Houston Geological Society Presents
An Informational Workshop
Flooding and Floodplains in the Houston Area: Past, Present, and Future: Part 2
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6) The “100-year” rain/flood/floodplain can change w/time!

......but why?

a) More data / longer record
b) Changing land use
c) Structural changes
d) Changing climate

[Graph showing streamflow over time]

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**b) Changing Land Use**

- **Urbanization**
  - Increased impervious surfaces:
    - decreased infiltration (increases runoff)
    - faster runoff (decreases *lag time*)
  - Bridges - (impediments to flow)
  - Storm drains (decrease *lag time*)
  - Failure of storm drains

- **Deforestation/agricultural changes**


*Presentation by W. R. Dupre' (UH) 2018*
**Infiltration** is ....  | high | low  
--- | --- | ---
Surface Slope | low | steep 
Soil Type | sandy | clay-rich 
Ppt. Intensity | gentle | heavy 
Soil Saturation | low | high 
Vegetation | hi % | low % 
Land Use | natural | urbanized 

Runoff is ....  | low | high 
--- | --- | ---

*Note longer record isn’t always better!*

**After Urbanization**
1) Decreased Lag Time 
2) Increased Peak Stage/Discharge 
3) Increased Volume of Runoff 

![Diagram of urbanization of drainage basin with graphs and tables showing the effects of urbanization on infiltration and runoff.](image)
Hydrographs from Similar Sized Storms on Brays Bayou

By the 1980s, > 95 % of the Brays Bayou watershed was developed.

Greater Houston Strategies for Flood Mitigation, 2018

Annual Daily Peak Discharge (cfs)

Post Addicks Dam

1929
**Remnant Prairie in Study Area**

- Upper Cypress Creek Watershed
- Atticks Watershed
- Drainage Divide

**Flood Damage Reduction Benefits of Coastal Prairie**

- Coasts Prairie
- Agriculture
- Developed

- Decreased Runoff due to Prairie Restoration

  Restoration of 1 acre of prairie would:

  - increase the infiltration capacity of undeveloped land by \( \sim3.5 \text{ inches} \) in a 100-year flood event...

  - offset the volume impact of \( \sim2 \) acres of a single-family subdivision, or \( \sim1 \) acre of commercial or retail development.

**c) Structural Changes**

1. Dams
2. Levees
3. Channelization
4. Detention/Retention Basins
1) Effect of Dams on Flooding

- InCREASED deposition (and flooding) upstream
- Decrease flooding & increased erosion downstream

Why???
Other implications??

Press & Siever, 2004
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Increased backwater due to deposition of sediment

Deposition of River Mouth Bar

Kissling et al., 2018

Increased backwater due to deposition of sediment

Deposition of River Mouth Bar

Kissling et al., 2018

Delta progradation into Lake Constance, Austria

River Profile Before Dam

River Profile After Dam

Backwater curve

New Base Level

Increased flooding

Old Base Level

Base Level

Increased backwater due to deposition of sediment

Deposition of River Mouth Bar

Delta progradation into Lake Constance, Austria
Growth of subaerial delta
Deposition of lake-bottom sediments

<table>
<thead>
<tr>
<th>Survey</th>
<th>Surface area (acres)</th>
<th>Total capacity (acre-feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>12,764</td>
<td>158,553</td>
</tr>
<tr>
<td>1965^3</td>
<td>12,236</td>
<td>146,769</td>
</tr>
<tr>
<td>TWDB 1994</td>
<td>11,854</td>
<td>133,990</td>
</tr>
<tr>
<td>TWDB 1994 re-calculated</td>
<td>11,800</td>
<td>136,381</td>
</tr>
<tr>
<td>TWDB 2011</td>
<td>10,160</td>
<td>124,661</td>
</tr>
</tbody>
</table>

~21% filled in 57 years
Half-life ~135 years

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Suspended Sediment Rating Curve*
Cypress Creek near Westfield, TX USGS 08069000

* Establishes a relationship between measured suspended sediment discharge with measured water discharge to allow extrapolation to periods when only water discharge is measured.

