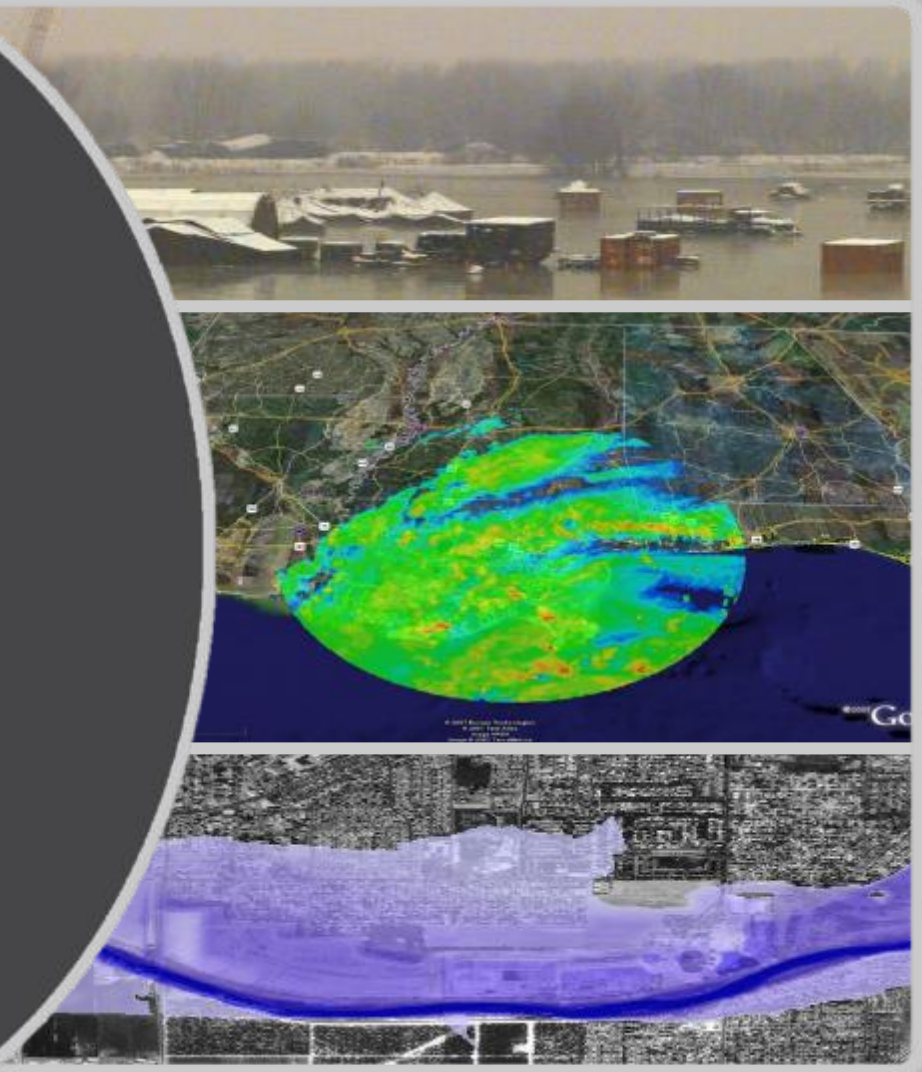
COMPOUND FLOODING

Charles W. Downer, PhD, PE, PMP



US Army Corps of Engineers

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Overall Classification of Briefing is CUI

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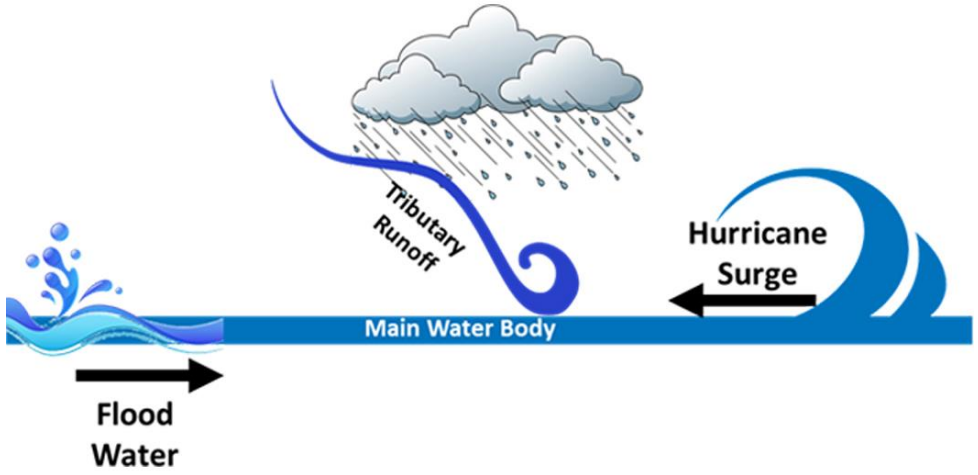
What is Compound Flooding?

Compound flooding refers to a phenomenon where two or more flooding sources occur simultaneously or subsequently within a short period of time.

Compound flooding is flooding caused by two or mor sources

Sources/Causes of Compound Flooding

- ***In the inland setting***
  - ***River overbank flooding***
  - ***River backwater flooding***
  - ***Flash flooding from intense local rainfall event***
  - ***Overwhelmed drainage systems***
  - ***Reservoir releases***
  - ***Reservoir uncontrolled discharge***
  - ***Structural failures***
- ***In the coastal setting - Add***
  - ***Storm surge***
  - ***Wind/waves***
  - ***Tides***



There are many possible sources/causes of compound flooding

Other Considerations

- ***Control features***
  - ***Levees/dikes***
  - ***Hydraulic structures***
  - ***Reservoirs/detention basins***
  - ***Pumps***
  - ***Surface drainage systems***
  - ***Subsurface drainage systems***
  - ***Structural failures***
- ***Initial conditions***
  - ***Soil moistures***
  - ***Stream stages***
  - ***Reservoir levels***
  - ***Groundwater table***
  - ***Tidal stage***

