Satellite Navigation Integrity Assurance: Lessons Learned from Hurricane Katrina

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Outline

- **The Destruction of Much of Greater New Orleans in late August 2005 (Hurricane Katrina)**
- **Flaws in Handling the Storm/Flood Threat Prior to August 2005**
  - **Original hurricane models became outdated over time**
  - **Failure to adapt to model changes after 1965**
- **Lessons for Satellite Navigation Integrity Design**
  - **Need flexibility to modify systems after initial approval**
  - **Avoid overwhelming focus on “hardest” problems**
  - **Need for probabilistic modeling and analysis**

Key Sources

- ***Decision-Making Chronology for the Lake Pontchartrain & Vicinity Hurricane Protection Project*, HPDC Final Report, March 2008; http://www.iwr.usace.army.mil/inside/products/pub/hpdc/Final_HPDC_Apr3_2008.pdf**

- ***US Army Corps of Engineers (COE) Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System*, Final Report of the Interagency Performance Evaluation Task Force (IPET), June 2008; https://ipet.wes.army.mil/**

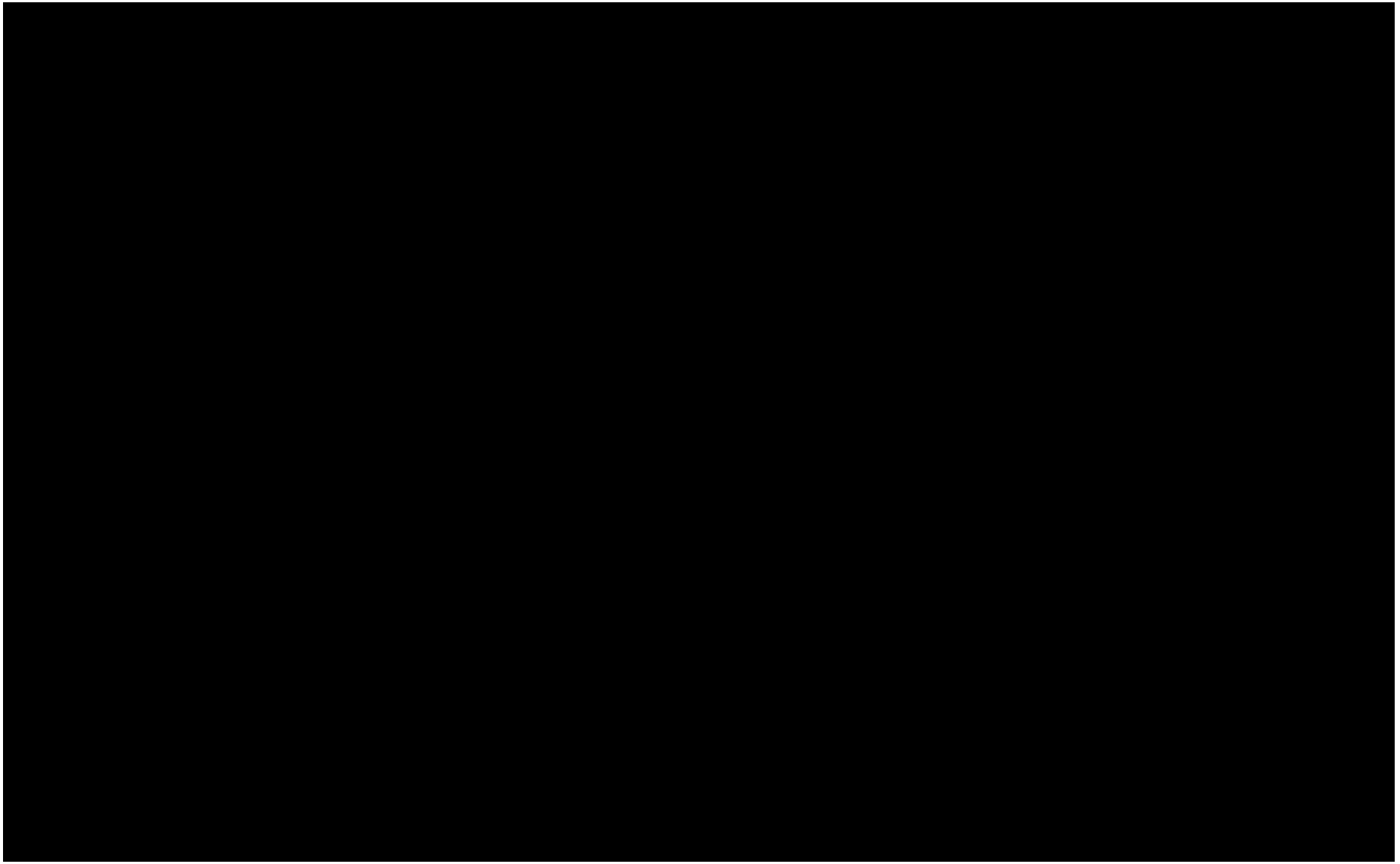
- **NOLA.com Hurricane Katrina Archive: http://www.nola.com/katrina/**

