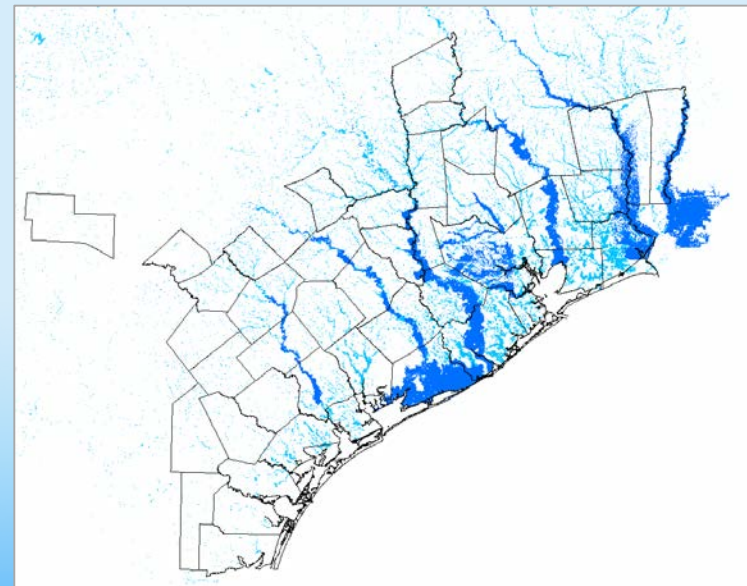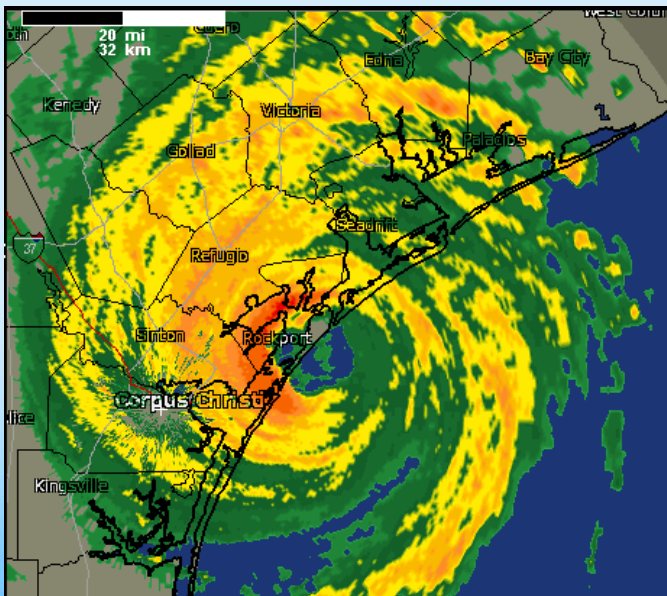# Hurricane Harvey: Flood Forecasting and Response
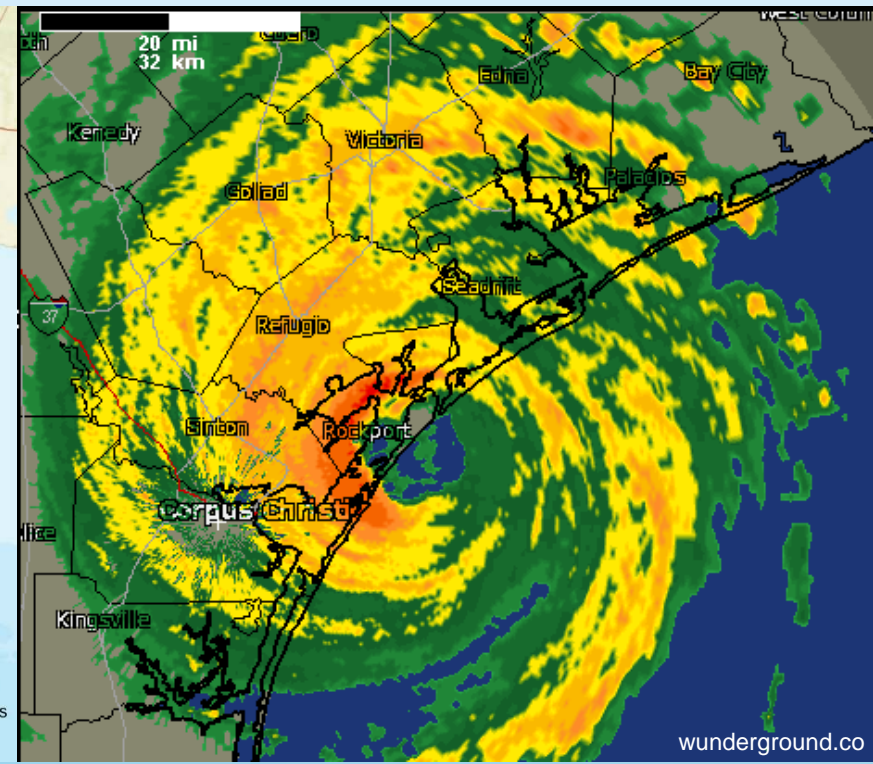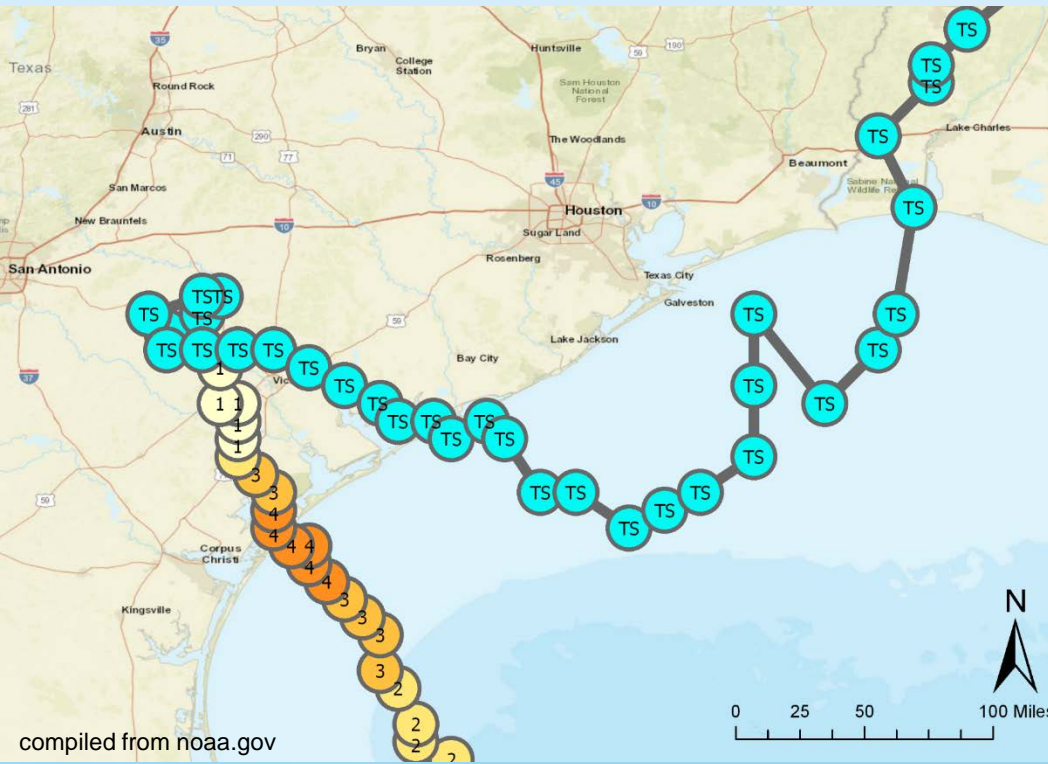
David R. Maidment
Center for Water and Environment
University of Texas at Austin

Storm Track for Hurricane Harvey

compiled from noaa.gov

wunderground.com

8/23/2017 8/24/2017 8/25/2017 8/26/2017 8/27/2017 8/28/2017 8/29/2017 8/30/2017 8/31/2017
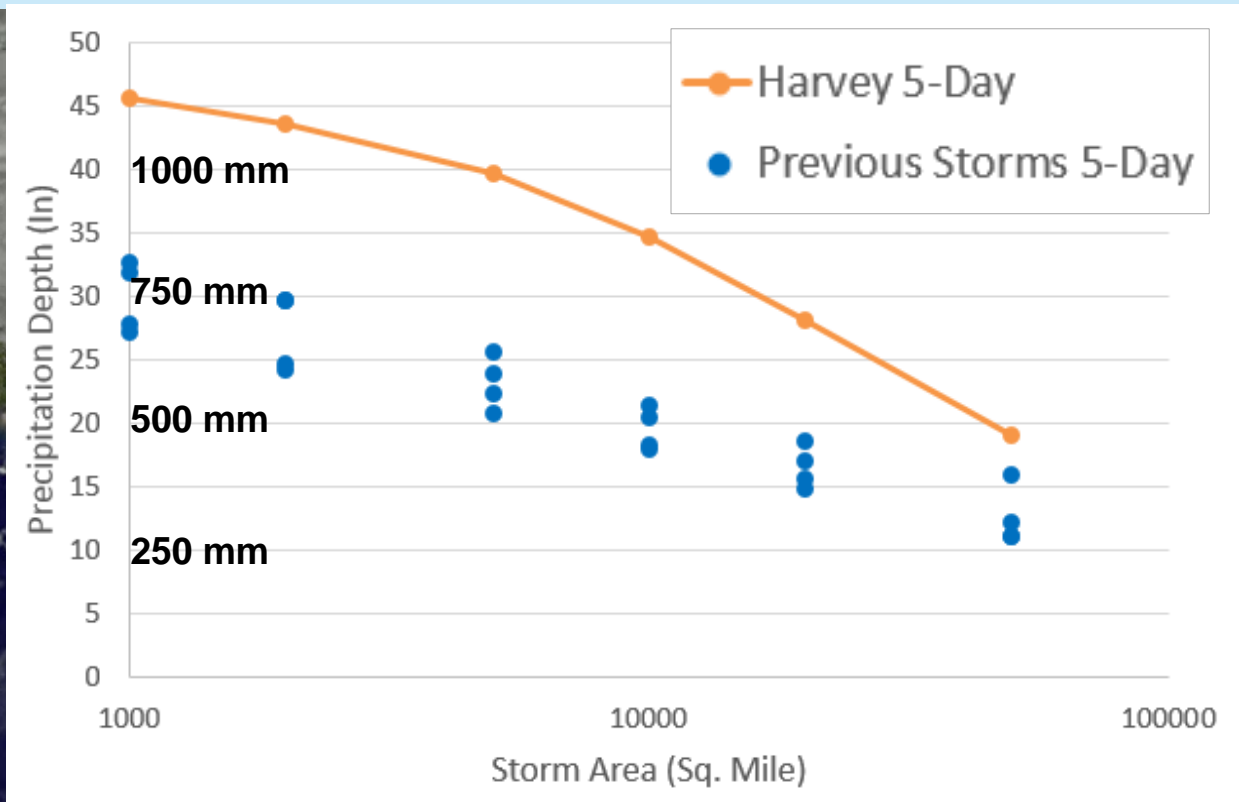
5 days

Hurricane Harvey Precipitation

Harvey **2-day** precipitation was the **worst recorded storm** in US history

Harvey **3-day** Precipitation averaged **5 inches** (**125 mm) more** than previous storms

Harvey **5-day** Precipitation averaged **11 inches (280 mm) more** than previous storms

Data Sources: NWS River Forecast Centers; Applied Weather Associates, Inc., NASA.
Analysis: John Nielsen-Gammon and Brent McRoberts, Texas A&M University

> 150,000 homes flooded in Southeast Texas

Texas Division of Emergency Management, Austin

- **State Operations Center**
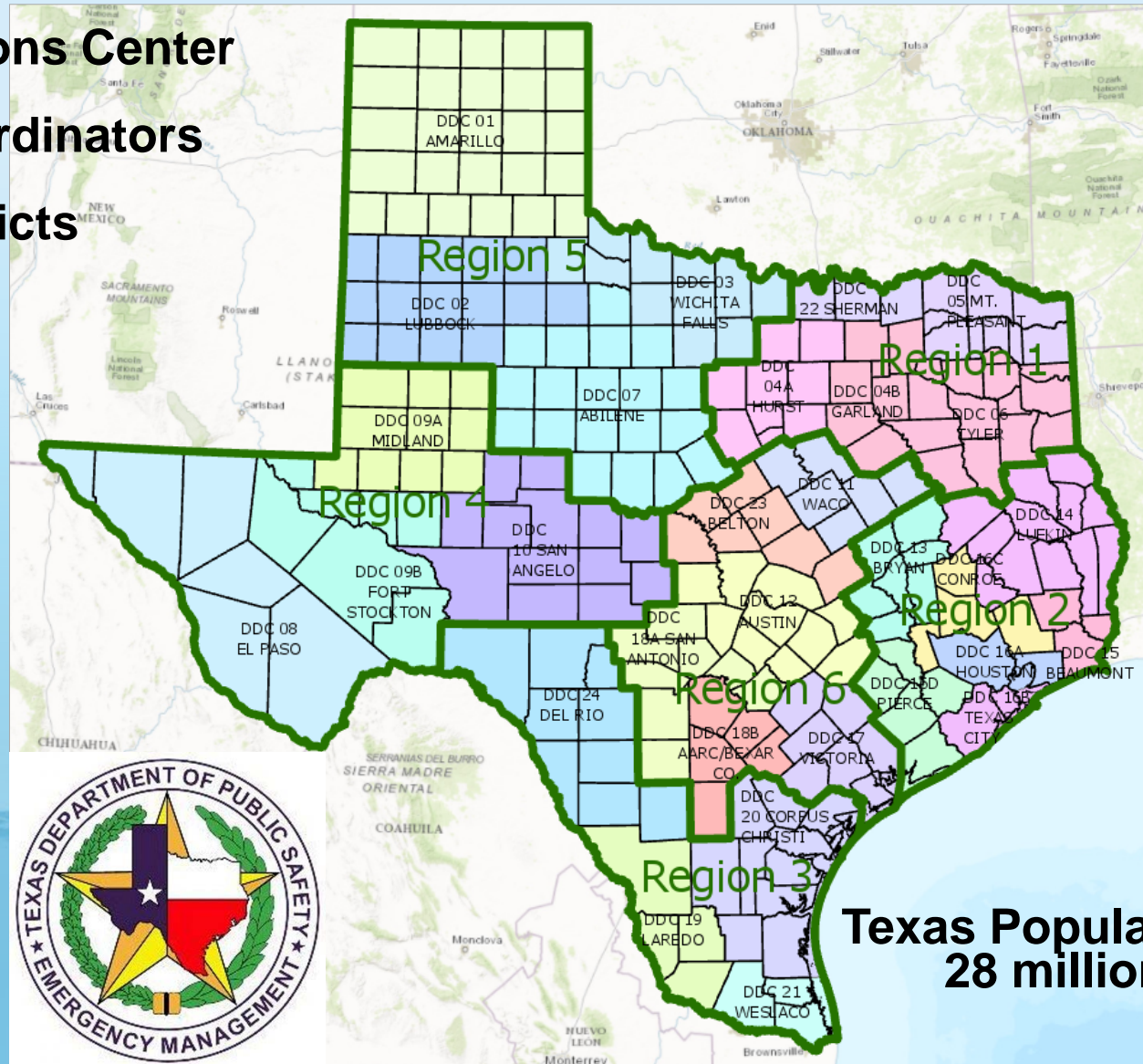- **Regional Coordinators**
- **Disaster Districts**
- **Counties**

**Chief Nim Kidd
Director, TDEM**

Death Toll:
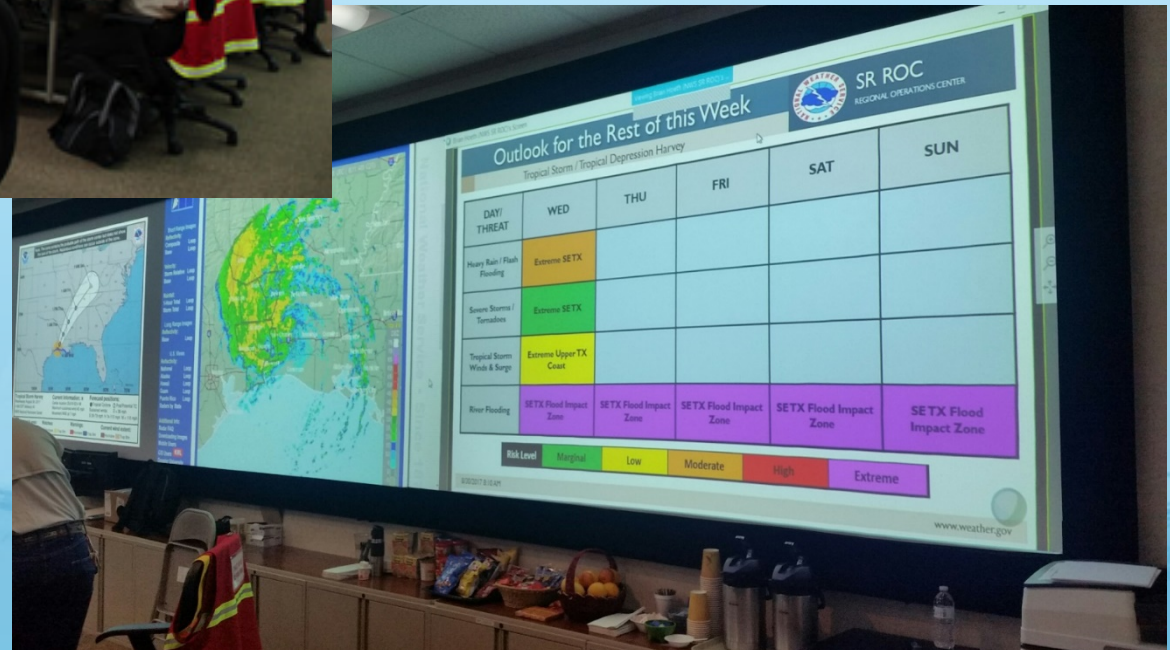
Harvey: 80

Katrina: 1800

**Texas Population:
28 million**

Flood Emergency Response in Texas

State Operations Center in Austin during Hurricane Harvey (August 2017)

Letter from Chief Kidd to President Fenves, UT Austin

Because of the catastrophic nature of this disaster, TDEM needs additional technical support for water data on an expedited basis and we believe Dr. Maidment's team and other personnel from the university can provide this for the state's response.

TEXAS DEPARTMENT OF PUBLIC SAFETY
5805 N LAMAR BLVD • BOX 4087 • AUSTIN, TEXAS 78773-0001
512/424-2000
www.dps.texas.gov

STEVEN C. McCRAW
DIRECTOR
DAVID G. BAKER
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DEPUTY DIRECTORS

COMMISSION
STEVEN P. MACH, CHAIRMAN
MANNY FLORES
A. CYNTHIA LEON
JASON K. PULLIAM
RANDY WATSON

Thursday, August 31

August 31, 2017

Greg Fenves
President
The University of Texas at Austin
Austin, Texas

"Doc, we need data"

President Fenves:

The Texas Division of Emergency Management (TDEM) along with more than 30 members of the Emergency Management Council, composed of other state agencies and organizations, are currently coordinating the state response to the catastrophic damages wrought by Hurricane Harvey.

Over the last year, Dr. David Maidment and his team have provided invaluable support for groundbreaking work developing a Texas Flood Response System for TDEM. Because of the catastrophic nature of this disaster, TDEM needs additional technical support for water data on an expedited basis and we believe Dr. Maidment's team and other personnel from the university can provide this for the state's response. I respectfully request that you provide any support available for Dr. Maidment and his team to assist in our current response.