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### Anticipated Sediment Loads (tons/year)

<table>
<thead>
<tr>
<th>Basin</th>
<th>Range</th>
<th>% Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cypress Creek</td>
<td>70,000-160,000</td>
<td>52-58%</td>
</tr>
<tr>
<td>Spring Creek</td>
<td>30,000-65,000</td>
<td>22-24%</td>
</tr>
<tr>
<td>W. Fork SJ</td>
<td>35,000-50,000</td>
<td>26-18%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>135,000-275,000</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

“...the major source of the total sediment load, [into Lake Houston] ...is contributed by Cypress Creek...” [BUT]

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### Caveats:

These data are the only ones presently available for measuring the relative sediment load of major tributaries. However, they do not:

1. ...measure sediment during high flood flows when most sediment is transported.
2. ...reflect any impact of post-1999 changes in land use.
3. ...measure transport of bedload sediment. 

Therefore, more data are needed before an accurate estimation of the sediment budget can be made!

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### Lane’s Balance between Sediment & Energy

**Sediment** (size & supply)  
**Energy** (slope & discharge)

lane, 1955, The Importance of Fluvial Morphology in Hydraulic Engineering

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**Collins et al., Formulating Guidelines for Reservoir Stability**

**Reduce Sediment Yield From Watershed**  
- Reduce Sediment Inflow from Upstream  
- Reduce Sediment Production  
- Trap Sediment Above Reservoir  
- Soil Erosion Control  
- Streambank Erosion Control  

**Minimize Sediment Deposition**  
- Route Sediments Around or Through Storage  
- Sediment Bypass  
- Sediment Puts Through  
- Off-Channel Reservoirs  
- Turbulent Density Currents  
- Drained Reservoirs (Sizing)  

**Increase or Recover Volume**  
- Recovered, Increase, or Reallocate Storage Volume  
- Mechanical Excavation  
- Hydraulic Excavation  
- Day Excavation  
- Drained Reservoirs  
- Streambed Sediment  

**Reducing Erosion & Depositing**

**Nature**  
- Sediment supply (volume)  
- Stream slope (steep)  
- Channel (straight)  
- Habitat (fish)  

**Presentation by W. R. Dupre' (UH) 2018**
Suspended Sediment Rating Curve
West Fork San Jacinto River near Conroe, TX USGS 08068000

Average sediment load (pre-dam) 59,722 tons/yr
Average sediment load (post-dam) 44,738 tons/yr
~25% decrease

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Sources of Sediment
• River Erosion
• Urbanization
• Sand Mining

Sites of Sedimentation
• River Bar deposition
• Overbank deposition
• Delta Bar deposition
• Obstructions to flow
• Sand Pits

Causes of Changes in Sediment & Sedimentation
• Building Dams
• Increased Runoff
  • due to urbanization
  • due to climate change [“non-stationary climate”]
• Sand Mining
• Construction
• Constrictions (local sites of deposition)
Riverine erosion may be even more problematic than flood inundation because:

1) It can damage or destroy homes well above and outside the regulatory floodplain.

2) It can destroy both structures and property, making rebuilding impossible.

3) It can occur progressively during floods smaller than the 1% flood, resulting in cumulative, long-term losses.
National Flood Insurance Reform Act (NFIRA) of 1994:

Required FEMA evaluate the technological feasibility of mapping Erosion Hazard Areas (both coastal and riverine) and the economic impact on the National Flood Insurance Program.

Schematic Sequence of Changes in Sediment Yield: Rural Watershed to Urbanized Basin

Effect of Changing Land Use on Sediment Production


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Riparian Buffer

Types of River Sand Mining Pits:
- Terrace pit
- Floodplain wet pit
- In-stream pit

Possible In-stream Sand Mining Impacts
- **Channel modifications** such as widening or deepening the channel, creation of deep pools, loss of riffles, alteration of bedload, alteration of channel flow, and degraded aesthetics.
- **Upstream and downstream erosion** and related impacts.
- **Modifications of aquatic habitat** including spawning beds, nursery habitat, shellfish habitat, and riparian habitat.
- **Degradation of water quality** including increased turbidity, reduced light penetration, increased temperature, and resuspension of organic or toxic materials.
- **Bridge scour** and other impacts to infrastructure

Findings from Sanderock & Ladson, 2014, Review of floodplain mining impacts and risks
**Floodplain Mining**

- “The main hazard is **pit capture**, via: lateral migration of river channel into the pit, sub-surface piping into pits and subsequent failure of pit walls, or spill of water into and through the pit.”