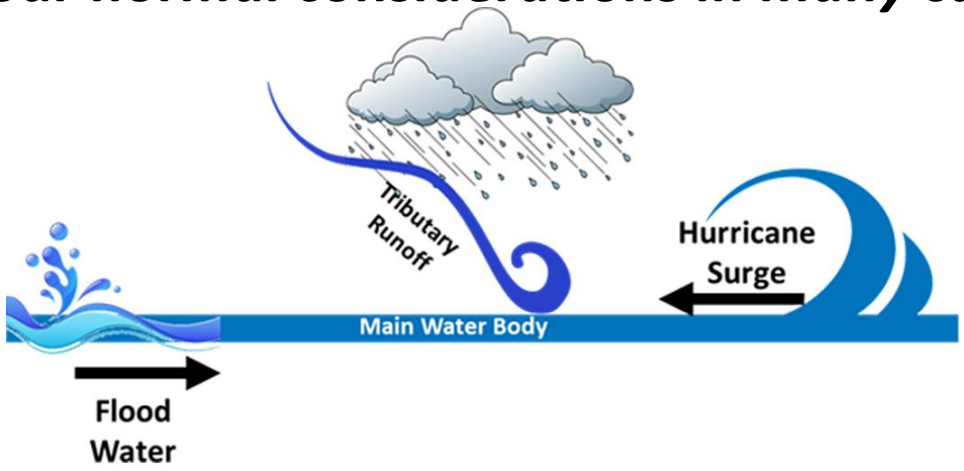
Initial conditions and control structures are important to consider

Interactions are Key

During a compound flooding event it's the interactions between different sources/causes of flooding that really cause the effects.

- ***High flows in a stream or river that might not normally be problematic could become so if high tides, reservoir levels, or storm surge prevent normal drainage.***
- ***Runoff from an intense local storm could safely be transported by the system, unless the system is already at or near capacity from a larger scale event.***

It's these kinds of issues that can be difficult to anticipate and plan for and have really been outside the realm of our normal considerations in many cases

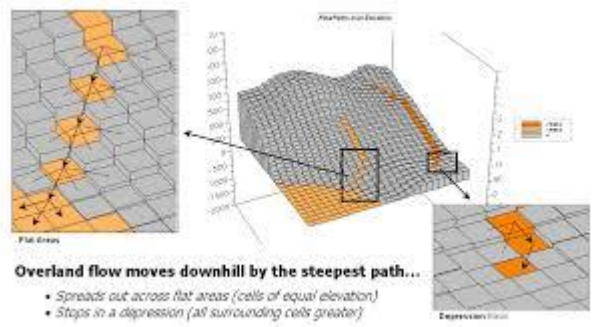


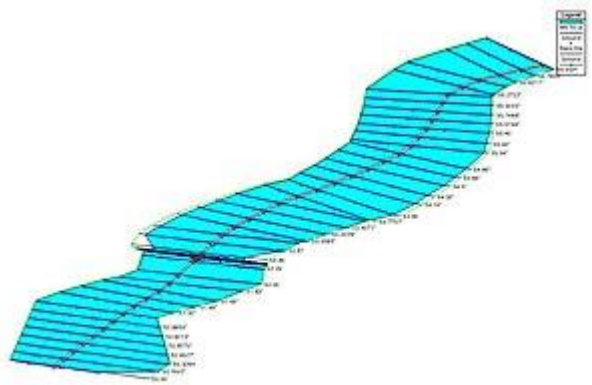
In compound flooding, interactions are key

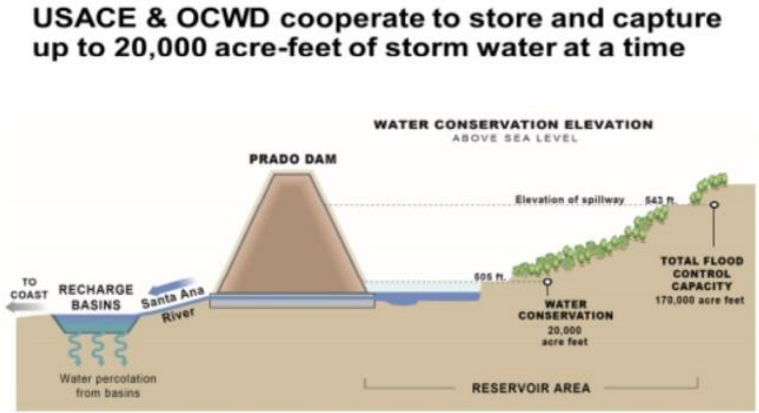
Why is Compound Flooding Difficult to Simulate

During a compound flooding event, the interactions among processes like tides, storm surge, sea-level rise, wind, and river discharge are very complex. Traditional models have been used to simulate one or more of the processes involved in compound flooding, but not all of them together.

In addition, you may not know apriori what conditions may occur. Making even conceptualizing a compound flood simulation difficult.







Compound flooding is difficult to simulate because many potential sources need to be considered

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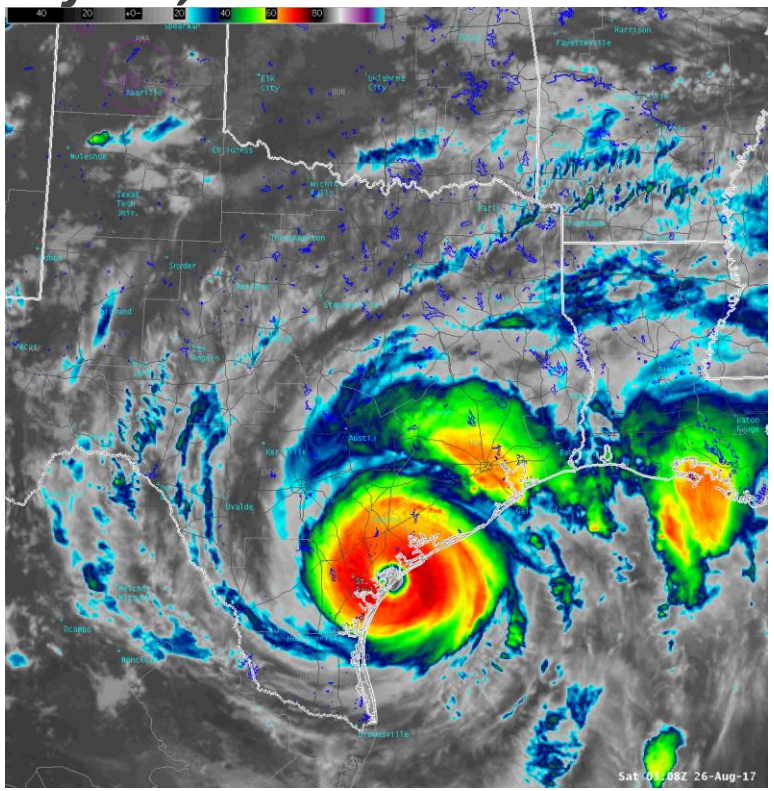
Hurricane Harvey as an Illustrative Example of Compound Flooding

Harvey came ashore near Port Aransas, Texas on August 25th 2017 as a Category 4 Hurricane with intense winds and storm surge. Harvey later stalled over southeast Texas for days causing flooding over a huge area, including the metropolitan Houston area. Storm surge, rainfall, streamflow, and reservoirs all contributed to historic flooding.



