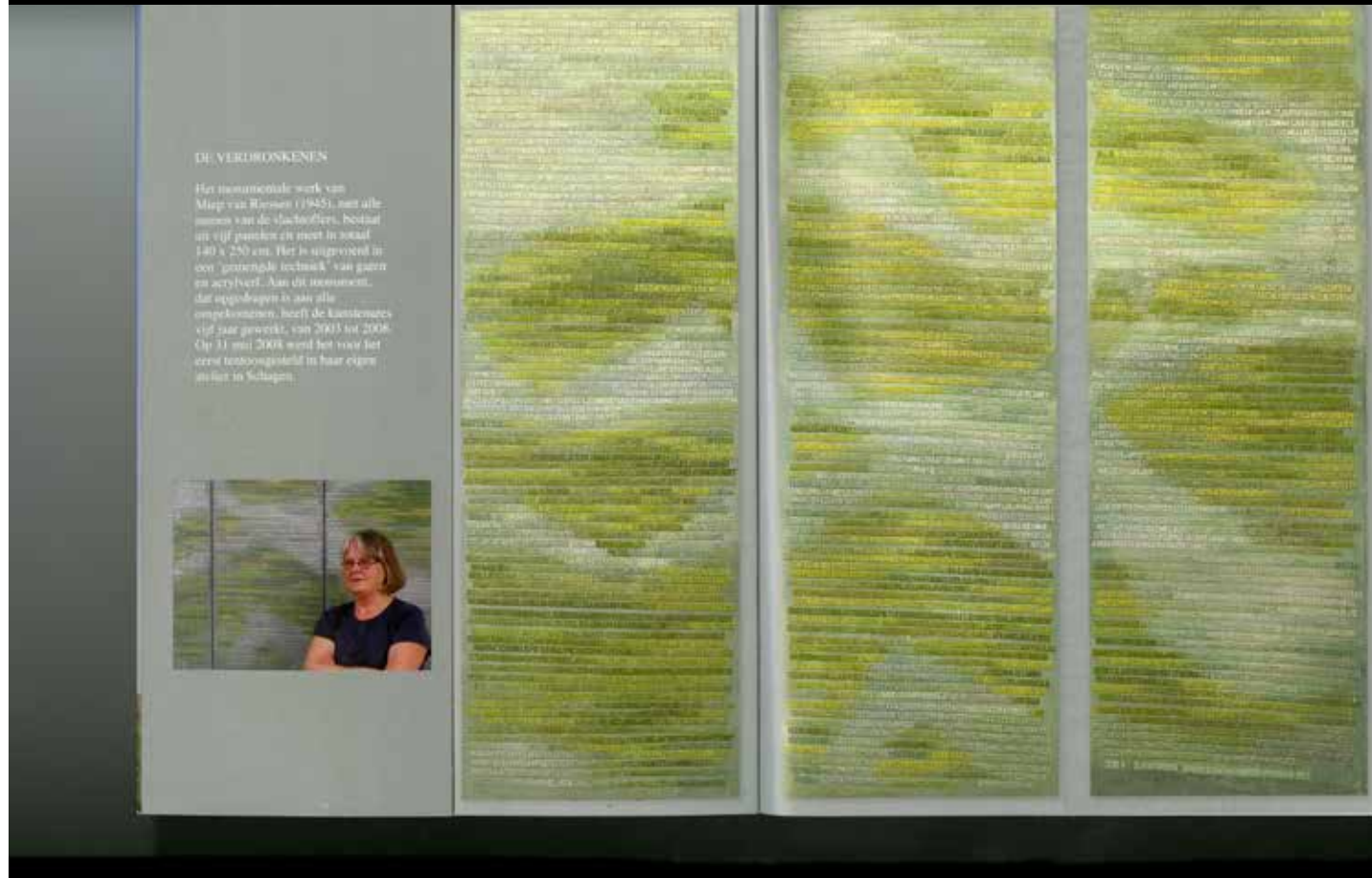
**DE SAMENSTELLERS**

Gefotografeerd in Amsterdam door een twaalfjarige voorbijaander. Deze geprojecteerde, de foto (1943) als lezer in Zierikzee, de tweede (1935) als lezer in Hilversum en de derde (1930) als conservator in Amsterdam. Op de bank op het Westinghousplein, die in 1959 geschonken werd door Schouwens-Duisveld aan Amsterdam.



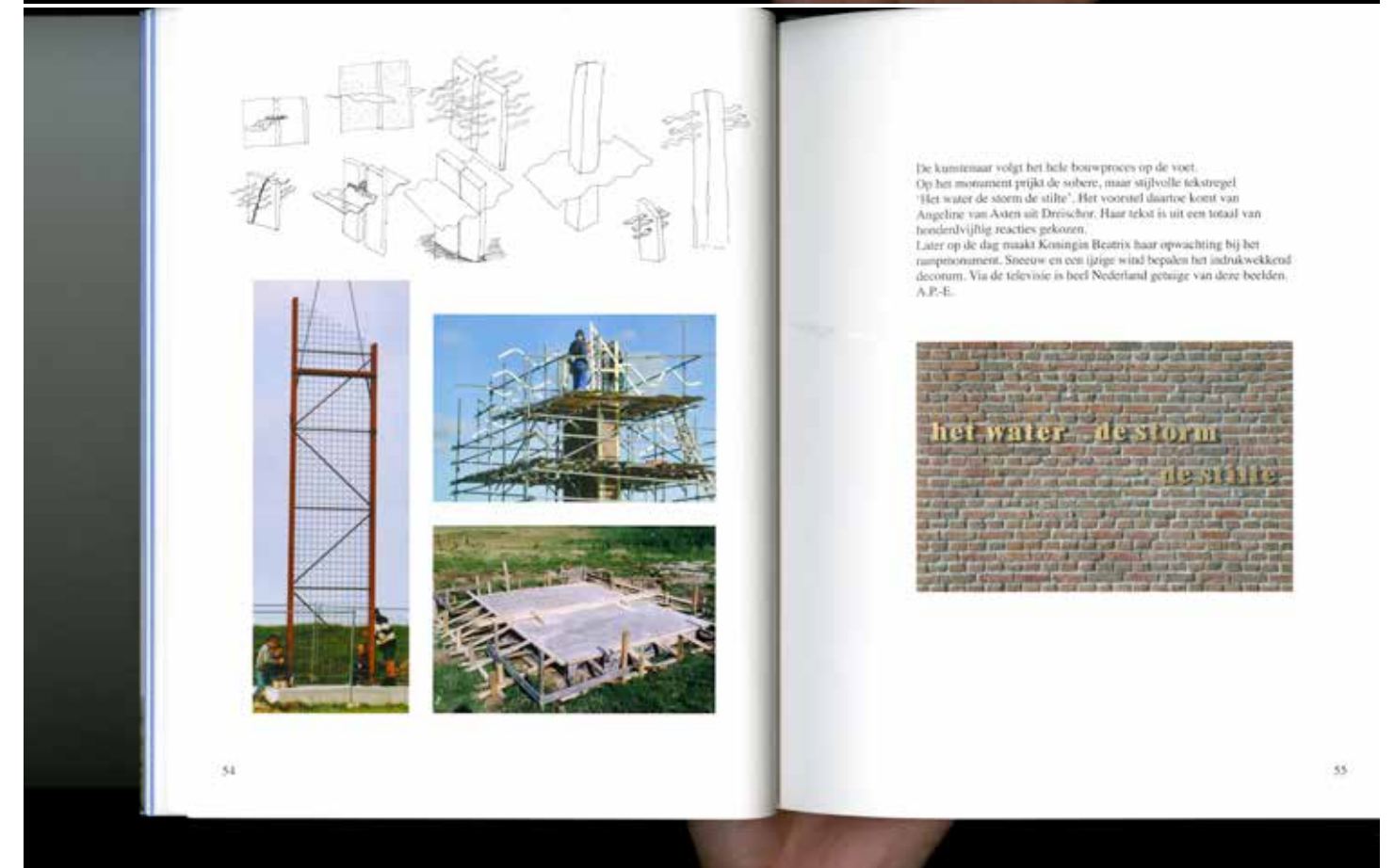
Zeeiland  
**OOSTERSCHELDEKERING**  
Schouwens-Duisveld

- plek** Aantet Oosterscheldekering
- titel** Sluissculptuur
- kunstenaar** H.W.M. (Bob) Stolzenbach (1943-1999)
- maten** twee blokken marmer van 250 x 50 x 300 cm  
marmeren grondplaat van 200 x 300 cm
- materiaal** marmer
- onthulling** 4 oktober 1986



**DE VERDRONKENEN**

Het monumentale werk van Miep van Rensen (1945), met alle namen van de slachtoffers, bestaat uit vijf panelen en meet in totaal 140 x 250 cm. Het is uitgevoerd in een 'grote stijl' techniek van gips en acrylverf. Aan dit monument, dat opgedragen is aan alle omgekomenen, heeft de kunstenaares vijf jaar gewerkt, van 2003 tot 2008. Op 11 mei 2008 werd het voor het eerst tentoongesteld in haar eigen atelier in Schagen.



De kunstenaar volgt het hele bouwproces op de voet. Op het monument prijkt de sobere, maar stijlvolle tekstregel 'het water - de storm - de stilte'. Het voorstel daartoe komt van Angelina van Avien uit Driessche. Haar tekst is uit een totaal van twaalf verschillende reacties gekozen. Later op de dag maakt Koningin Beatrix haar opwachting bij het rampmonument. Sneeuw en een ijzige wind bepalen het indrukwekkend decorum. Via de televisie is heel Nederland getuige van deze beelden. A.P.E.



Art from disasters - United States



Collage by author

“Your mission is to create images that are so compelling they can’t be forgotten, and so realistic they can’t be dismissed.”

-Barry Bergdoll, MoMA curator of Rising Currents Exhibiton



Houston Chronicle.

Blackburn - further imagery of Houston Solutions

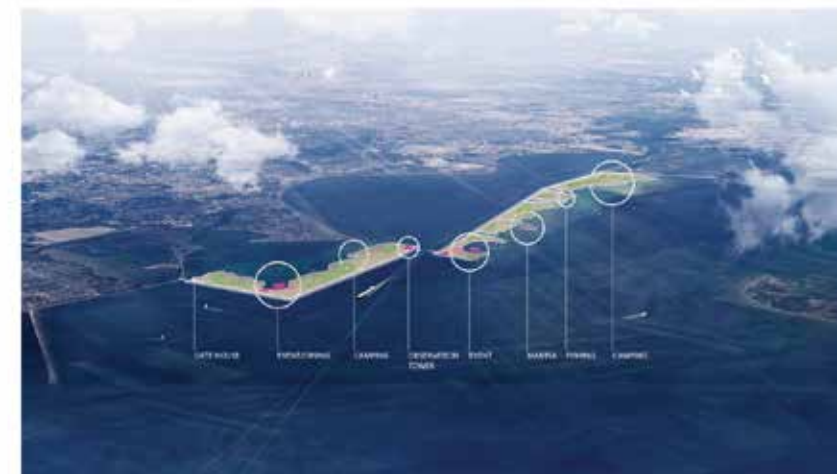
Figure 28. The Clear Lake Sign Erected after Hurricane Ike



Note: This sign was removed after only being in place for a couple of months because it interfered with real estate sales.