- “Pit capture impacts on a rivers geomorphic characteristics, sediment transport, hydraulics, hydrology, water quality and aquatic habitat, with these impacts extending upstream and downstream of the pit as well as the area of the pit itself.”

- “After pit capture the stream will deposit its bedload in the pit,” which may result in both upstream and downstream erosion.”

Avoid siting pits in a ‘channel migration zone’

“In Washington State and Arizona, floodplain mine regulators have adopted the concept of a Channel Migration Zone to assist in the identification of suitable sites (Rapp & Abbe, 2003).

This considers the dynamism of the river channel through **historical analysis** of channel migration to identify areas that are disconnected from river migration.

**Mining is restricted** to floodplain terraces or areas of the floodplain where there are structural measures in place to limit the migration of the channel.”

**Guidelines for Maricopa County, Arizona**

**Erosion Hazard Area**

“An area where, based on erosion rate information and other historical data, [lateral] **erosion** or **avulsion** is likely to result in damage or loss of buildings or infra-structure within a **60 year period**.*”

(Section 577 of National Flood Insurance Reform Act of 1994)

* Time period may vary with statute
100 feet
Narrow (<25'), non-vegetated buffer: HIGH erosion (and pit capture) hazard.

12-31-2001
1-25-2004

7-31-2015
Spit formed by sediment entering the pit
April 2015 flood breach

1-23-2017
New spit formed by sediment entering the pit during Tax Day Flood
Post 4/2016 fill

Post 9/2015 fill
April 2015 flood breach

Turbidity plumes indicating water and sediment flow into the sand pits during Hurricane Harvey on August 30, 2017
2) Effect of Levees

But!

1. Encourages development on prior floodplain
2. Levees can fail, either by:
   - overtopping,
   - poor maintenance,
   - erosion,
   - subsidence, or
   - under-seeping!
3. Levees can act as dams, trapping water & flooding homes

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3) Early Channelization Approaches

- Increase channel cross section area to hold more water (widening & deepening);
- Increase flow velocity, e.g.
  - Concrete lining channel
  - Straightening channel
  - Improving cross sectional efficiency

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Slope increased by 2x
Velocity increased by ~ 1.4x!
But isn't Reduced Flooding Good?

- Concrete-lining & removal of natural vegetation reduces natural habitats.
- Concrete-lined channels look bad and reduce groundwater recharge and baseflow.
- Channelization can increases downstream flooding and erosion!
- Encourages development of floodplains

4) Effects of Detention Basins

- **On-site**: detains storm water on site before it enters the channel
- **In-line [linear]**: Deep areas adjacent to the channel that can store floodwater once it begins rising in the channel.
- **Regional**: built by flood control agencies to address flooding on a larger geographic scale and is funded by taxes or stormwater fees paid by a number of developers. Regional detention is used to reduce existing flooding or help prevent increased flooding from new developments. (may be wet-bottom or dry-bottom)

4) Effects of Detention Basins

**b) Changing Climate**

**ANALYSIS OF IMPACTS OF NON-STATIONARY CLIMATE ON PRECIPITATION FREQUENCY ESTIMATES**

“There has been a growing concern among users of NOAA Atlas T4 products that they ...... may not be appropriate in presence of *non-stationary climate*.”
ANALYSIS OF IMPACTS OF NON-STATIONARY CLIMATE ON PRECIPITATION FREQUENCY ESTIMATES

- The current **NOAA Atlas 14** frequency analysis methods are based on the **assumption of stationary climate** in both **historic** and **future** precipitation records.
- As such, they **may not be suitable** for frequency analysis in the presence of non-stationary climate conditions…
- It has thus **become necessary to assess the potential for incorporating non-stationarity in precipitation frequency estimates**.