Sincerely,

W. Nim Kidd, CEM ®, TEM
Chief
Texas Division of Emergency Management
Assistant Director
Texas Homeland Security
Texas Department of Public Safety

cc: Sharon Wood, Dean, Cockrell School of Engineering

Helicopter Rescues in Beaumont

Day 5: Tuesday 29 August

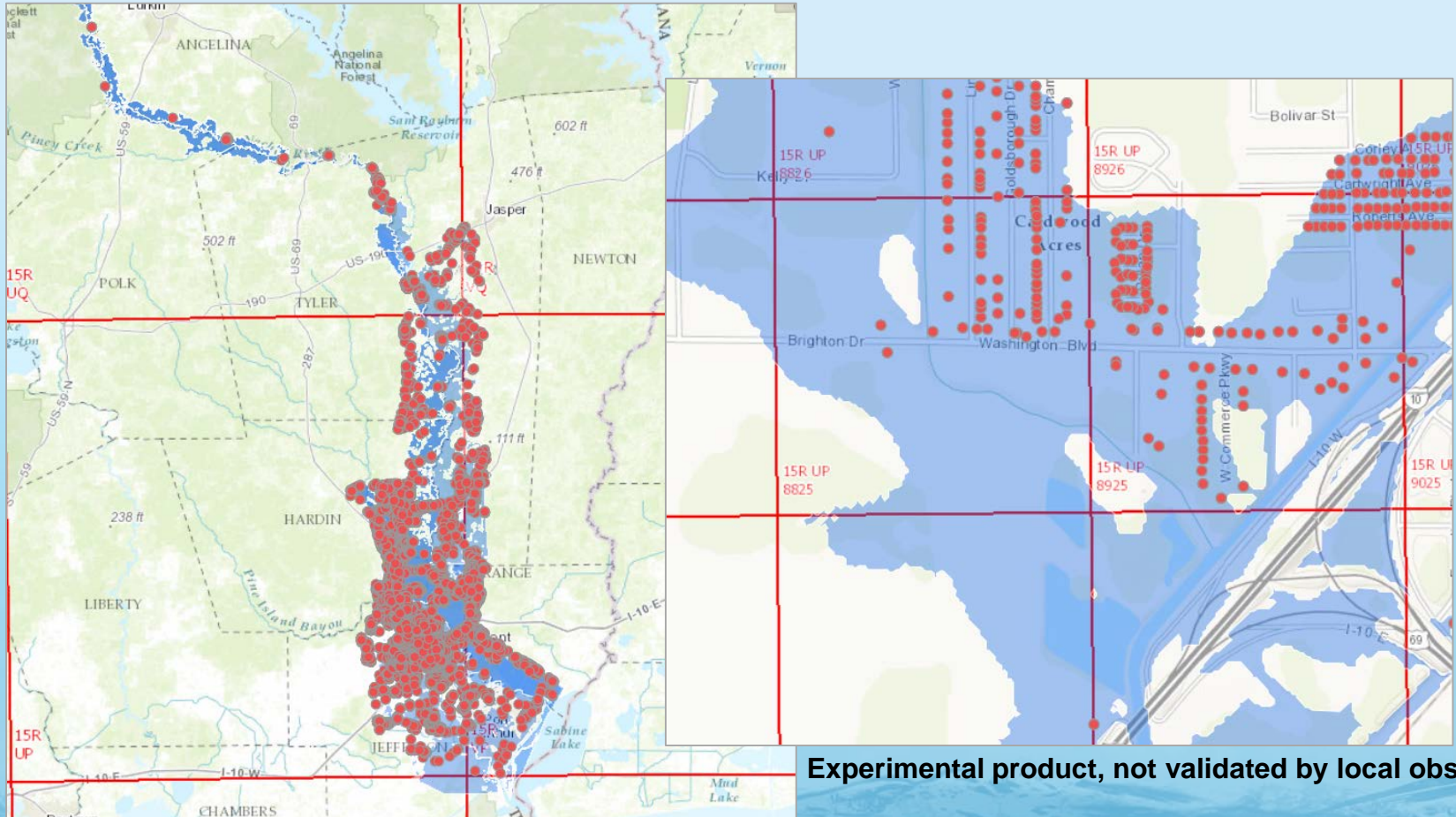26 inches (660 mm) of rain fell on Beaumont overnight

Beaumont became like Venice

All 26 Urban Search and Rescue teams mobilized across nation

Air space above city completely filled with helicopters
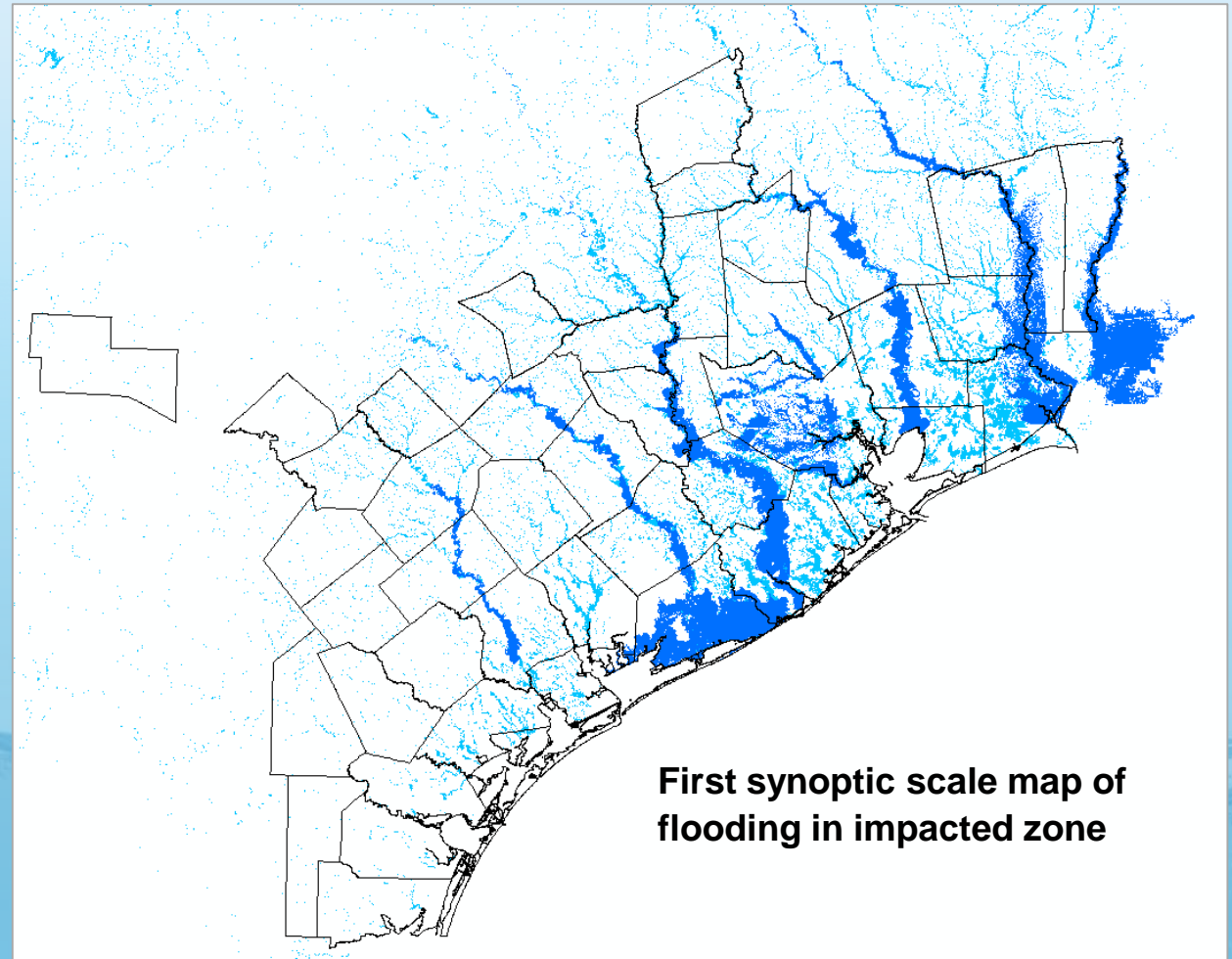
Inundation Maps for Search and Rescue

Experimental product, not validated by local observation

Forecasting by NWS West Gulf River Forecast Center
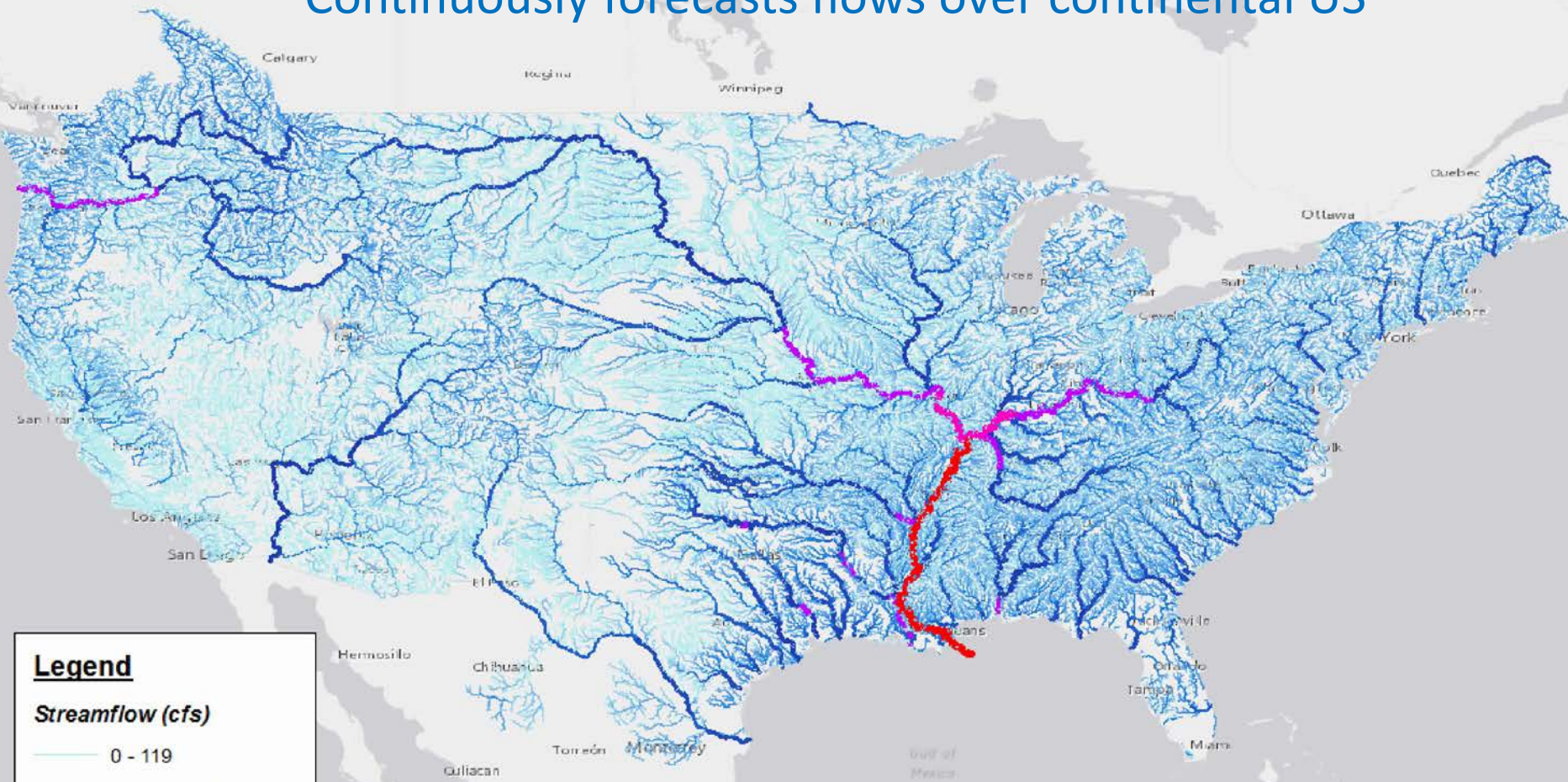Inundation Mapping by US Army Corps of Engineers
Overlay on Address Points by University of Texas at Austin

Maximum Flood Inundation Extent from Hurricane Harvey

Legend:
- ☑ Declared Disaster Counties
- ☐ (white)
- ☑ MaxFloodExtentUSACE (dark blue)
- ☑ National Water Model (light blue)

First synoptic scale map of flooding in impacted zone

National Water Model

Continuously forecasts flows over continental US

Legend

Streamflow (cfs)

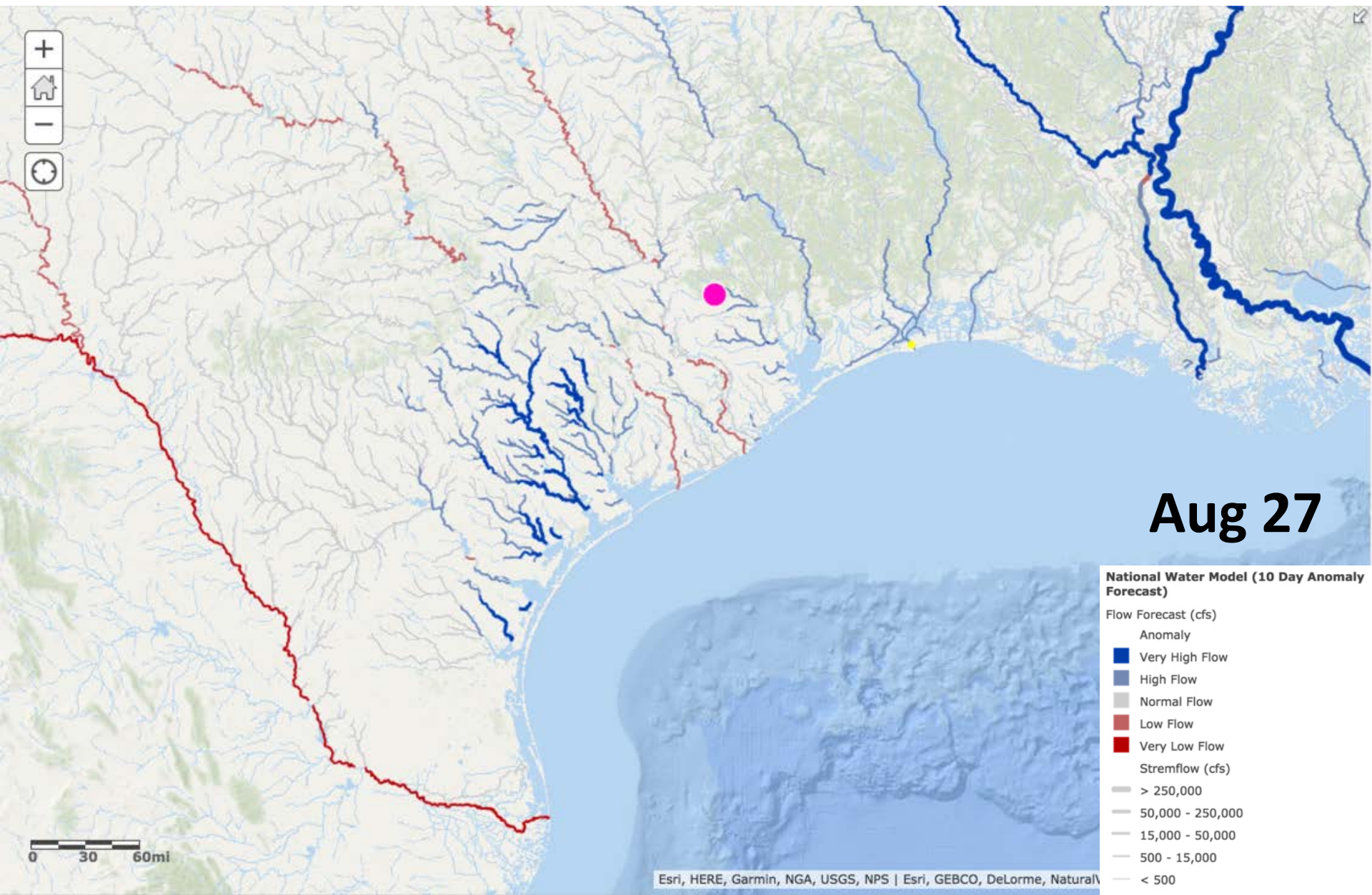|	
——	0 - 119
——	119 - 7,520
——	7,521 - 88,700
——	88,701 - 201,900
——	201,901 - 460,000
——	460,001 - 1,200,000

05/01/2015 00:00
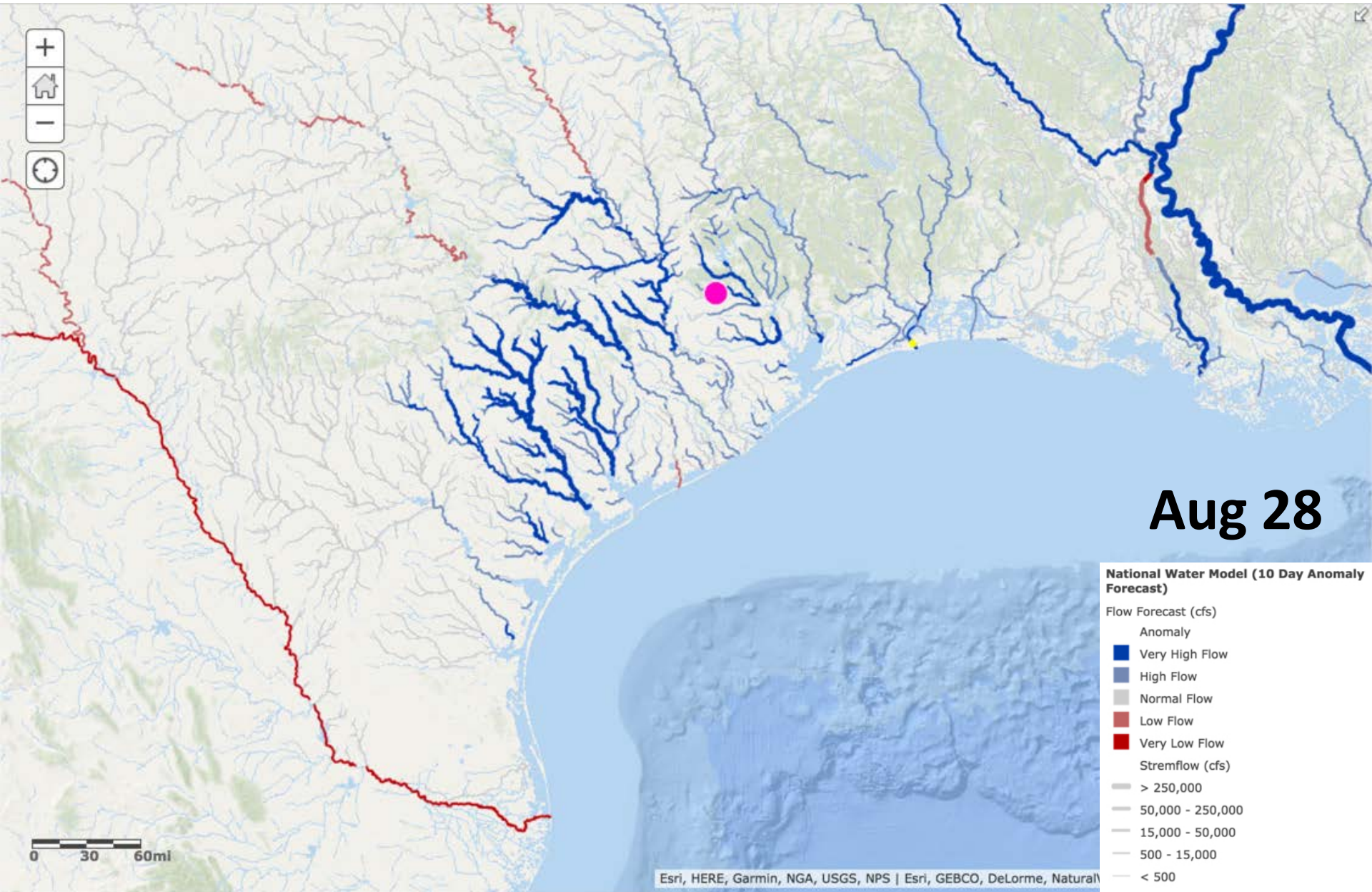
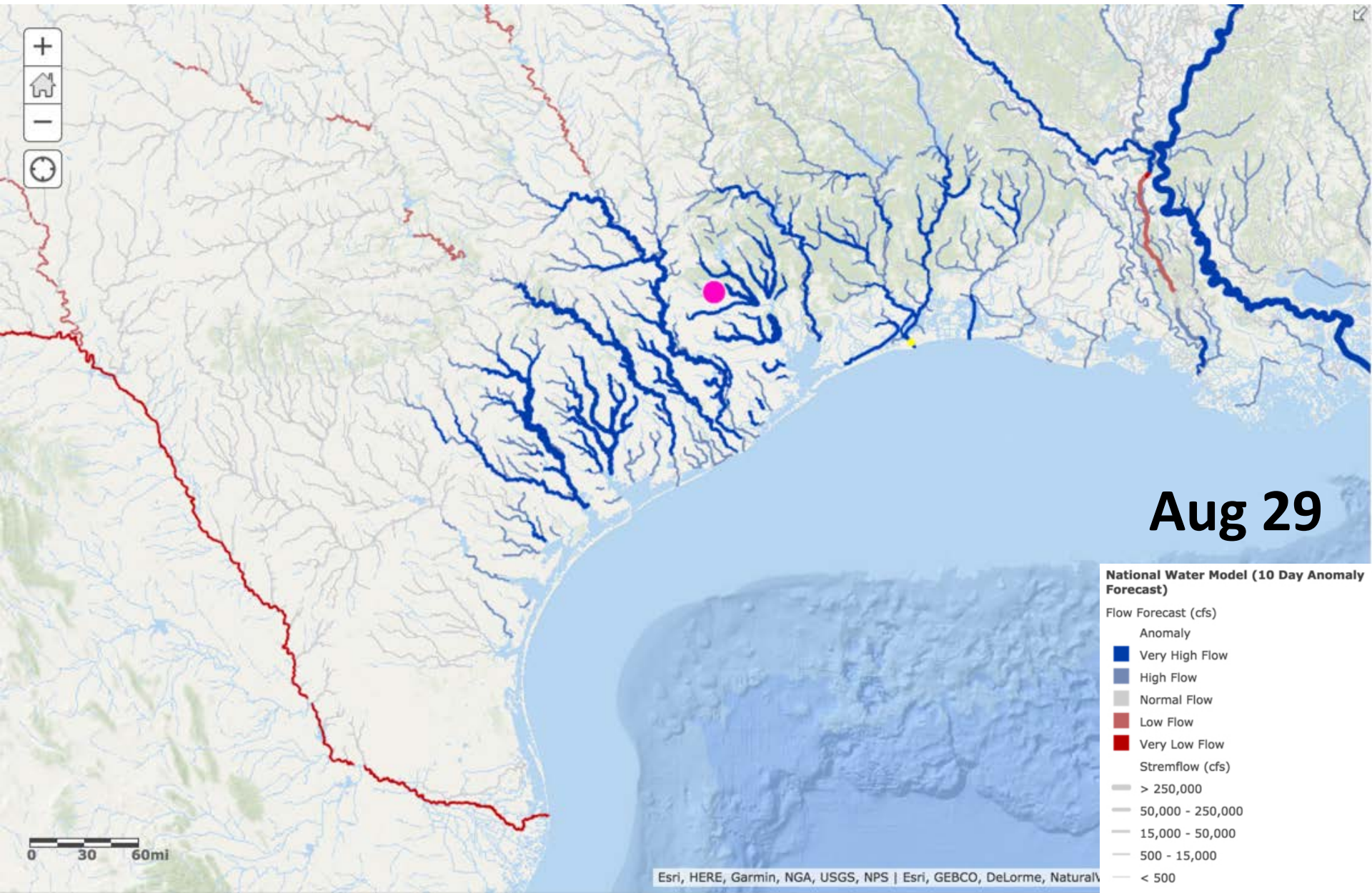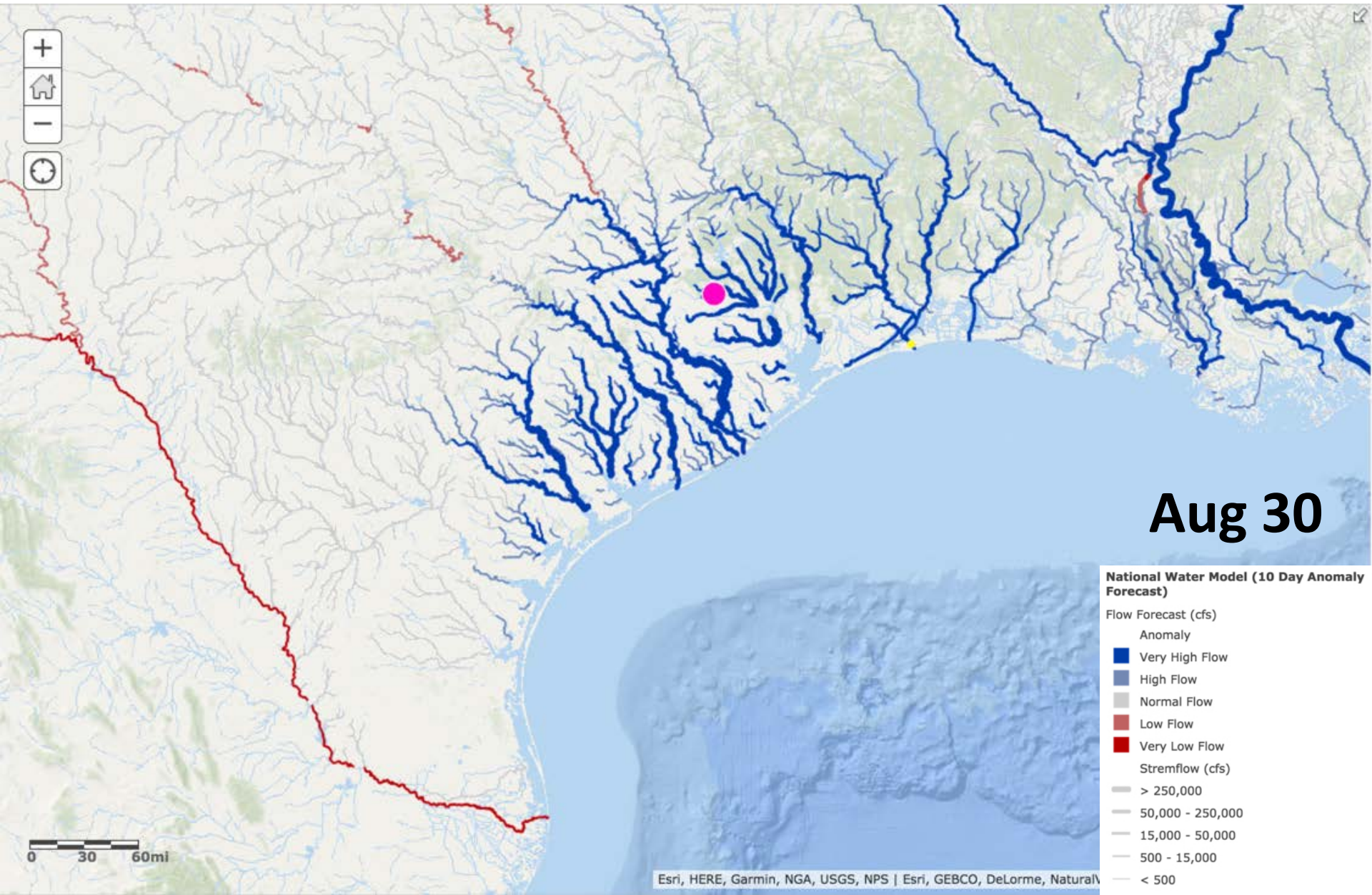# National Water Model: 10 day forecast on Aug 25, 10am (streamflow difference from normal)