Source: Photo from author's collection

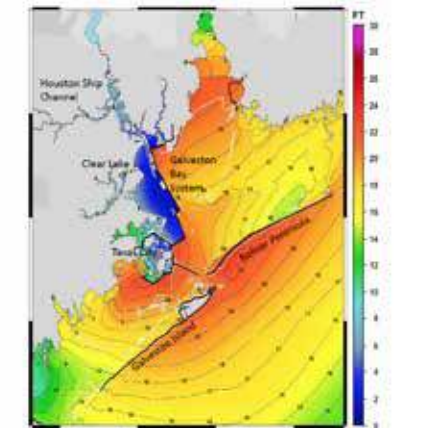
Figure 32. The Galveston Bay Park Alternative



Note: The Galveston Bay Park alternative is shown here connecting the Texas City levee system at the bottom left with high land on western shore of Trinity Bay in Chambers County at the upper right. Some recreational concepts are also depicted.

Source: Image and conceptual plan courtesy of Rogers Architects

Figure 33. Map Showing the Effectiveness of the Mid-bay Alternative



Note: This map shows the placement of the mid-bay alternative, including the Galveston backside levee alignment and elevated roadways along the coast, for a small Category 4 storm coming ashore along the southern end of Galveston Bay and the Houston Ship Channel.

Source: Analysis by Dr. Clair Dawson for the SRPED Course

Galveston Hurricane

BuyersBeWhere - Brody

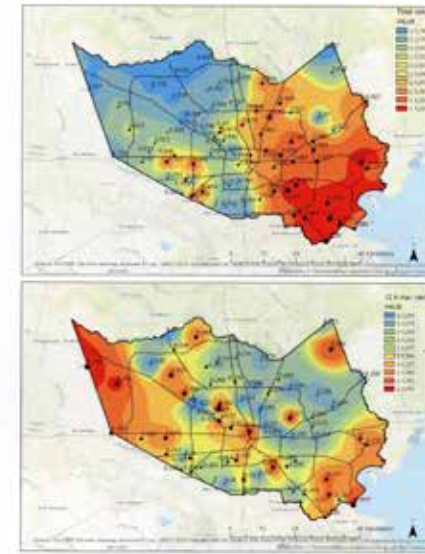


Figure 4.4 (a) Cumulative 5-day precipitation totals (in) and (b) maximum 12-hour rainfall (in) intensities in Harris County, Texas. Red areas indicate the highest precipitation totals whereas blue areas indicate the lowest. Black dots show the location of precipitation gauges.

An overview of the HGFC stream gage network is presented in Figure 4.5. The red markers illustrate locations where water levels exceeded the top of the channel at 12:00 AM (CDT) on August 28. By the morning of August 30, much of the water had receded from the neighborhoods and returned to within the confines of the channels with the exception of Cypress Creek, Buffalo Bayou, and Clear Creek, where local watershed conditions prevented the water from receding quickly.



Figure 4.5. Status of the HGFC stream gages as of August 28, 2017 12:00 AM (CDT). Locations marked in red are out of bank and locations in yellow are near the top of bank. Figure courtesy of Mps (www.harriscountytexas.org).

Record-setting flooding during Hurricane Harvey occurred throughout the greater Houston region. To give the reader a sense of the extent and severity of flooding region-wide, the following sections focus on the hydrologic and hydraulic response in a few key watersheds: Buffalo Bayou and contributing areas, the San Jacinto River and Houston Ship Channel, and the Brazos River.



Figure 4.6. Map showing the locations of key areas discussed in the following sections: Buffalo Bayou, the San Jacinto River, Lake Houston, and lower portion of the Houston Ship Channel, and the Brazos River near Sugarland, Texas.

Figure 4. The Great Hurricane: Galveston Island, September 8th, 1900 (Image Courtesy: Library of Congress, USA)



From Kothuis, see Bibliography for full citation

The people who were exposed to the floods had to be rescued (by emergency workers), to escape (by themselves or with help from other citizens), or to wait until the water was gone. A first review of the acquired data shows examples of all of these. More data are needed to get an overview of the number of people rescued by emergency services or by other citizens as the required means (as the amount of boats, firemen etc.) to save them. Also in multiple areas the water level declined so quickly that people did not have to escape or be rescued.



Figure 6.4. Texas National Guardmen rescue a resident by boat during flooding caused by Hurricane Harvey in Houston, Aug. 27, 2017. (Courtesy of Army National Guard photo by Lt. Zachary Ward.)

**Evacuation response and individual choices**

Evacuation decisions can also be considered as symbols. The decisions made by authorities are not always fully responded to, as even in case of a mandatory evacuation some people will not evacuate. This was also the case in Houston. In case of large-scale events like Harvey, it is impossible for authorities to check all houses and force people to evacuate. Evacuation decisions by authorities therefore have a strong symbolic value to encourage people to act (and most people will do so). However, each individual makes their own decision how to prepare depending on their own values, circumstances and information at hand. Parts of this information can also come from unexpected or unconventional sources. For example from 'The Waffle House', a fast food company that tries to be open during storms as long as possible. When they close (code red), the situation is considered really bad. In general, other businesses, organizations and people act sooner. Figure 6.5 shows the 'storm's severity index' used by the Waffle House and their locations that were closed during Hurricane Harvey, seemingly even for FEMA an indication of the gravity of the event. During Harvey, a wide variety of response measures by the government, people and businesses could be seen in the timeline of the event we compiled in the Harvey Hackathon. People were not only rescued by rescue workers, but in many cases by fellow-citizens as well.



Figure 6.5. Example of better message by 'The Waffle House' and the index (image courtesy of Twitter archive)

**Future research needs**

The forecasts and response to Harvey can contribute to a better understanding of evacuation, and to improve the preparation for evacuation. More fact finding has to be done about the timeline of decisions and geographical distribution. Also a better understanding of the official information about probabilities, costs and benefits of evacuation is needed.

Future lines of research can be defined to define optimal evacuation strategies based on a risk based approach and taking uncertainties of forecast and consequences into account. Using the risk based approach, cost benefit analyses decision support instruments can be used to support the call for evacuation. These lines of research makes the assumptions made by the Mayor of Houston explicit and reduces the meaning making in the aftermath. This line of research also puts the risk as the cornerstone of emergency planning which gives the opportunity to define the effectiveness of better planning, exercises, information systems etc.

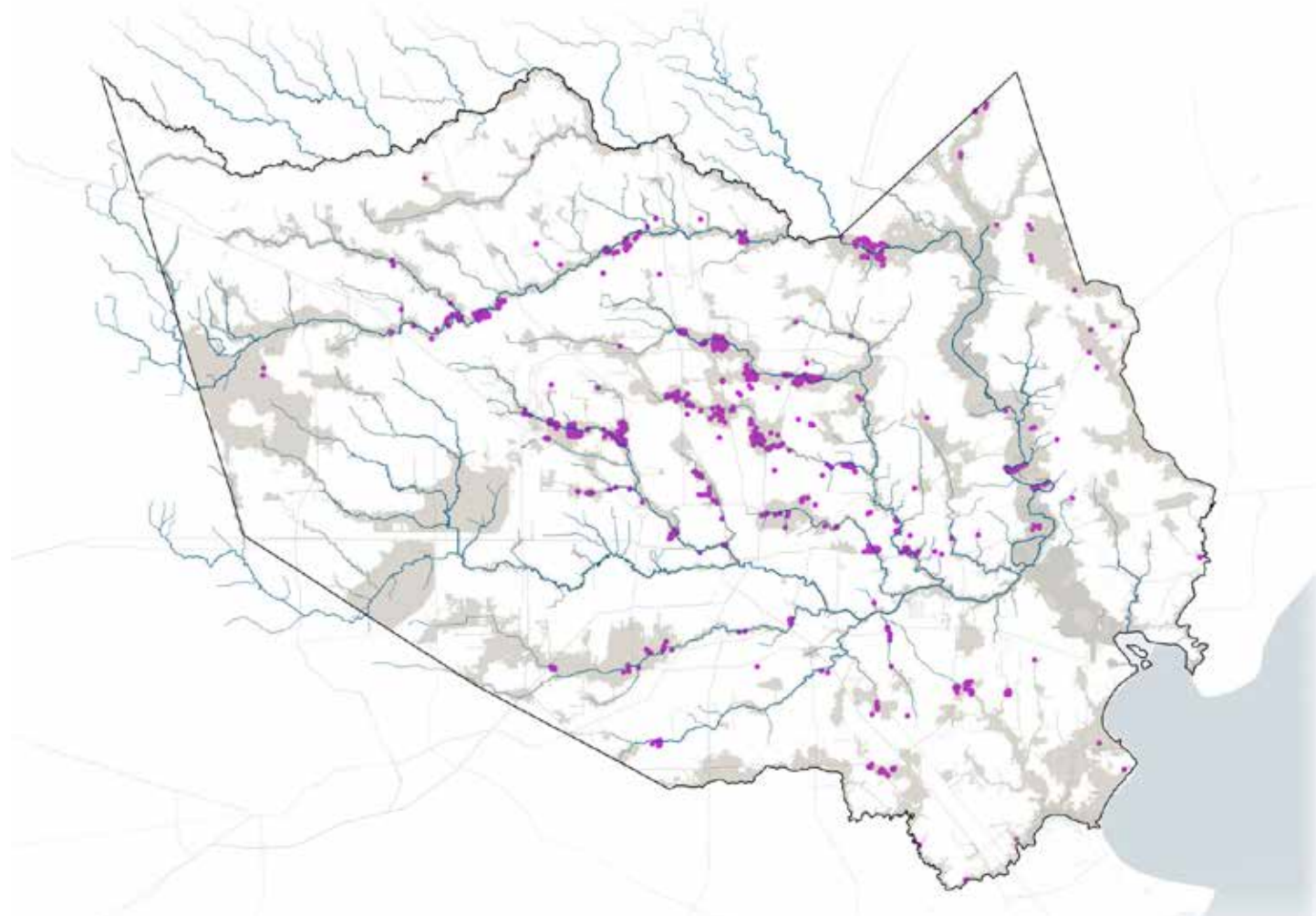
Also for the Netherlands a better understanding of the call for evacuation is important, as well as the way the decision are communicated and result in response of the public and emergency services. Although experiences in the U.S. cannot directly be copied to the Netherlands because of different cultures, still many lessons can be learned from research on cases like Harvey.

**6.3. Emergency Response**

In the Daily Flash of August 18, 2017, the European Response and Coordination Center (ERCC) managed by Directorate General for European Civil Protection and Humanitarian Aid (DG ECHO), identifies Tropical Cyclone Harvey as one of the weather events that are being monitored, mentioning the storm warnings for the Windward Island and eastern Caribbean Sea. While the storm had been tracked by several meteorological institutes (including the NOAA), the storm then also appeared on the radar of emergency response organizations, including the COEMA (Caribbean Disaster Emergency Management Agency). These emergency management authorities start implementing various emergency protocols, and issuing severe storm warnings. Different actions were undertaken, such as pre-emptive evacuations, pre-positioning of emergency response resources, and activating civil protection measures. In the Daily Flash of 28 August 2017 (see Figure 6.7), the ERCC reports that Harvey had made landfall in the United States the day before and mentions the disaster proclamation for the state of Texas and the activation of the FEMA response. The ERCC continued tracking Hurricane Harvey and updated the situation in their Daily Flash, including maps of the hurricane's path.