Map of LP&V HPP Region

“Lake Pontchartrain and Vicinity Hurricane Protection Project”

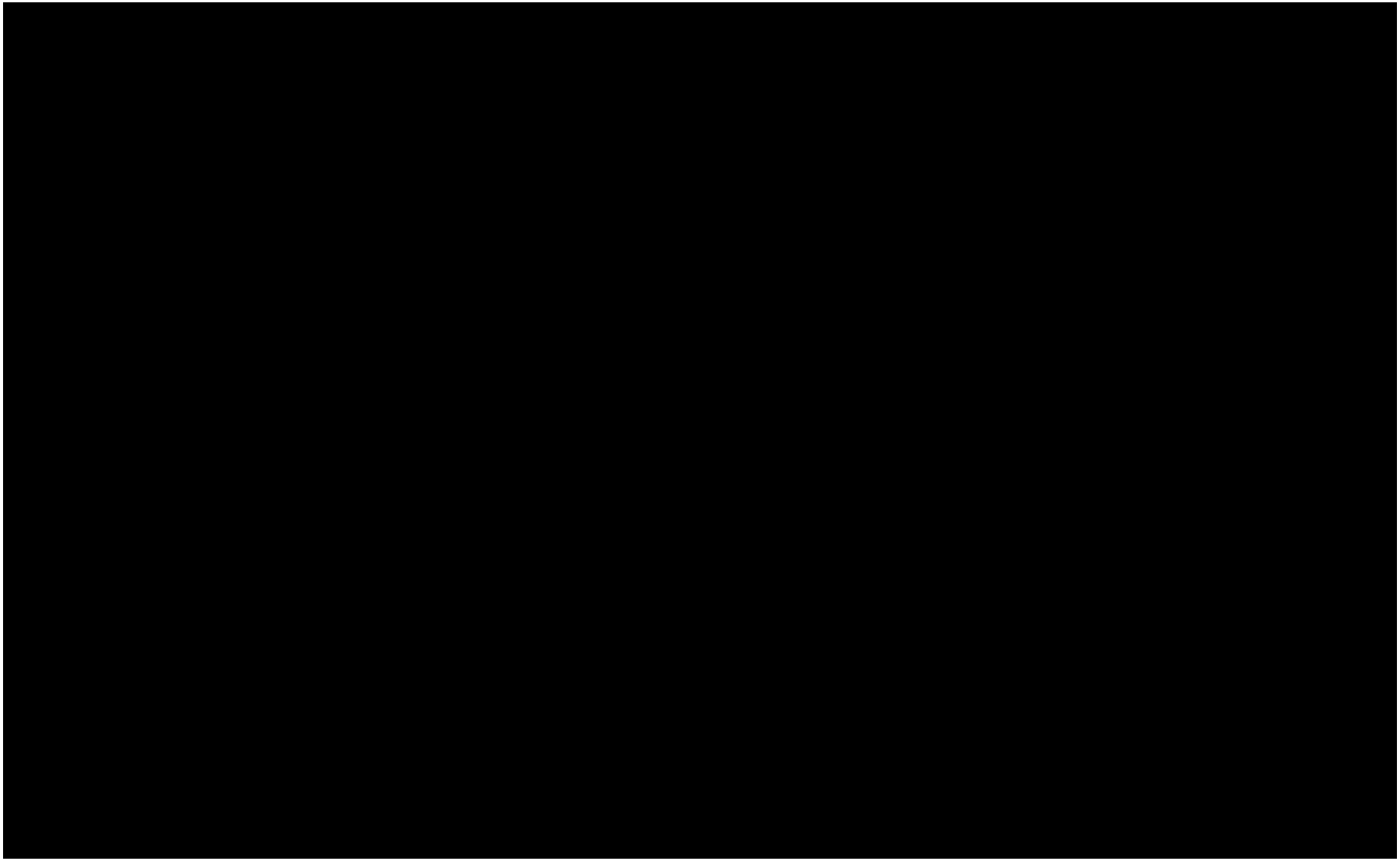
Map 2-1 of HPDC Report

Hurricane Katrina: The NOLA Animation



http://www.nola.com/katrina/graphics/wide.ssf?/katrina/graphics/flashflood.swf

Hurricane Katrina: Max. Flood Depths

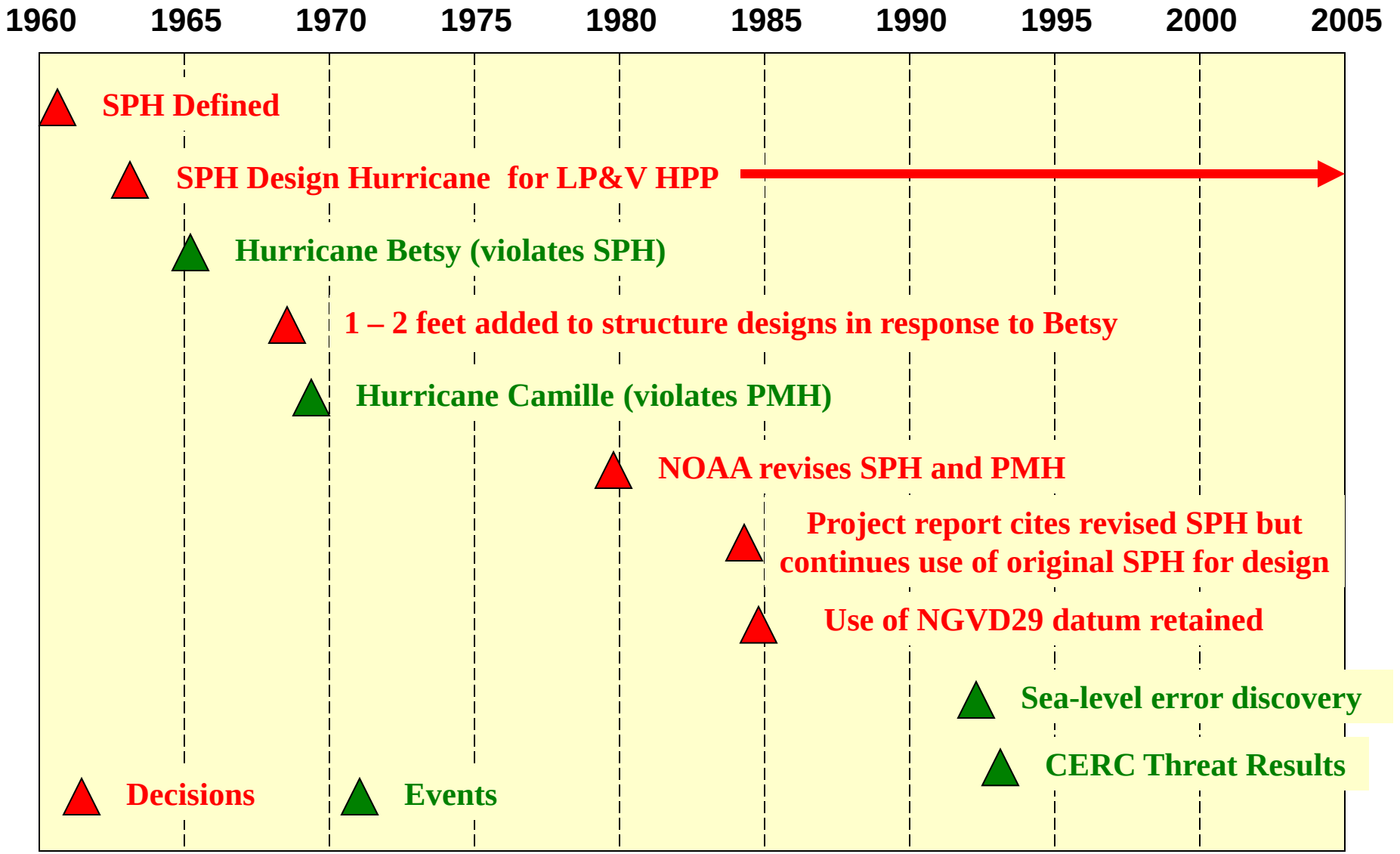


http://www.nola.com/katrina/graphics/wide.ssf?/katrina/graphics/depths.swf

Threat Models for Hurricane Impacts

- **U.S. Army Corps of Engineers (COE) pioneered the use of threat models in designing flood-protection systems along the Mississippi River c. 1900.**
- **COE threat models defined "standard" and "worst-case" flooding events based on past experience.**
  - **Which one to defend against was a policy-level decision**
- **This approach was used to define two hurricane impact threat models c. 1955 – 1960 (from HPDC):**
  - ***Standard Project Hurricane (SPH)*: "the most severe storm that is considered *reasonably characteristic* of the region."**
  - ***Probable Maximum Hurricane (PMH)*: "the hurricane that may be expected from the most severe combination of meteorological circumstances that are *reasonably possible* in the region."**