Aug 26

National Water Model (10 Day Anomaly Forecast)

Flow Forecast (cfs)
Anomaly

- Very High Flow
- High Flow
- Normal Flow
- Low Flow
- Very Low Flow

Stremflow (cfs)
- \> 250,000
- 50,000 - 250,000
- 15,000 - 50,000
- 500 - 15,000
- < 500

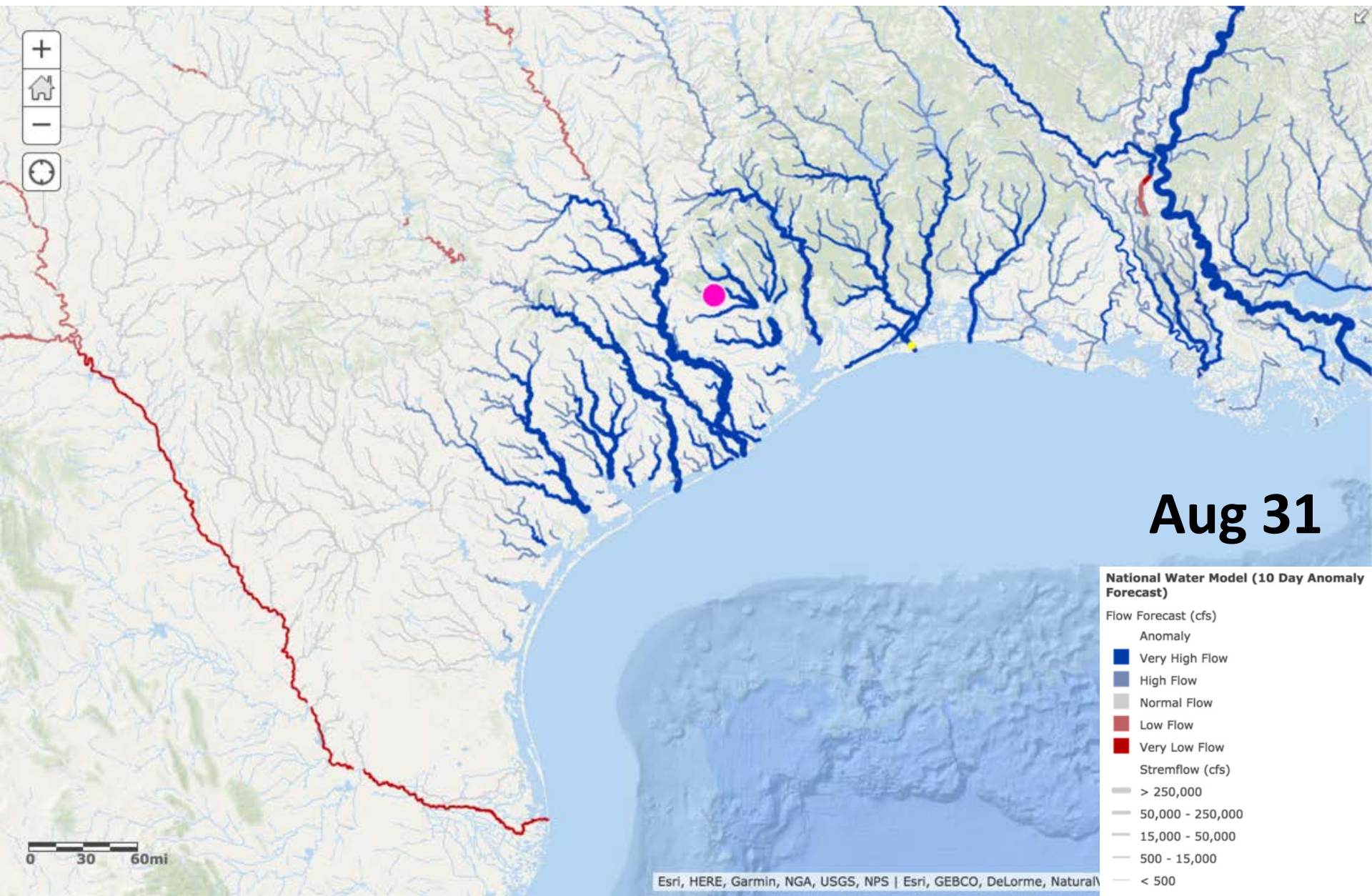Esri, HERE, Garmin, NGA, USGS, NPS | Esri, GEBCO, DeLorme, NaturalV

0   30   60mi

National Water Model: 10 day forecast on Aug 25, 10am (streamflow difference from normal)

Aug 27

National Water Model (10 Day Anomaly Forecast)

Flow Forecast (cfs)
Anomaly

■ Very High Flow
■ High Flow
■ Normal Flow
■ Low Flow
■ Very Low Flow

Stremflow (cfs)
— > 250,000
— 50,000 - 250,000
— 15,000 - 50,000
— 500 - 15,000
— < 500

0   30   60mi

Esri, HERE, Garmin, NGA, USGS, NPS | Esri, GEBCO, DeLorme, Natural\

National Water Model: 10 day forecast on Aug 25, 10am (streamflow difference from normal)

Aug 28

National Water Model (10 Day Anomaly Forecast)

Flow Forecast (cfs)

Anomaly
- Very High Flow
- High Flow
- Normal Flow
- Low Flow
- Very Low Flow

Stremflow (cfs)
- > 250,000
- 50,000 - 250,000
- 15,000 - 50,000
- 500 - 15,000
- < 500

Esri, HERE, Garmin, NGA, USGS, NPS | Esri, GEBCO, DeLorme, NaturalV

0   30   60mi

National Water Model: 10 day forecast on Aug 25, 10am (streamflow difference from normal)

Aug 29

National Water Model (10 Day Anomaly Forecast)

Flow Forecast (cfs)

Anomaly

- ▬ Very High Flow
- ▬ High Flow
- ▬ Normal Flow
- ▬ Low Flow
- ▬ Very Low Flow

Stremflow (cfs)

- ▬ > 250,000
- ▬ 50,000 - 250,000
- ▬ 15,000 - 50,000
- ▬ 500 - 15,000
- ▬ < 500

Esri, HERE, Garmin, NGA, USGS, NPS | Esri, GEBCO, DeLorme, NaturalV

National Water Model: 10 day forecast on Aug 25, 10am (streamflow difference from normal)

Aug 30

National Water Model (10 Day Anomaly Forecast)

Flow Forecast (cfs)
Anomaly

— Very High Flow
— High Flow
— Normal Flow
— Low Flow
— Very Low Flow

Stremflow (cfs)

— > 250,000
— 50,000 - 250,000
— 15,000 - 50,000
— 500 - 15,000
— < 500

0   30   60mi

Esri, HERE, Garmin, NGA, USGS, NPS | Esri, GEBCO, DeLorme, NaturalV

National Water Model: 10 day forecast on Aug 25, 10am (streamflow difference from normal)

Aug 31

National Water Model (10 Day Anomaly Forecast)

Flow Forecast (cfs)
Anomaly

- Very High Flow
- High Flow
- Normal Flow
- Low Flow
- Very Low Flow

Stremflow (cfs)
- > 250,000
- 50,000 - 250,000
- 15,000 - 50,000
- 500 - 15,000
- < 500

Esri, HERE, Garmin, NGA, USGS, NPS | Esri, GEBCO, DeLorme, NaturalV

0   30   60mi

Texas Address Points

9.28 million points

Point on every building used for dispatching emergency response vehicles by 911 systems

TNRIS
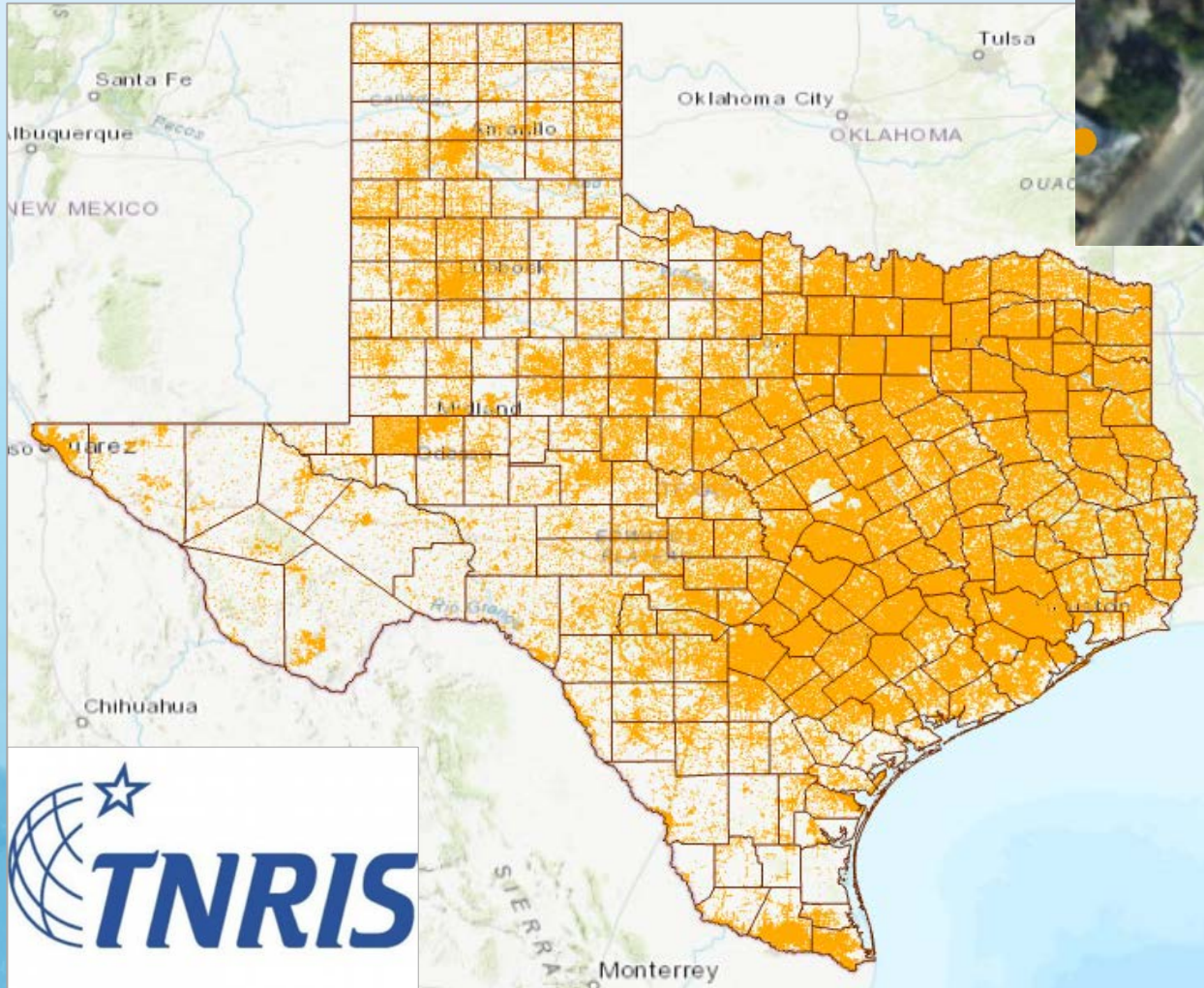
Address Points and Population for Texas Counties

$$y = 1.1474x^{1.0709}$$
$$R^2 = 0.9028$$
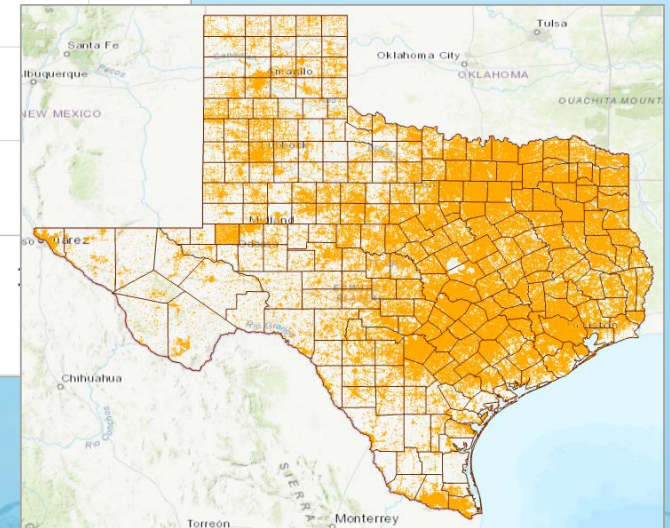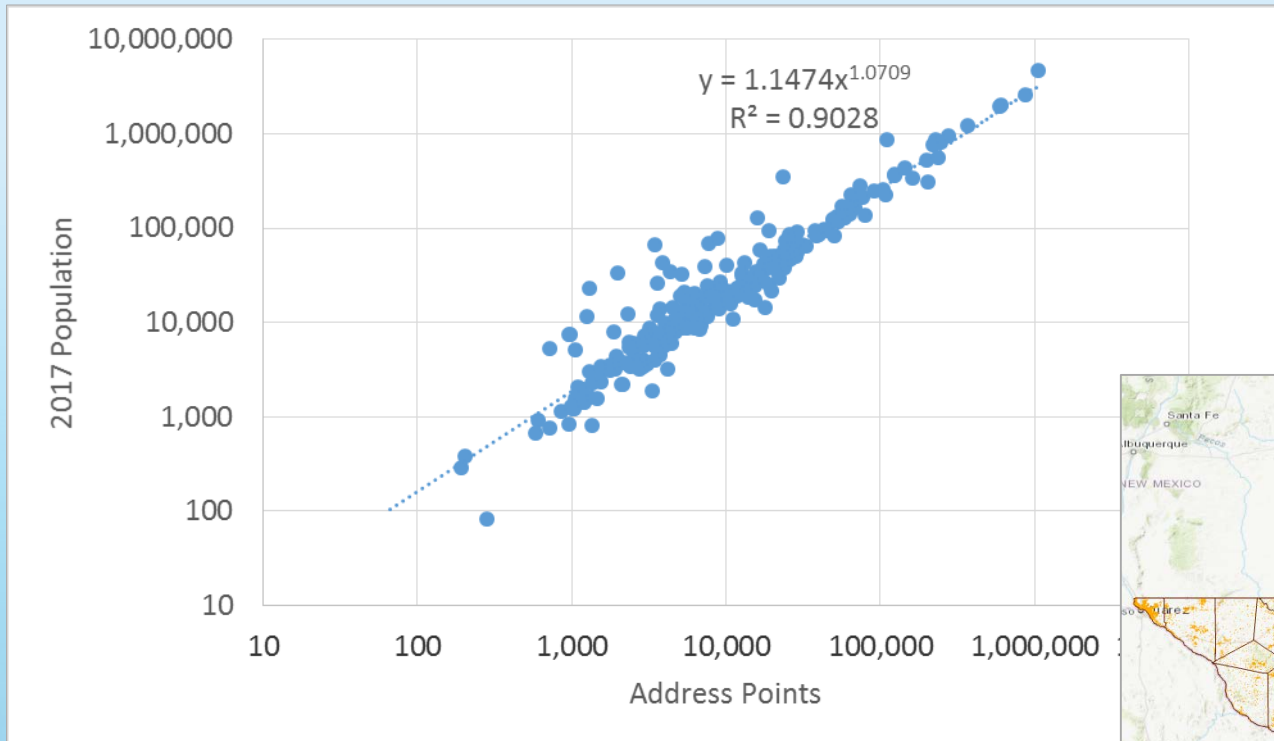
Texas Address Points = 9.28 million

Texas 2017 Population = 28.29 million

Average People per Address Point = 3.05

National Address Database (NAD)

National Address Database
Status by State as of April 26, 2018

U.S. Department of Transportation
Office of Chief Information Officer

Legend:
- 20 Accepted (45.49m)
- 2 In Progress
- 5 In Queue
- 4 No Data / No Statewide Program
- 5 Not in Public Domain
- Not Yet Contacted

Not all states have 100% coverage
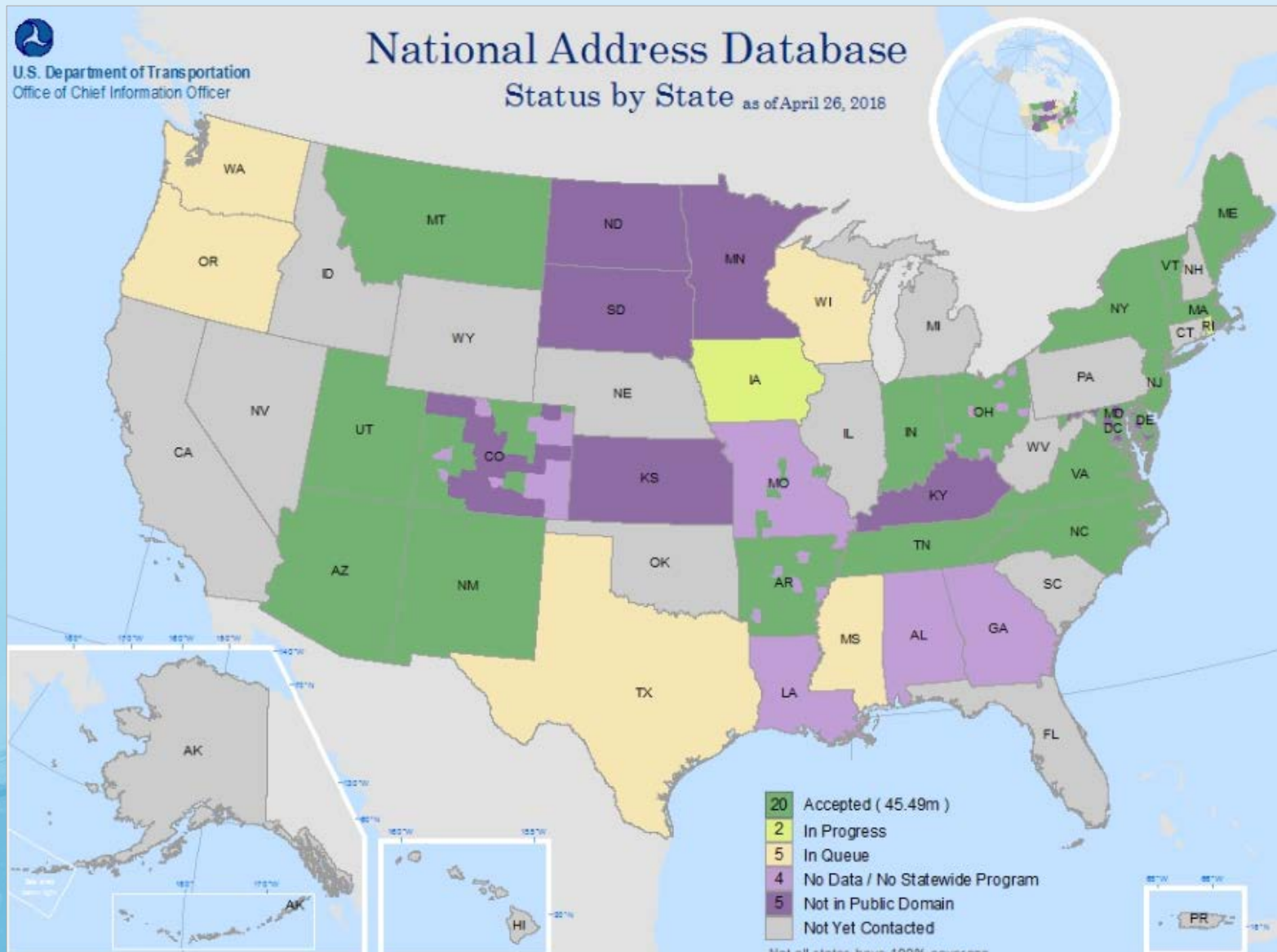
FEMA National Flood Hazard Layer in Texas