# Buyouts

Images, propublica



# Ike Dike

**Houston Galveston Area Protection System (HGAPS)**

**1 - Galveston Seawall**  
**2 - Texas City Levee**  
**A - May 14th Dike**  
**B - Southern Dike**  
**C - Highway 148**  
**D - Oyster Reef**  
**E - Bridge Disposal Sites**  
**F - Bolivar Highway 67**  
**G - Galveston FM 3005**  
**H - Galveston Levee**  
**I - Raising Ty City Dike**  
**J - Raising Jetty**  
**K - Bolivar Access Ways**

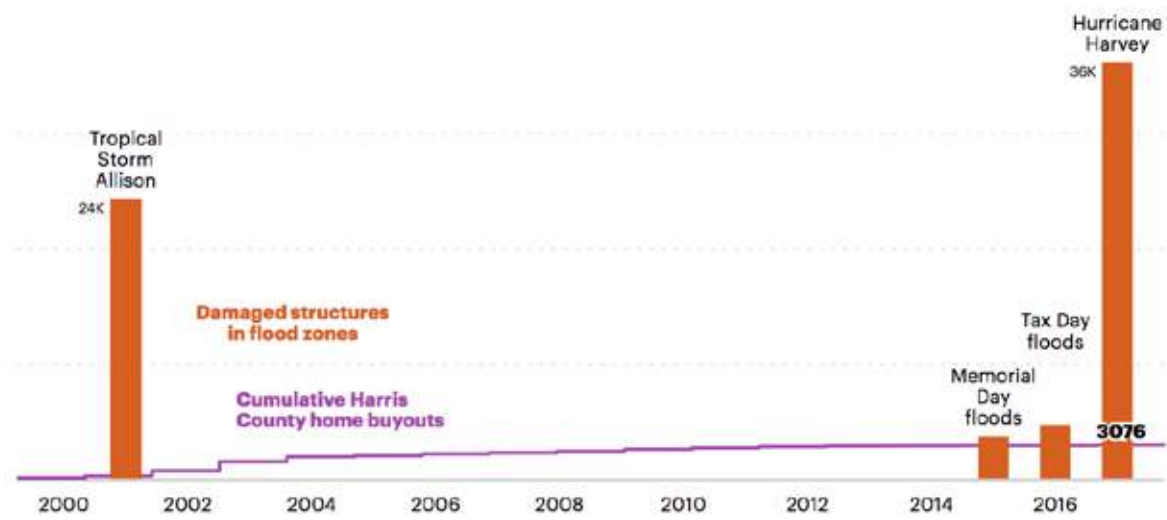
structures designed and built in the Netherlands. The information learned in these projects has already led to the development of innovative concepts that maintain circulation or reduce wind setup (e.g. environmental barriers or mid-bay solutions).

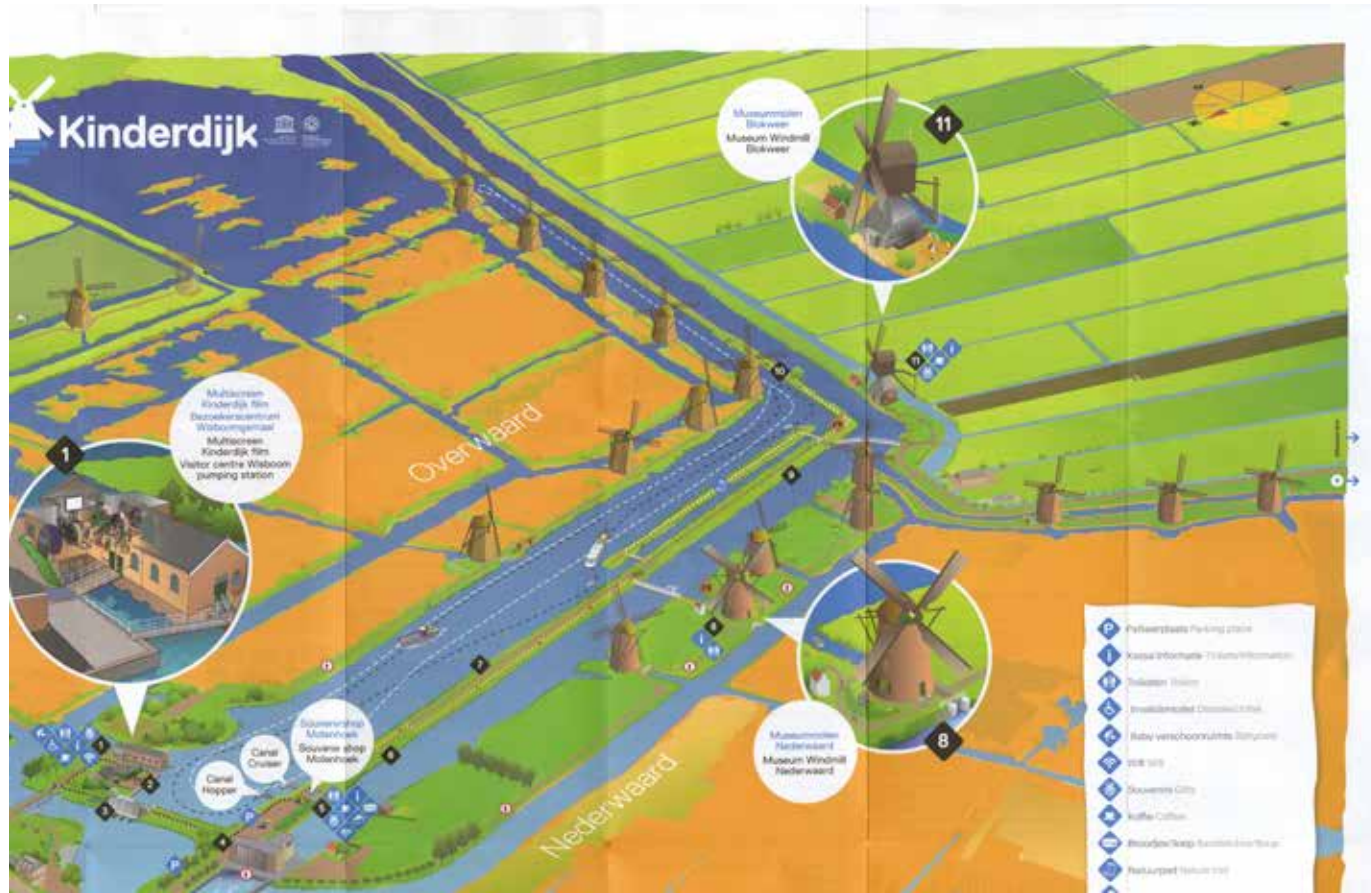
The lessons learned from the designs developed for the hydraulic barrier at Bolivar Roads can also be applied to the design of barriers in other locations. Any barrier that crosses the ship channel will have to include both a navigational section and an environmental section. Thus, Van der Toorn & Karim and Smulders' analyses of gate operation and material gives insight into the feasibility of constructing and operating a hydraulic barrier that crosses the navigational channel. And, Schiepers' innovative steel design provides an interesting alternative to previously considered gate structures for the HSC. Similarly, the design of an environmental surge barrier by De Vries addresses some of the difficulties in maintaining environmental flows in the channel, while building a structure that will withstand high flow velocities. Finally, the inflatable gate design developed by Van Brauvelen provides an interesting idea for in-bay situations. While the hydrodynamic forces at the coast are probably too large to sustain such a structure, the application of rubber barriers at other locations in the region merits further research (e.g., Clear Lake at Kemah).

The hydraulic structures developed for the HGBR will need to be covered with advanced warning and flood prediction systems to address the complex problem of rainfall runoff and storm surge and the real-time operation of structures. To develop such systems, probabilistic analyses, as well as complex hydrodynamic models warrant further development. I have enjoyed the opportunity to interact with students from the Netherlands that have visited the HGBR and am enthusiastic about future collaboration with TU Delft; overall, the work by Dutch students was both impressive and comprehensive in covering many areas of hydraulic design, and when combined with the other projects from the Multifunctional Flood Defenses (MFFD) Program and Delta Interventions Studio, the body of work is an amazing collection of research on the problem of surge in Galveston Bay.

HYDRAULIC INFRASTRUCTURE DESIGN

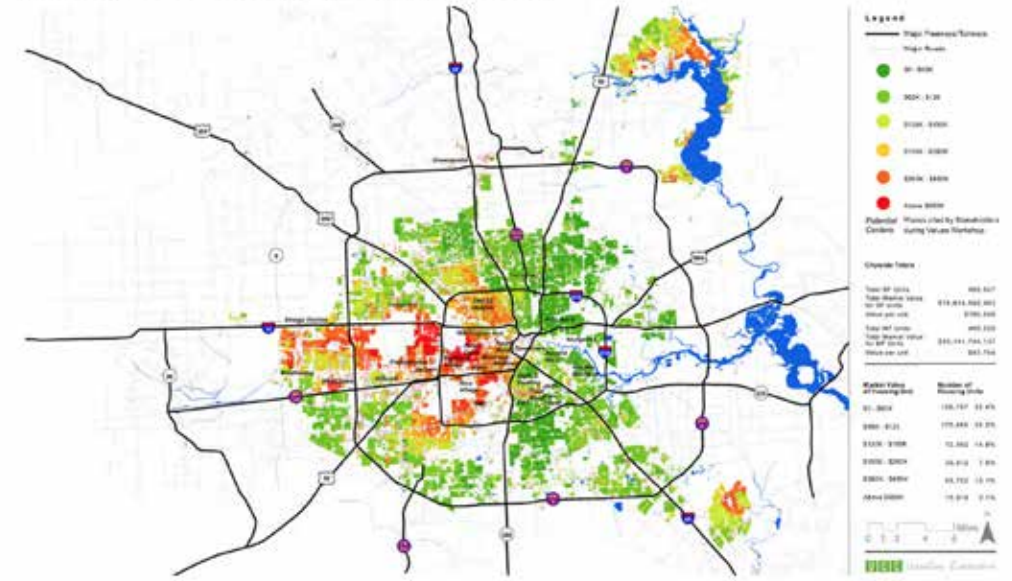
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Housing Character and Diversity

Figure 7: Housing Affordability  
Data source: City of Houston, U.S. Decennial Census and American Community Survey (ACS) Homeownership data



DESIGNWORKSHOP

Urban Houston Framework | 33

**6 Siphon weir**  
In 1881, a siphon weir was built in the dike behind the two low basins (storage basins). Due to the removal of the sluice at Nieuwe-Lakeland, the area it served also started to drain to the Overwaard low basin, as does the Streefkerk polder. The weir was a solution to discharge the additional water. The estimated volume of water that drained from Nieuwe-Lakeland and Streefkerk into the Overwaard basin would be returned to the Nederwaard using this weir. This means that, if required, the siphon weir could also discharge the surplus Overwaard water. This increases confidence in the entire Abbleswaard water management system. The main function of the siphon weir today is to move water from one basin into the other.

**7 Overwaard**  
The Overwaard water board had eight windmills built on the Boven dijk, which were completed in 1740. These wooden, octagonal cap windmills are flatched with wood and also have an internal waterwheel. The wooden Overwaard windmills are lighter, therefore their foundations are less robust. However, these mills pose a greater fire risk. In 1981, the second Overwaard mill burnt down. However, it has been rebuilt. Windmill 2 now has the largest 'sail diameter' of all the World Heritage Kinderdijk site windmills, that is to say that the stocks are the longest, namely 29.04 metres.

**Gemeenelandshuis Overwaard and Nederwaard**  
The water boards owned impressive buildings at strategic locations, these were called 'Gemeenelandshuizen' (common houses) or 'Wardhuizen' (landlord houses).