Hurricane Harvey illustrates compound flooding concepts

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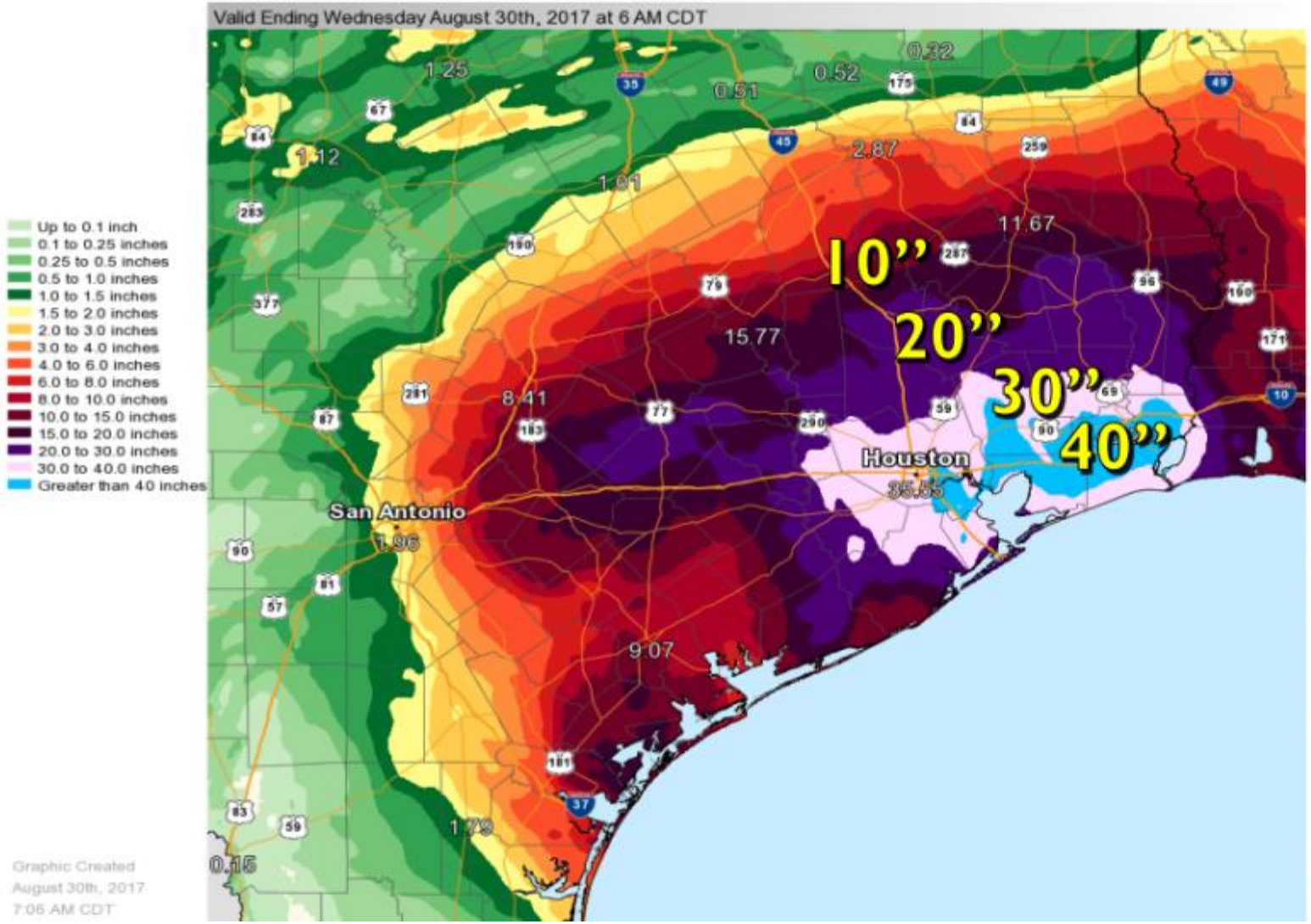
Rainfall



5 Day Point Rainfall Amounts in Inches

- Harvey continued to produce record breaking **rainfall totals** of **45 to over 50 inches**… with continued rainfall
- **Cedar Bayou - 51.88**
- **Berry Bayou - 44.88**
- **League City - 49.84**
- **Mary’s Creek - 49.80**
- **Goose Creek - 44.08**
- **Greens Bayou - 41.36**
- **Buffalo Bayou - 35.60**
- **Addicks Dam - 33.44**

Point rainfall data courtesy

Compound flooding is difficult to simulate because many potential sources need to be considered