129 counties as of 18 June 2018

Large areas of Texas lack flood information
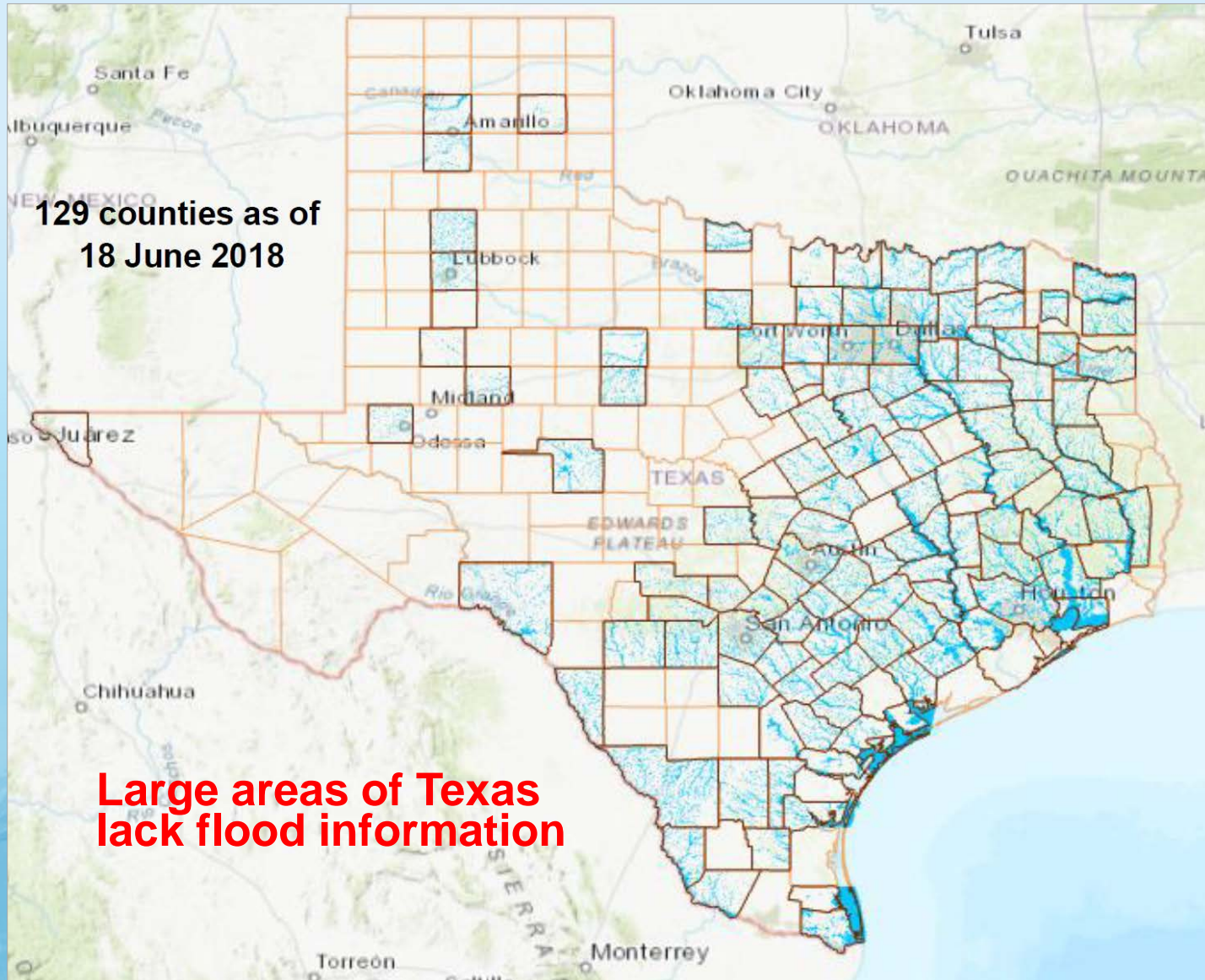
Real-Time Flood Inundation Mapping
Onion Creek at Highway 183
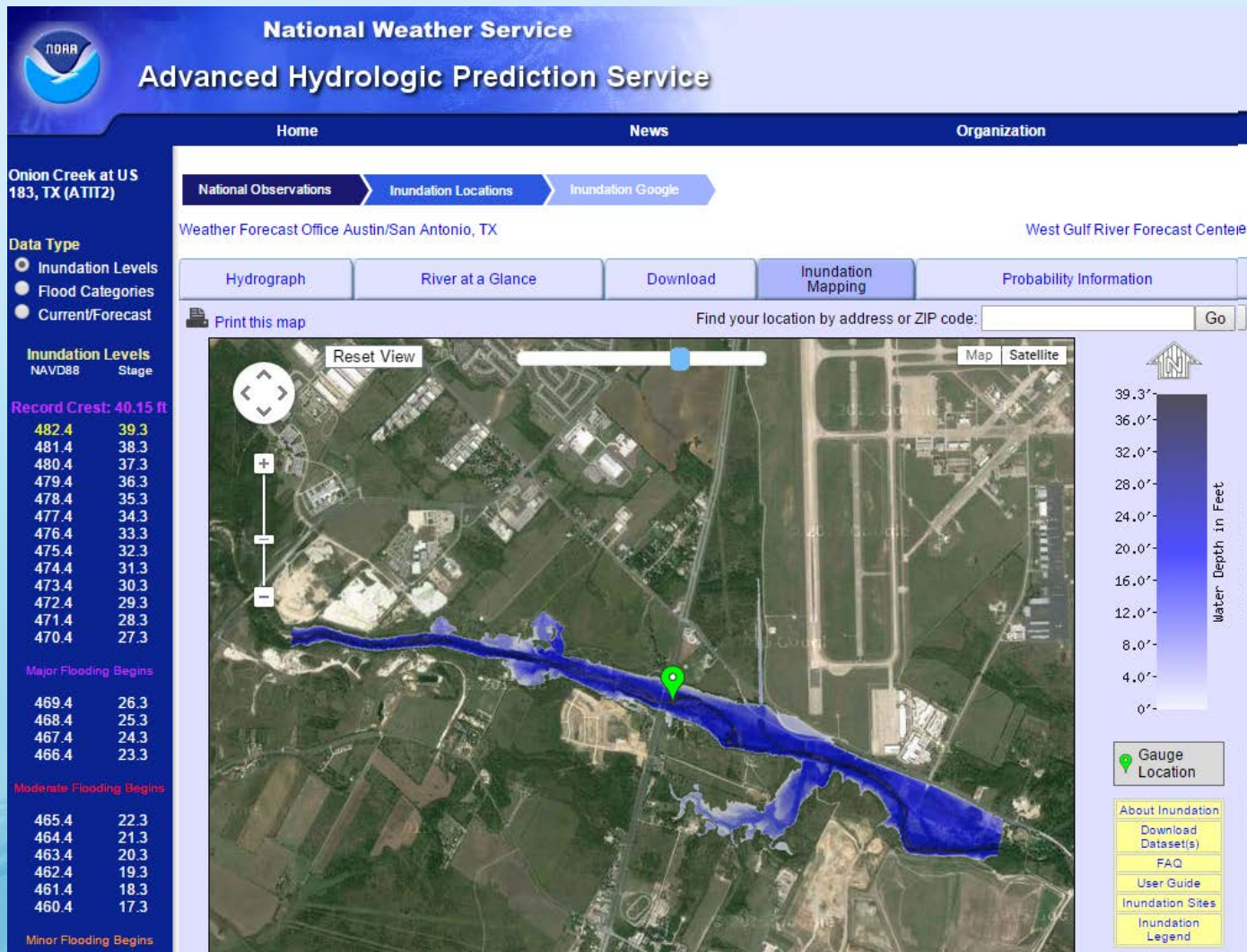
USGS Rating Curve at a Stream Gage

08159000 Onion Ck at US Hwy 183, Austin, TX

Measure Water Level

Determine Discharge

USGS WaterWatch

Last updated: 2016-11-18

KISTERS Hydro | NWM Viewer
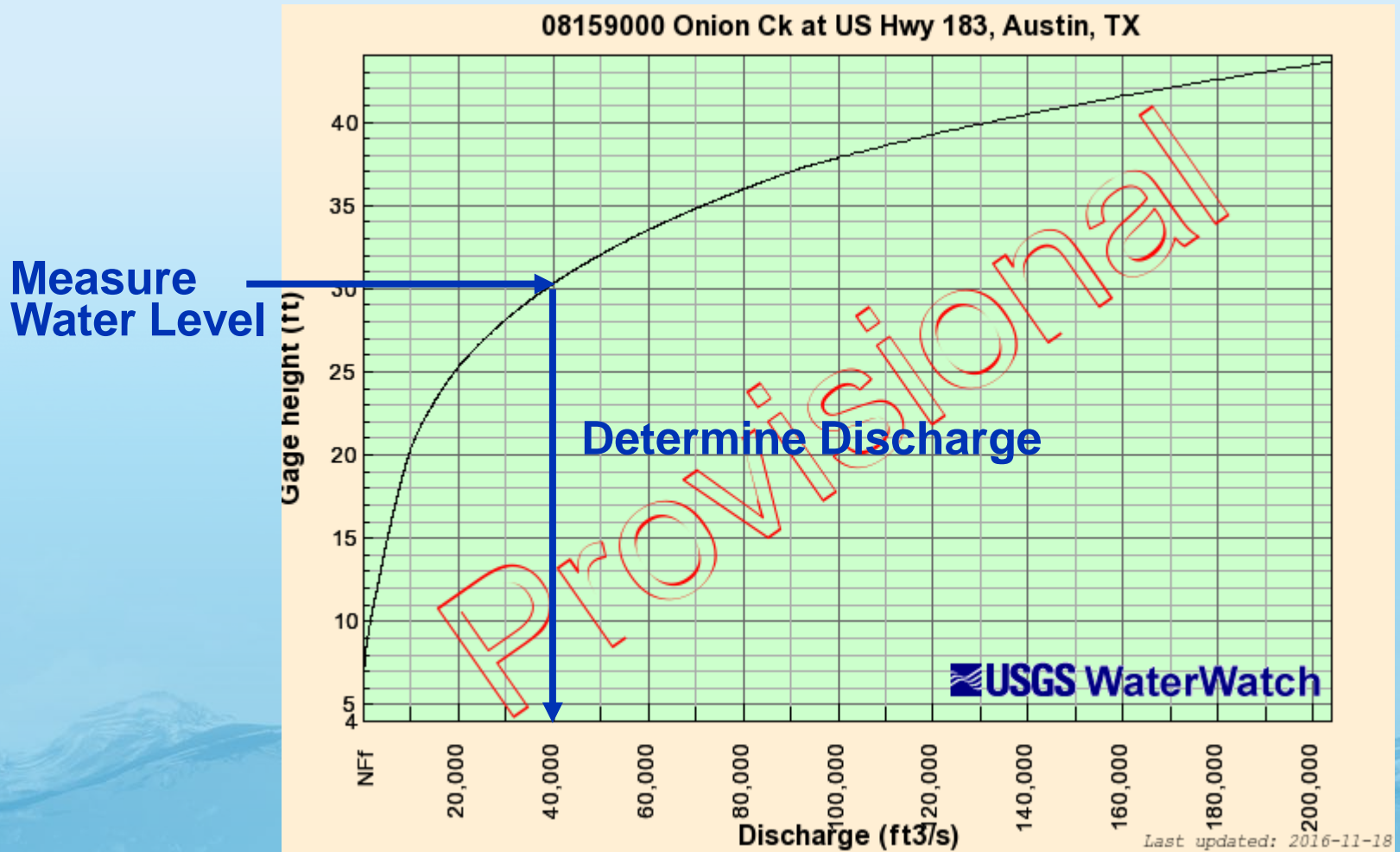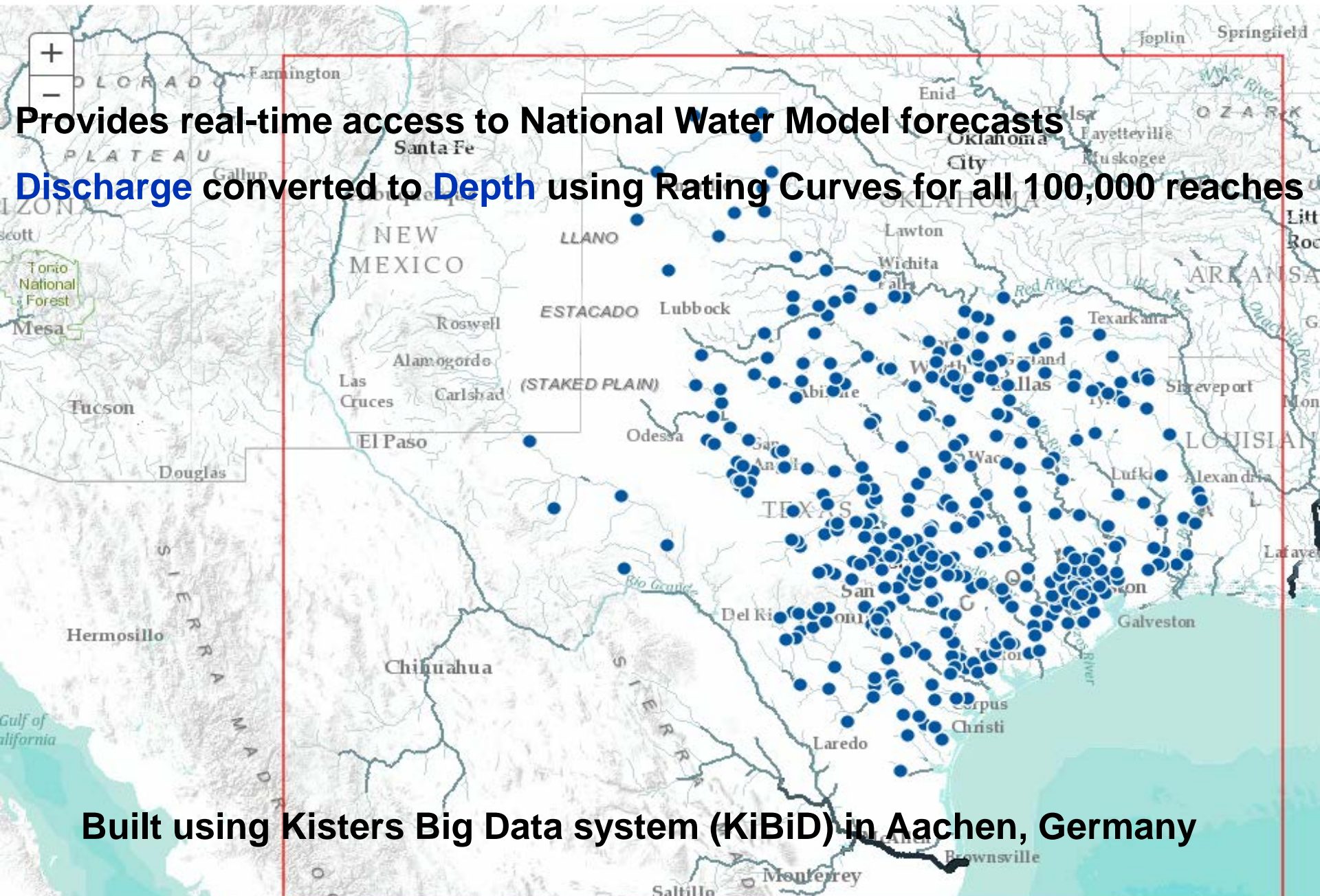
Provides real-time access to National Water Model forecasts

Discharge converted to Depth using Rating Curves for all 100,000 reaches

Built using Kisters Big Data system (KiBiD) in Aachen, Germany

Real Time Charts for Discharge and Depth
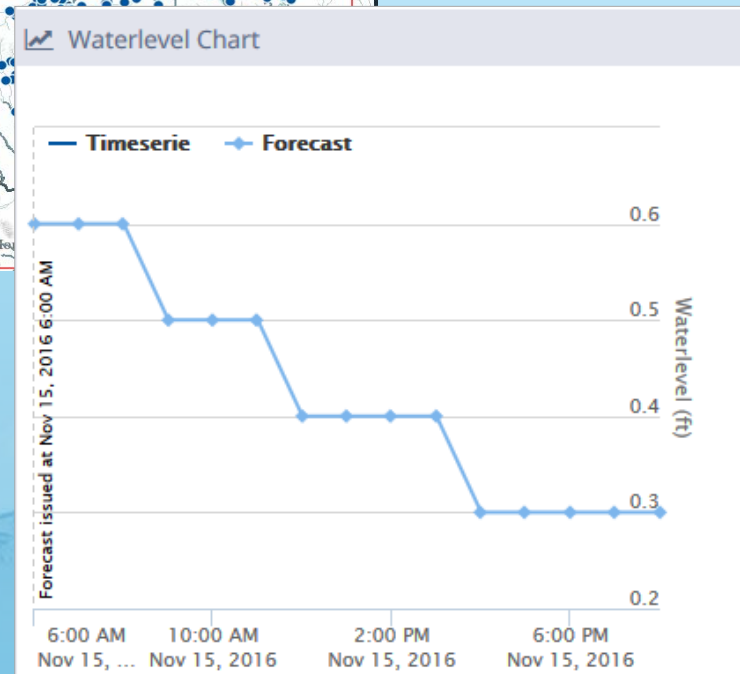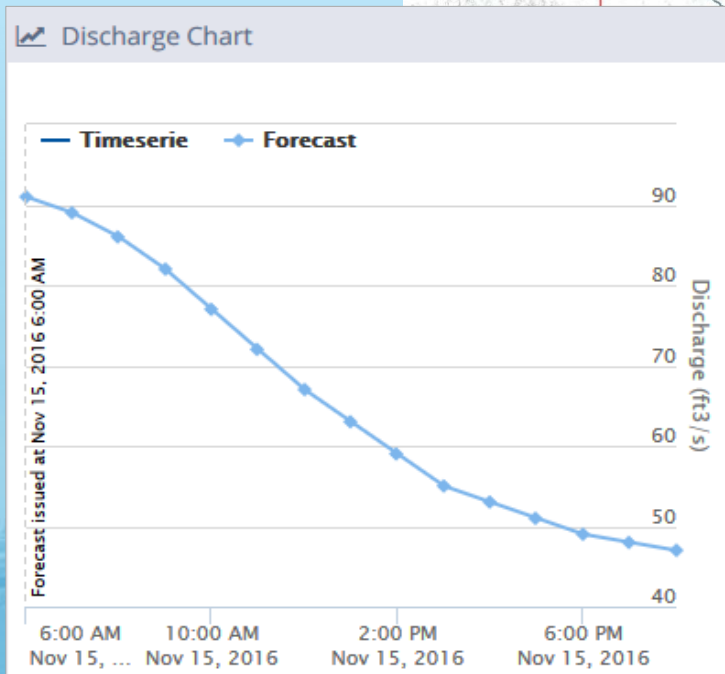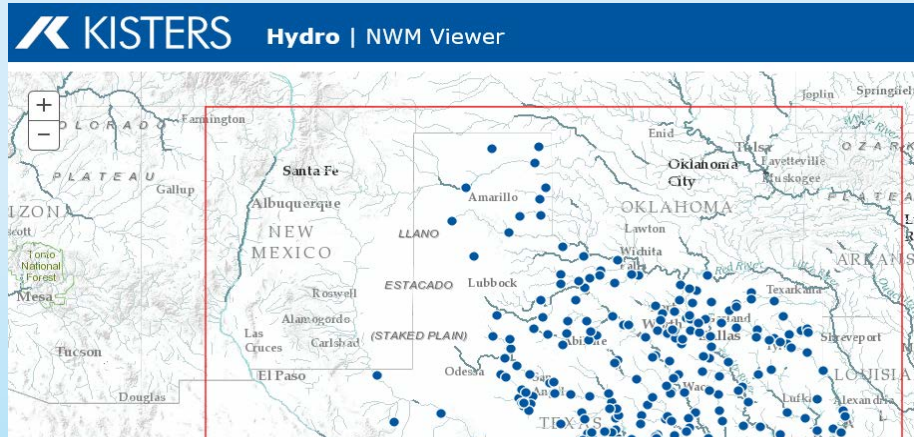
Flood Inundation and Impact
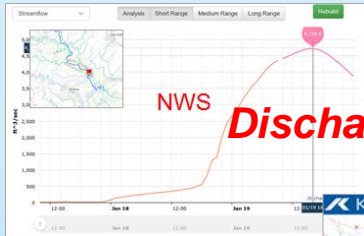
Take discharge forecast from the National Water Model

Discharge

NWS
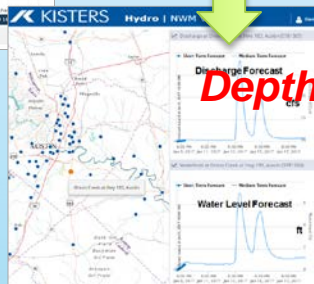
Transform discharge to depth by rating curve or hydraulic model
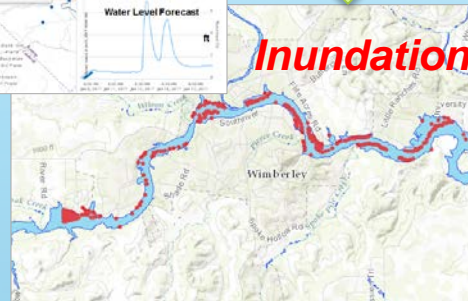
Depth

Create flood inundation map from water depth

Inundation

Assess impact on people and property

Impact

TDEM

District
DDC 16A HOUSTON
DDC 16D PIERCE
DDC 16B TEXAS CITY
DDC 16C CONROE
DDC 17 VICTORIA
DDC 15 BEAUMONT
DDC 14 LUFKIN
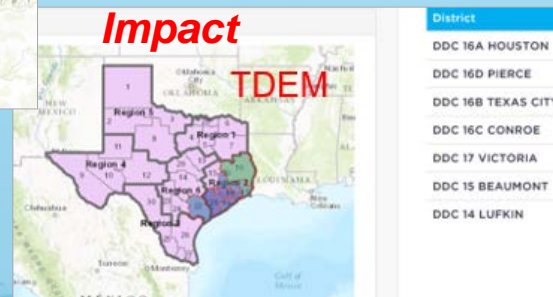
Flood emergency response depends on assessment of impact

