

A satellite image of a hurricane over the ocean, with a black text box overlay in the center. The hurricane's eye and spiral cloud bands are clearly visible. The text box contains the title and author information.

# Houston after Hurricane Harvey: Towards Resilience?

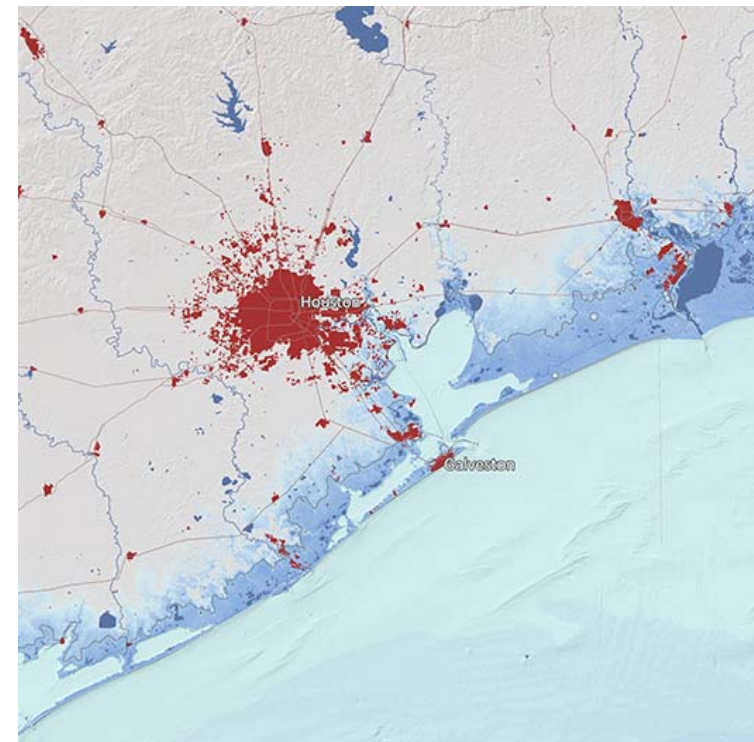
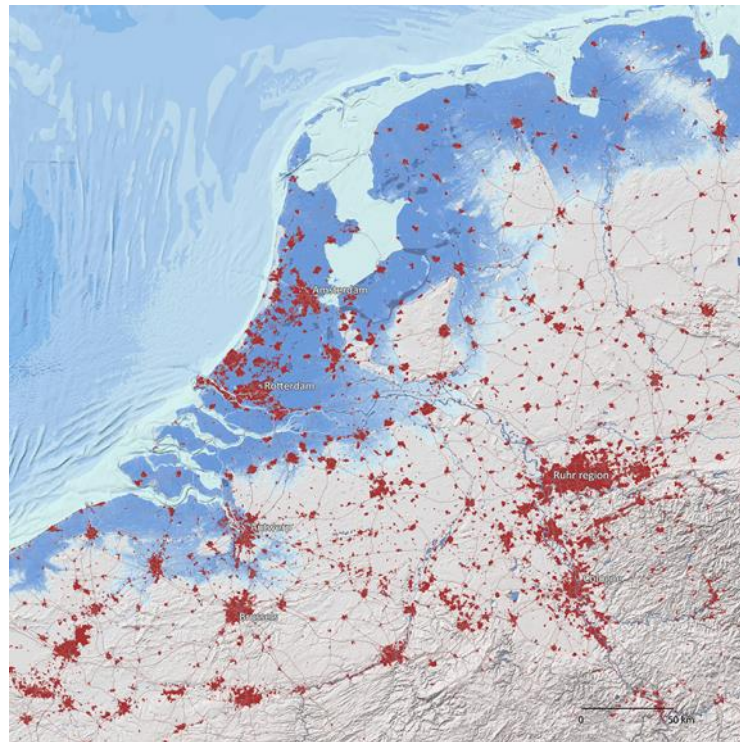
*prof. dr. ir. Bas Jonkman, Hydraulic Engineering*

*Contributions: dr. B. Kothuis, ir. K. Lendering,  
dr. A. Sebastian*

# Agenda

- Houston: general background
- Hurricane Harvey
- Lessons and resilience

## Compare Texas to The Netherlands?



# Compare Texas to The Netherlands?



## TU Delft collaboration with Texas

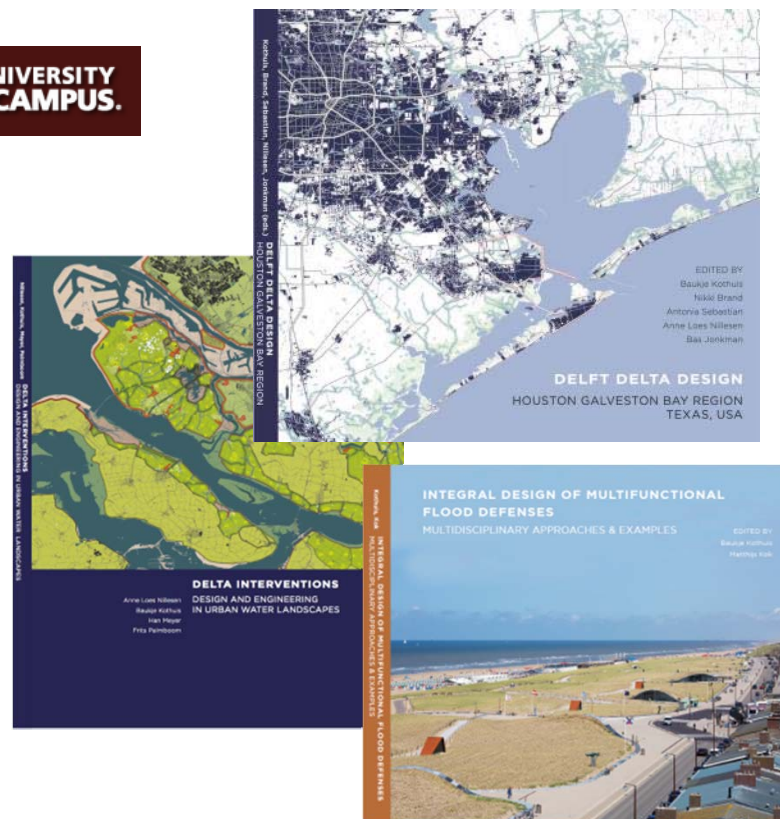


TEXAS A&M UNIVERSITY  
GALVESTON CAMPUS.



