PFHA Panel Discussion on Gaps and Challenges

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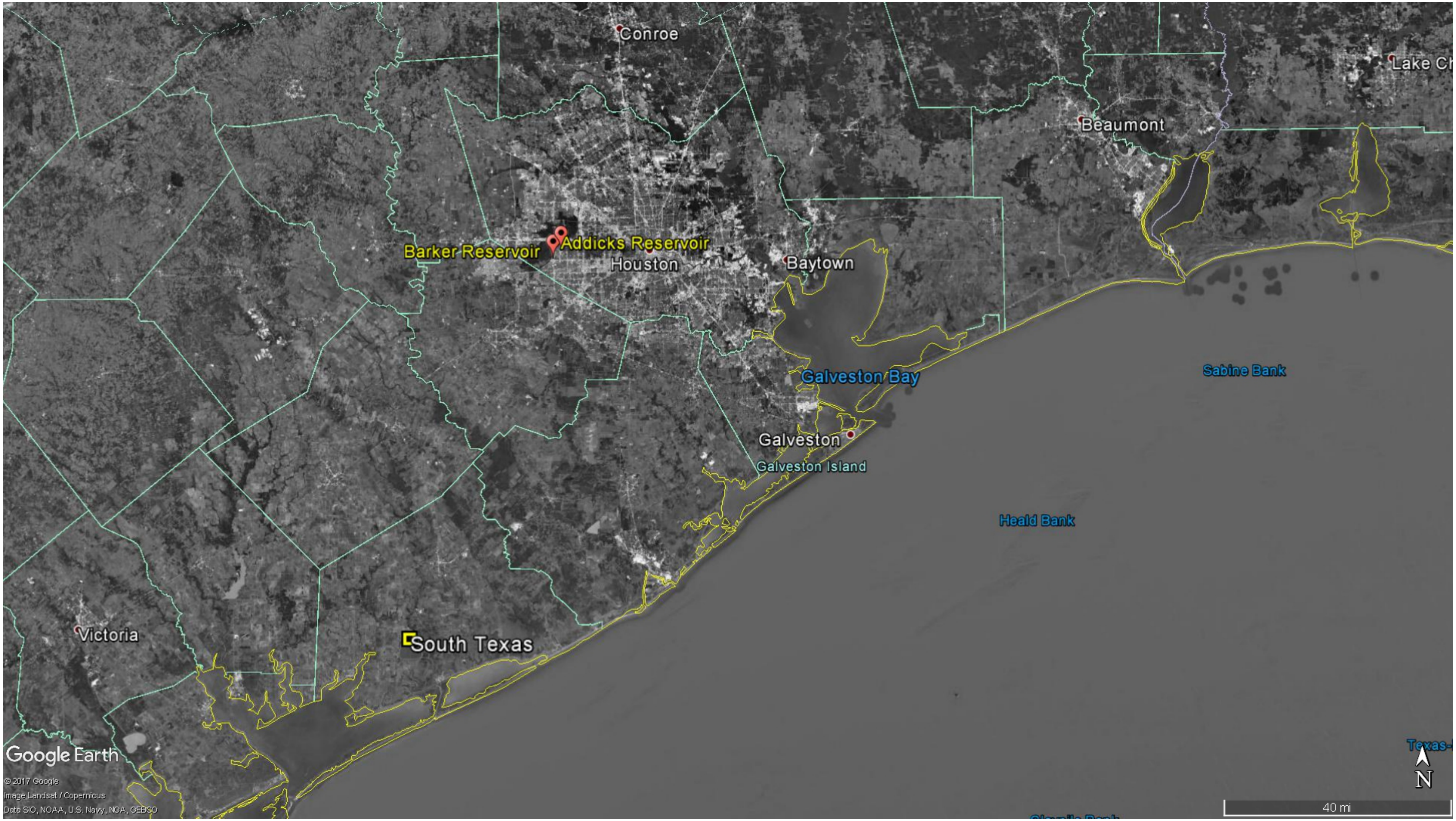
Office of New Reactors