Address Points in Harvey Impact Region

2.46 Million Address Points
in 34 counties
~ 7 million people
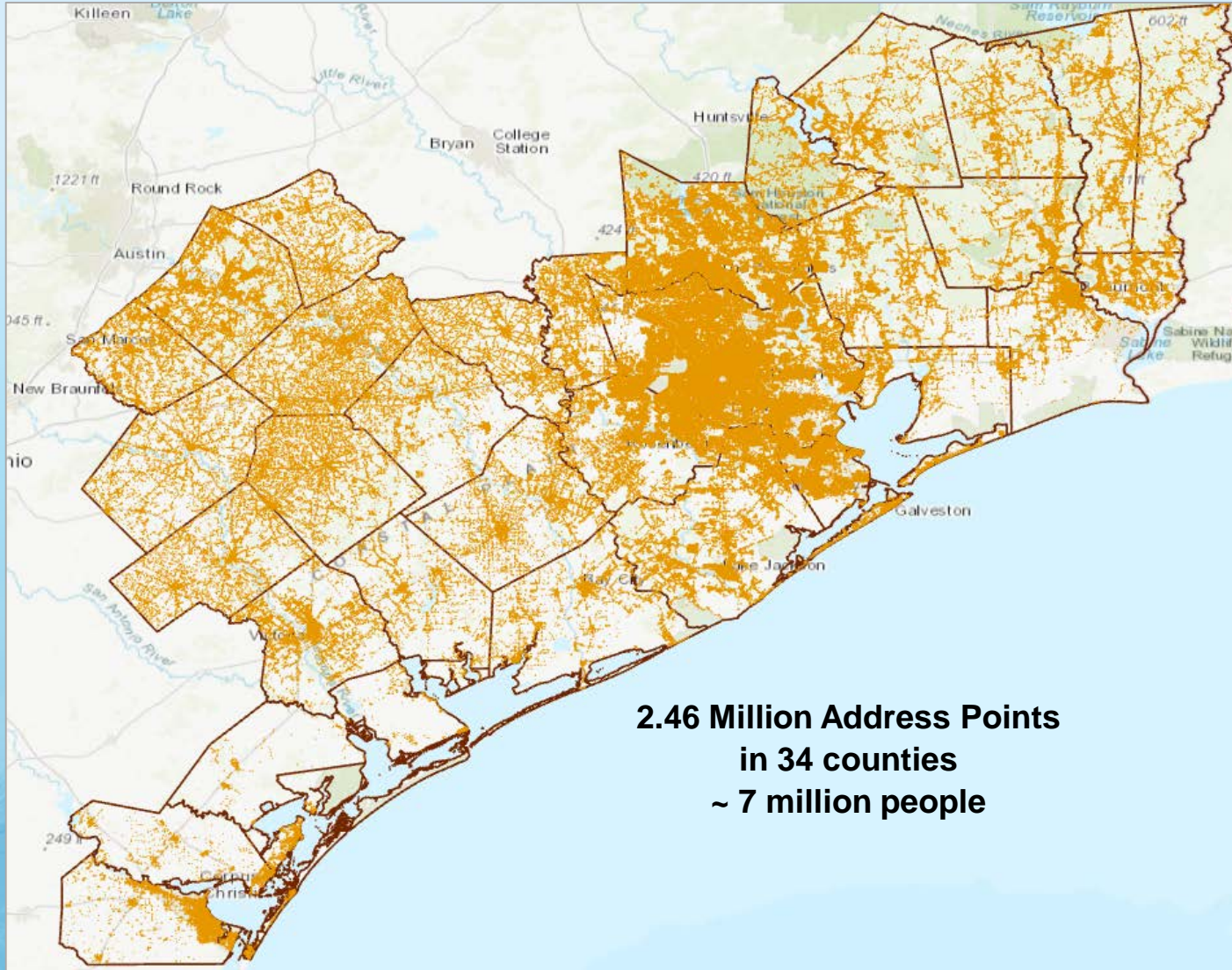
Flood Impact from National Water Model forecast at 3PM Friday 25 August
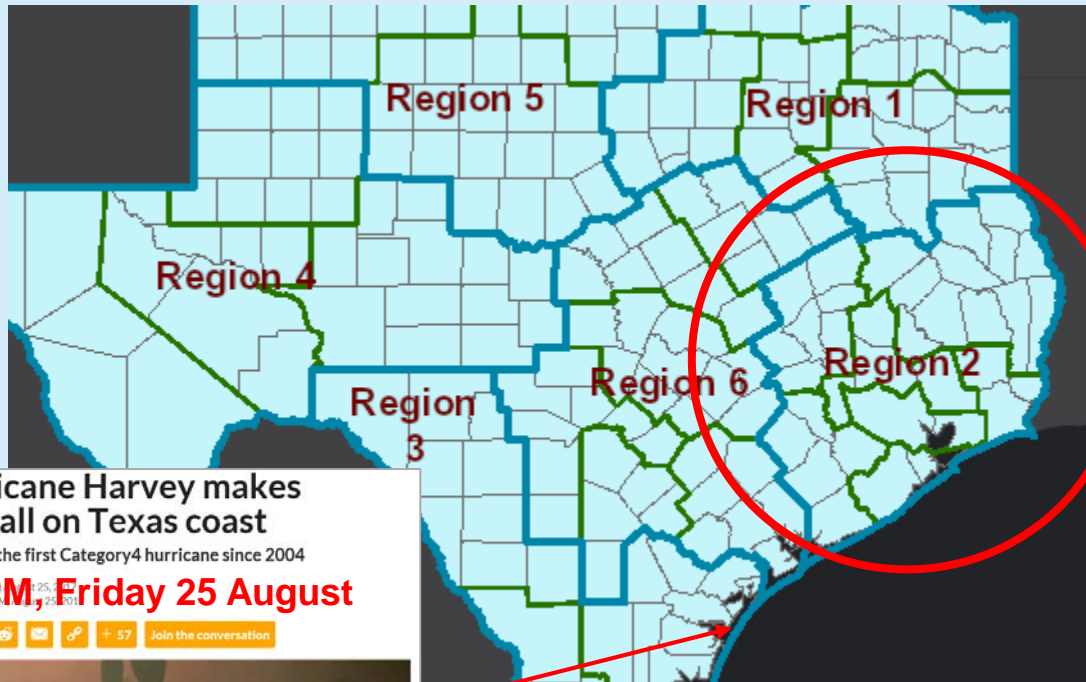
Using National Water Model Medium Range forecast

Houston is going to get inundated

Hurricane Harvey makes landfall on Texas coast
Harvey is the first Category4 hurricane since 2004

10 PM, Friday 25 August

Region	Address Count	Time At Max
Region 2	238465	8/29/2017 6:00:00 AM
Region 6	22120	8/27/2017
Region 1	3209	9/2/2017
Region 4	1761	8/27/2017 3:00:00 AM
Region 3	1425	9/4/2017 12:00:00 PM
Region 5	103	9/4/2017 6:00:00 AM

Buildings Damaged
Data: Texas Division of Emergency Management

Total = 152,800

NWM Predicted Top 5 Counties
Harris
Fort Bend
Brazoria
Galveston
Montgomery

Actual Top 5 counties
Harris
Orange
Fort Bend
Montgomery
Jefferson
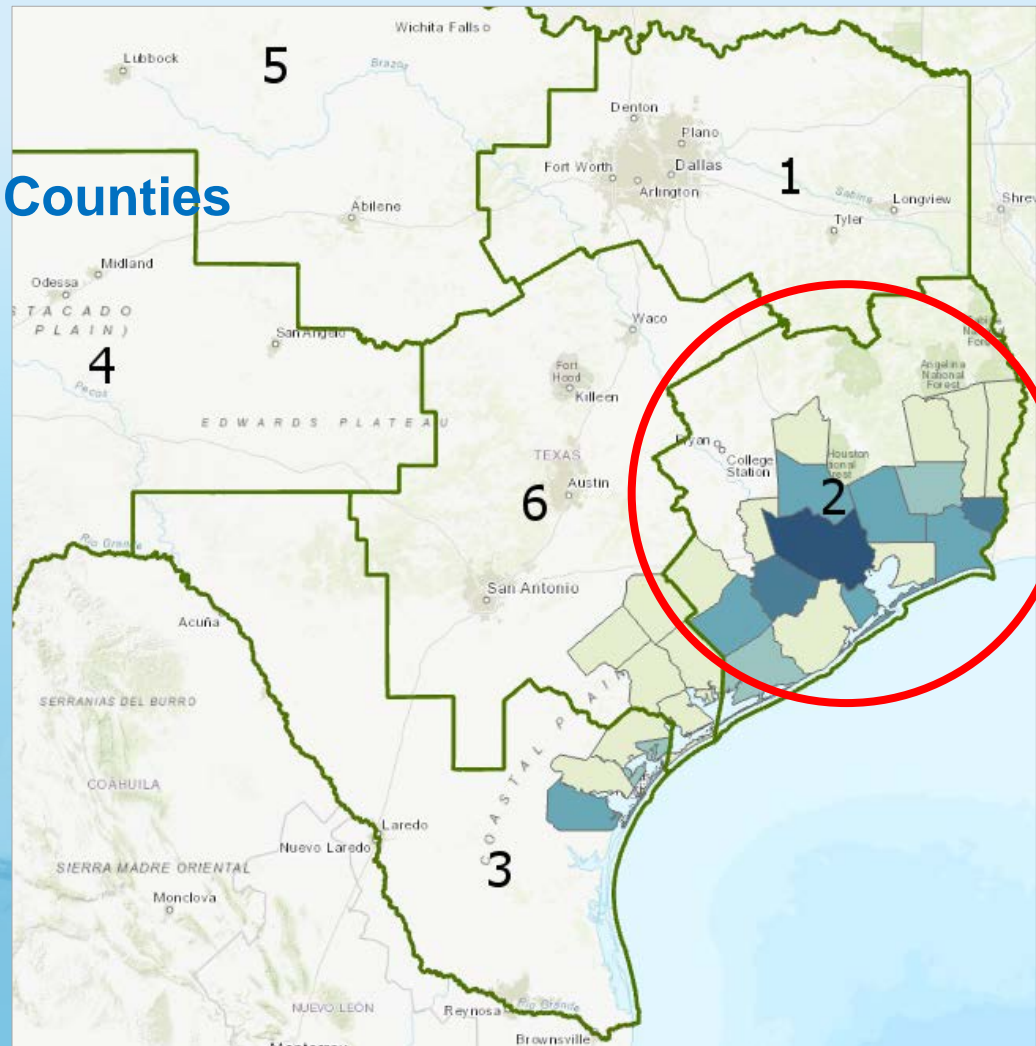
National Water Model correctly located the major damage zone before the hurricane reached the coast

Actual Damage
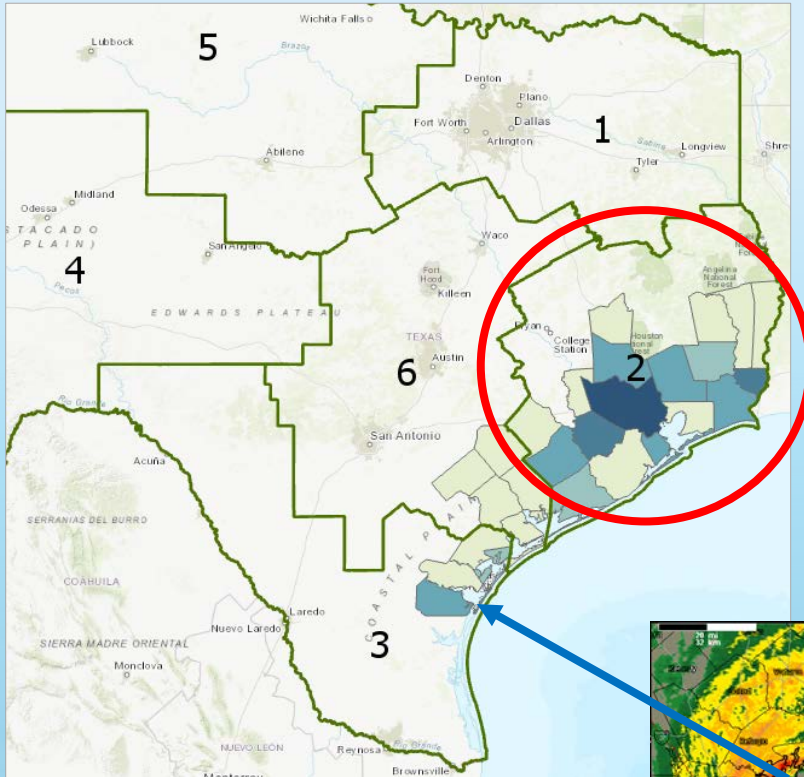
Forecast Damage
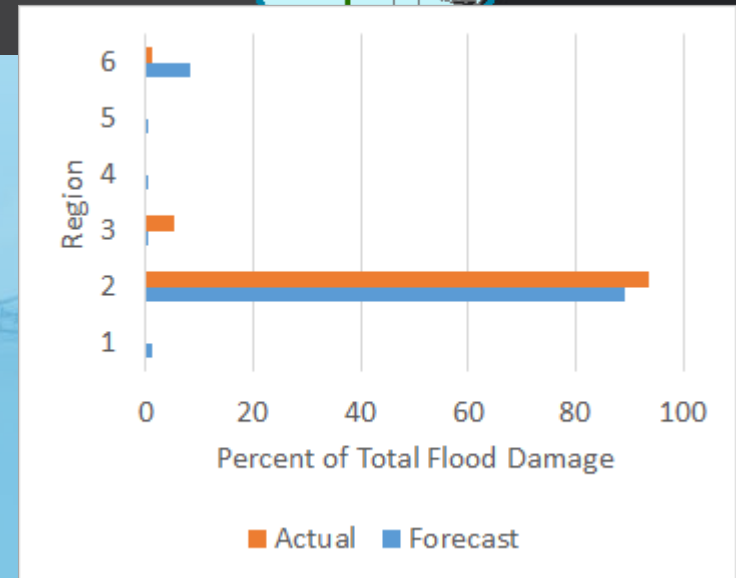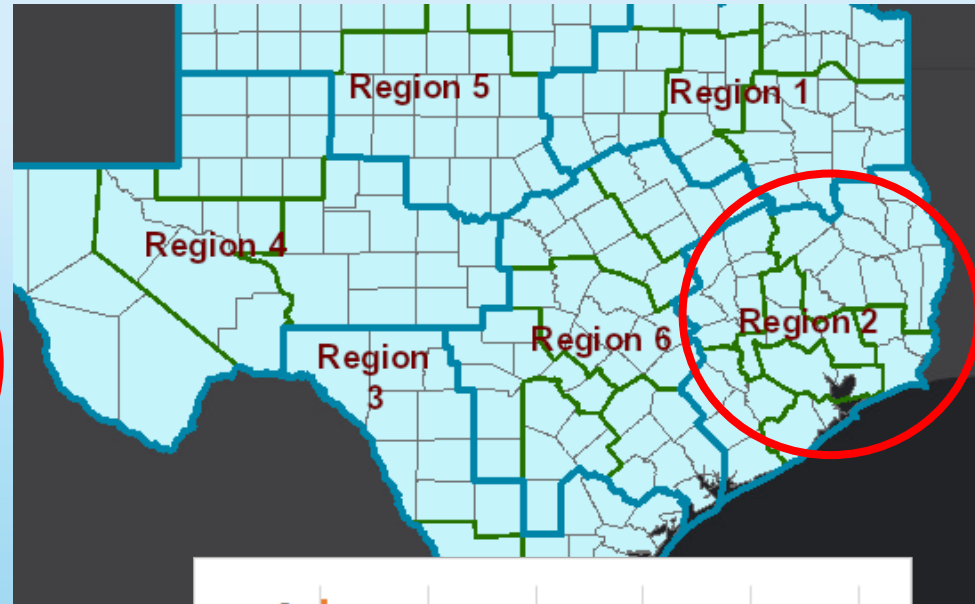
Method for Determining Flood Risk:
Height Above Nearest Drainage (HAND)

Flooding occurs when Water Depth is greater than HAND

Address Point

Flood

HAND

Normal
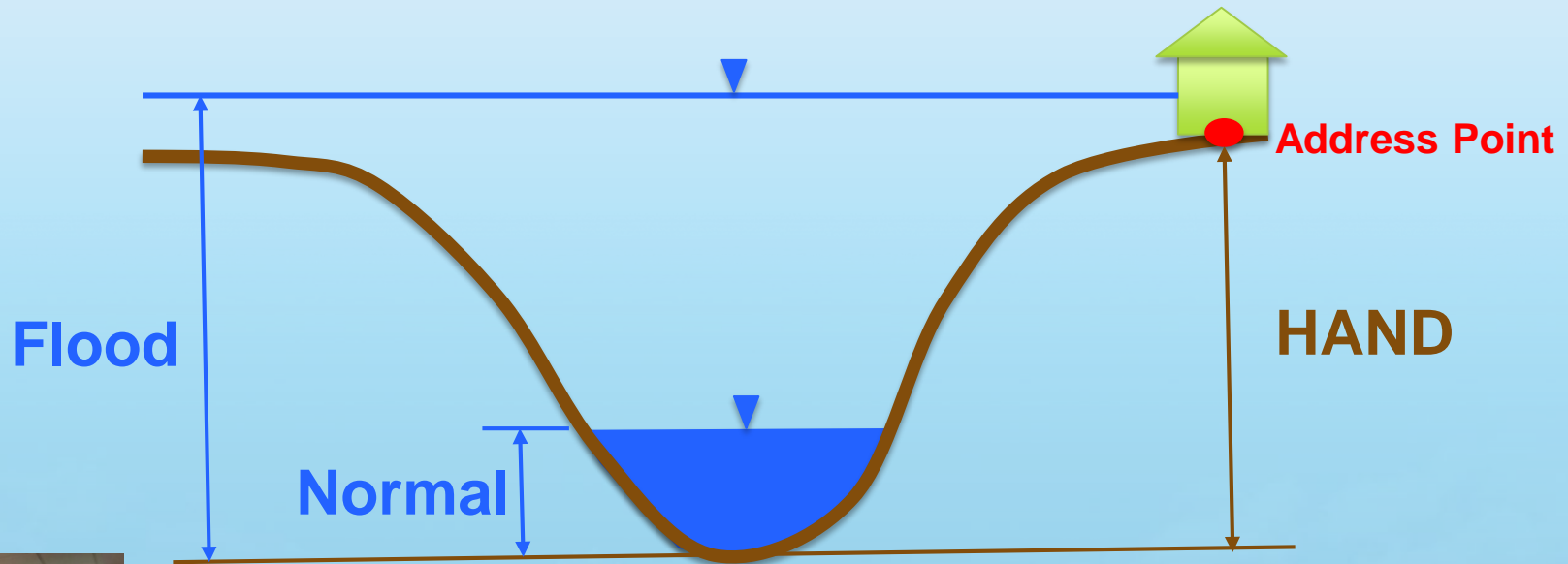
Computed for continental US
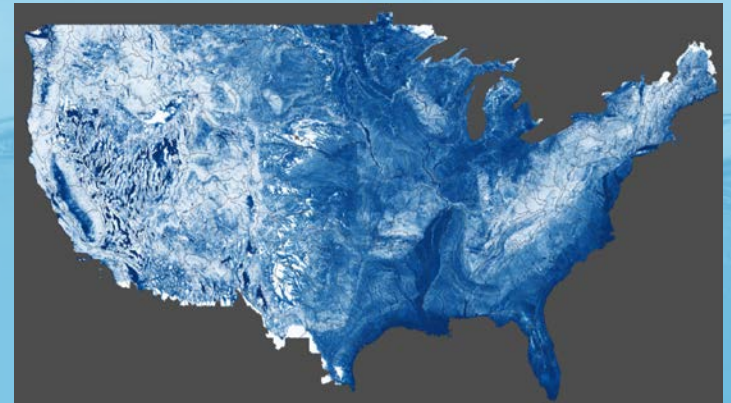
Reach Hydraulic Parameters

Comid	y	A	R	P	T	V	Ab	As
5781175	3							
5781175	4							

A_s Surface Area

Wetted Bed Area A_b

L

V Volume

T

Depth y

A

P
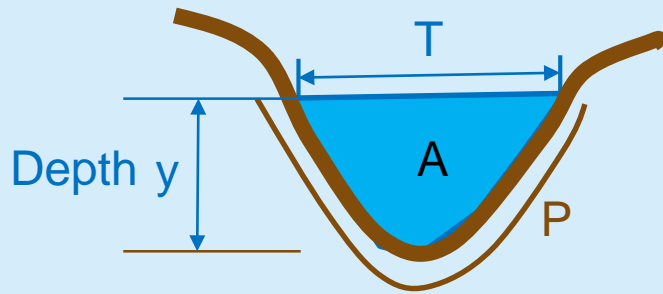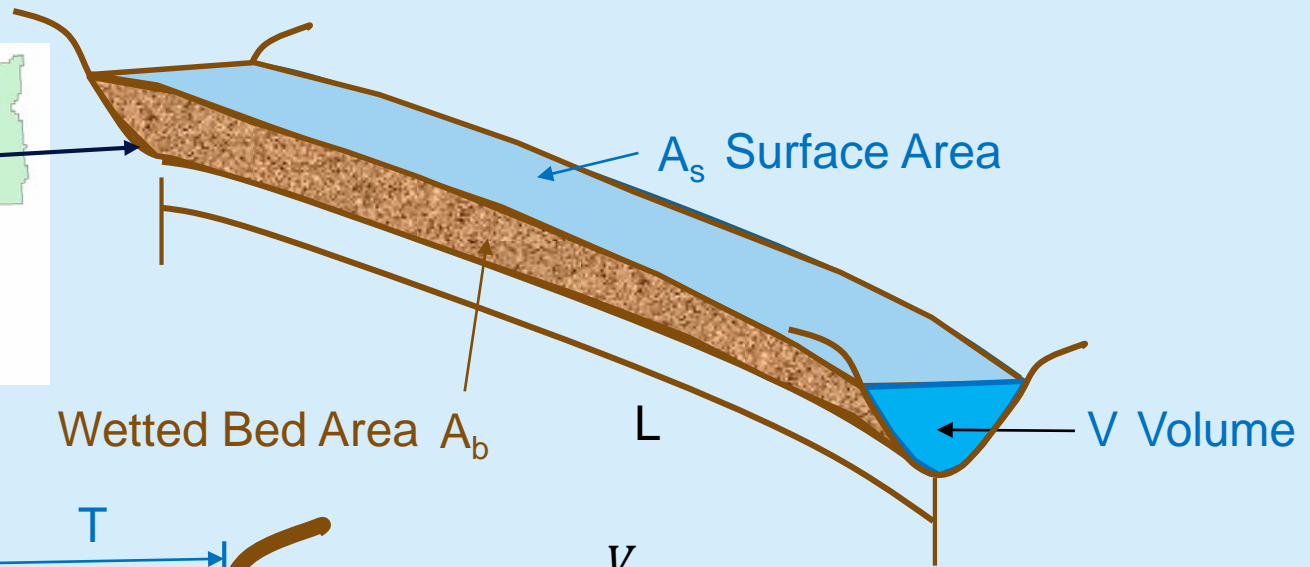
$$A = \frac{V}{L}$$ Cross Section Area

$$P = \frac{A_b}{L}$$ Wetted Perimeter

$$T = \frac{A_s}{L}$$ Top Width

$$R = \frac{A}{P}$$ Hydraulic Radius

Flood Inundation Mapping – NHDPlus-HAND Method
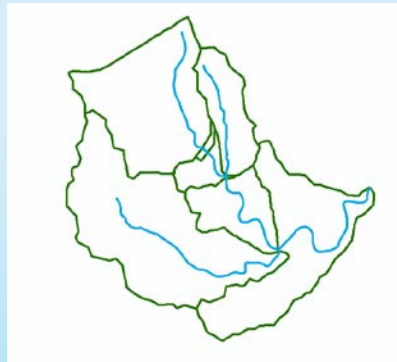
NHDPlus