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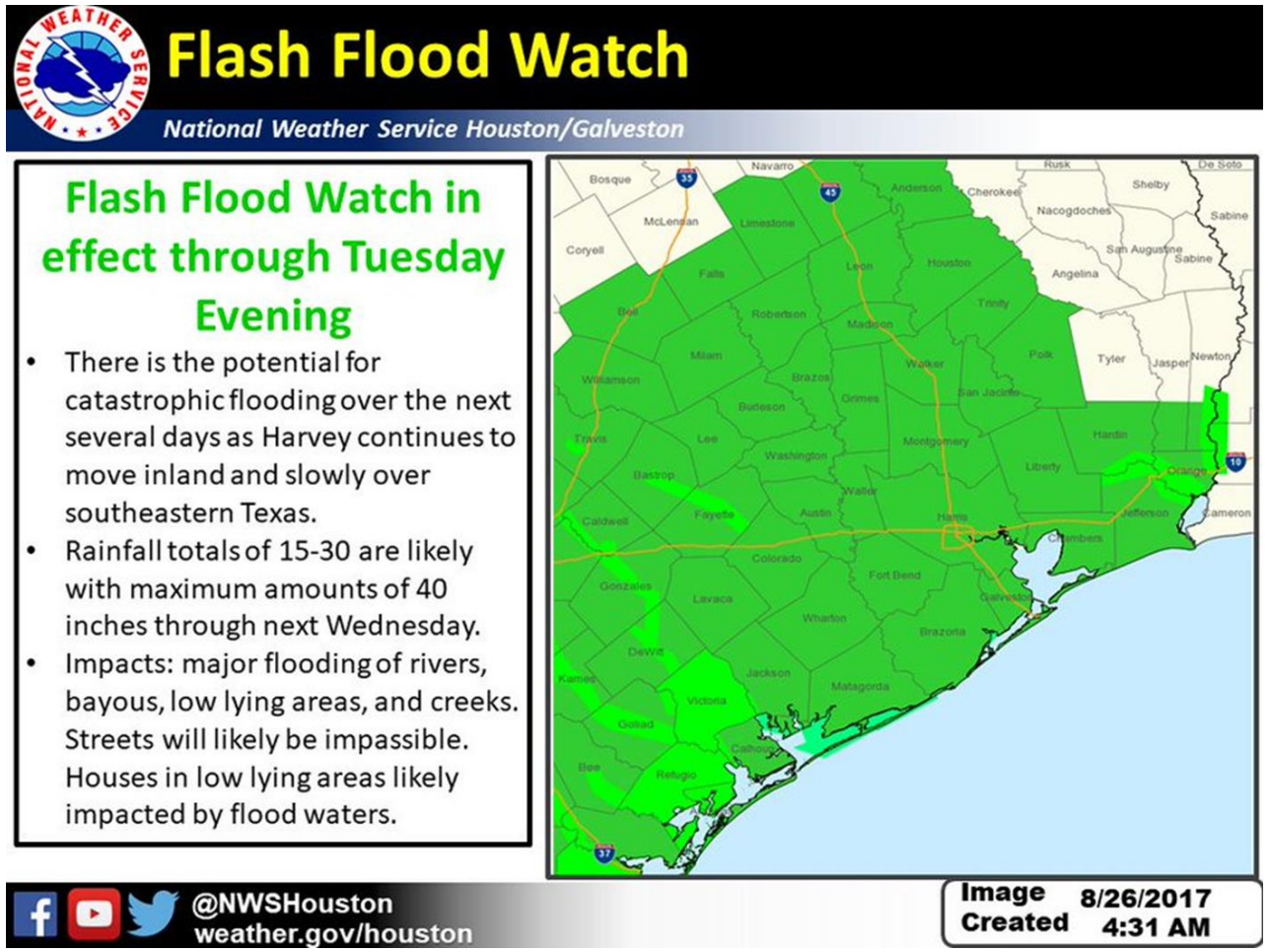
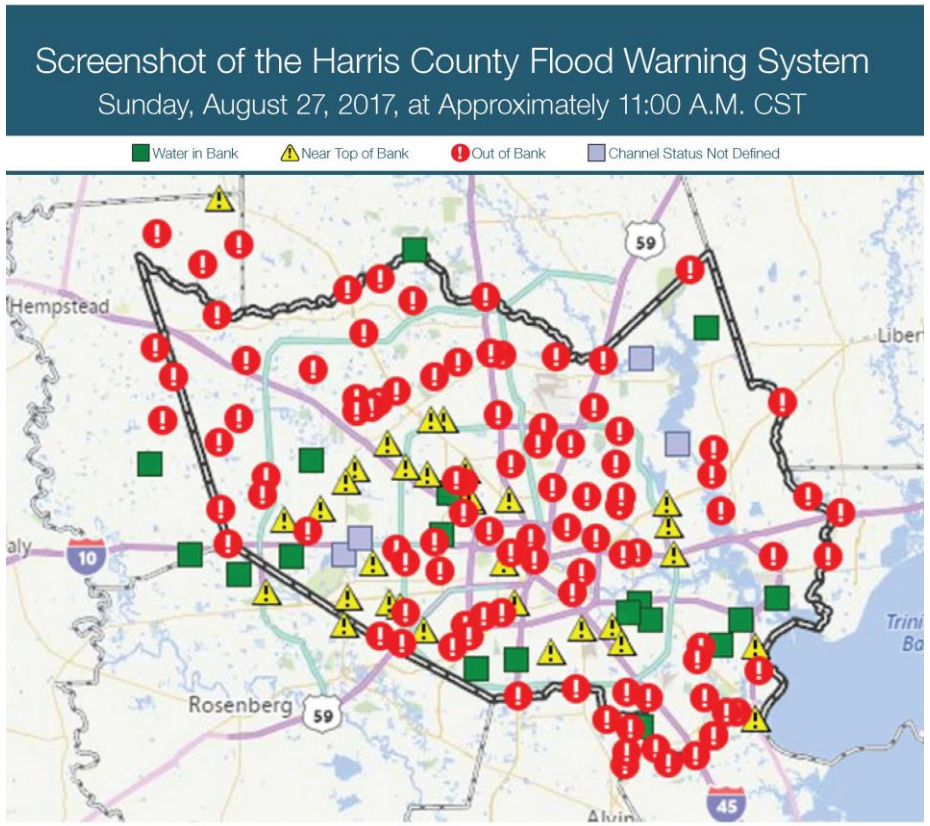
Flash Flooding

Flash flooding occurs from intense rainfall overwhelming local drainage. During Harvey, much of southeast Texas experienced flash flooding, which caught drivers unaware.