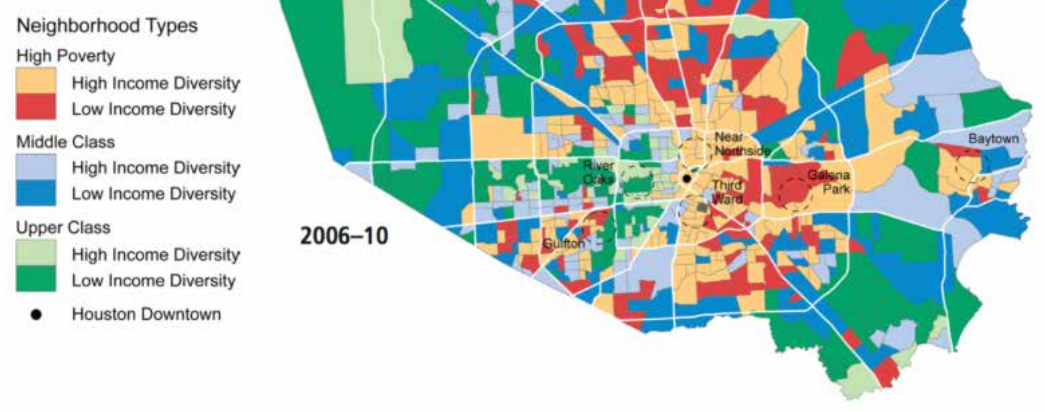
**8 Museum Windmill Nederwaard**  
Eight brick storage mills, built in 1735, stand guard on the west side of the Middelbuis. This is the central path through the Kinderdijk windmill area. With your back to the Lakeland, the Nederwaard windmills are on the right and the Overwaard mills on the left. The Nederwaard windmills form the last stage of the western tower sector of the Abbleswaard drainage system, the Nederwaard. The second windmill has been turned into a Museum Windmill and can be visited via a bridge. It is operated if there is sufficient wind.

**The language of the sails**  
Can windmills speak? The custom of expressing a certain situation by the position of the sails continues in the world of windmills and in Kinderdijk.

If you stand in front of a windmill and observe the sail cross (which turns anti-clockwise), you can see the following positions:

- The 'St. Andrew's cross' ('vest' position) (sails diagonal) is used when the mill is not in use for a longer period.
- The 'St. Georges Cross' (sails vertical/horizontal) is the position for a short period. The mill is halted for a short time - for instance a night - but can rapidly be started. In this position, the miller can immediately climb onto the bottom sail to set the sails.
- In the 'training position' the bottom sail is just past the vertical, the top sail is then past the highest point, meaning the morning or 'going' position. When the miller or one of his relatives dies, the mill will remain in this position for a longer time.
- Mill dressed overall: the miller decorates the mill with strings of flags from set and to set and. This is done on special occasions like a wedding.

Figure 5b. Neighborhoods by Income Level and Income Diversity, 2006-10



## 2019 Houston/Galveston Hurricane Preparedness Meetings

Date	Location (City)	Time	Event/Location	Point of Contact
May 5-11	National	Daily	<a href="#">National Hurricane Preparedness Week</a>	Houston/Galveston National Weather Service Office (281)337-5074 <a href="mailto:sr-hgx.webmaster@noaa.gov">sr-hgx.webmaster@noaa.gov</a>
May 18	League City	10 AM	<b>Hurricane Preparedness Event</b> League City - Home Depot 3200 South Gulf Freeway League City, Texas 77573	
May 30	Friendswood	10 AM - 1130 AM	<b>Friendswood Hurricane Town Meeting</b> Friendswood Public Library 416 South Friendswood Drive Friendswood, TX 77546	
June 6	Friendswood	630 PM - 800 PM	<b>Friendswood Hurricane Town Meeting</b> Friendswood Public Library 416 South Friendswood Drive Friendswood, TX 77546	
June 6	Texas City	600 PM	<b>Texas City Preparedness Event</b> Doyle Convention Center 2010 5th Avenue North Texas City, TX 77590	
June 8	City of Houston and Surrounding Region	10 AM - 3 PM	<a href="#">2019 Houston/Galveston Extreme Weather Ready Expo</a> George R. Brown Convention Center, Hall E 1001 Avenida De Las Americas Houston, TX 77010-6099	<a href="http://hurricaneworkshop.com">hurricaneworkshop.com</a>
June 15	Jamaica Beach	10 AM - 11 AM	<b>Hurricane Town Meeting</b> Jamaica Beach Fire Station 16628 Termini San Luis Pass Road Jamaica Beach, TX 77554	City Administrator 409-737-1142

Houston City official website

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**Sand Nourishment**  
A flexible and resilient, adaptive coastal defence measure

**Introduction**  
In sandy coastal areas, sand nourishment can be considered as an efficient measure to preserve the shoreline and adjacent coastal functions such as recreation and nature. Nourishment is the supply of sand to the shore. It strengthens the coastal profile and adds sediment to the littoral budget. Generally the sand is extracted from the deeper sea bottoms, which may have large reserves of suitable sand. In coastal defence areas where the erosion could be too fast or frequent, the use of coarse grained river sands might be an option. This latter option is being explored for the Rotterdam coast.

**Monitoring**  
A dynamic coast needs intensive coastal surveying. This is to ensure proper decision making regarding the preservation of the coastline and coastal zone and to safeguard economic development and associated large capital investments.

**Efficient method and its effects**  
In the Netherlands coastal nourishment proved to be successful and efficient. It contributes to a major reduction in maintenance costs of the coastal protection when compared to hard defences. Moreover, it also has benefits for other coastal functions, like recreation and nature conservation. Nourishment is a sustainable method, as it fits within the natural processes of sand transport and sedimentation. The resilience of coastal systems is safeguarded or can even be enlarged.

**The 'Sand Engine'**  
In recent years, the possibilities of using very large nourishments as a low strategy for coastal management are being discussed. An example is the innovative pilot project 'The Sand Engine' in town of Delfland in the Province of South Holland, the Netherlands. The plan consists of depositing a large amount of sand (23.5 million m<sup>3</sup> - 2011) in a depot just off the coast that will serve a multitude of functions: coastal protection, nature and recreation. The idea is that the natural longshore sediment transport processes will gradually redistribute the sand along the coast towards the North, leading to coastal growth and protection and thus increasing space for coastal development (Province of South-Holland, 2009). The pilot Sand Engine will be accompanied by monitoring and research. If this pilot

**The Netherlands: challenges for the 21<sup>st</sup> century**

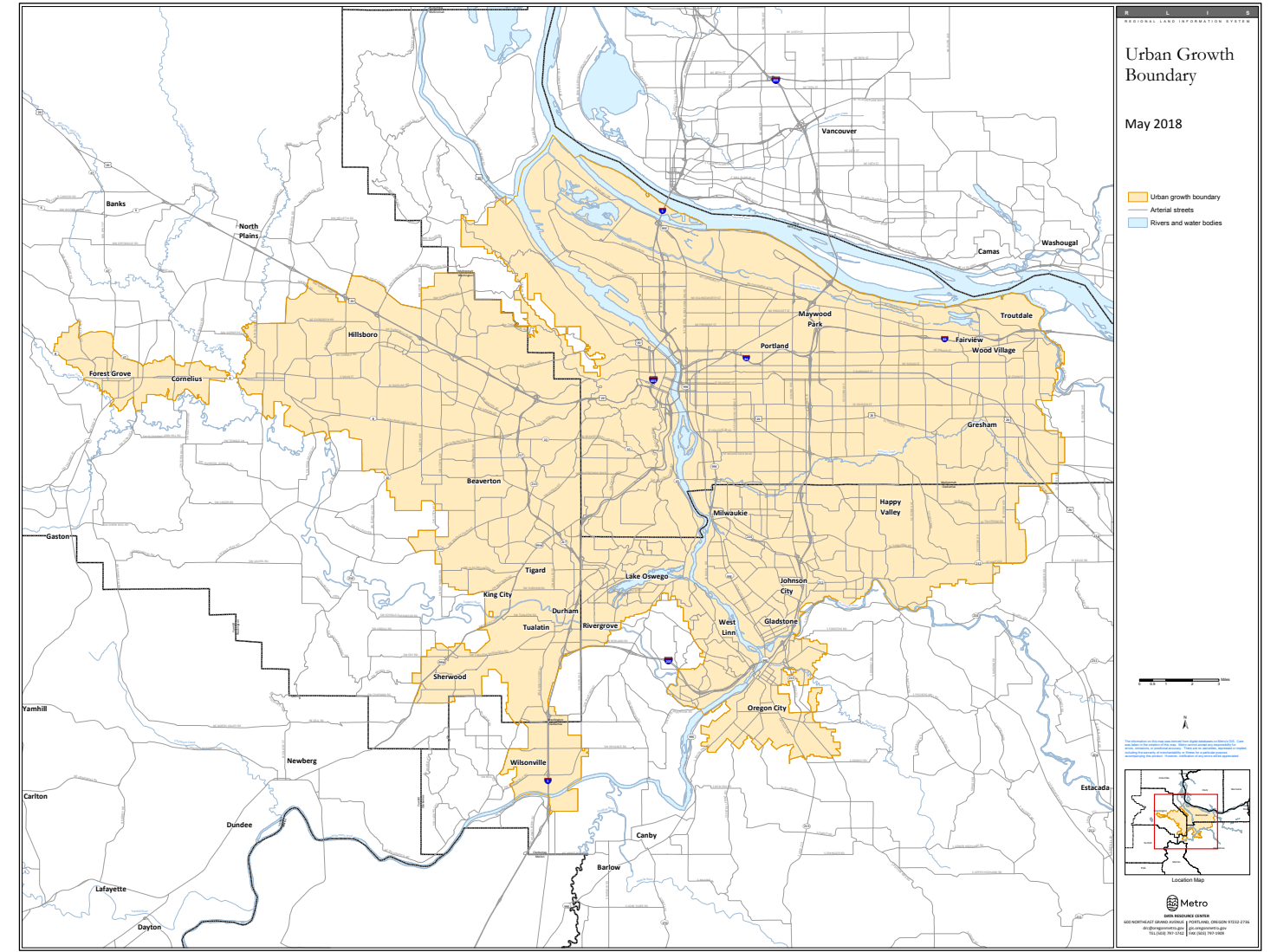
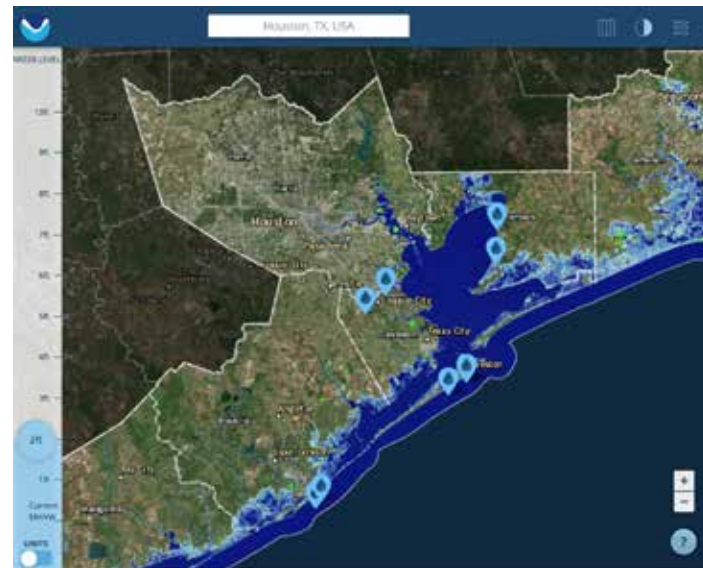
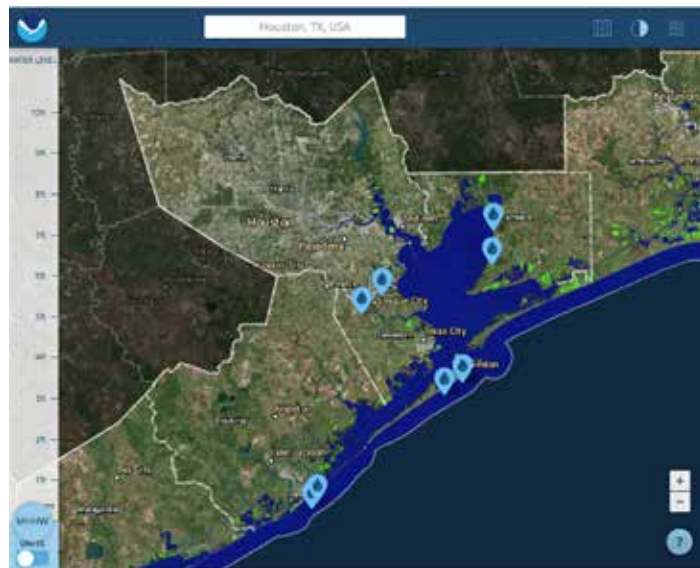
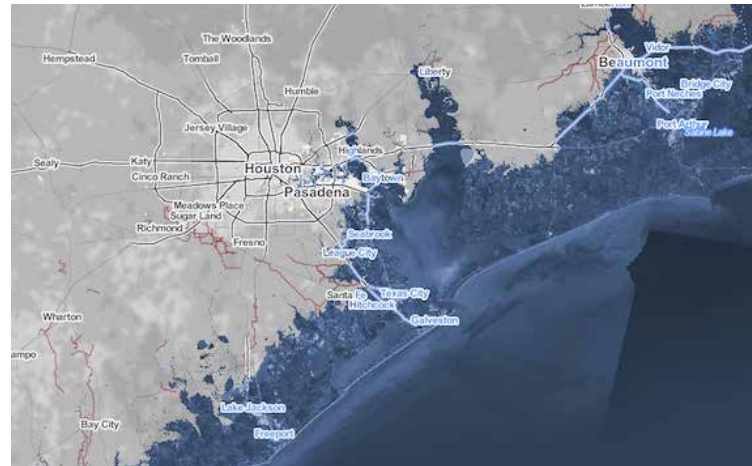
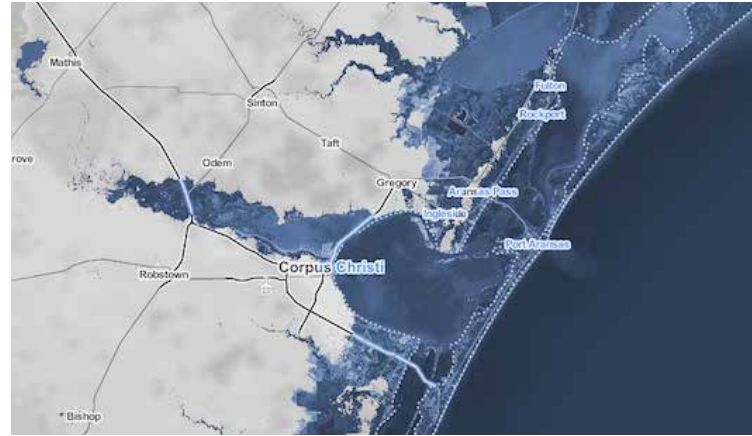
**Introduction**  
Dealing with the challenges posed in the 21<sup>st</sup> century requires a paradigm shift in the approach to water and coastal management. This shift is needed to implement some of the far-reaching recommendations of the second Delta State Committee (2008). It uses an integrated approach to planning with cross-sectoral strategies based on the two pillars of safety and sustainability. This vision helps strengthen the principle of 'working with nature' for future flood protection in coastal environments.