HPP Response to New Information



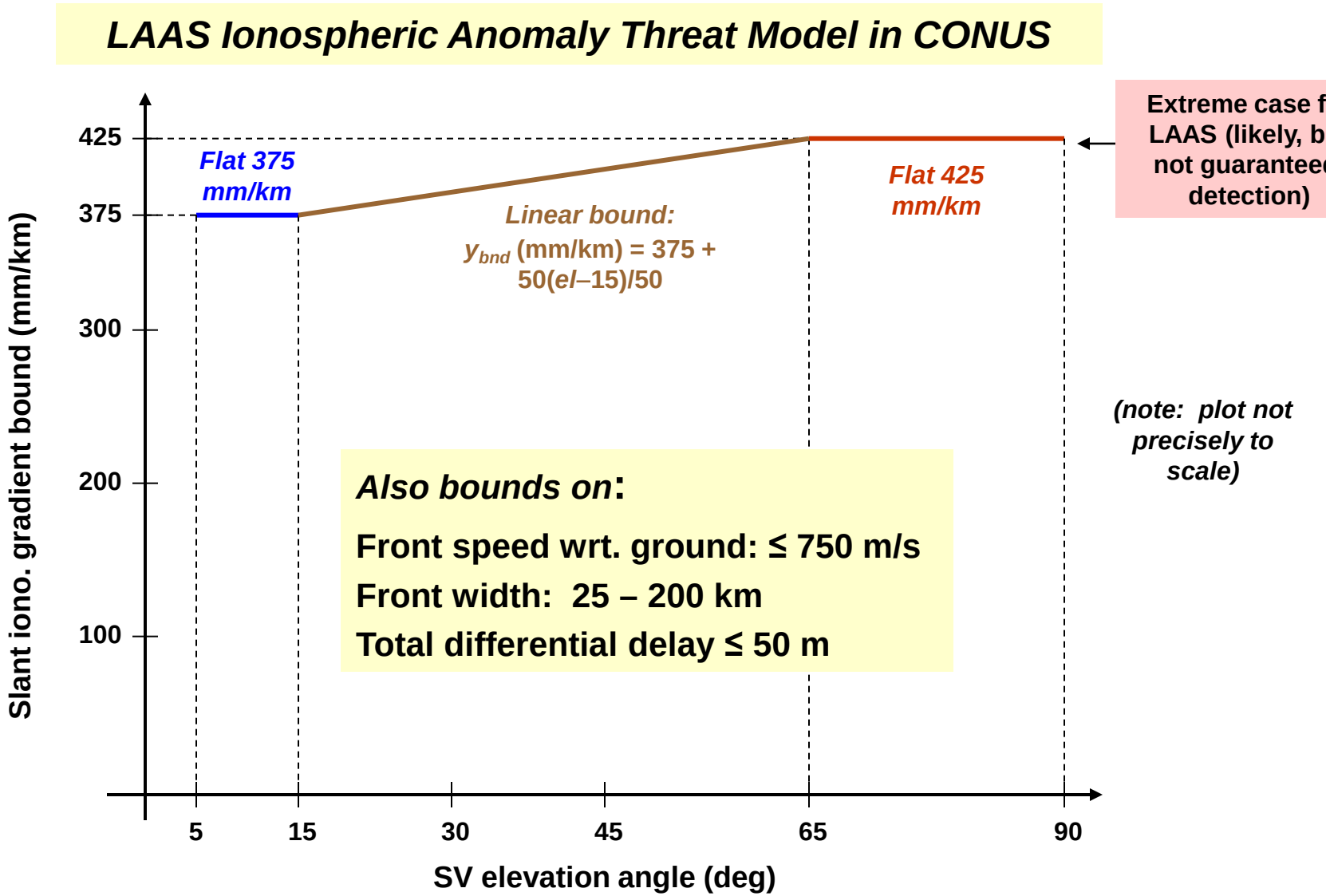
Political Warfare over Project Design (1969 – 1992)

- **COE/Local differences over optimal project design led to decades of political wrangling, delays, and cost overruns.**
  - **COE favored "Barrier" plan and floodgates to protect outfall canals – deemed optimal vs. hurricane surge**
  - **Local authorities opposed barriers and instead favored higher levees opposing LP and outfall canals**
    - » **for rainstorm flood outflow and recreational reasons**
- **Protracted infighting led to court decision halting barrier plan in 1977 on environmental grounds.**
- **Congress eventually forced COE to adapt locals' preferred "High Level" (and accept costs) in 1985.**
  - **Already well past original planned completion date**

Lessons for Integrity Assurance (1): *Maintain Flexibility*

- **Ongoing political battles and cost growth effectively prevented LP&V HPP from adapting to the growing understanding of the threat, *even though specific changes were studied and acknowledged to be wise*.**
  - **Examples from trade-off studies performed over the years cited in HPDC report.**
- **Even glaring mistakes discovered later (e.g., mean vs. local sea level inconsistency, discovered in early 1990's) were not corrected.**
- **Flexibility to respond to changes in understanding of the threat (and other things) must be maintained and given the highest priority.**

Lessons for Integrity Assurance (2): *Avoid Distractions ("Hard" Problems)*



Lessons for Integrity Assurance (3): *Probabilistic Threat Modeling*

- **Deterministic SPH and PMH hurricane models proved both *inaccurate* and *fragile* with respect to new information (i.e. subsequent hurricanes).**
- **Accordingly, IPET report examines future hurricane threat via probabilistic methods.**
  - **Bounded space of parameter values → compute joint probability of each combination (possible hurricane)**
  - **Evaluate all combinations or use Monte-Carlo sampling**
- **Advantages of probabilistic threat modeling:**
  - **Much easier to update with new information**
  - **Does not create one arbitrary "worst-case" event**
  - **Provides a much better basis for cost/benefit analysis**