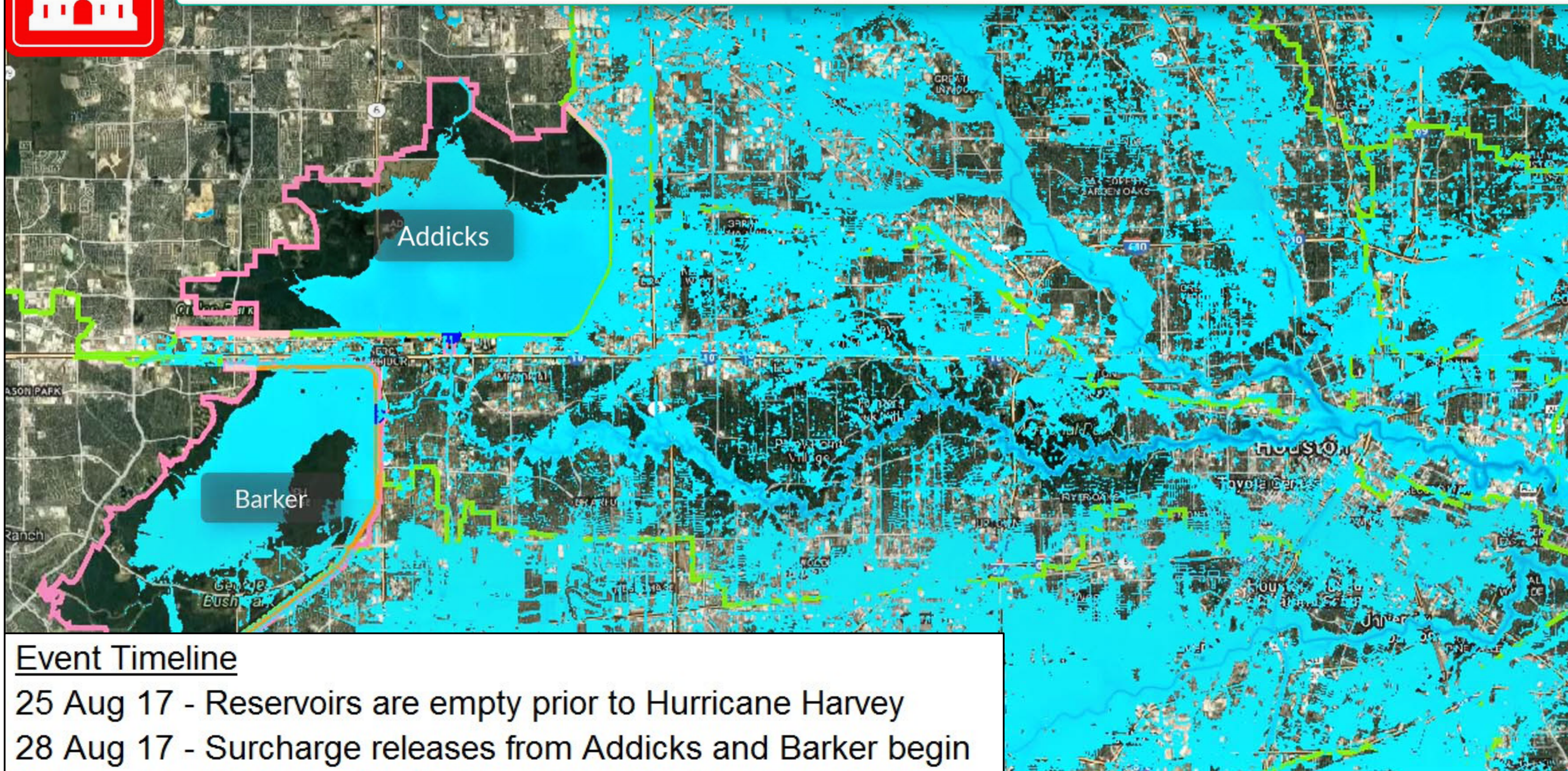
New Considerations:
Presentation of Results at Site

- Future is certain:
  - 2D hydraulic modeling and inundation mapping is a common technology for non-screened hazards.
  - There are multiple entities with capabilities to perform these rapid assessments.
  - Inundation maps are FEMA standard for communication of flood hazard information (warning time, inundation depth/duration, and recession time).
- Next section: Example from USACE & Hurricane Harvey
  - During a flood event, information gaps will be filled regardless of root cause
  - Info gaps will be filled by media outlets, emergency management agencies, other agencies.
  - Incident modeling & mapping can be done *by you*, *with you*, *for you* or *to you*.