**Recommendations of the second Delta State Committee**  
Since 1990 annual sand nourishment, using this principle has become standard practice in the Netherlands. It is an economically viable way of protecting the mainly sandy coastline. It increases coastal resilience and provides a flexible response to the uncertainties of future sea level change.

**Conclusions**  
A high rate of sea level rise of 1.3 m by the year 2100 has been taken as a worst case scenario. Sea level rise will increase the frequency of flooding. The second Delta State Committee also developed a vision beyond 2100 for water management covering the entire country. Such a long-term vision will help prepare Dutch society for the increasing flooding risks associated with the impacts of climate change. In addition to the increased risks of flooding and coastal erosion, increased salt water intrusion will threaten future drinking water supplies and horticulture, agriculture and industry.

**Conclusions**  
Combating these impacts is achievable using integrated solutions, such as significantly increasing the fresh water storage by raising the level of our largest fresh water lake and the surrounding dikes. This also combats salt water intrusion and provides greater safety against flooding. Long term, adaptive measures need special institutional arrangements and reserved funding.

**Conclusions**  
The key to future prosperity for the Netherlands is to develop comprehensive management plans for the saltwater, rivers, coast and sea - a challenging vision.



# Appendix B – Travel Records

## Netherlands Travel Documentation

### Grant Application

**Dana Moore | Undergraduate BDS**  
Spring Break | 2019

## Deltawerken : Storm Surge Mitigation Precedent for Houston, Texas

### I. Introduction

The Earth's rapidly changing climate is the most daunting problem facing our world today. Many cities in the United States area already facing the inevitable infrastructural failures brought on by climate-change related stressors like drought, climate induced storms, and sea level rise. Planners, architects and governments alike are looking for precedents at home and abroad to mitigate these issues. One such city is Houston, Texas, a metropolis historically famous for its lack of zoning regulation, now regretting its laissez-faire regulatory nature.

A proposed system of floodgates and barriers nicknamed the "Ike Dike" is modeled after the Netherlands' Deltawerken, or Delta Works of South Holland and Zeeland, a storm surge mitigation system constructed in response to the devastating 1953 flood. Since its construction, the Delta Works have proved successful at preventing loss of property and life. If we truly wish to exemplify Houston as one of the country's first resilient cities, it is essential to study the effect of the Deltawerken on the urban population since its genesis. This can only be done through direct observation and documentation.



### II. Execution

I propose traveling to the Netherlands to see the Deltawerken over Spring Break 2019 to collect data, predict trajectories and form impressions of how the barriers have altered life and architecture in Holland, Zeeland and Belgium. I will work to establish contact with the architecture department of Delft University of Technology in Rotterdam, where I can find both history and expertise on this topic.

I also have a personal connection to a family member of a prominent Deltawerken government engineer, and would use this opportunity to interview him and have an escorted tour of several gates. I will also interview residents on their opinions of the Deltawerken and their impressions of its future and usefulness. This personal component is a key piece of understand humanist flood mitigation.

### III. Realization

My proposed travel plan is to fly into Amsterdam, train to Rotterdam and then connect with responsive parties at Delft University on Day 1. The I plan to rent a car and traverse the Deltawerken with the freedom to stop and interview locals for the next four days. During this time I will document my findings through sketches, photography and mappings. My last stop will be the flood memorial in Breskens. I think beyond documentation, it is important to tap into the imagery of memory related to the disaster that prompted the Deltawerken.



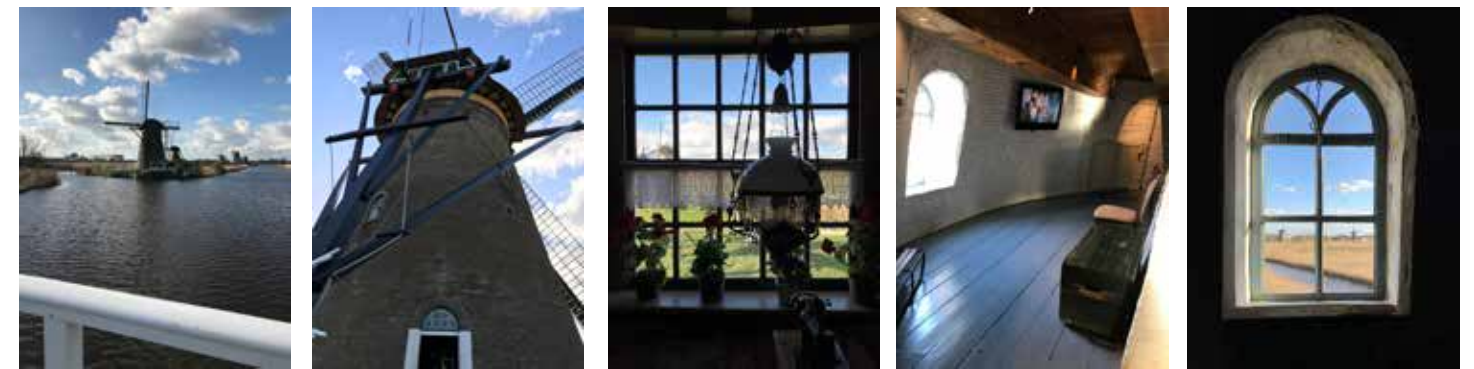
### V. Activation

In the last decade, the Houston-Galveston megalopolis has been hit by a 100 year storm and a 500 year storm, two events that have reopened the conversation of widespread flood infrastructure. With the wealth disparity present in Houston, the disproportionate burden these issues and their infrastructural solutions will place at the feet of our most vulnerable populations is a powerful precedent to set for other American resiliency plans. Careful assessment of European precedents combined with an approach informed by the city's history, demographics, and free market could set the tone for resilient cities in the American South. The penultimate goal of this thesis is translation: from problem to solution, from private knowledge to public knowledge, and from data to visualization. With the Dutch as our guide, together we can build a better Texas.