Catchments and Flowlines
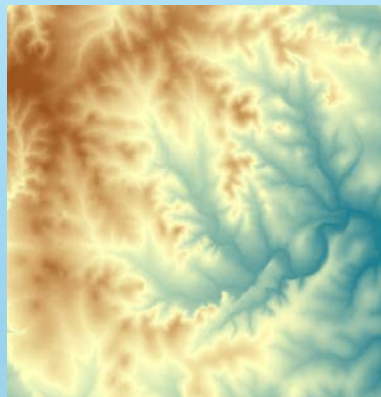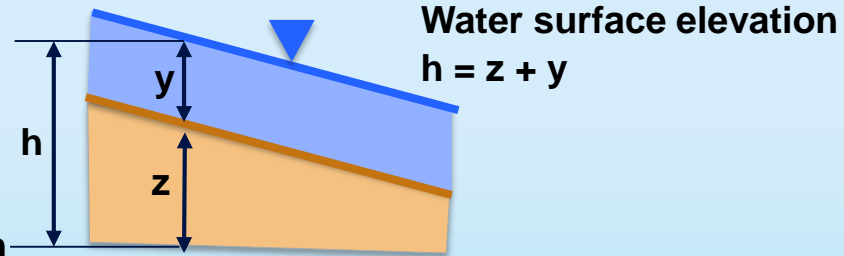
Digital Elevation Model

Water surface elevation
$h = z + y$

Geodetic datum
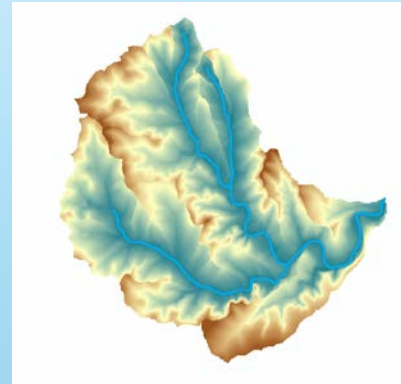
Height Above Nearest Drainage (HAND)
(relative elevation of land surface cell above cell in NHDPlus stream to which it flows)
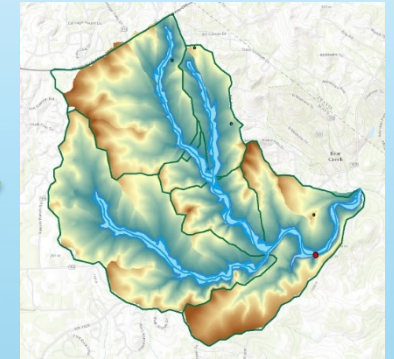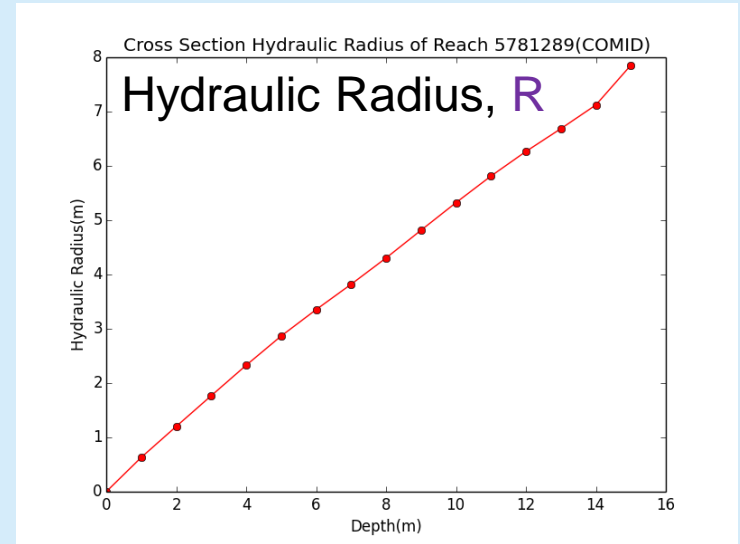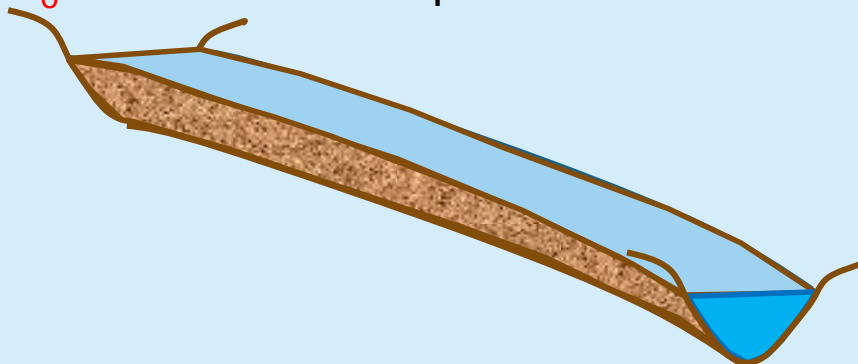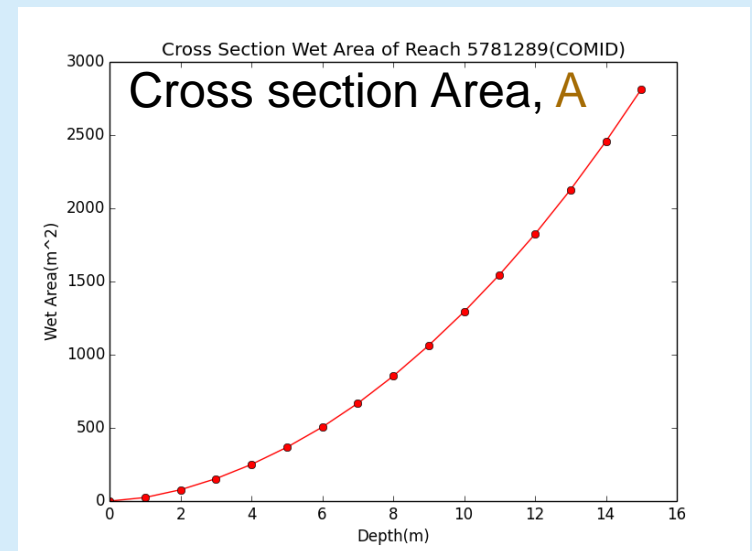
Inundation map
Height above drainage < 15 ft)
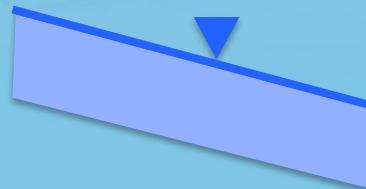
Rating Curve Computation

Flood Discharge, Q (cfs)

$$Q = \frac{1.49}{n} A R^{2/3} S_o^{1/2}$$
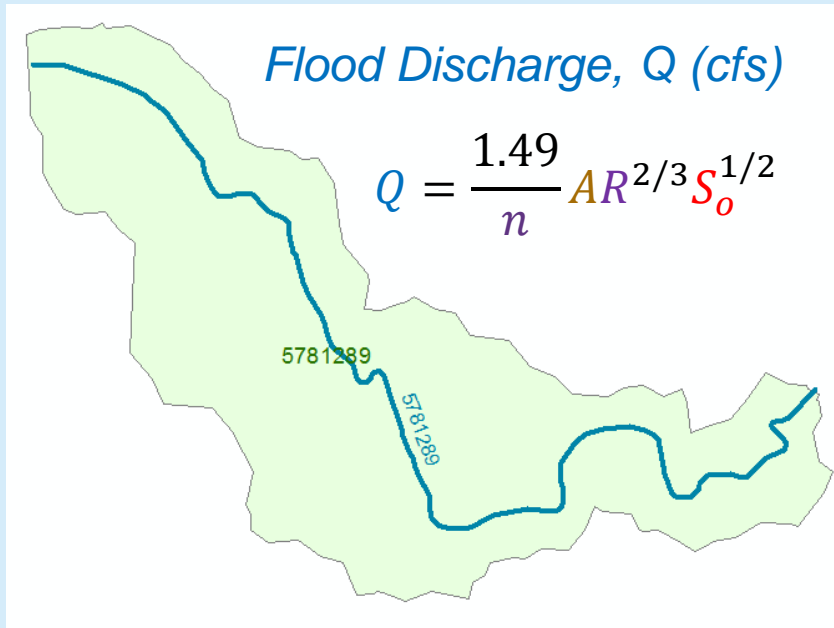
5781289

n = 0.035 Manning roughness of channel
S_o = 0.0163 Bed slope

Cross Section Hydraulic Radius of Reach 5781289(COMID)

Hydraulic Radius, R

Flood Depth, h (ft)

Cross Section Wet Area of Reach 5781289(COMID)

Cross section Area, A

Rating Curve – Connects Discharge with Depth
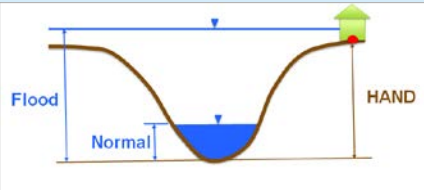
Rating Curve for Eanes Creek, ComID = 5781289

Flood Depth, y (ft)

$$Q = \frac{1.49}{n} A R^{2/3} S_o^{1/2}$$

Forecast Discharge, Q, from National Water Model
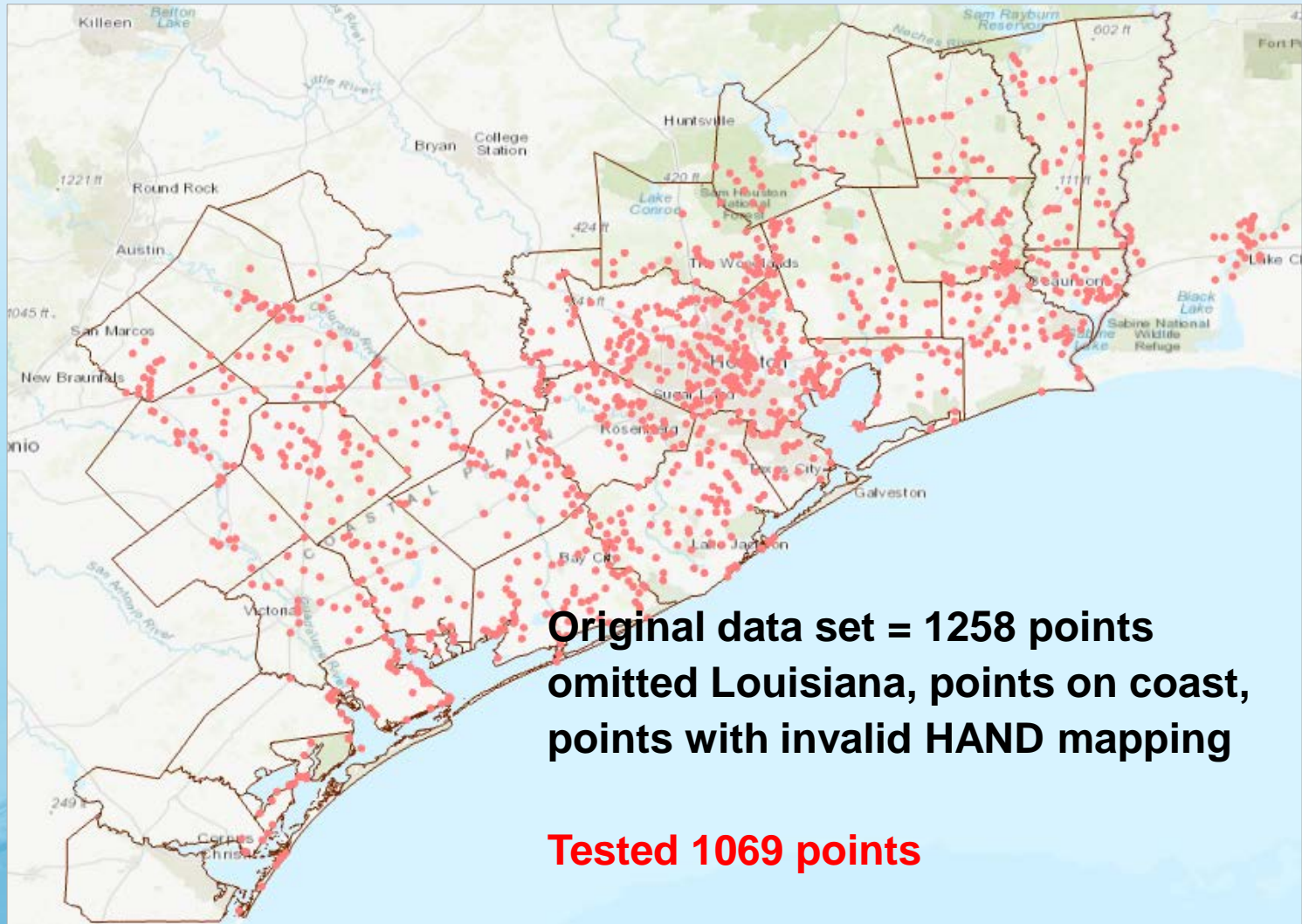
Water Depth (ft)

Discharge (cfs)
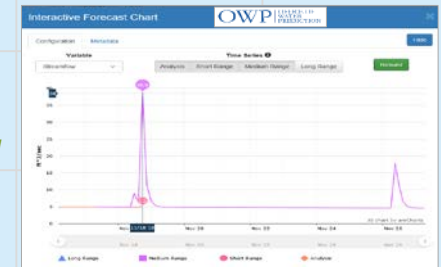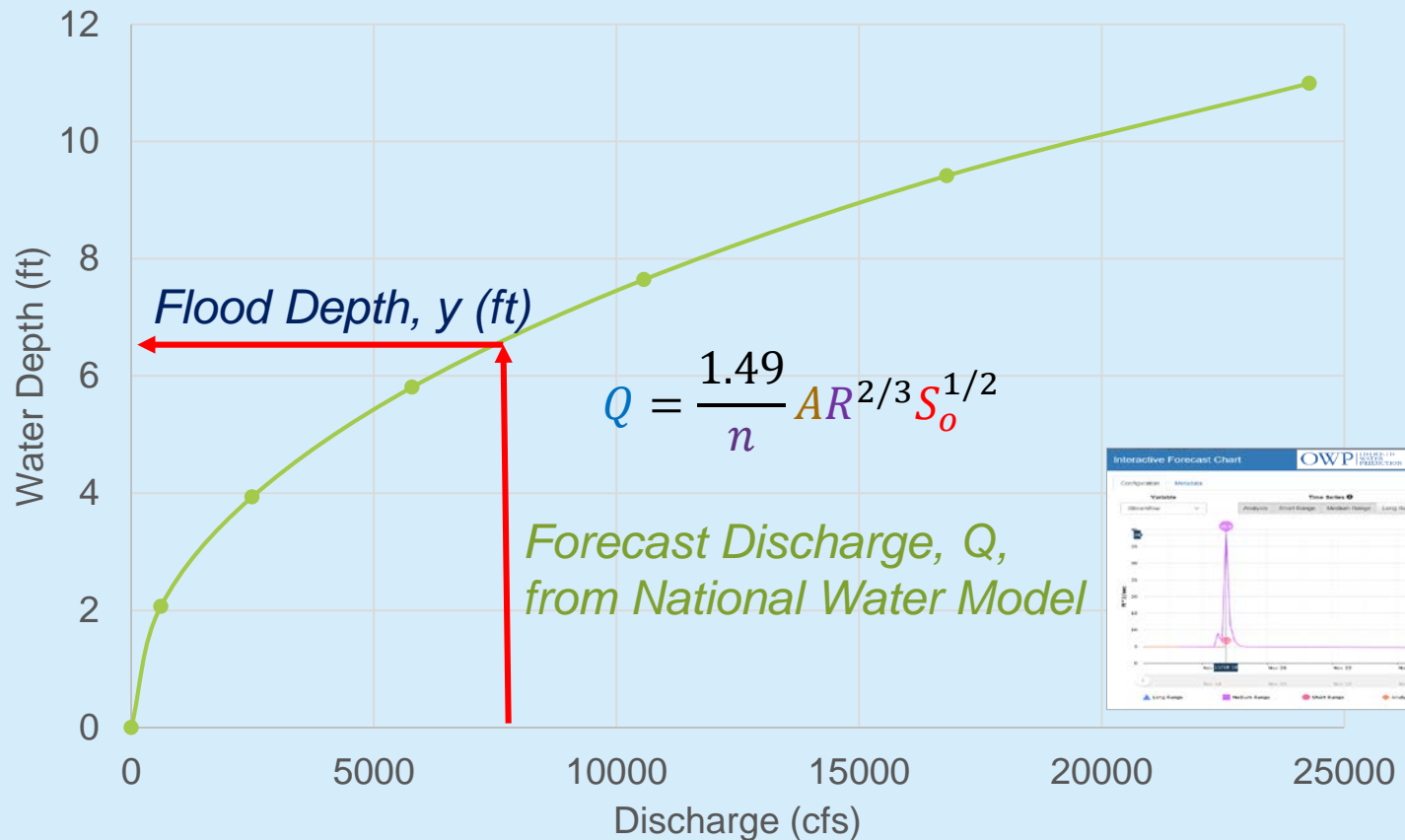
High-Water Mark Data Collection

- USGS field crews began work on September 2 and continued through October 5, 2017 identifying and surveying HWMs
- USGS field work consisted of 71 staff members from 9 Water Science Centers including Texas, New Mexico, Oklahoma, Arizona, Missouri, Florida, New York, Nebraska, Mississippi
- USGS field crews surveyed 2,123 HWMs, resulting in 1,258 water-surface elevations *Largest High Water Mark collection ever*
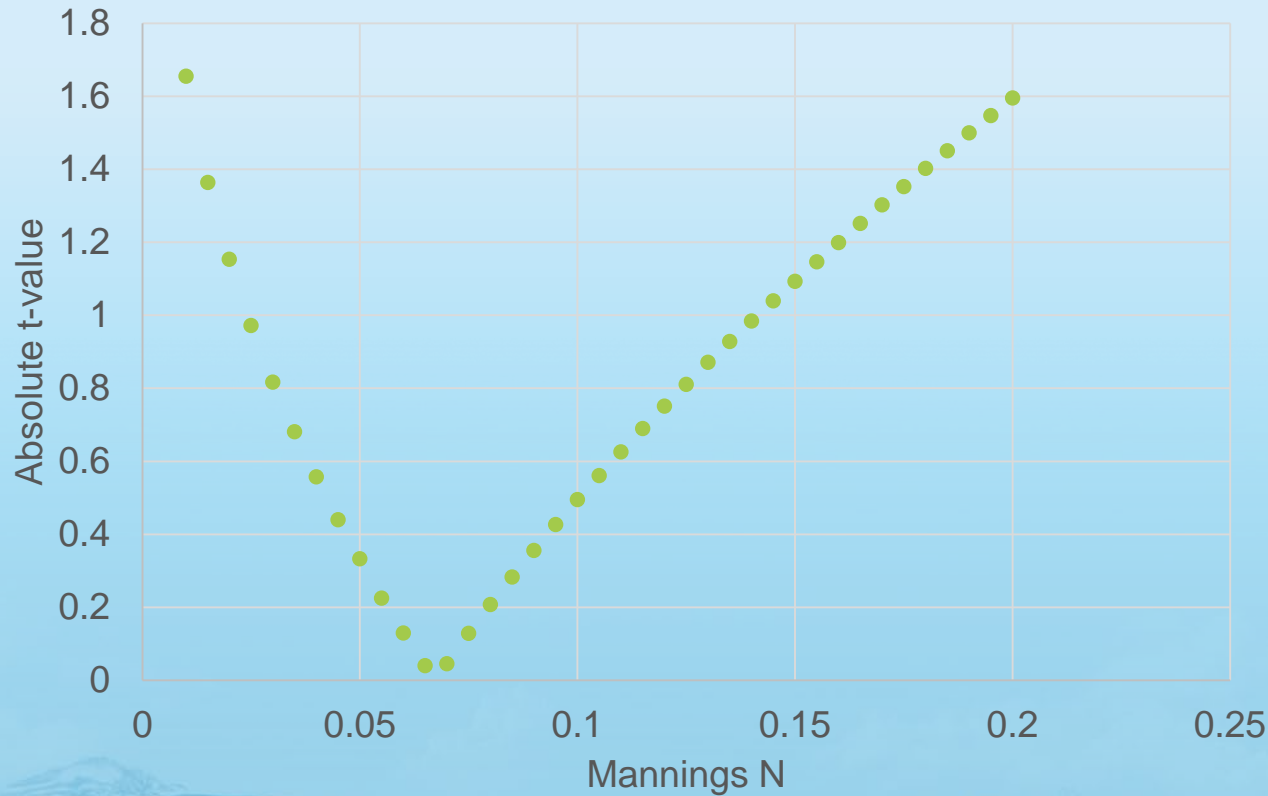
USGS Peak Stage Heights

Original data set = 1258 points
omitted Louisiana, points on coast,
points with invalid HAND mapping