RICE  
Unconventional Wisdom

TU Delft

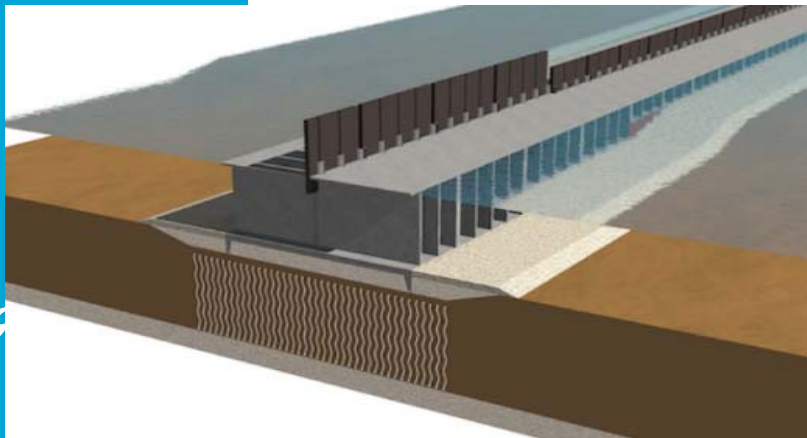


- Involved since 2012
- Research & design by students from civil engineering, architecture and TPM
- 30+ student projects, 40+ exchanges
- Review & design activities by TU Delft and partners
- Successful grant application NSF-PIRE
- MSc and PhD theses, Reports by faculty, Book & Book chapters