Summary

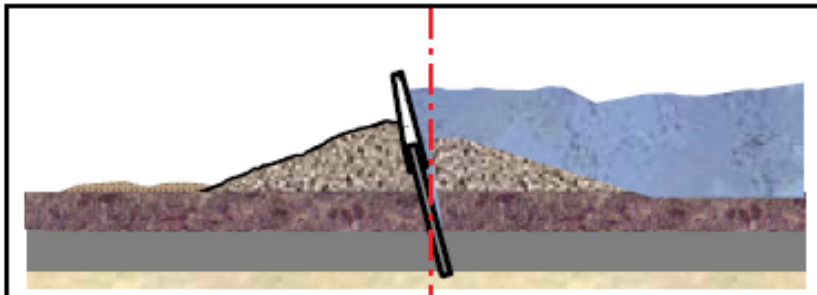
- **Hurricane Katrina was an avoidable man-made disaster that could (and was) predicted in advance.**
- **Mistakes in the design process for the LP&V HPP provide lessons learned for other safety-critical design endeavors.**
- **Lessons specifically relevant to satellite-navigation integrity assurance include:**
  - **Need for flexibility in adapting to new information**
  - **Avoid focusing too much on the "hardest" problems (even if they are real problems)**
  - **Shift from deterministic to probabilistic threat modeling to aid in applying the above lessons.**

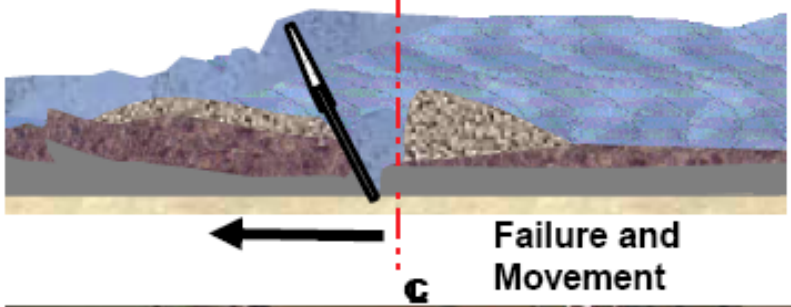
Backup Slides follow…

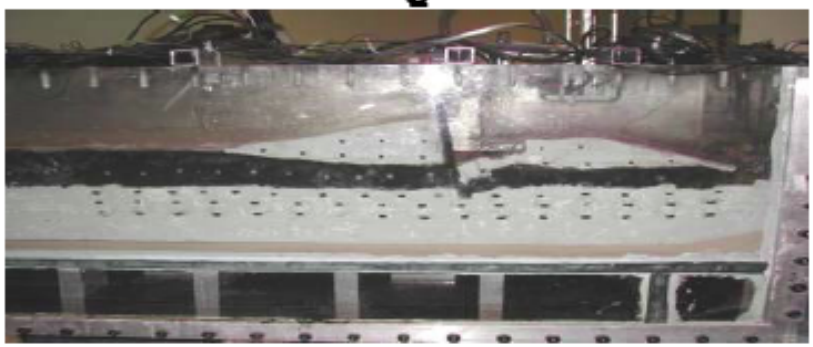
Causes of the Disaster

- **The system of levees protecting New Orleans failed spectacularly under conditions it should have comfortably handled.**
  - **Katrina was not "the big one," but it became so.**
- **Multiple reasons for this discovered after-the-fact, including:**
  - **Inaccurate modeling of the fundamental threat**
  - **Unwillingness to modify mitigation efforts as mis-modeling became apparent over time**
  - **Levee design, construction, and installation defects**
  - **Failure of the levee system to be managed as a system**
- **These flaws had both engineering and political/organizational underpinnings.**