Photos  
Day 1 - Rotterdam



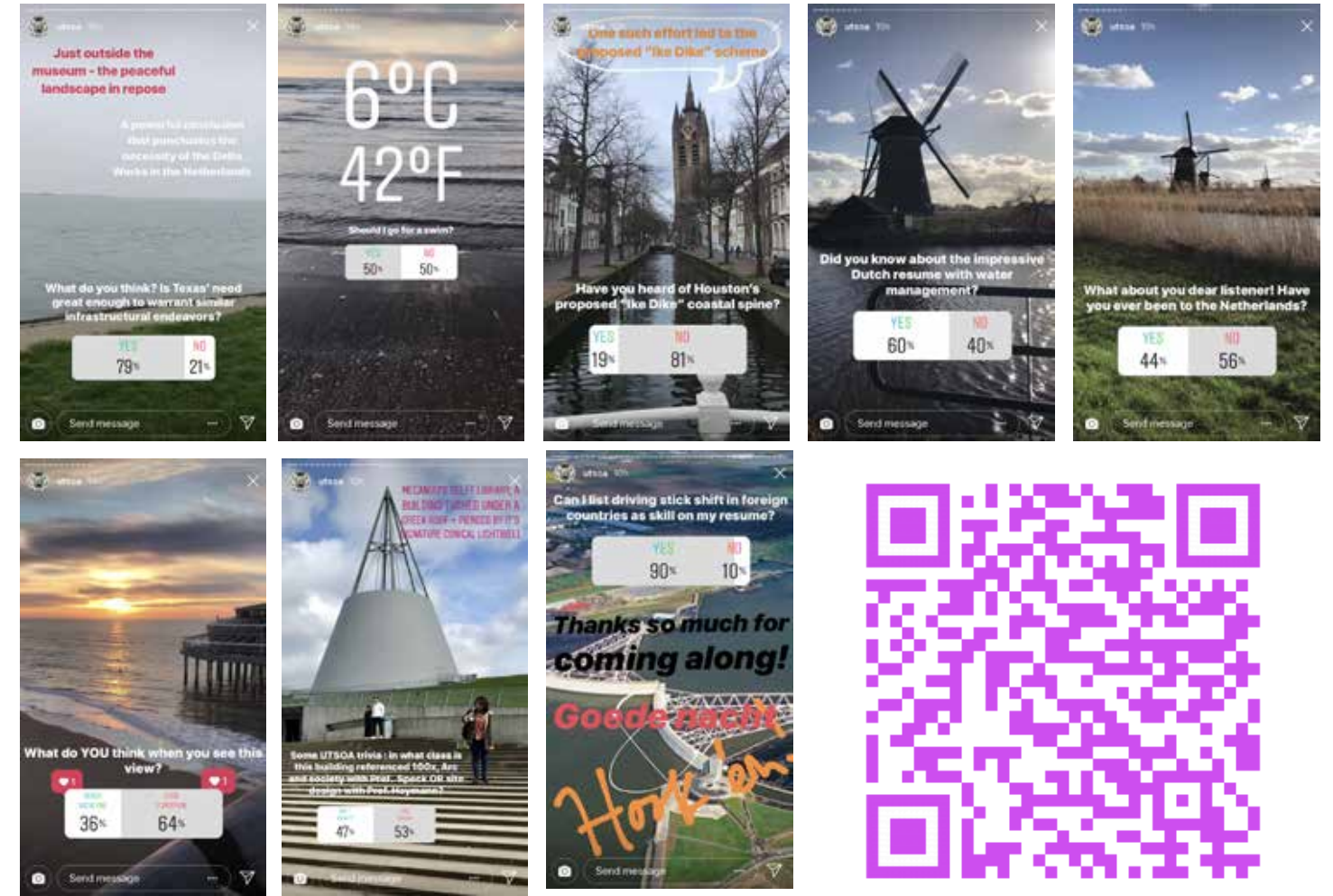
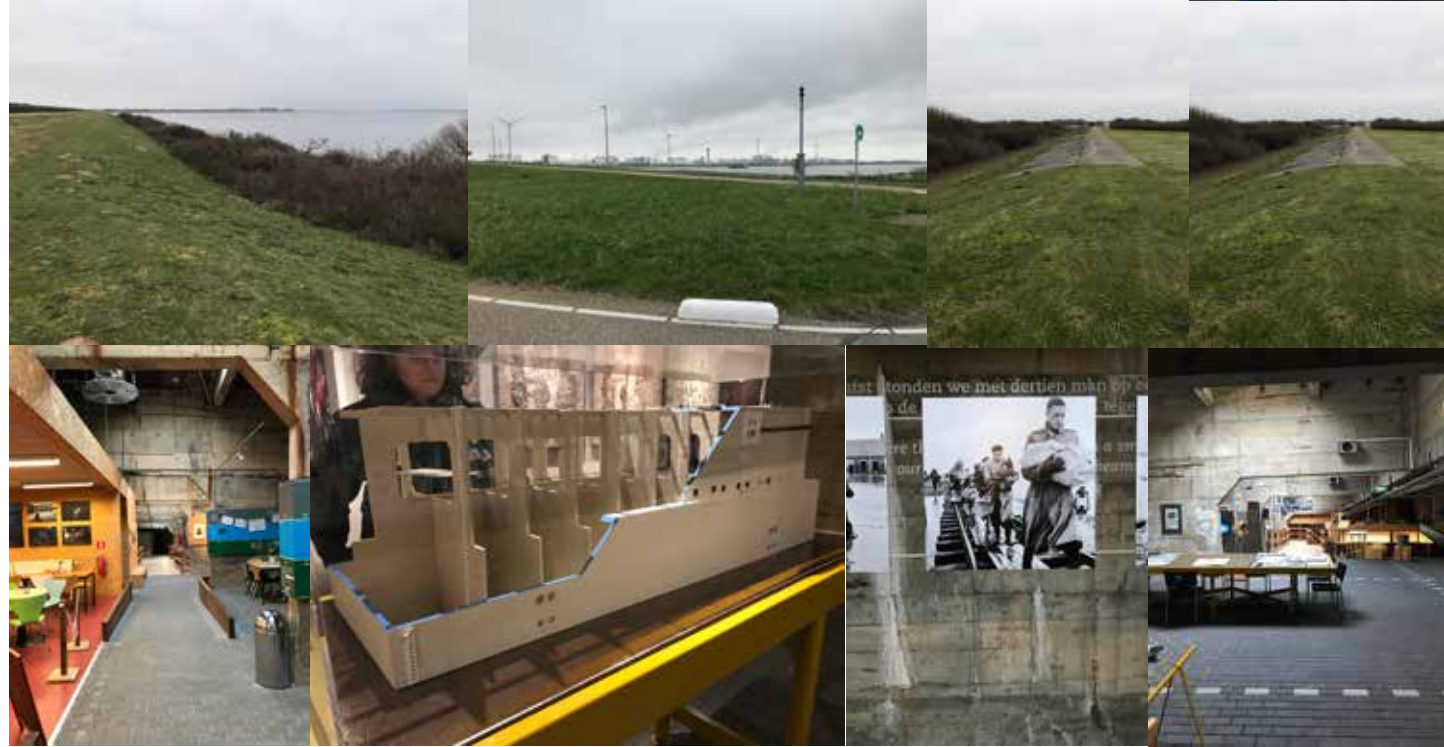
Day 2 - Kinderdijk



Day 3 - TU Delft







Scan for more

Houston, Texas | The Sentinel City

Dana Moore, School of Architecture, dmoore5419@utexas.edu

The University of Texas at Austin School of Architecture

Advisors: Simon Atkinson, Dean Almy

SENTINEL CITY AS FRAMEWORK

Houston, Texas is one of a dozen Sentinel Cities in the U.S. that will be the first to exhibit signs of climate change induced stress. The 21st century's rapidly changing climate is the most daunting problem facing our world today. Many cities in the United States are already facing the inevitable infrastructural failures brought on by climate-change related stresses like drought, warming induced storms, and sea level rise. Planners, architects, and governments alike are looking for precedents at home and abroad to mitigate these issues before they reach their own cities. One such city is Houston, a metropolis historically famous for its lack of zoning regulation, now regretting its laissez-faire regulatory nature. The first in this series of Sentinel Cities is Houston because it is a microcosm of many larger national issues: the role of government in climate resiliency, industry giants in the public sphere, sanctuary city status and demographic divides along economic lines. A resiliency plan for Houston would go far in modeling the country's stance on mitigating the changing climate with the plethora of social issues that accompany mega-cities in America. Ideally, this project would go on to address each of the identified Sentinels indicated in the graphic below.



NEED FOR AN INTEGRATED APPROACH

The "like Dike" coastal proposal is inherently flawed because it addresses the problem of Houston flooding during storm events in only one direction - from the sea. There are many problems built into Houston's city planning that exacerbate flooding issues during a crisis. The most important of these is the city's pre-existing watershed confluence in Galveston Bay, into which all its bayou drain. During a storm event, this body of water temporarily rises dramatically because of storm surge, the total rise of water on the positive side of a storm system. When the Bay is rising due to storm surge and the bayous are rapidly filling with storm water and runoff, the river and the sea both pour into Houston's highly populated coastal edge and back up the bayous, causing flooding in the city center and along bayous.



DELTA WORKS AS PRECEDENT

The proposed "like Dike" is a system of floodgates and barriers modeled after the Netherlands' Deltawerken. If we truly wish to exemplify Houston as one of our country's first resilient cities, it is essential to study the effect of the Deltawerken on the urban population since its construction. This can only be done through direct observation and documentation. Over spring break I was able to travel to Holland to study these structures within the context of the entire Dutch history of water management. I was fortunate enough to run the "trial" scheme across professors at Delft University, and discuss it with long-time hydraulic engineer and veteran of the first two Delta Plans, Robert Muis, a family friend. Lastly, I was able to visit the Maatschappij, the grandest and most recent of the Delta Works, and see other works during my travels.



CURRENT MITIGATION EFFORTS

One proposed solution is the "like Dike," a system of floodgates and barriers modeled after the Netherlands' Deltawerken, or Delta Works, of South Holland and Zeeland, a storm surge mitigation system constructed in response to a devastating 1953 Flood. Since its construction, the Delta Works have proved successful in preventing loss of property and life. If we truly wish to exemplify Houston as one of the country's first resilient cities, it is essential to study the effect of the Deltawerken on the urban population since its construction.



RESEARCH + PRELIMINARY DESIGN PHASE | CONCLUSIONS

Houston, Texas is uniquely suited to become the model case study for American city resiliency. By adopting Dutch social and spatial techniques to Houston's unique geography and demographics, this thesis can set a precedent for resiliency plans in America that protect vulnerable populations in our cities, who disproportionately bear the burden of climate stress. The production phase of this thesis will result in policy and design at the scale of the state, city and neighborhood.



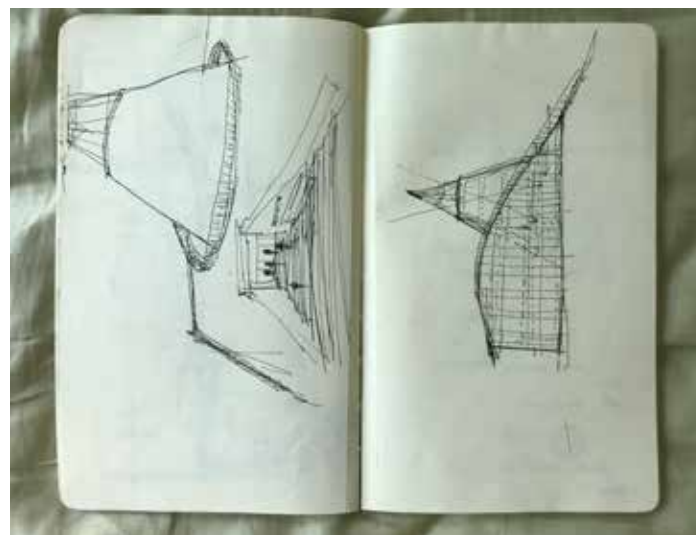
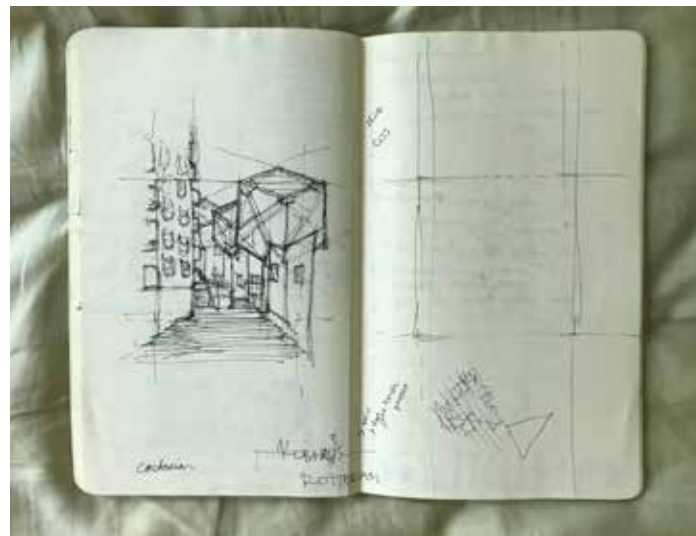
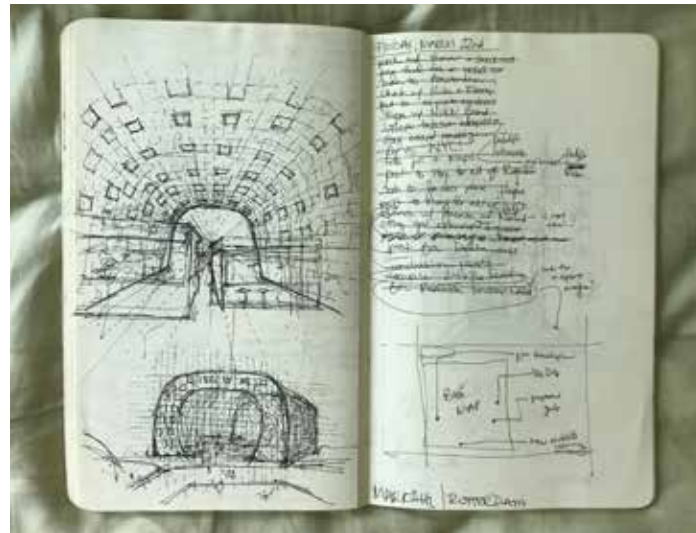
Houston, Texas : The Sentinel City