## *Vulnerability*

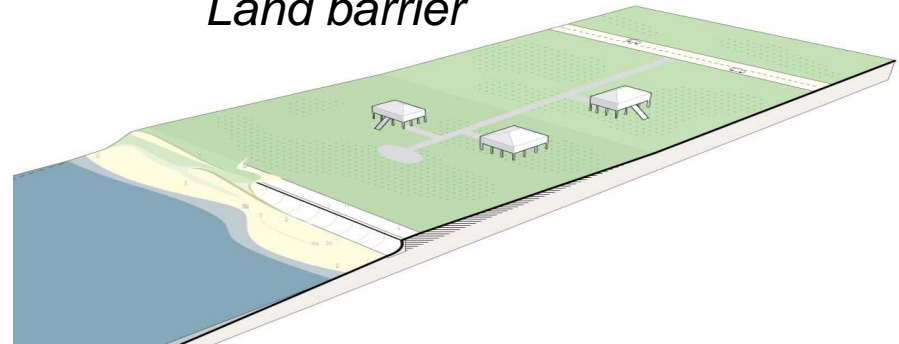


## *Storm surge barriers*



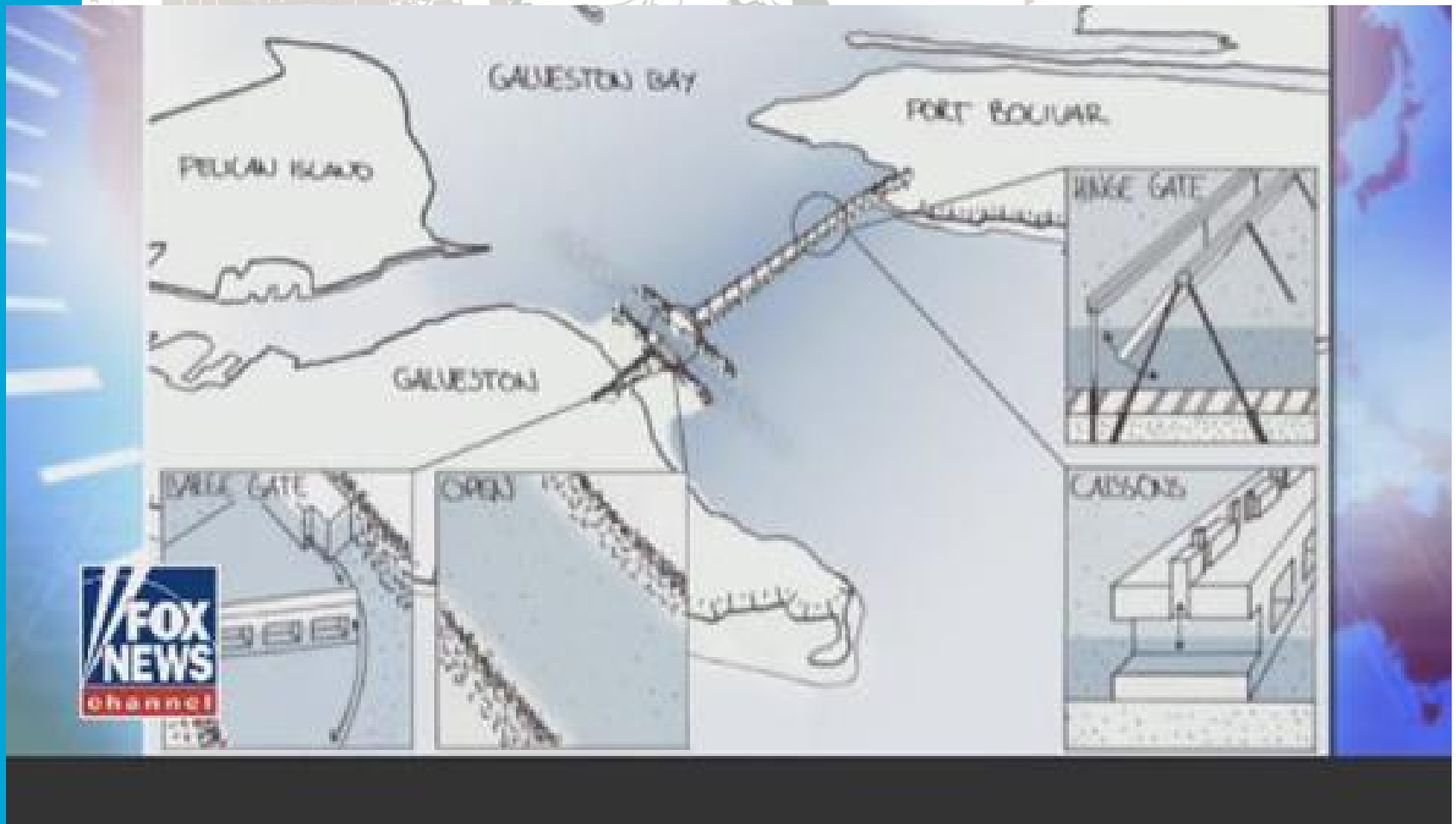
## Topics and Activities

### *Land barrier*



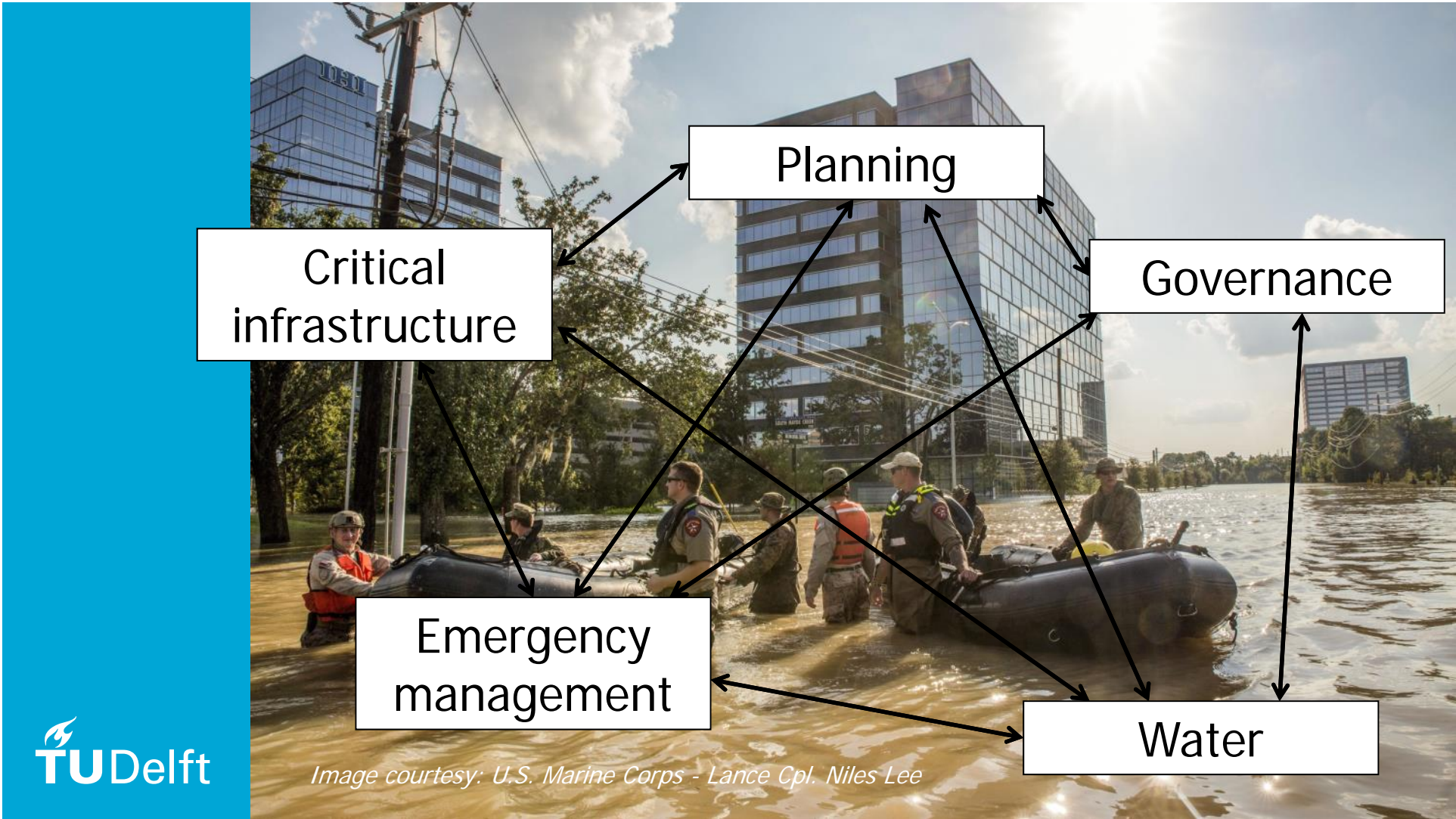
### *Hurricane proof housing*











## Hurricane Harvey Research

- Fact-finding, public sources
- 4 – 6 weeks (Sept / Oct)
- Preliminary
- Team of 5 authors, >10 contributors
- Various disciplines involved
- Hackathon