Tested 1069 points

Calibration for all points (HAND – USGS)
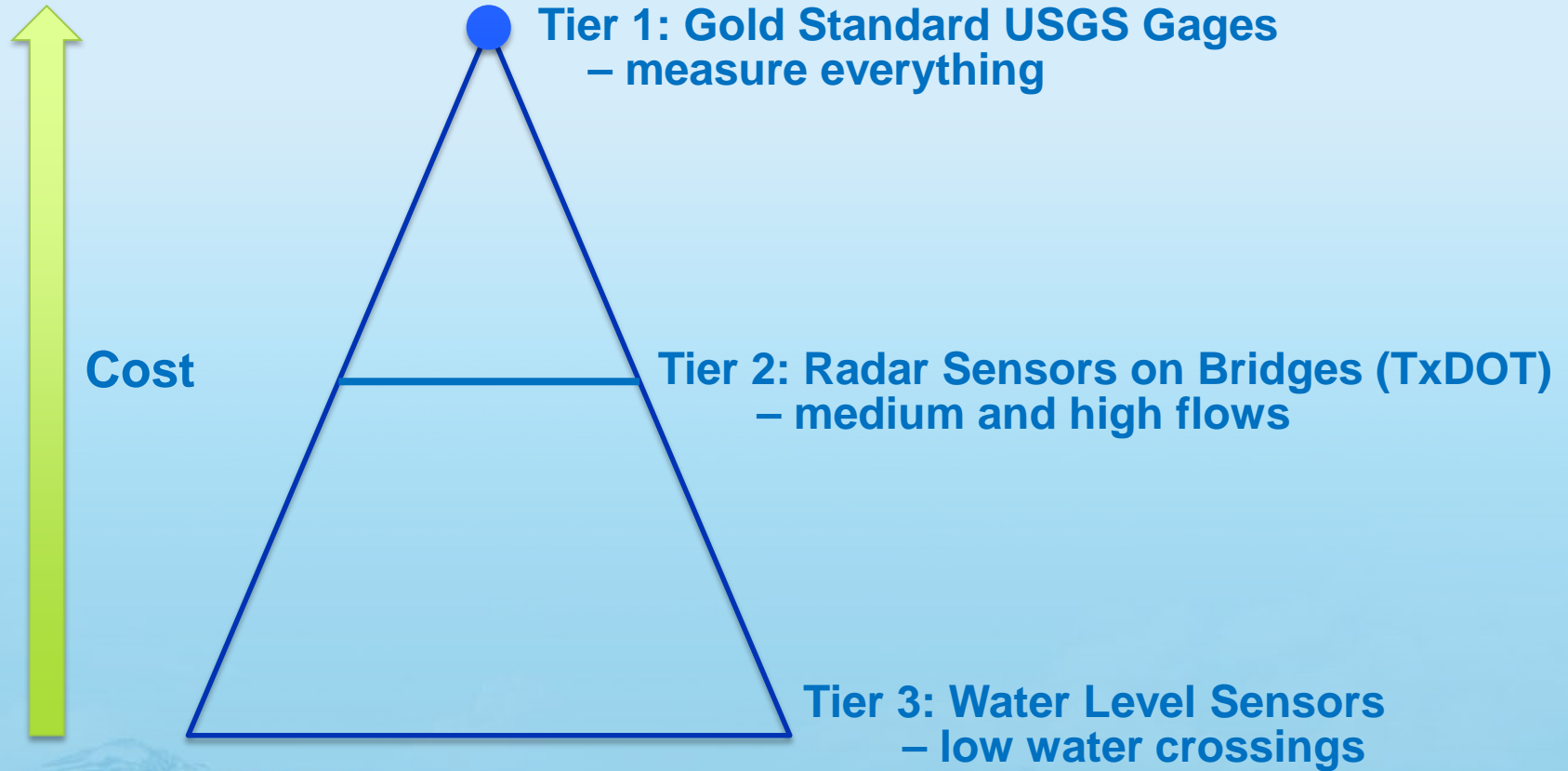# n = 0.065

$$t = \frac{\text{mean}}{stdev/\sqrt{n}}$$

For main rivers n = 0.04, off rivers n = 0.11

Densified Water Measurement

Cost ↑

Tier 1: Gold Standard USGS Gages
– measure everything

Tier 2: Radar Sensors on Bridges (TxDOT)
– medium and high flows

Tier 3: Water Level Sensors
– low water crossings

27,000 Texas bridges on 15,700 stream reaches forecast by the National Water Model
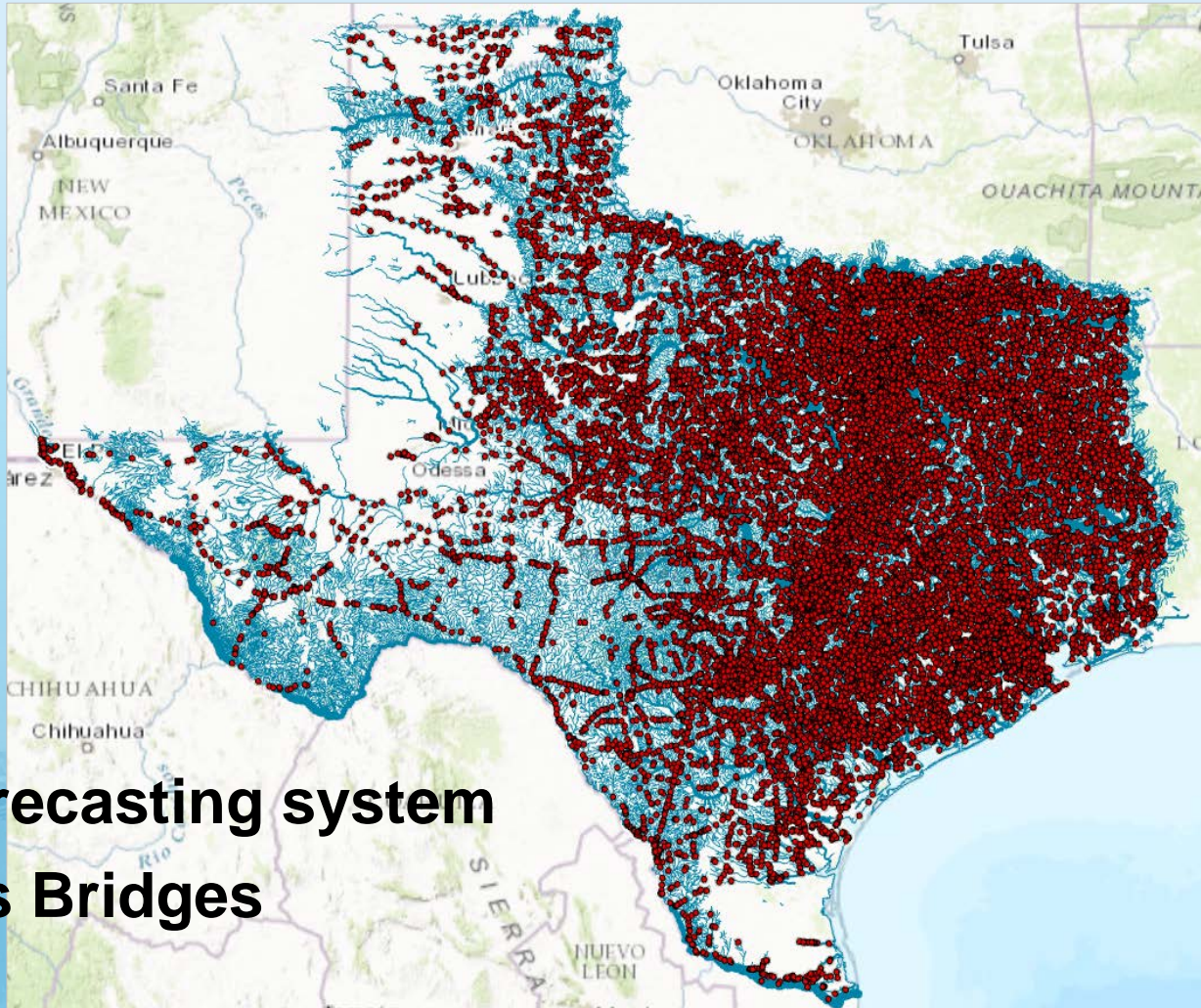
**Flood forecasting system
for Texas Bridges**

Radar Measurement of Discharge from Bridges
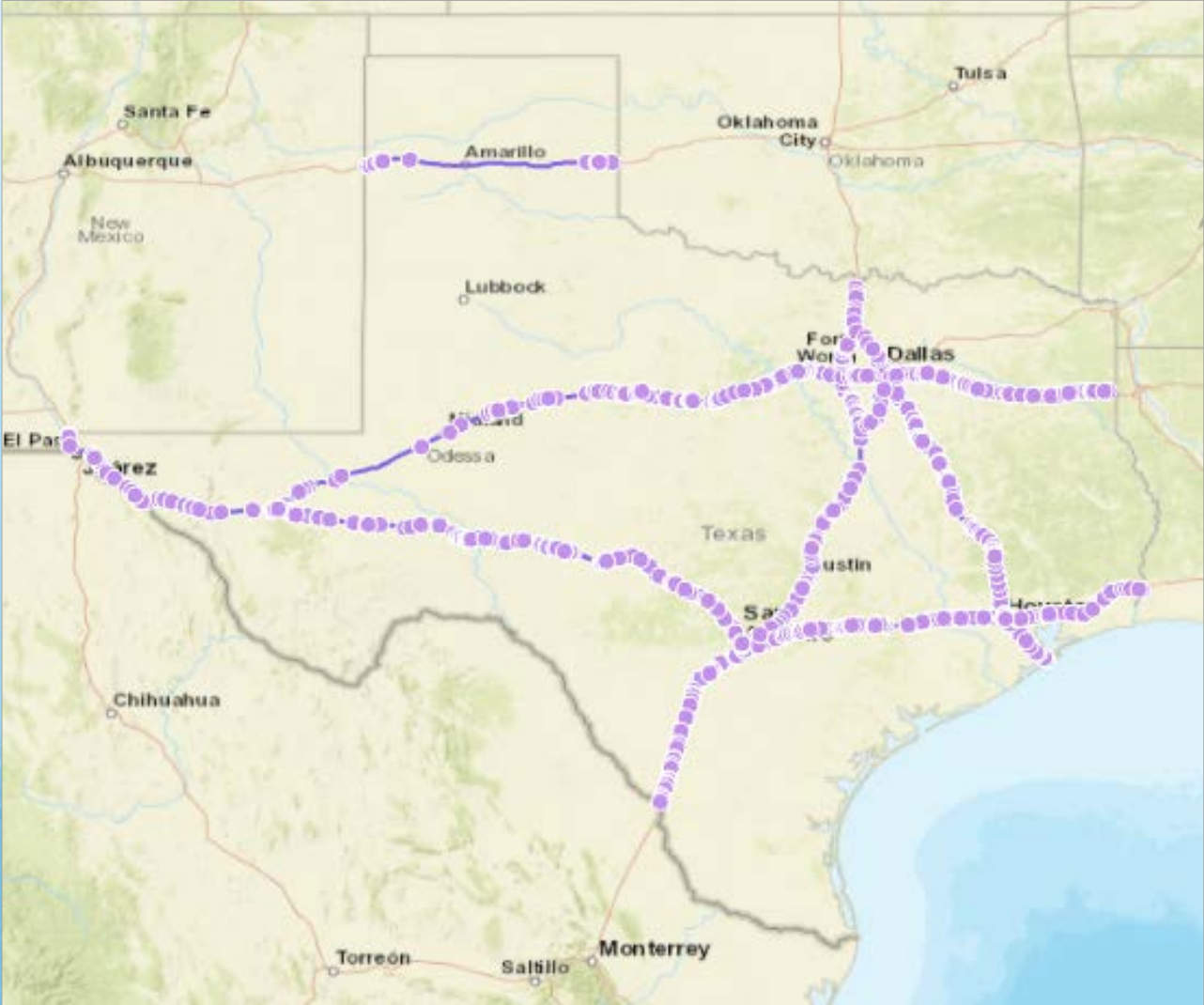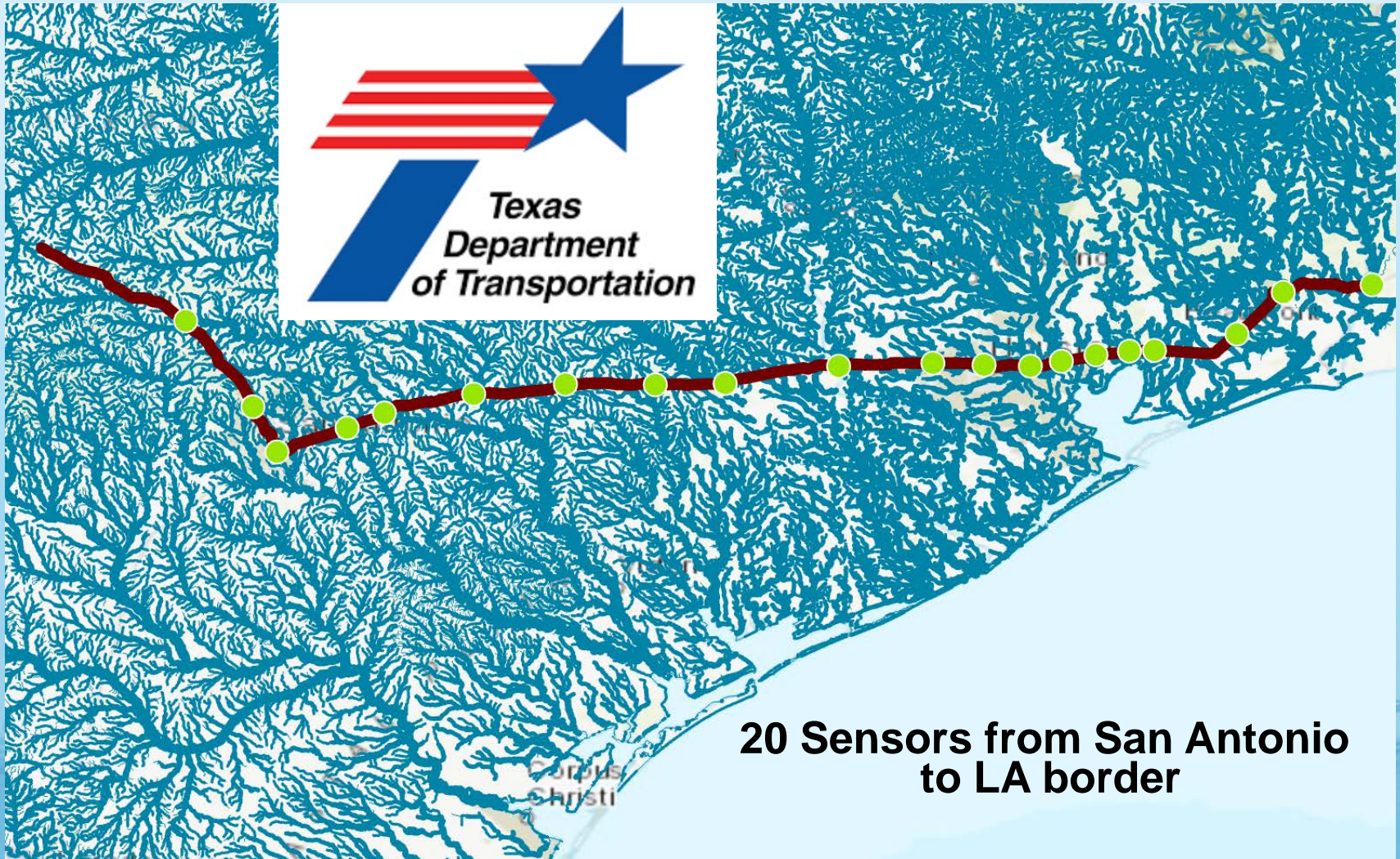
Combine with Acoustic Doppler Current Profiler velocity profile to get discharge

Measure velocity at one point on water surface
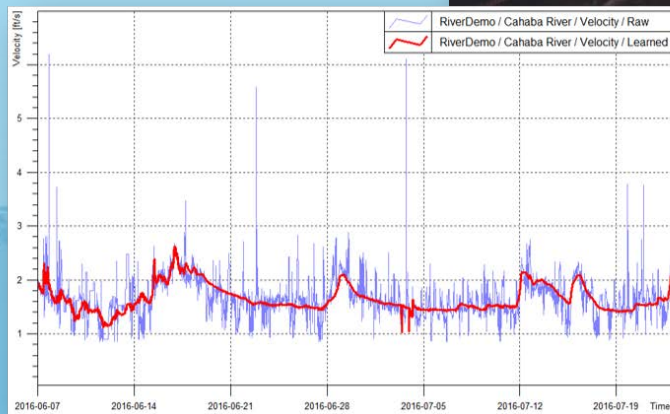
Instrumenting the Interstates as "Picket Lines" for storms passing across Texas
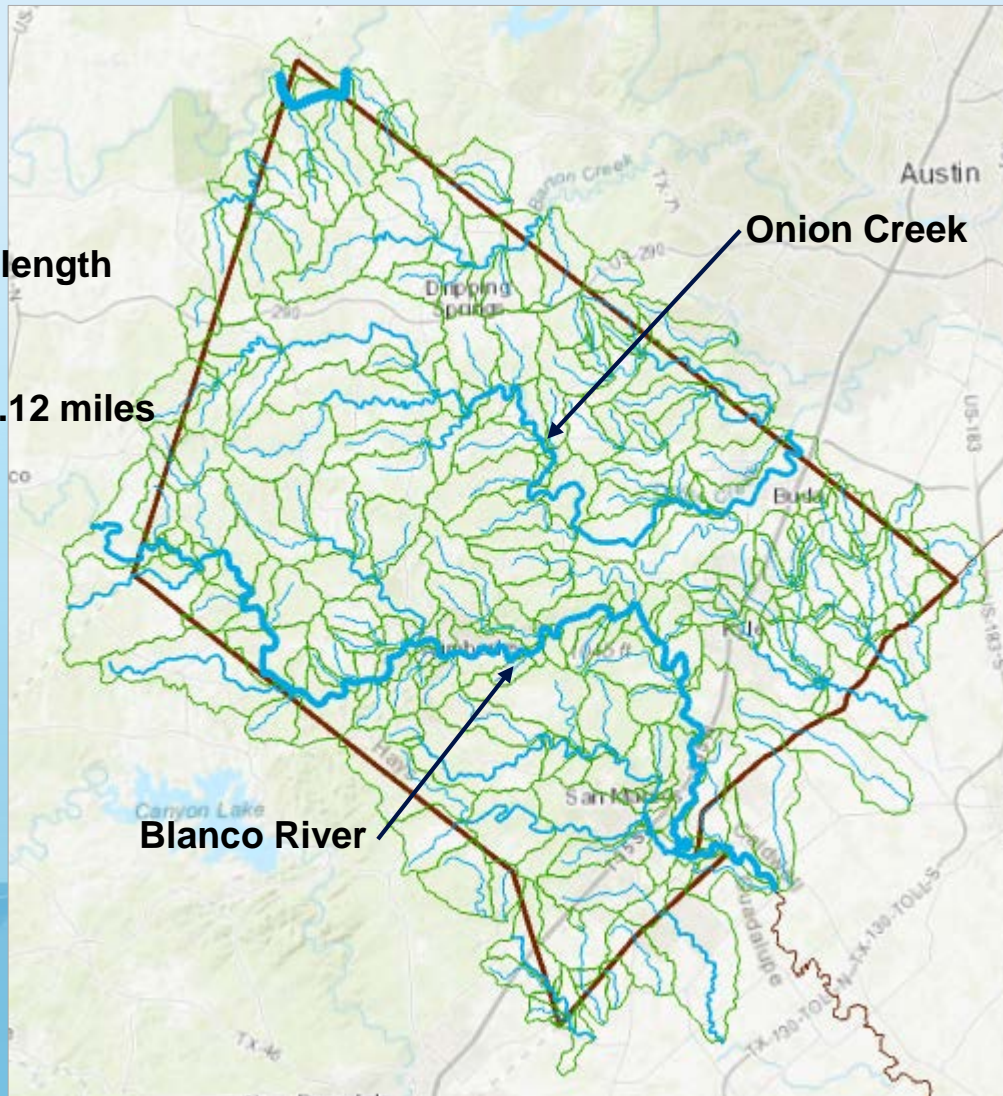
Radar Streamflow Measurement on I-10

20 Sensors from San Antonio to LA border
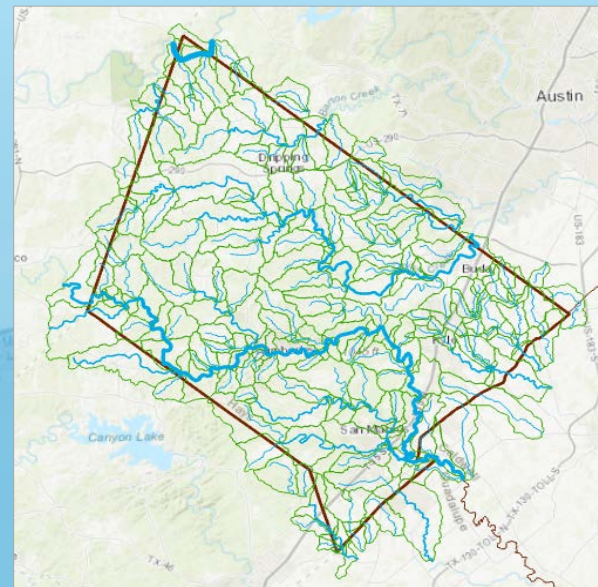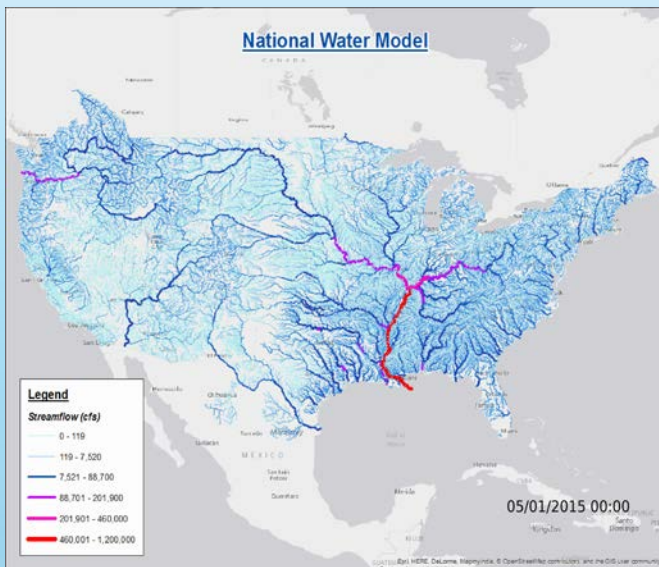
National Water Model in Hays County

312 Flowlines

1111 Km in stream length (690 miles)

Average length = 2.12 miles

Onion Creek

Blanco River

# Real-Time Water Measurement in Hays County (combine this with NWM forecasts)

Real-Time Connection between NWM and Observational Data
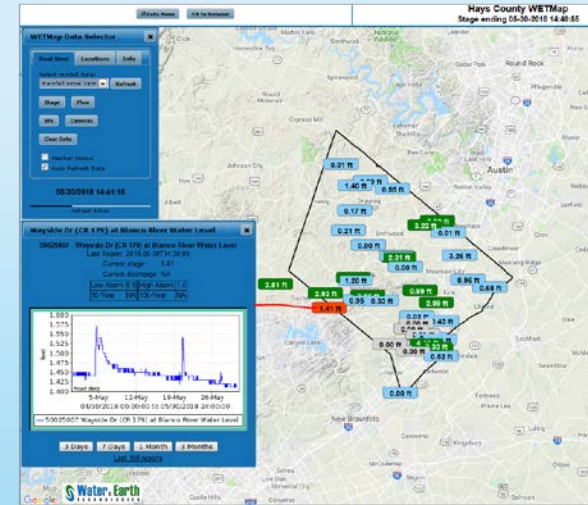
How to have a continuously updated, locally calibrated real-time map and forecast?