Intense rainfall caused flash flooding before the effects of river flooding peaked

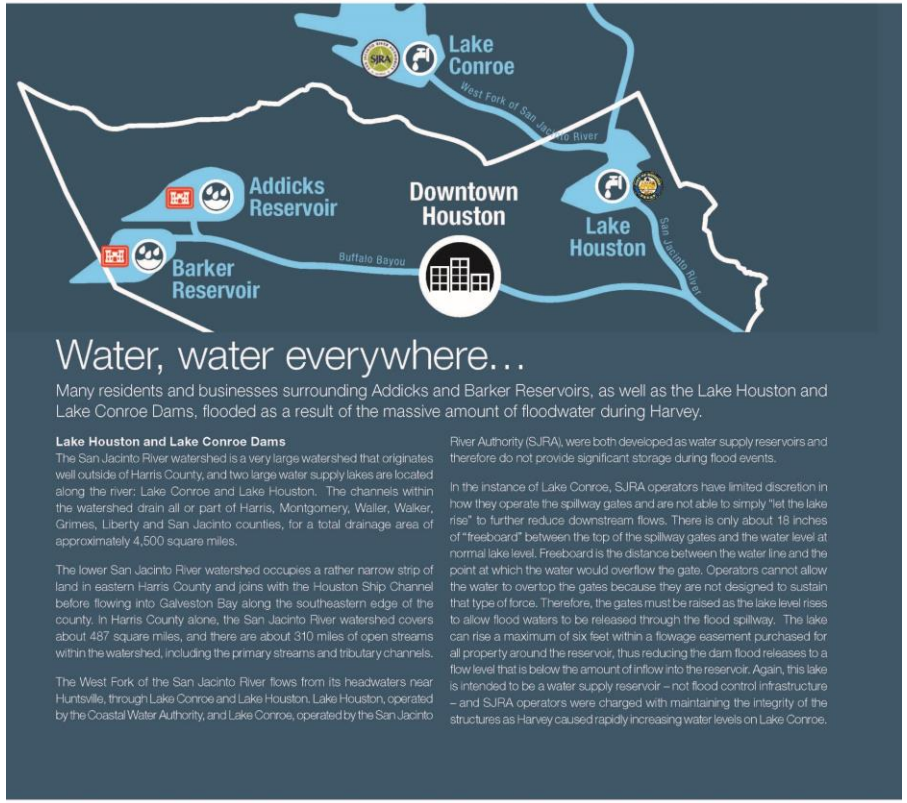
Streamflow



Runoff from widespread heavy rainfall caused streams and rivers to swell with excessive runoff. 90% of stream gages in the area were at flood level and nearly 50% hit all time highs (62% in Harris county). Many streams experienced 500-yr flow/stages.

Compound flooding is difficult to simulate because many potential sources need to be considered

Reservoirs



Reservoirs in the Houston area normally control floods while providing water and recreational opportunities. However, the high stream flows exceeded the capacity of the system and uncontrolled (spillway) flows were recorded at many of the lakes and reservoirs.

Lake	Elevation (ft)	Discharge (cfs)
Houston	53.1	425,000
Conroe	206.2	79,140

Compound flooding is difficult to simulate because many potential sources need to be considered

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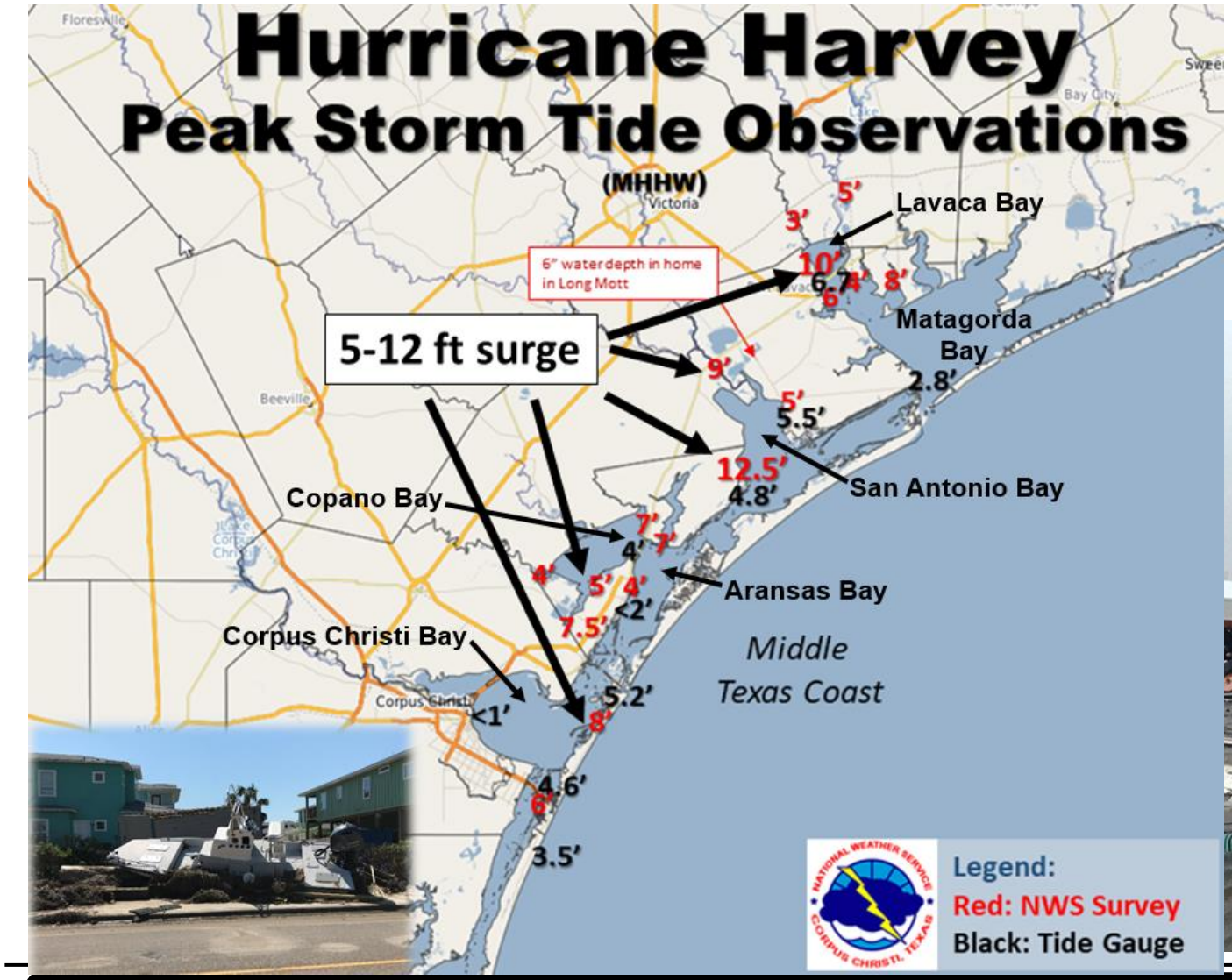
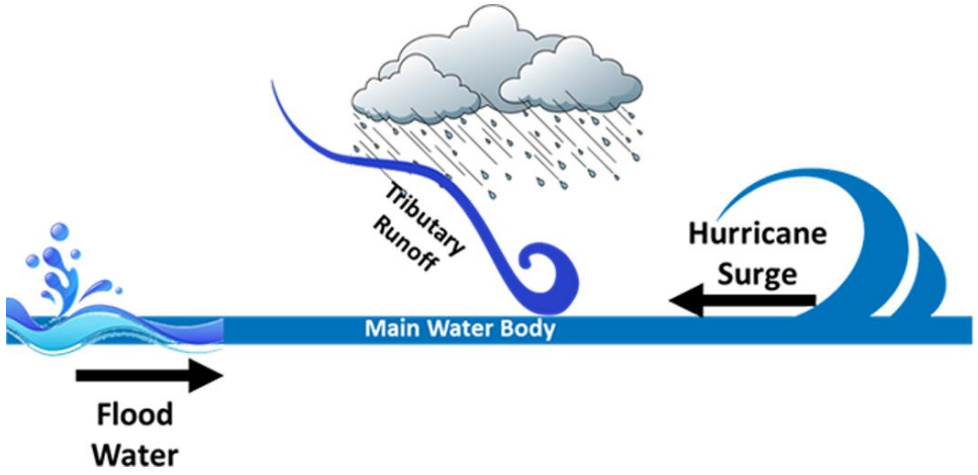
Coastal Flooding