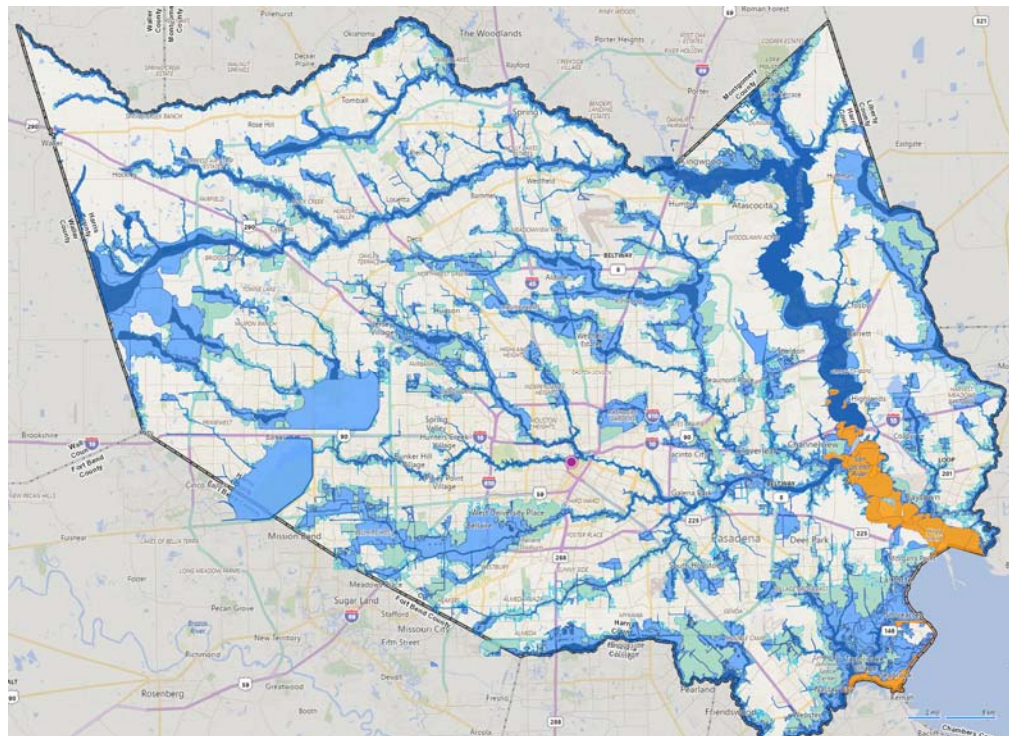


# Hurricane Harvey: Findings



# Flood Management

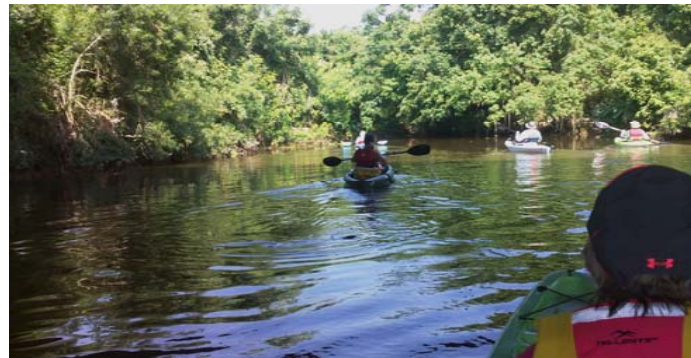
*Floodplains are used to as the primary indicator of flood risk and drive decisions regarding flood management.*



- 100 year floodplain
- 500 year floodplain
- Floodway
- Coastal 100 year flood plain