NOAA Atlas 14 and Climate Change

- **2018 version will assume “stationarity”**
- **Reasons for change from 1961**
  - Better methods
  - More stations
  - Longer data records
  - **Intensifying rainfall**
- But: 2018 version will already be **“out of date”**
- Current risk higher, future risk higher still

Key Messages

1) Harvey was exceptional
2) Odds of extreme rainfall have increased and will continue to increase
   - Increase in probability (ballpark) by a factor of 3 (2x-8x) / °C global warming
   - Increase in rainfall (ballpark) ~15% (10-30%) per °C global warming

Warming has made extreme rain events more frequent over Houston

...we conclude that global warming made the precipitation [from Harvey] about 15% (8%-19%) more intense, or equivalently made such an event three (1.5-5) times more likely.

http://climatexas.tamu.edu
One measure of heavy precipitation events is a two-day precipitation total that is exceeded on average only once in a 5-year period.

**Changing Approaches to Flood Control**

**Structural Responses:** (1930’s-present): e.g. building dams, levees, floodwalls, channelization
- *Flood Control Act of 1936.*

**Floodplain Management:** (1960’s-present):
Combined floodplain management with structures
- *National Flood Insurance Program of 1968;*
- *National Disaster Protection Act of 1973;*

**Post-flood Non-structural Mitigation:** (1980’s-present):
Includes property acquisition and Δ land use.

<table>
<thead>
<tr>
<th>Policy</th>
<th>Support</th>
<th>Oppose</th>
<th>Nonresponse</th>
</tr>
</thead>
<tbody>
<tr>
<td>A program to buy homes in areas that have repeatedly flooded with local state and federal moneys</td>
<td>63.2%</td>
<td>27.5%</td>
<td>9.2%</td>
</tr>
<tr>
<td>Construction of a new reservoir to protect west Houston</td>
<td>84.7%</td>
<td>8.2%</td>
<td>7.1%</td>
</tr>
<tr>
<td>Greater restrictions on construction in flood plains</td>
<td>82.7%</td>
<td>10.7%</td>
<td>6.7%</td>
</tr>
<tr>
<td>Establishment of a regional flood agency with taxing authority to plan for the prevention of regional flooding</td>
<td>67.1%</td>
<td>22.0%</td>
<td>10.9%</td>
</tr>
<tr>
<td>Denying federally financed flood insurance to homeowners whose homes that have flooded three of more times since 2001</td>
<td>42.0%</td>
<td><strong>45.7%</strong></td>
<td>9.4%</td>
</tr>
<tr>
<td>Policy</td>
<td>Support</td>
<td>Oppose</td>
<td>Nonresponse</td>
</tr>
<tr>
<td>-----------------------------------------------------------------------</td>
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</tr>
<tr>
<td>Not allow homes that have flooded three or more times since 2001 to be rebuilt by buying out these homeowners with local and federal moneys</td>
<td>61.5%</td>
<td>28.4%</td>
<td>10.1%</td>
</tr>
<tr>
<td>Requiring sellers of homes to fully disclose prior flood damage to their homes and prior flooding in the surrounding neighborhood</td>
<td>89.2%</td>
<td>6.6%</td>
<td>4.2%</td>
</tr>
<tr>
<td>Preventing development/ construction on native prairies and wetlands in western and northwestern portions of Harris County</td>
<td>67.3%</td>
<td>19.2%</td>
<td>13.9%</td>
</tr>
<tr>
<td>Require government compensation for homes that are flooded due to the release of water from local reservoirs</td>
<td>77.2%</td>
<td>14.7%</td>
<td>8.1%</td>
</tr>
<tr>
<td>New building codes that require homes built in flood prone areas be elevated/reduced to avoid flooding</td>
<td>85.6%</td>
<td>9.5%</td>
<td>4.5%</td>
</tr>
</tbody>
</table>

The 237 Flood Bond Projects Include:

- $1.2 billion (~50%) for channel improvements
- $401 million (~15%) for detention basins
- $242 million (~10%) for floodplain land acquisition
- $12.5 million (~5%) for new floodplain mapping
- $1.25 million for an improved early flood warning system
- $500 million (20%) unallocated