Compound flooding is difficult to simulate because many potential sources need to be considered

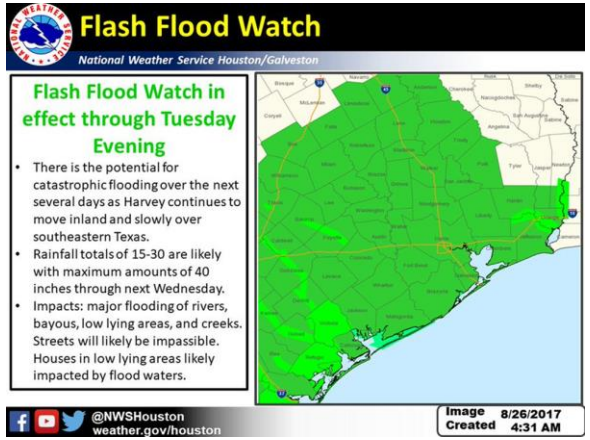
Systems at Play

- ***Flash flooding from intense local rainfall***
- ***Overwhelmed local drainage system***
- ***River overbank flooding***
- ***River backwater flooding – reservoir and tide stages***
- ***Reservoir releases***
- ***Uncontrolled reservoir releases***
- ***Storm surge***



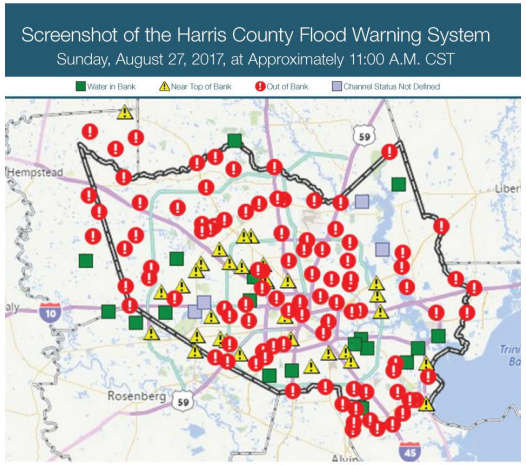
There are many possible sources/causes of compound flooding

Synopsis

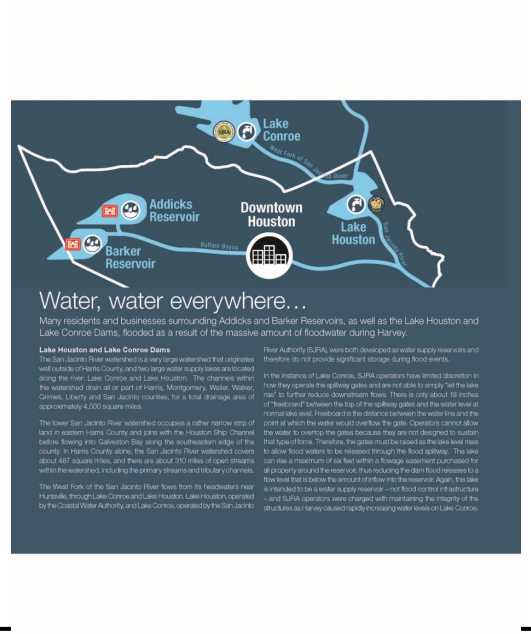


Local runoff adds to stream flooding

Overbank flow adds to local flooding



Stream flow adds to tidal flooding.



Lake discharges causes downstream flooding

Streamflow causes reservoir flooding

High lake levels cause backwater effect in streams

Lake discharge adds to tidal flooding

Tidal flooding causes backwater effect in streams.

During Harvey many types of flooding and interactions occured

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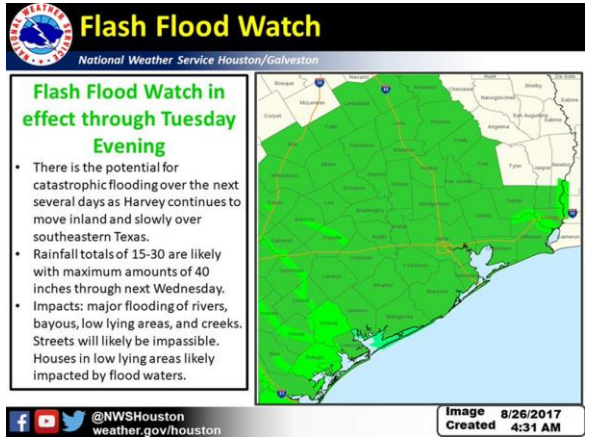
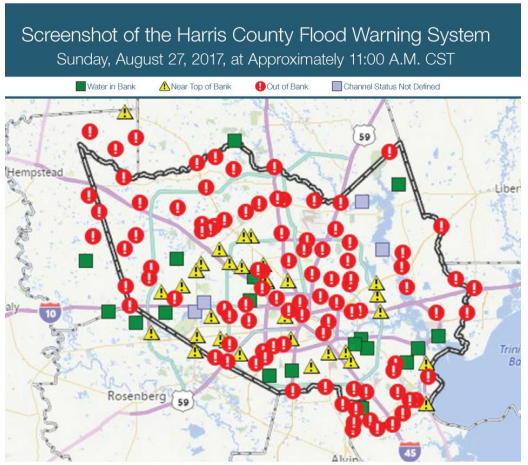
Models?