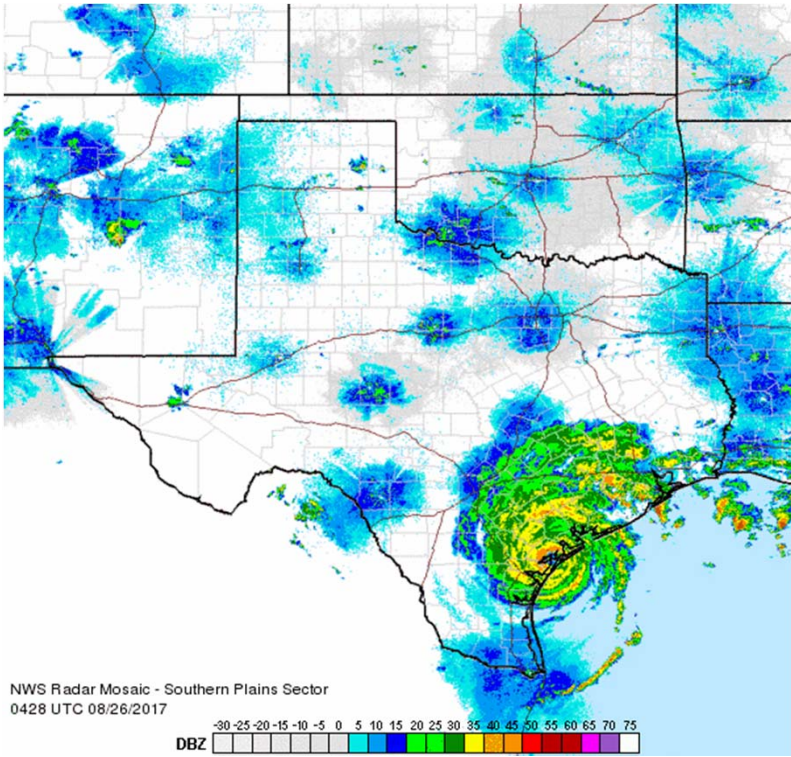
# Flood Management

*Many of the creeks and bayous in the region have been channelized.*



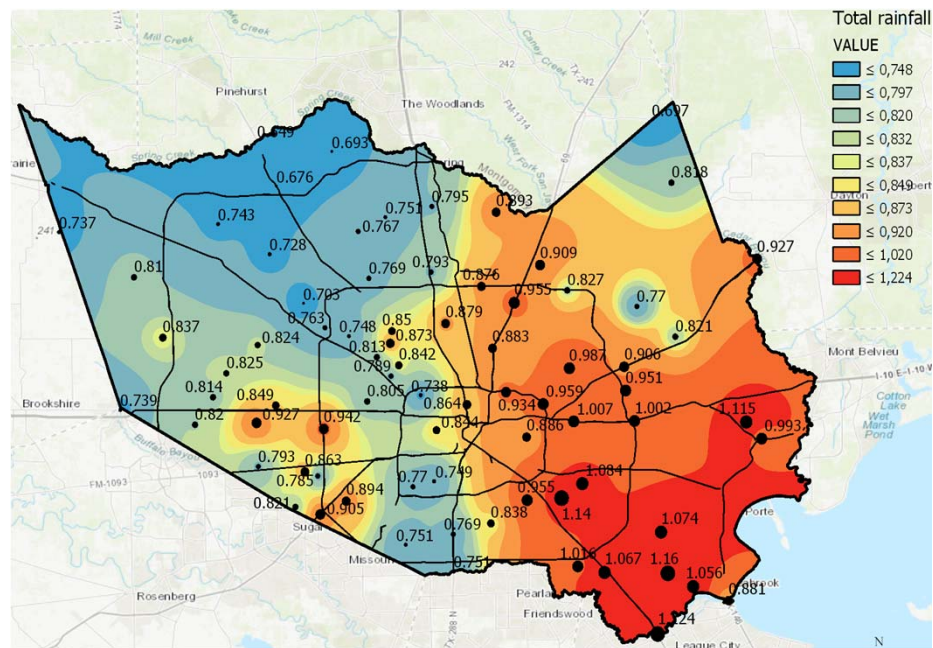
# Hurricane Harvey

*Hurricane Harvey made landfall near Rockport, TX on August 25, 2017.*



# Harvey in Houston: Precipitation

*Harvey dropped substantial rainfall over a period of 6 days (August 25-31)*



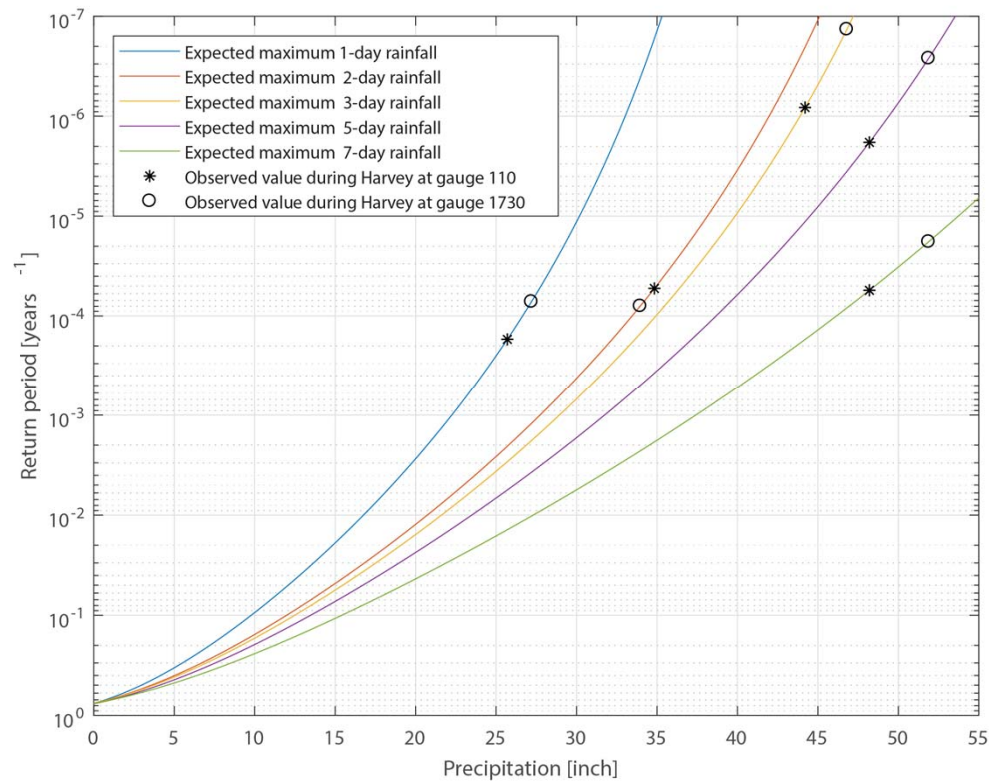
Upwards of 760 mm with a maximum of 1244 mm of rain was recorded in Harris County.

In some areas, 12-hour precipitation totals exceeded 531 mm.

Across large portions of Harris County, rainfall totals exceeded the 1000-year return period.

# Harvey in Houston: Precipitation

*Rainfall totals exceeded the 1000-year return period in large parts of Harris Co.*



Upwards of 760 mm with a maximum of 1244 mm of rain was recorded in Harris County.

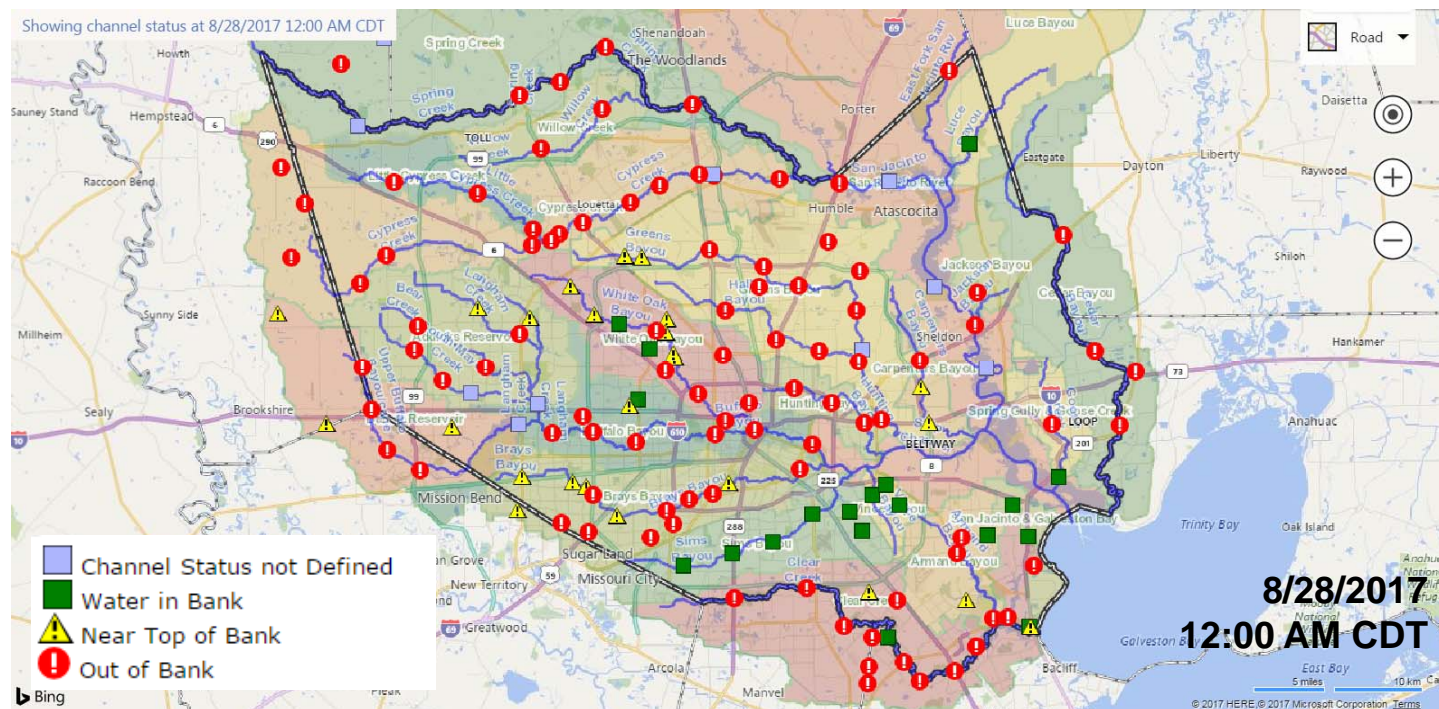
In some areas, 12-hour precipitation totals exceeded 531 mm.

Across large portions of Harris County, rainfall totals exceeded the 1000-year return period.