Author: Dana Moore  
Advisors: Simon Atkinson, Dean Almy

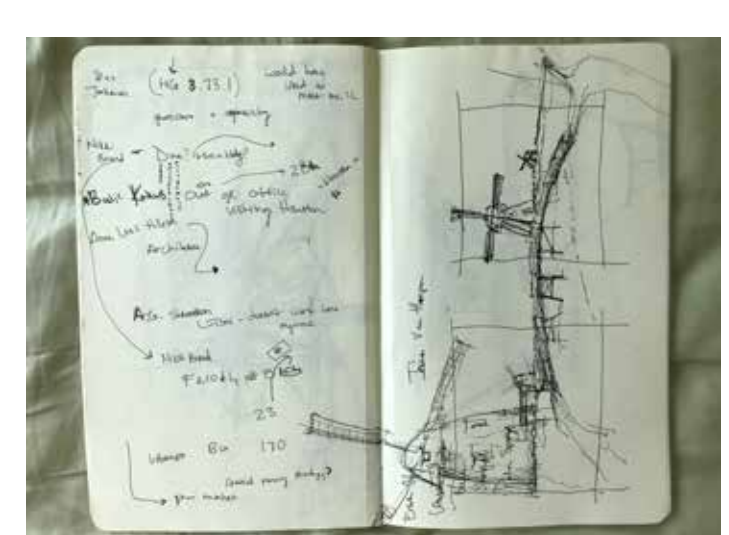
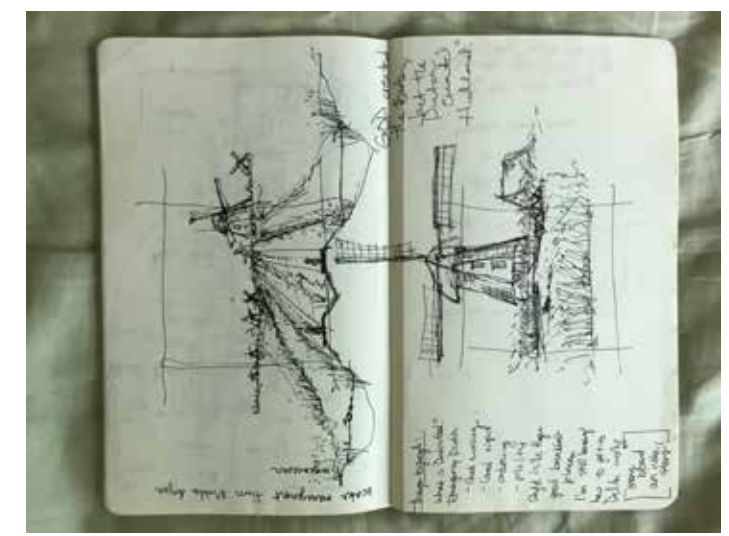
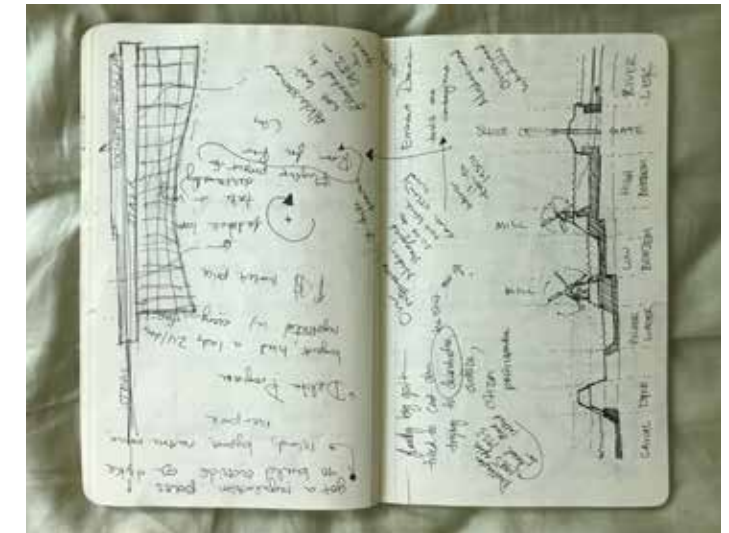


Travel Note and Sketches \*\*\*transcription was via automatic scan to text

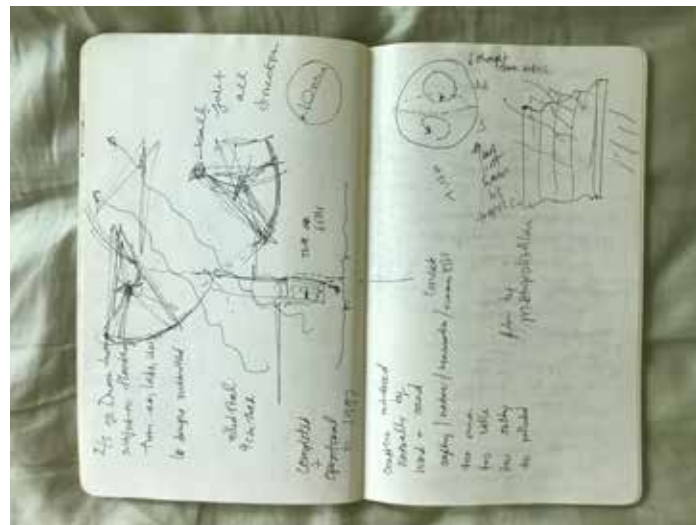
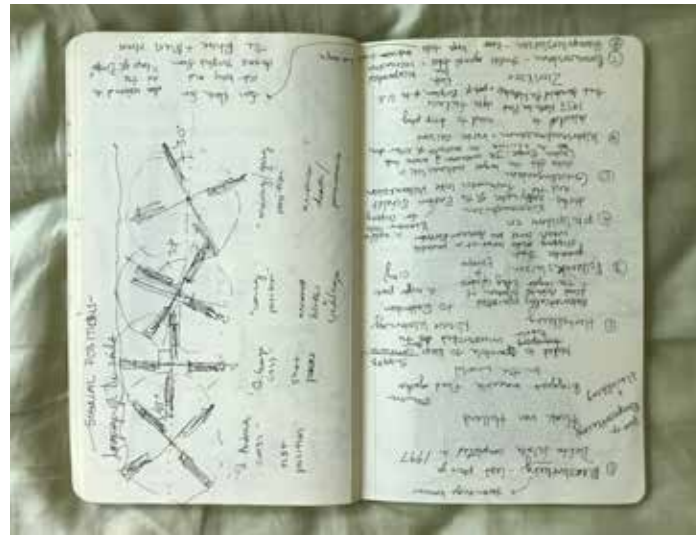
From Premala: Rotterdam AirBnB Houseboat host: Emi is bff, Emiliano Gandolfi, curator of NAE for 8yr  
 "money is just the manifestation of attention and energy  
 Watersnoodamp museum: Ria Geluk says hi to Bas!  
 Interior by Utrecht "Podium" firm for first caisson, expanded into the next four but changed twice already by Kermer and Hermd firm  
 The museum is just inhabotating the English donated cias-sons big concrete frames for emergency flood mitigations, then new farther dikes were constructed  
 Dikes wre bombe dby allied forces to flood the germans, and post WWII there were other needs, social, infrastructural Kuubhaus  
 Kinerdijk notes: Romans said, too wet, cant build here. St. Elizabeth's Flood  
 No one knows exactly why got the name, 1738 - millers built the 8 brick windmills, 1940, eight thatched  
 Stepwise drain system. Gauge (lead) mill would signal to others  
 Notes from Delft: Baukje is actually visiting Houston, Bas out of town, Nikki possibly, call and give number  
 Delta travel day: Maeslantkering triangular truss framework, big trade route had to keep open, only 2 times closed, once was false alarm-ish  
 Farther down waterweg is kering in de hollandsche I jussel, closes five times a year and protects lowerst parts of the country  
 Why both? Closing full harbor costs 100mill euro/day  
 "fighting the water" = bullshit. We love the water. Ex. Zanmotor, artificial sand isalnds, Hook of Holland, in his little town, after storm, special place for sea cement, tide will spread the sandafter 20yrs, naturally done  
 examples of DW used in New Orleans, IHNC Barrier, sluice, barrier, sluice, problem was dikes on edge  
 sea water not warm ebough in Nederlands for Hurrricanes  
 Hurricane systm only about rain (not true my guy, we get storm surge too)  
 1750 to new Zealand dikes end to end, in 22yrs only twice closed, most from the SW spring time  
 biggest moveable in the world  
 thames barrier, Enlgand, maselant guy went there and created international istorm - Russia joined, st Petersburg derivative  
 italy joined, venice, money went to the mafia (what??) Doge's Palac first floor cloumns are wonky bc keep sinking and replacing  
 SW Holland Deltawerekn overview, 1958 Hollandshe I Jiselkerig why still open to Antwerp? Very strong dikes on southern edge  
 2017 US Coast Guard in charge guy visited and said immeidatly what is the price tag, half a bill \$  
 tax eberyone pays - water safety, local tax country tax, waterboards for dirnking water, gateas and cluices.  
 San technique - all done by nature, New Delta Plan for extra protection 25 yrs



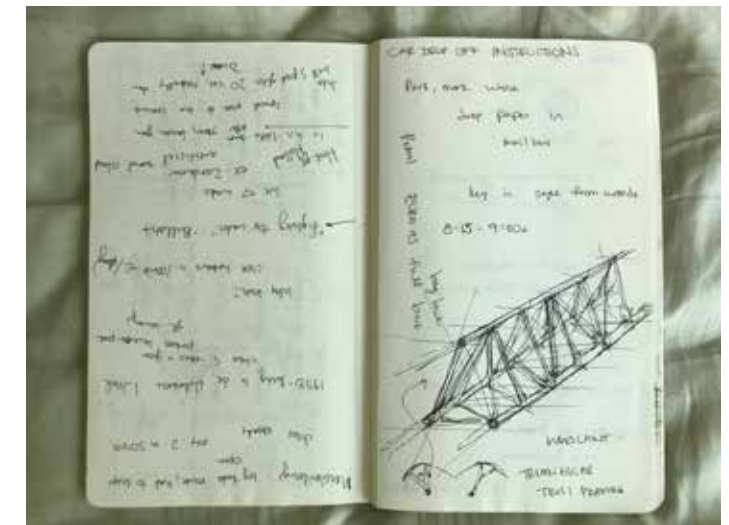
Next problem is river water: Give room to the river, subtraction, make deeper, bypass system around city/village, pump from canals to river to sea  
 What if both at the same time? (rain + surge) 1/1500 chance  
 Move water to lakes sluices of smart water system, hold there for 48 hrs, pump out of lakes into river  
 If not enough water? Salt water flows into rivers if no rain  
 Bad for plants and life, pump out of lakes into river to keep at bay the backflow  
 2003 dike barrier in dry summer bc made of peat, cracks when dry, inspections of dikes during dry periods and wet. If too dry then they spray the,  
 dry periods are getting longer and longer, 1953 = 16hr storm, high tide and low tide, so 24 hrs and 24 extra spray peat and stays wet, don't have to every day or etc  
 actual gate: painted on inside too, task took 4 years during maintenance season april 15 to spe 30<sup>th</sup>, on spe 30<sup>th</sup> test closure every year 3000 ppls, festival  
 bottom tubes fills with water to make it sink faster, 300,000 litres of paint by hand, 7 yr construction 10m length of pipes ball joint transpo walls 22 m high, dry dock now, fill half during storm season, why white? Steel heats and expands max 20cm Eiffel tower laying on its side  
 comuters alert when high time, iperatonal team, 8 hrs before closure, 2 hrs until they can get out (they = commerce ships) gap of 80cm bc of flux if rough waters collides and break and that is v expenice  
 sink to protects, open gates into 1.5 hrs to sink, sink slow so no tsunami to Rotterdam slow bc dirst leaves with sle fpropogating current as well. You can lift + lot then close and sink, tidal diff 1.5 m  
 kids make dikes when they play on the beach in the sand - the knowledge is there  
 schools 7-8 leaning people survived trauma, still scared  
 30' pumps get water out so can lift again, comes out the ends that stay on dry land  
 one power station on each side, and diesel near back always close in 2 hrs, open again take longer on backup bc of pumping  
 operations bldg., comp. not on internet, not hackable, even sensors on close dloop, matenance by contractors and subs  
 last test closure: touring w minister women wants to get in the bldg. to make her book more belivable, finished book in jan, can yu rread it before I publish it? 400 pgs, so good! Hacking at barrier, did not concern flood, kept it closed, river went still for days (in book obvi)  
 in may book is ublished woman is going to come and do a signing netflix making movie about climte change and featur- ing maeslantkering  
 land use? Hiking biking training bc good elevation to train on 2/3 of dutch territory subject to flooding from sea, lakes, rivers,  
 10 designs submitted  
 rolled steel 9cm thick  
 ompleted and operational in 1997  
 sinks as fills, 10m diameter ball joint all directions move- ment, concrete sill  
 coastline reinforced naturally wind and sand  
 safety/nature/recreation/economics