Needed Interactions



Hydrology
Overland flow

Overbank and backwater effects



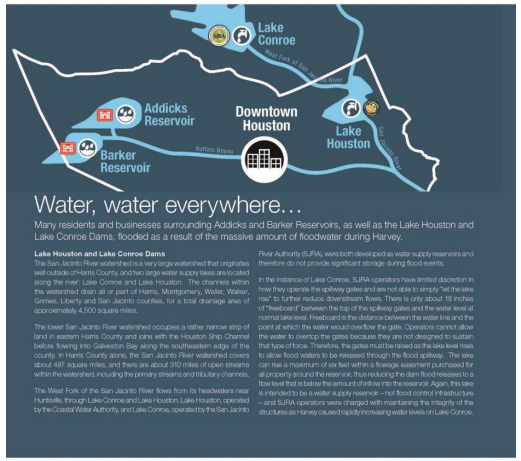
Stream flow

Discharge to tidal streams

Backwater effect

Stream inflows

Backwater effects
Discharge to stream



Reservoir

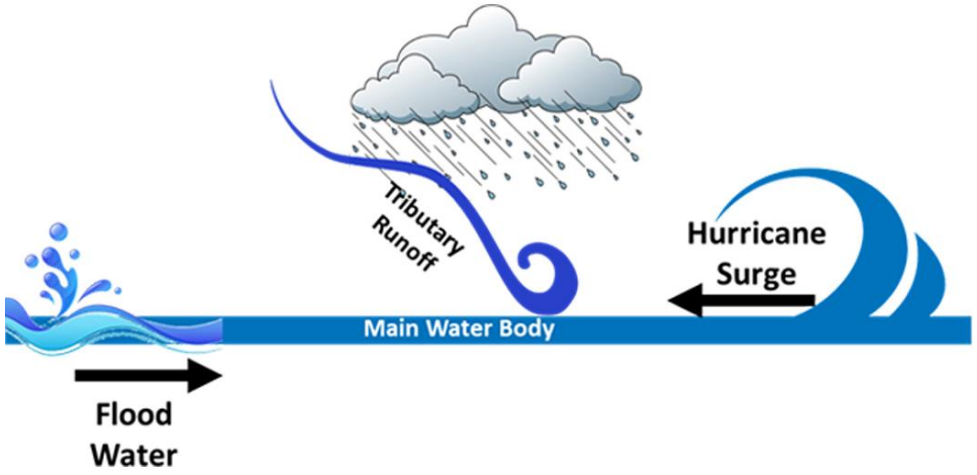
Coastal
Open ocean

Discharge to tidal streams

Compound flooding is difficult to simulate because many potential sources need to be considered

Simulating Compound Flooding is a Work in Progress

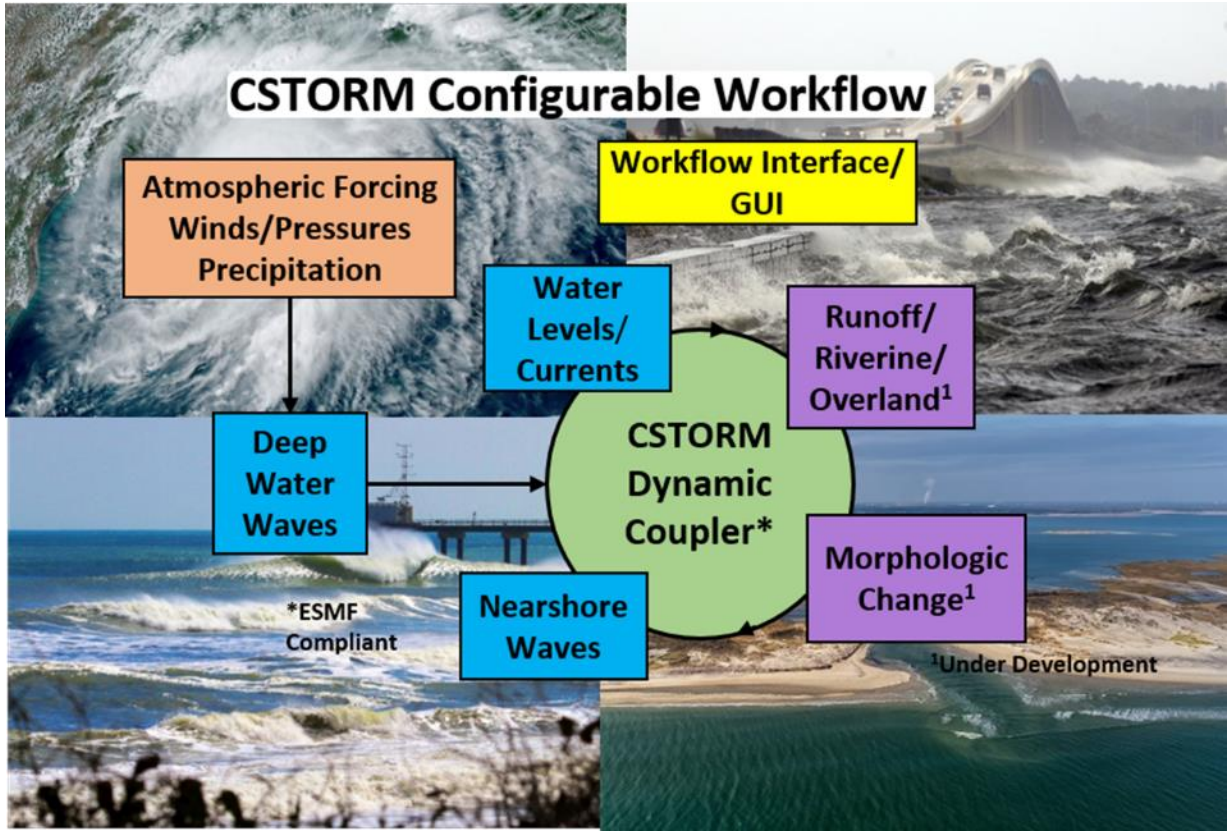
- *Current USACE Systems*
  - *CEWMS – inland operational model*
  - *WAT – system to tie many tools together*
  - *CSTORMS – coastal storm modeling*
- *Current USACE Integrated Models*
  - *AdH*
  - *GSSHA*
- *Other Federal Systems*
  - *NWM (NWS)*
  - *GSFLOW/MODFLOW (USGS)*