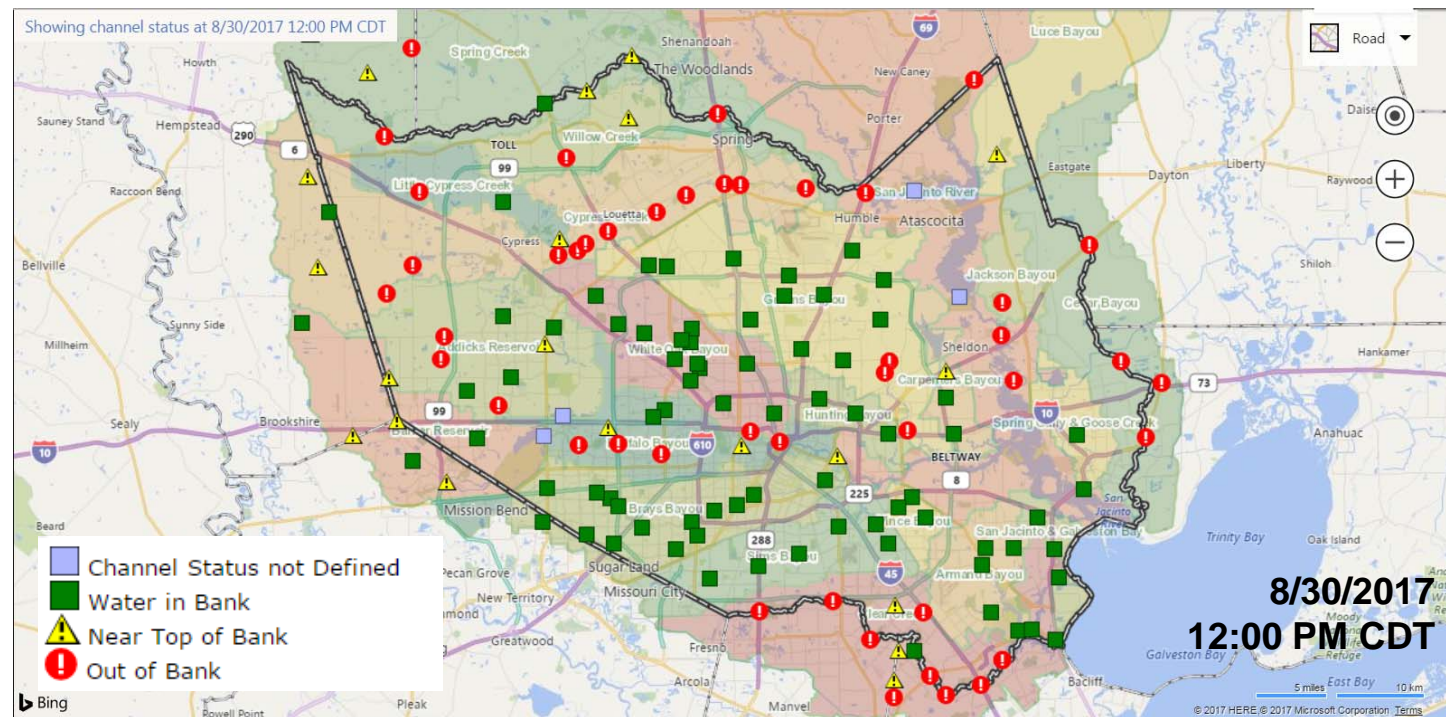
# Harvey in Houston: Flooding

Flood levels in many of the bayous peaked in the early morning of 8/28. Preliminary estimates based on water levels suggest that flood levels in many these watersheds exceeded the 500-year event.