too much, too little, too salty. Too polluted  
 film by metropolis films  
 east coast warm bc tropics  
 north sea straight down from the arctic, cold  
 back to Kinderdijk notes: the alblasserwaard area windmills  
 pumping stations dikes and waterways work together to  
 drain soil, 19 windmills draining the polder ground since  
 middle ages  
 low and high bozeems = storage based + sluices  
 1738-1740 built windmills  
 replaced first by steam power and then by diesel  
 "We are only human, and the Gods have fashioned us for  
 love." – Aegon Targaryen  
 Questions for Rob:  
 Chief engineer, physical geography, oceanogprhay la the  
 beginning study, waves, sedimetns, ecology. Frim 3 sides: third  
 side is time  
 Advising from Holland to china, designing in Beijing  
 Coastal emigration  
 81% of coatline built up area in Belgium, w/out zoning  
 in Netherlands regulation, hospitals, universities, etc  
 biggest sluice complex in harbor leadeing to Amsterdam  
 cruise ships is enough there enough  
 Belgium going to build artificial breaker islands 1990 official  
 coastal policy to fix 1990 montioring on coastal erosion  
 Sand spraying  
 Costal dynamic policy – sand nourishment  
 Dune reinforcement at North Sea 3 to 4x deeper  
 Data collection  
 15yrs ago said NO to development alongthe coastline com-  
 mittee cut in new to the ministries of housing and econmocs  
 Amsterdam by schipol airport late  
 Too big for windmill polders, 1850 UK steam engines, 3 big  
 pumping stations  
 Dike ring, water out to ring  
 Ships were wrecked, schip hol, took year to drain, then saw  
 the ships  
 80% nature in the Netherlands coastline  
 50mill/ yer thru AMS, 60% fly thru, 40% would like  
 KLM and Air China – 3mill tousidts mayor deal  
 Air BnB has covenant with city but others? No  
 Flex, no contract workers, transient bc no job, no home bc no  
 lans  
 Enough is enough  
 Shortening of coaltine 900kmzandmoort = purification cor-  
 als of water, leeward side of hard leements there is eroisuon,  
 Start small, plz can we have camping or cafetira then cabins  
 then hotels  
 Keeping coaline natural is the key  
 1697, house, 1760 new part  
 effects on urbanism 8 yrs to 50 yrs maeslant berrier gate –  
 by the free mkt not deisnged by gov  
 VERY religious pple lving there, 300,000 people in the coast-  
 al towns no insurance Duentepay for low 1950s farmers and  
 religion – storm was act of god  
 Engineers from the North come in 90% of marina is for  
 yachts that don't even move  
 Space usage is weird  
 Small communitas ask, can we get tourism>



Recreations for locals,  
 45 tall pillars, 1mm accuracy started from small to big  
 Rotterdam dloffing from sea and river  
 Pipelines also in Rotterdam multinational  
 Technical secretary secretary for IPSS for costal cities  
 "rainbow dredging"  
 integrated management  
 put their name at the top = idotr of your writing  
 summary and put real material on the website  
 climate coastal cooperation  
 payed by the taxparyer  
 Vietnamese coastal effects in asia – 13 times as mission  
 leader  
 Shanghai pere and post pollution era, 20,000 sour-  
 ces of pollution ebb and flow of the river  
 Water movement model, then prioritise nad reorganize the  
 ministries  
 ACE not stupid, they can build a dike  
 New Orleans, dams withelf sediments from mississippi delta  
 Taking out oil sinking and shrinking  
 Biloxi, LA 0 mayor gets federal money and then theyrebuild  
 in the same place  
 Guld, 2% rise m in the last 30 years  
 26' needed for typhoons  
 geological fracture? Sinking, hosuton plan: Big visions  
 1980s big oil always fiishing scret  
 time is the ingredient other factors beside slimate change  
 subsoil mechanism  
 geological slipping, spatial and temporal.  
 Yippee!  
 "The world is changed, I feel it in the water, I feel it in the  
 earth, I smell it in the air. Much that once was is lost"  
 relation b/w flood and urbanism  
 not a lot of empirical data coastal crucial spot in the system,  
 SPEED center in Hosuton  
 ecological response to the Netherlands  
 mutli-functnol bc it is also road infrastructure  
 sprial, what is the 1000 year plan?  
 Talk with Nikki: series of hypotheticlas, proper lifespans  
 eresits event of a certain, larger sizes and more often quickly  
 erode infra, upgrade more often  
 Elevate the house, must be independt from the gov't, cul-  
 ture where flood safety is separated from gov., left to them  
 who are considered knowlegdble, too important for oyur  
 opinion,promote more of residential facilitated the leisure  
 economy, makes sense but exact blog after havrey  
 Rice – offside blog, outside, tale of two cities, integrated sto-  
 ries, 15pt plan, ACE – very secretive, really involved after IKE  
 bc competition btw schemes and it was a zero sum games,  
 after havery just fihgitng eahcother, international companies  
 sniffing around for big contracts, ACE, Delta Scenario  
 Riverplain buyouts, TAMU delta program, NAFWIS exec agen-  
 cy of ministry, older than all other ministries really, Delta  
 commissioner w/out interference from parliament/ cabinet,  
 independent, Reichwaterstracht, formaily, 2<sup>nd</sup> Delta Program,  
 Room for the River identified weak spots agreementbtw  
 countries on how much water is sent down  
 Capacity of river increased by a lot, 2 options, 1. Cooperate,  
 you are in cahge, 2. We will do it for you



Flagship, we will do it ourselves, incentives tied to it, shortage of bridges so get 1 more "spatial quality projects" spatial planning objectives, riverpark, park attaché dto the bypass, got a regulation passed to build outside of the dike, sialnds, bypass, nature reserve river park,Delta program buyout hired a lady 24/7 negotiated with every single family that was displaced, increased from market price, positive feedback loop, room for the river city

Need passionate acadmeics like me, Stefan Nijhuis, Steenbergen, both at TU Delft  
Ooze = Ava and Silvan, working with the delta pple on their india work  
Water and sanitation in slums

## Appendix C – Web Tools and Resources



IPCC Global Warming of 1.5C Summary for Policymakers



Interactive Houston Flooding Article



Central Houston



Bayou City Initiative



Houston Emergency Prep Guide

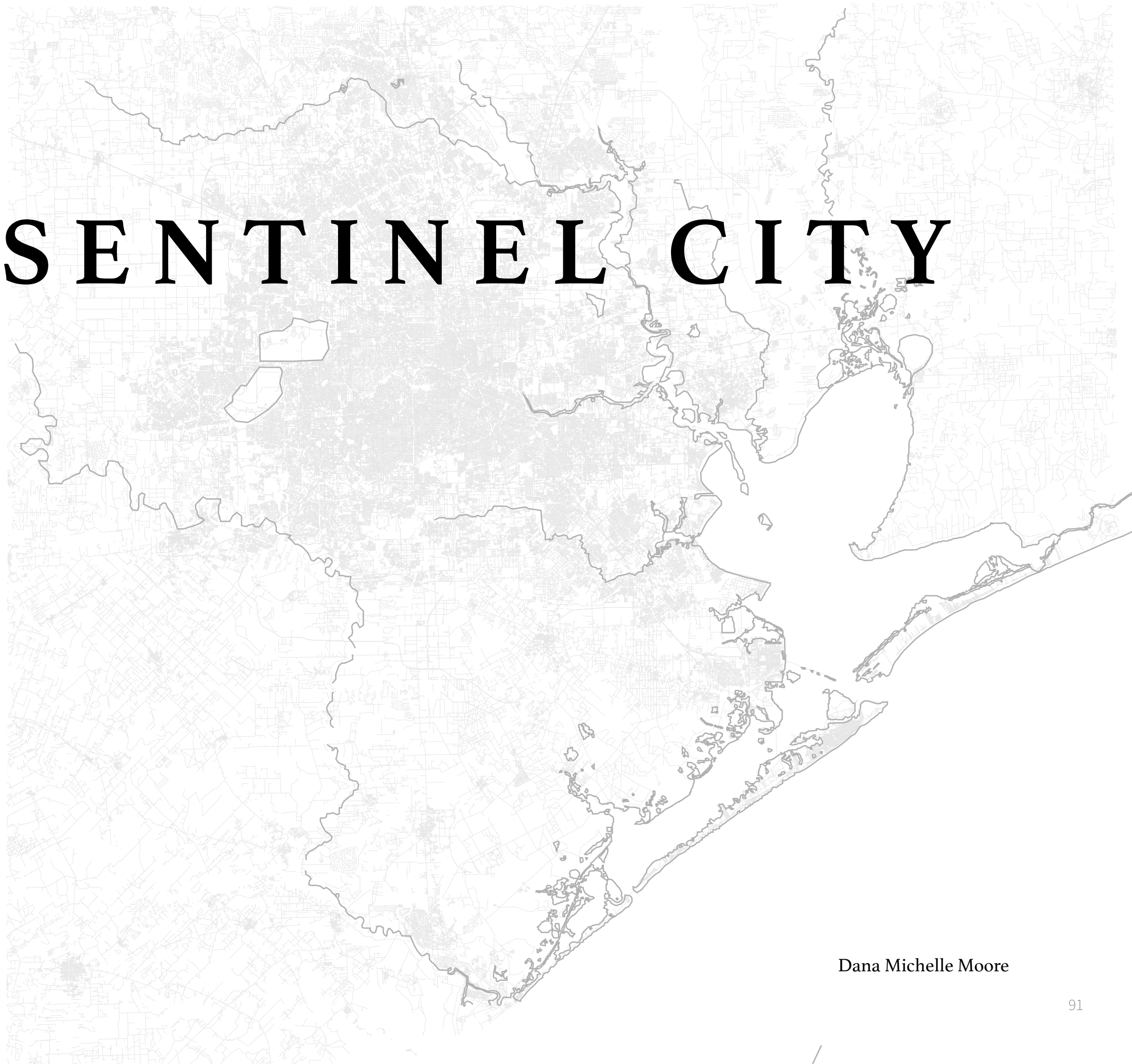


Katie Prairie Conservancy



Sea Level Rise Interactive Web Tool

# THE SENTINEL CITY



Dana Michelle Moore