I-Wall Levee Failure Illustration







Confirmation in Centrifuge

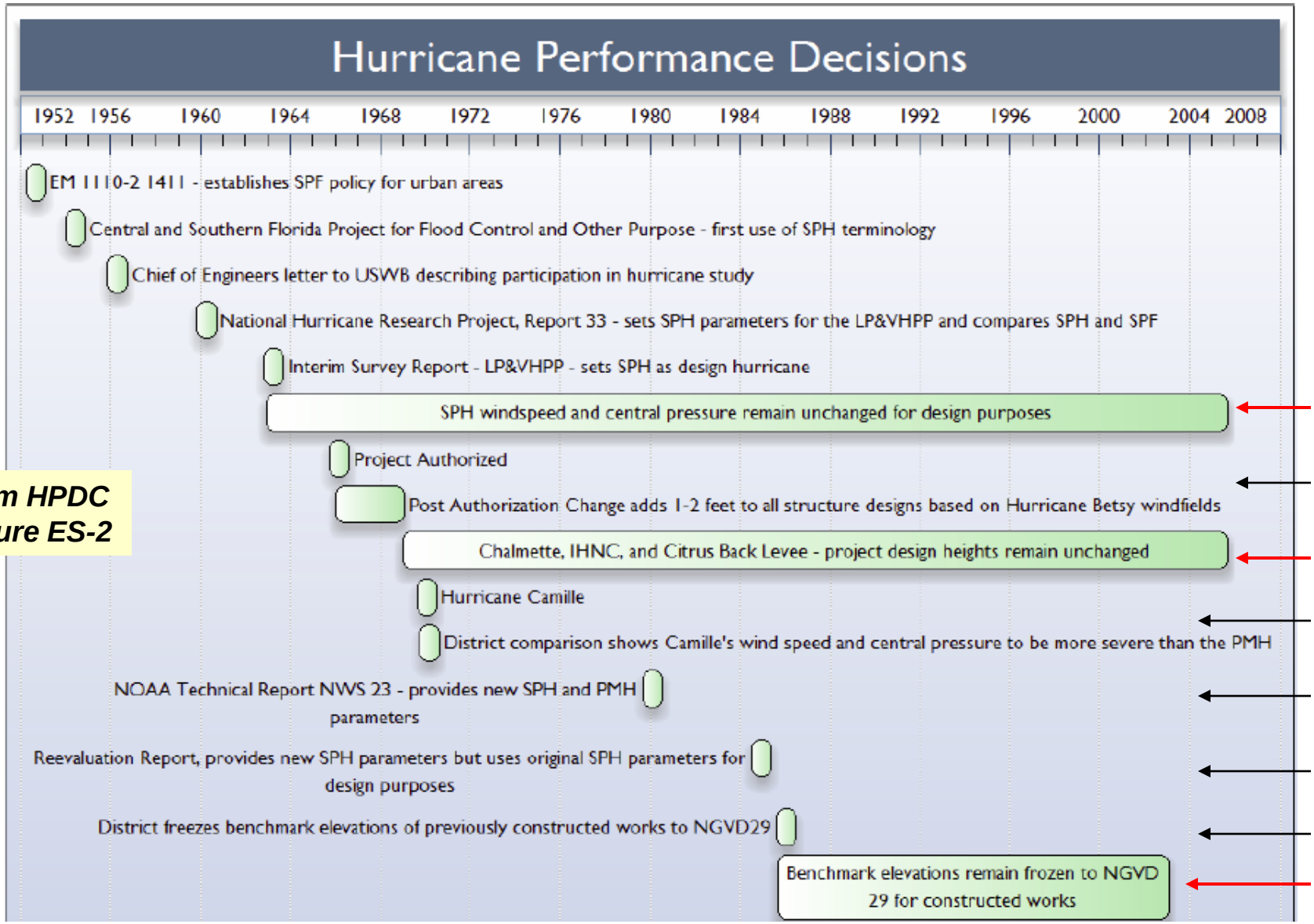
17th Street Canal Breach

- Deflection of I–wall by surge/waves
- Full hydrostatic pressure along wall splits levee into two blocks
- Weak clay below peat fails allowing protected half of levee to displace

Displacement of wall and part of levee

IPET Report, Vol. I, Figure 20

Hurricane Performance Decisions Over Time



from HPDC Figure ES-2