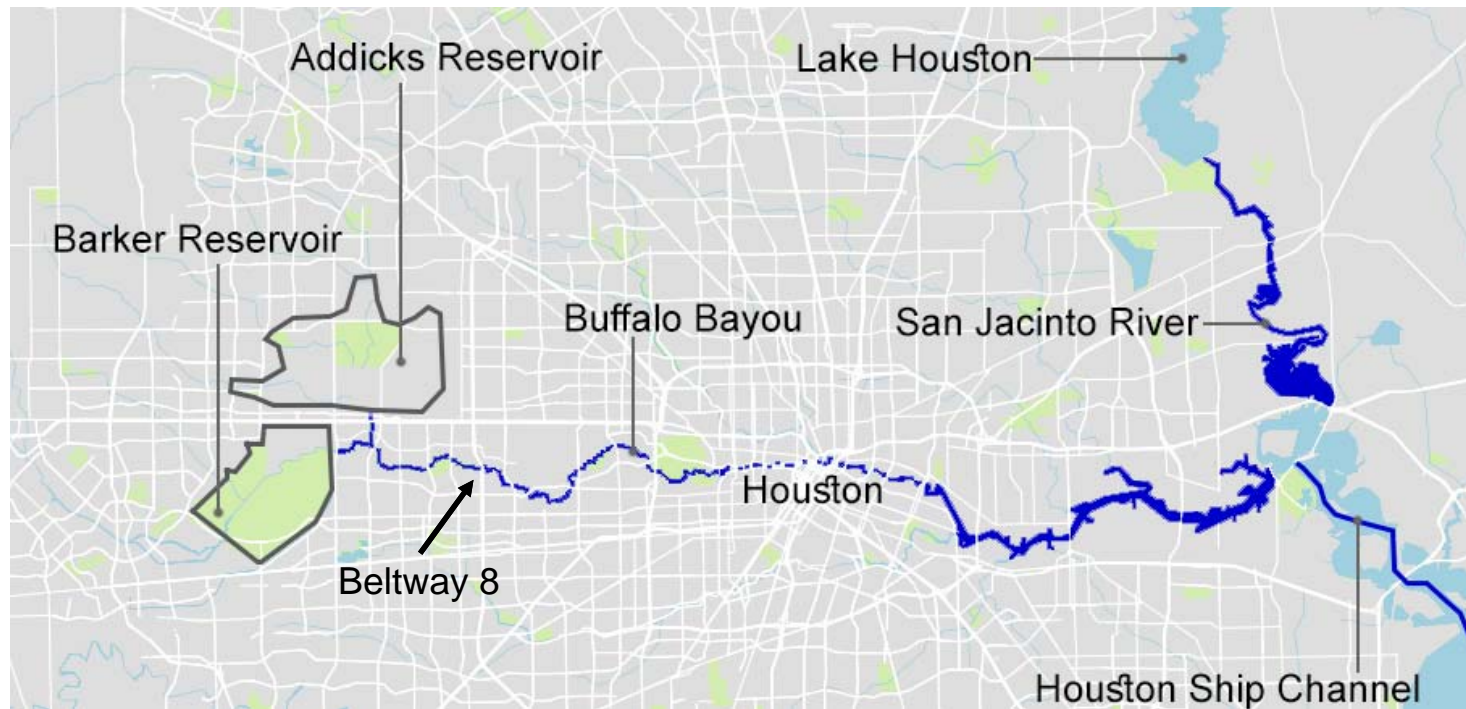


# Harvey in Houston: Flooding

*In most watersheds, flooding subsided within 24-48 hours.*

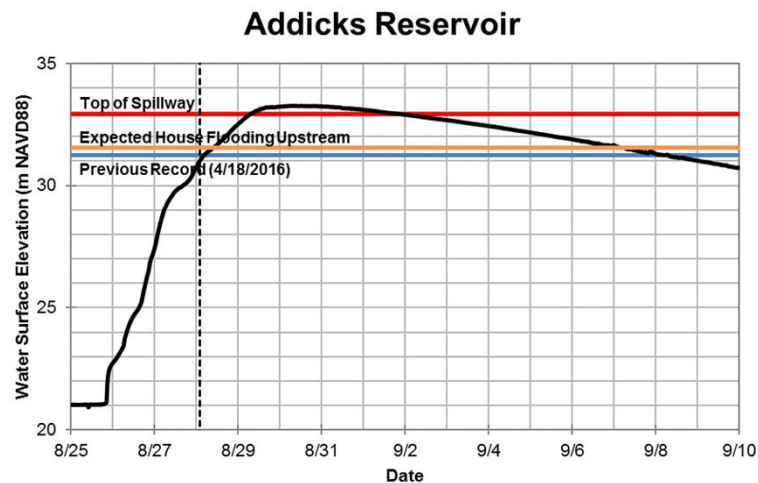


## Harvey in Houston: Addicks & Barker



## Harvey in Houston: Addicks & Barker

*On August 27, the USACE announced that it would begin releasing water the next day to prevent overflowing emergency spillways, catastrophic failure of the dams, and further flooding in upstream communities.*



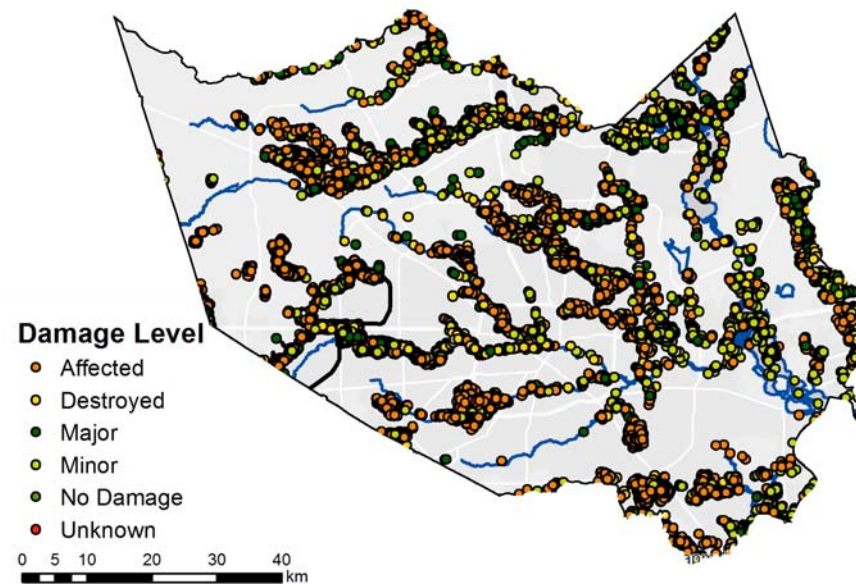
Between August 25 and 28, approximately 254 and 457 mm of rain fell in the contributing areas upstream of the Addicks and Barker reservoirs

Even though the USACE started releasing water on the morning of August 28, water levels in Addicks overtopped the emergency spillways for a period of approximately 2 days



# Harvey in Houston: Damages

*Harvey was an extreme event in terms of its damages.*



- 119,000 homes affected with 800 completely destroyed
- 500,000 cars damaged
- 300,000 people without power

## Harvey in Houston: Industrial & Environmental Impacts

*Harvey demonstrated that environmental impacts can cascade from natural hazard events.*



- 24 storage tanks ruptured
- 3 million barrels per day of refining capacity down

## Harvey in Houston: Industrial & Environmental Impacts

*Numerous industrial and chemical facilities were affected by flooding.*

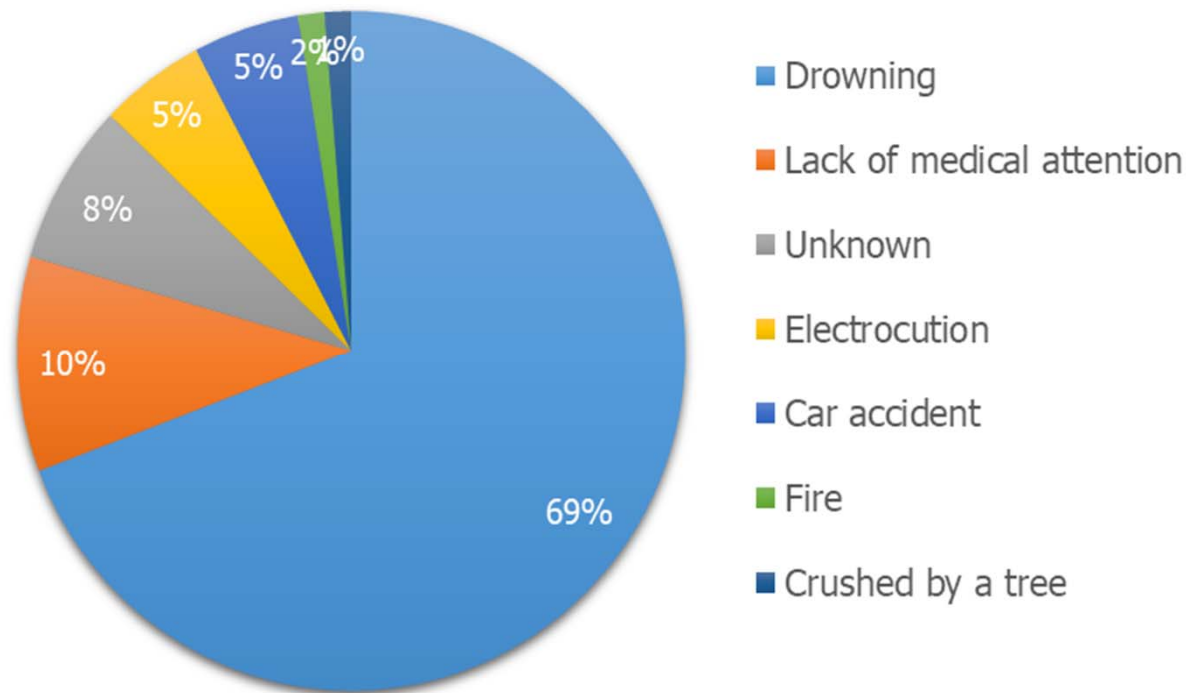
- The Arkema facility lost power, resulting in explosions and release of toxic chemicals into the environment





## Harvey in Houston: Fatalities

*Harvey caused 78 fatalities in Texas; 53 of which occurred in the Houston area. The majority (54) of the casualties in Texas were due to drowning*