Simulating compound flooding is a work in progress in the Federal government

CURRENT TECHNOLOGY – ERDC'S COASTAL STORM MODELING SYSTEM

• ***CSTORM-MS is an efficient, highly skilled, extensible, integrated and robust modeling system for quantifying the risk of coastal communities to storm events including considerations for sea level rise.***



Forcing

- Tropical cyclones
- Extratropical cyclones
- Precipitation (proposed)

Response

- Water level (storm surge, astronomical tide, SLC)
- Currents
- Wave height, peak period, direction
- Wind speed, direction
- Overland runoff (proposed)
- Riverine (proposed)
- Sub-surface flows (proposed)

CSTORM is an Integrated Modeling Platform Currently for Coastal Analysis

USACE Top 10 R&D Priorities

1 Mitigate and Adapt to **Climate Change**

2 Win **Future Wars**

3 Modernize our Nation's **Infrastructure**

4 Support Resilient **Communities**

5 Enable Smart and Resilient **Installations**

6 Ensure **Environmental** Sustainability and Resilience

7 Secure Reliable Installation **Energy**

8 Revolutionize and Accelerate **Decision Making**

9 Improve Cyber and Physical **Security**

10 Protect and Defend the **Arctic**

Priorities are not ranked; numbers are for identification purposes only

USACE R&D STRATEGY

Scan the QR Code at right to download a copy of the **USACE R&D Strategy** and other USACE R&D communication products

★ SUPPORTING SCIENCE, RESEARCH, AND DEVELOPMENT TO DELIVER ENDURING WATER RESOURCE SOLUTIONS

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USACE CIVIL WORKS STRATEGIC FOCUS AREAS (SFAs)

Sustainable Species Management

Measuring, predicting, and managing harmful, nuisance, threatened and endangered species

NextGen Water Resources Infrastructure

Building smarter, longer-lasting infrastructure

Innovations in Sediment Management

Maximizing beneficial use of sediments

Comprehensive Water Risk Management

Effectively and efficiently managing water before, during, and after it hits the ground

I-4A: Innovative Applications of Big Data Analytics, AI, & Autonomy

Leveraging robotics, AI and data as a force multiplier

Crisis Mitigation, Response, & Recovery

Proactively saving lives and communities

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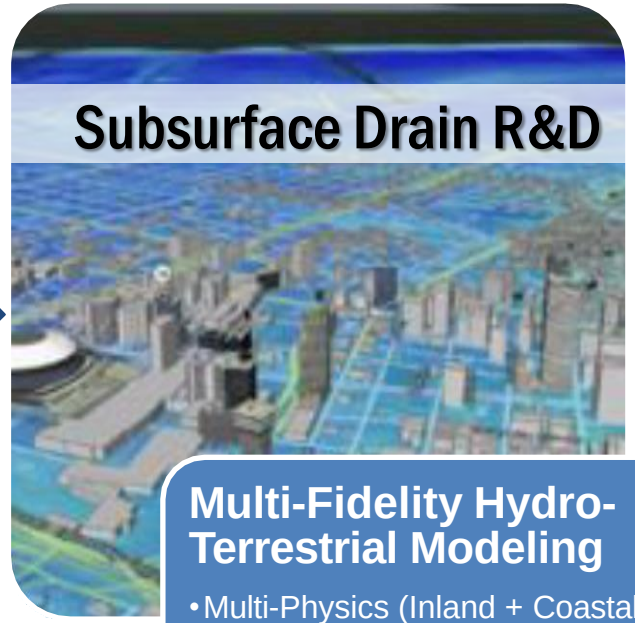
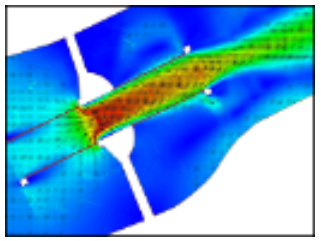
Comprehensive Water Risk Management

Integrated Earth Observations

- Remote Sensing (Satellite +)
- In-Situ Sensing
- Atmospheric, Ocean & Land Surface
- Automated Updating
- Assimilation & Continuous Model Validation



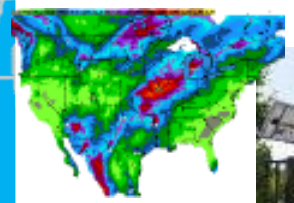


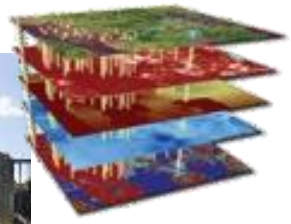
Multi-Fidelity Hydro-Terrestrial Modeling

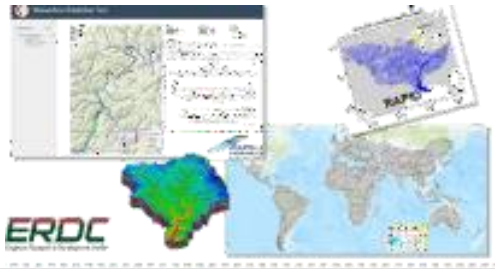
- Multi-Physics (Inland + Coastal)
- Ensemble Methods
- ML/AI Capabilities
- Modular, Modern, Efficient
- Open Science/Collaborative
- Driver for Environmental & Sediment Modeling

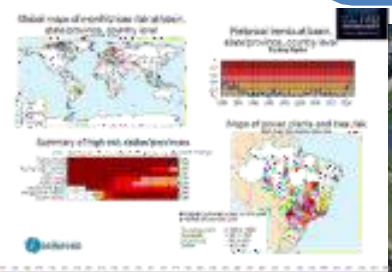
Decision Support

- National Storm Hazards Database/Tools for Efficient Lifecycle Planning & Design
- Robust Real-Time National Hydro-Terrestrial Simulation
- Tradespace Design Analysis
- Probabilistic Seasonal Projection Capability
- Updated Guidance









Development of Comprehensive Water Risk Management – Key SFA Served by This Proposed Research