First Responder Input to Inundation Mapping

Rock on road at current water level ➡️ **Point location sent in by text** ➡️ **Inundation map**

Local Impact in this area
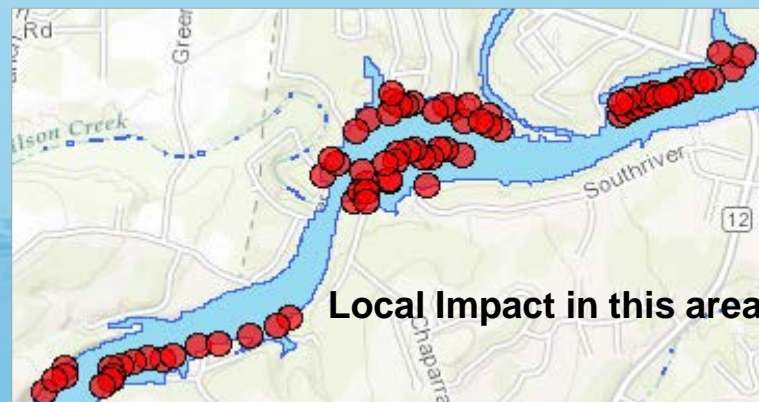
Chief Todd Pomroy, Austin Fire Department
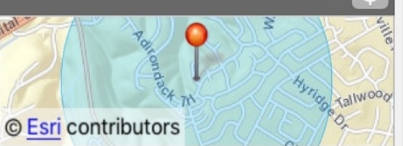
Pin to Flood Map
Collecting Observations for Real-Time Inundation Mapping
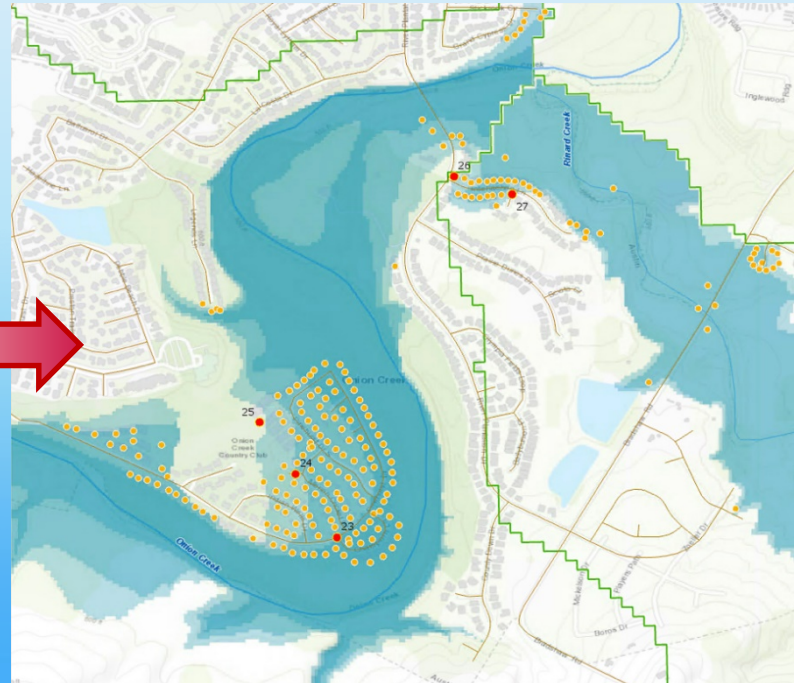
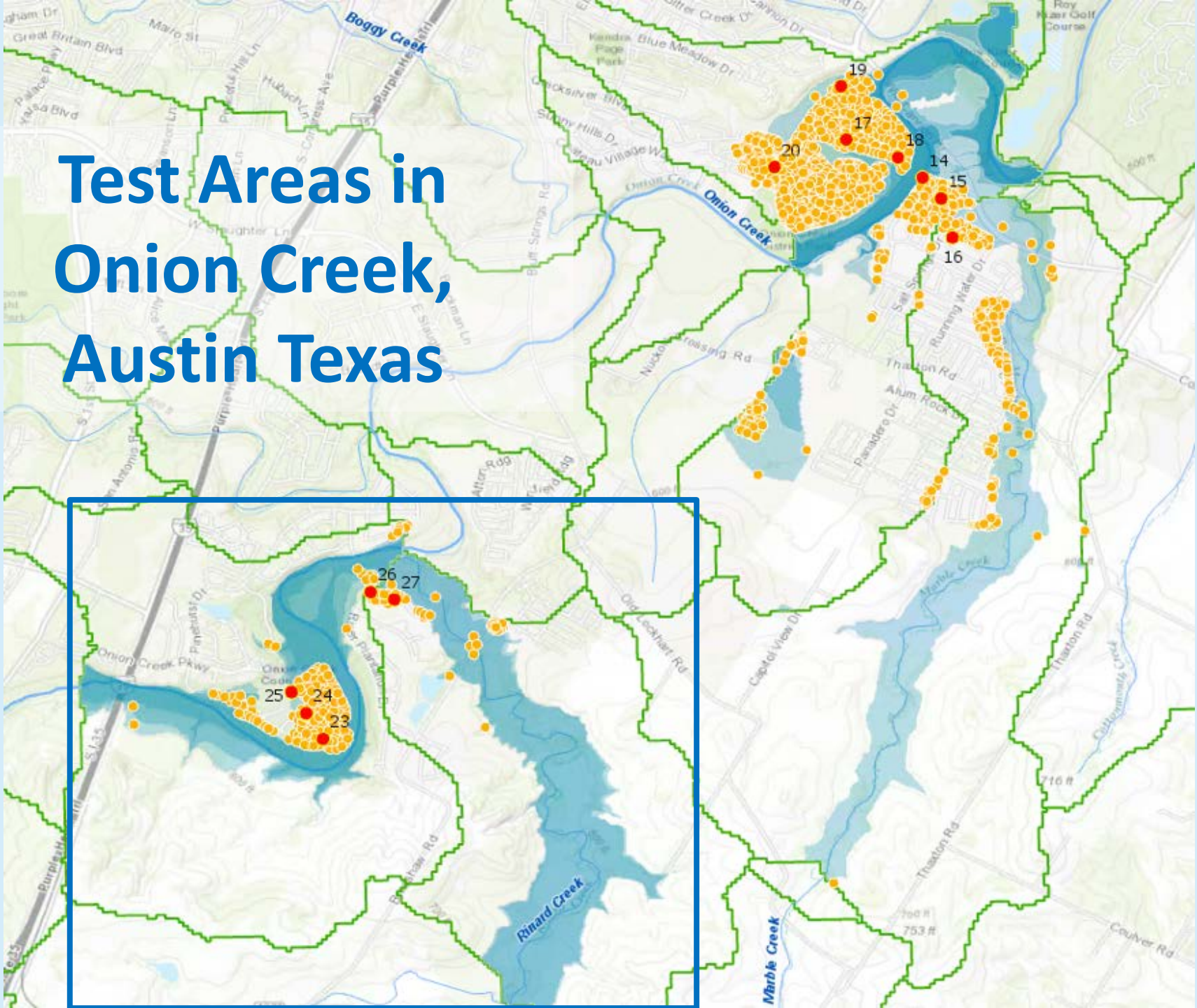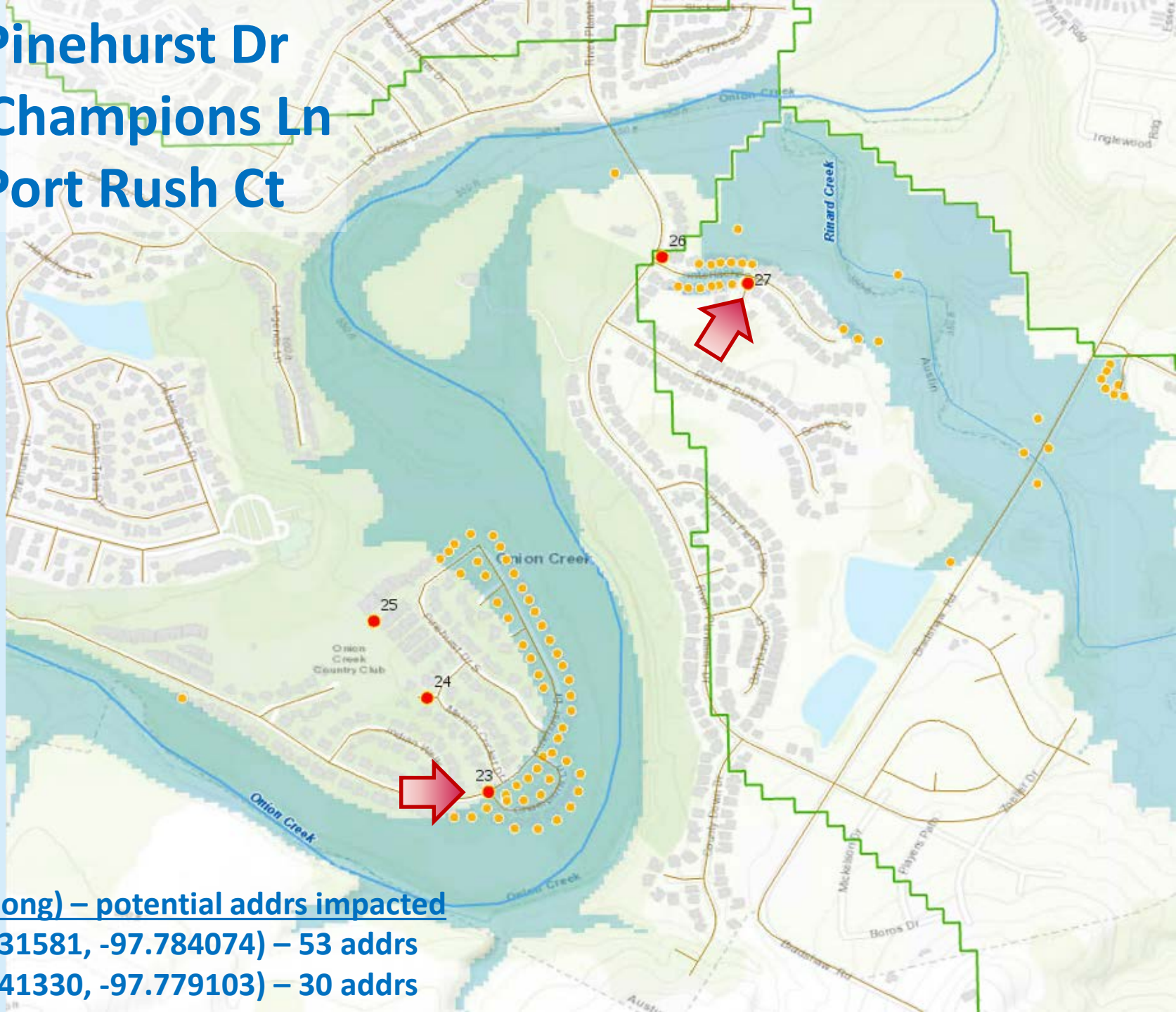**Test Areas in Onion Creek, Austin Texas**

23 – Pinehurst Dr & Champions Ln
27 – Port Rush Ct
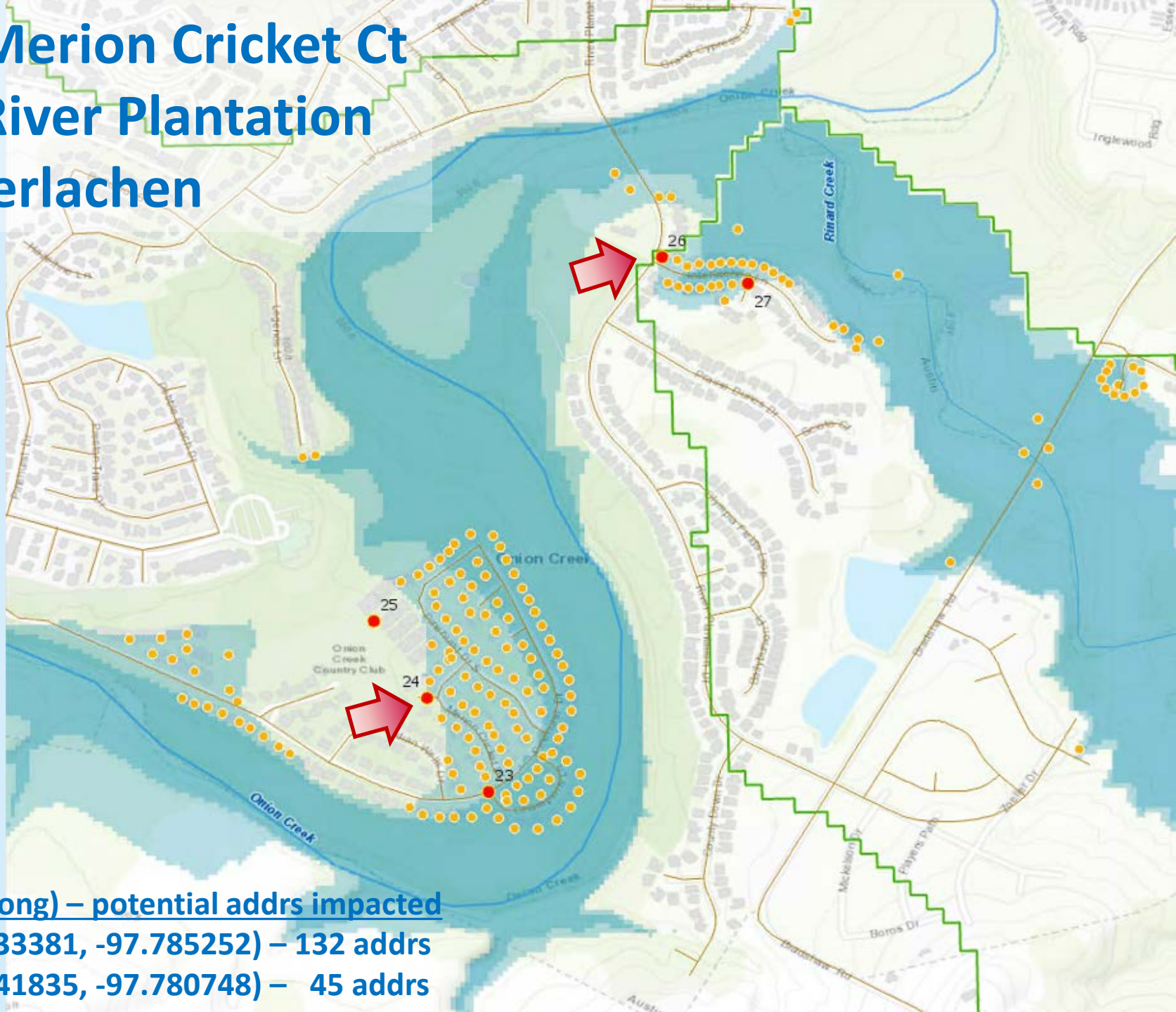
Pin – (lat,long) – potential addrs impacted
23 – (30.131581, -97.784074) – 53 addrs
27 – (30.141330, -97.779103) – 30 addrs

24 – Merion Cricket Ct
26 – River Plantation
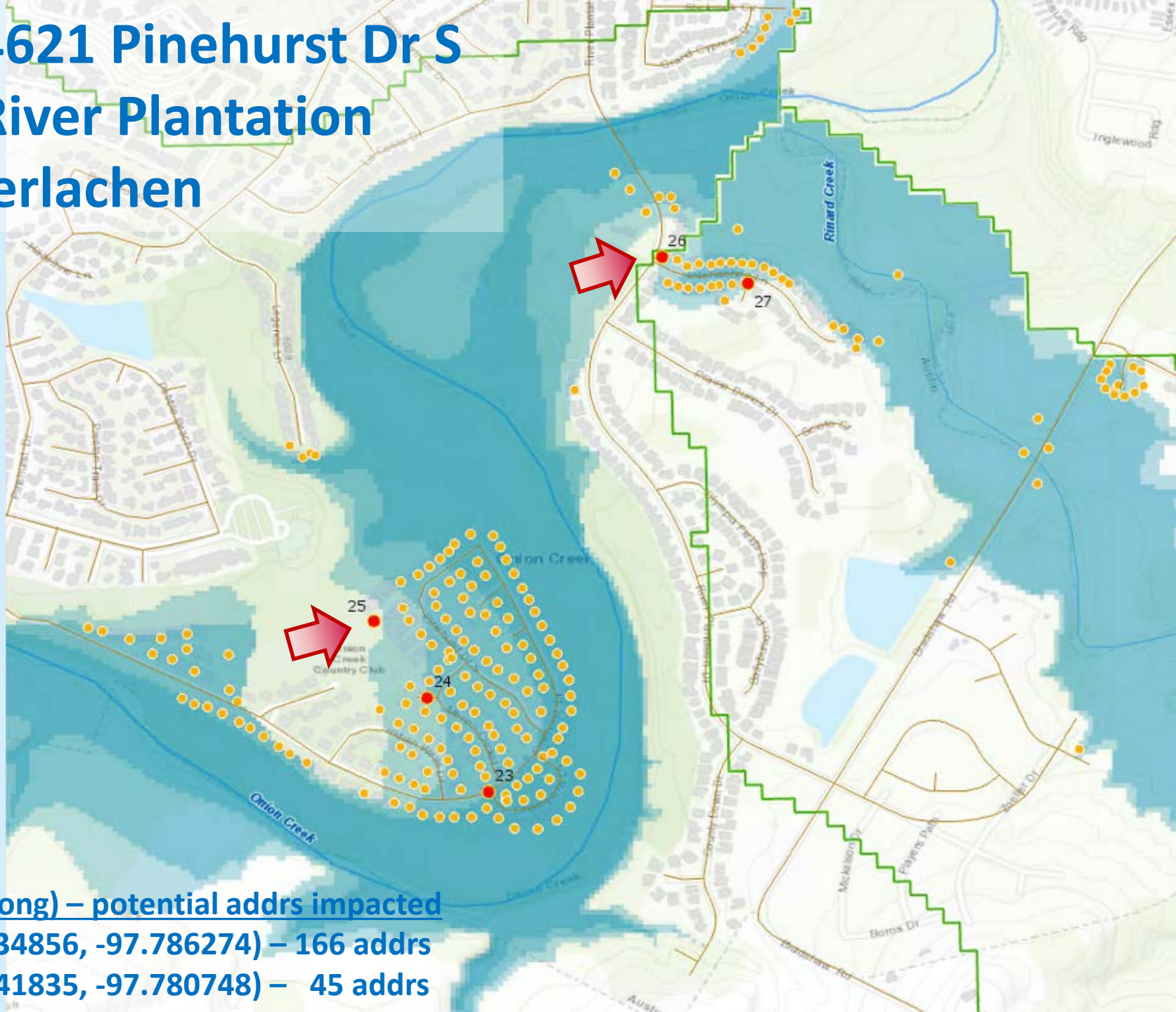**at Interlachen**

Pin – (lat,long) – potential addrs impacted
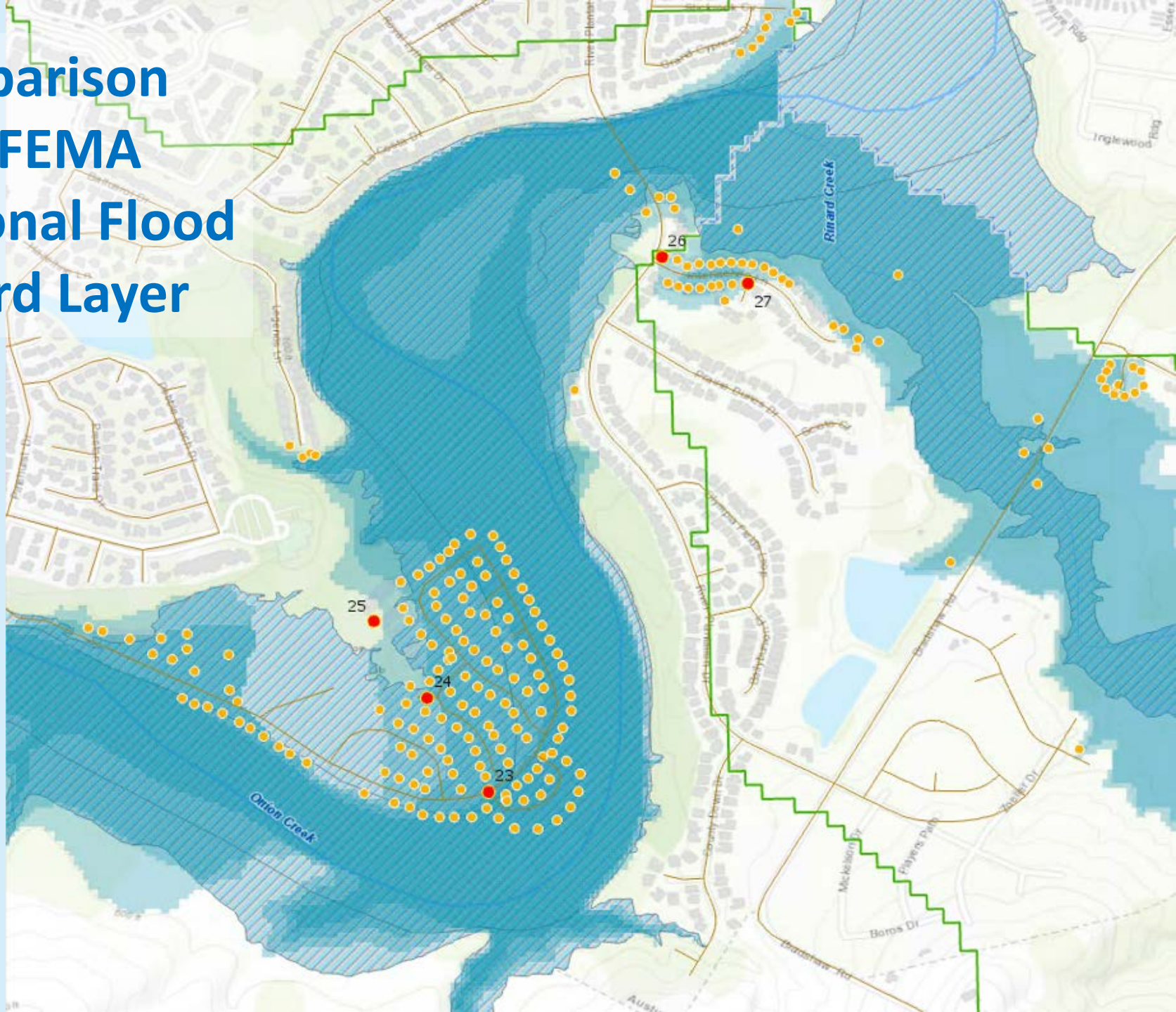24 – (30.133381, -97.785252) – 132 addrs
26 – (30.141835, -97.780748) –   45 addrs

25 – 4621 Pinehurst Dr S
26 – River Plantation
at Interlachen

Pin – (lat,long) – potential addrs impacted
25 – (30.134856, -97.786274) – 166 addrs
26 – (30.141835, -97.780748) – 45 addrs

Comparison with FEMA National Flood Hazard Layer

Connecting Local and National Information

- **Close the gap** between National Flood Forecasting and Local Flood Emergency Response

- Demonstrate forecasting of flood impacts at "stream and street level"

National

Local

Weather and Hydrology

National Weather Service and federal agencies
National Water Center

River Flooding and Emergency Response

Local, State and Regional Agencies
Citizens