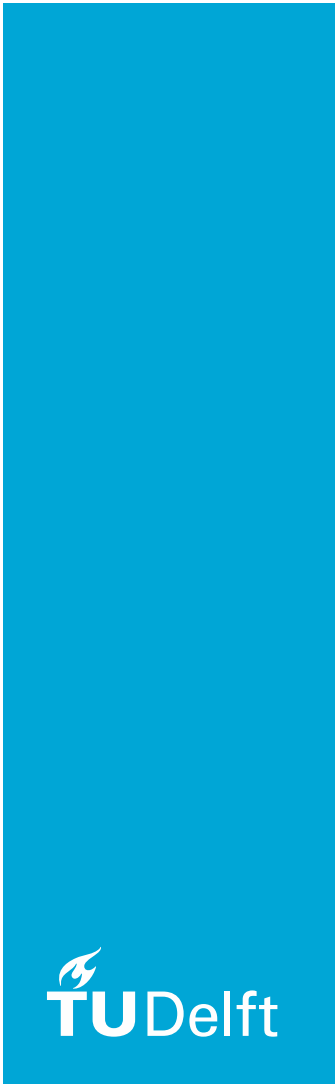




## Evacuation and Emergency Response

*No large-scale mandatory evacuation was ordered during Harvey and many people were asked to “shelter-in-place;” however, rising waters during the event necessitated thousands of rescues in Texas (>100,000).*





# Lessons and resilience



# River Flood Management

Lesson 1: Infrastructure for “higher than design standard” events



‘Broaden the Bayou’



‘Room for the River’

# Protecting Critical Infrastructure

## *Lesson 3: Cascading effects on chemical plants*

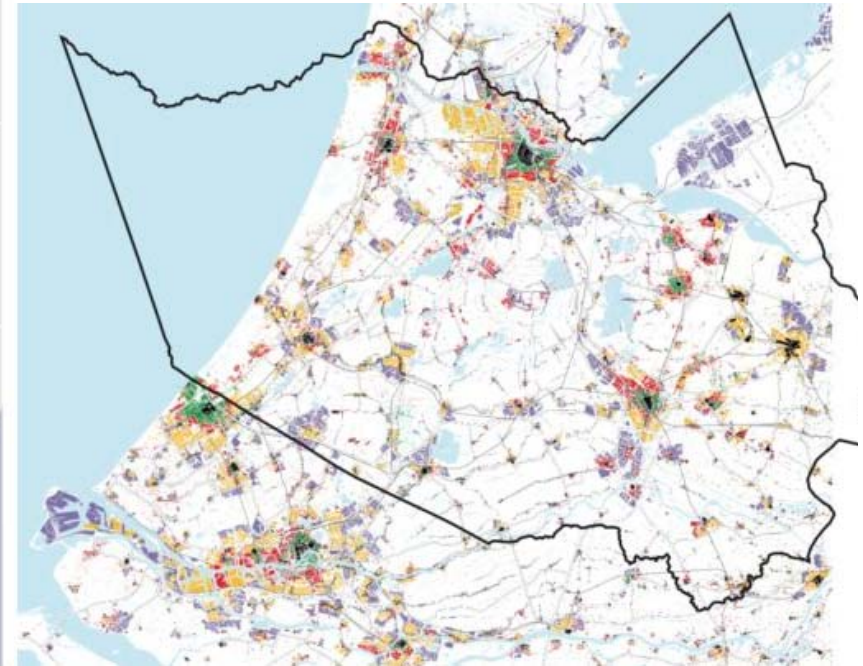
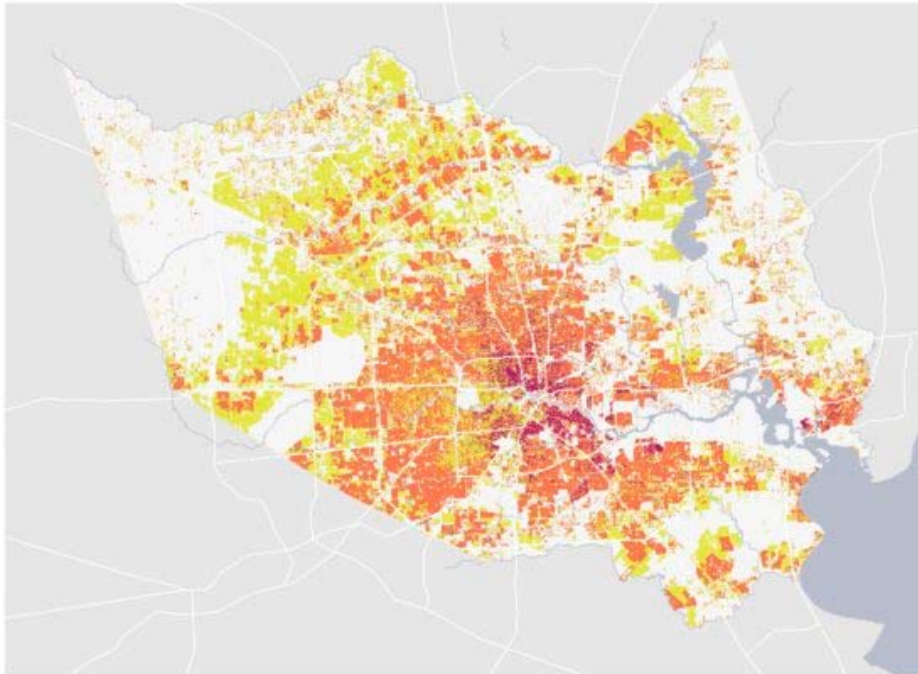


Port of Rotterdam Shipping Containers

# Spatial Planning

*Lesson 4: development has exacerbated flood risk*

YEAR BUILT  
PRE 1945  
1945 - 1982  
1983 - 2016



# Emergency Response

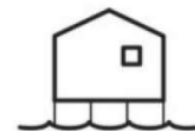
*Massive evacuation of Houston impossible, optimal local evacuation strategy?*





## Closing remarks

- Harvey was an extreme event
- Lack of resilience (?):
  - Water infrastructure overloaded
  - Planning exacerbated flood risk
  - Emergency response overwhelmed



*Drawings: Xiangcheng Xing*

# Sint Maarten (1)

NRC, 12/10/17  
Prof. R. Nijssen



je

ing

## Sint Maarten (2)



- Elke tien jaar een orkaan, elke 20 a 30 jaar een extreme
- Afweging (kansen, schade, kosten)
  - Orkaanbestendig huis
  - Repareerbaar huis (met orkaanbestendige kern)
  - Houten huizen en stevige shelter
- “Build back better”: watervoorziening, stroom en infrastructuur