Hurricane Harvey: 10-Day Forecast of Inundation from Barker and Addicks Dams



27 Aug 2017 - Hurricane Harvey Inundation



<u>Event Timeline</u>

25 Aug 17 - Reservoirs are empty prior to Hurricane Harvey
28 Aug 17 - Surcharge releases from Addicks and Barker begin
29 Aug 17 - Water begins flowing around north end of Addicks
29 Aug 17 - Releases increase from Addicks and Barker
30 Aug 17 - Addicks and Barker reach peak elevations
03 Sep 17 - Releases decrease from Barker
09 Sep 17 - Releases decrease from Addicks
15 Sep 17 - Surcharge releases end

Presentation released on Sept 4

Source: https://www.hcfcd.org/hurricane-harvey/flooding-impacts-in-connection-with-the-reservoirs/

Hurricane Harvey: VIDEO
Inundation Mapping of Barker and Addicks Dam

These inundation maps are provided by the United States Army Corps of Engineers Galveston District to assist communities to understand current operations at the Addicks and Barker Reservoirs.

Disclaimer

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PFHA Gap/Challenge #1

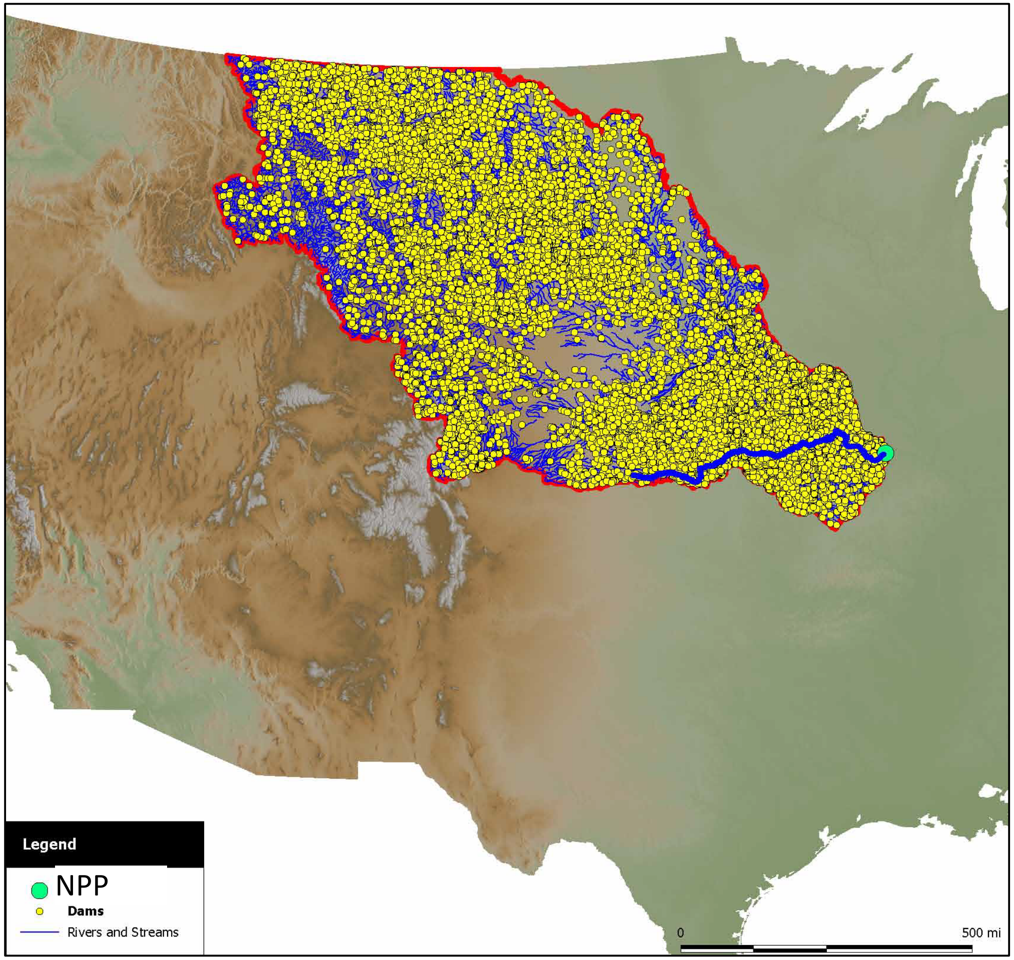
- Static vs dynamic flood hazard information
  - Previously, CDB was reported as a maximum elevation reported to 0.1 ft.
  - Going forward, flood hazards represented as dynamic inundation maps. These show progression of inundation and key associated effects (e.g., water velocity) over time.
  - How can dynamic inundation maps be used to feed PRA models?
  - What does the nuclear PRA community need and is it what the Civil Eng community is producing?

PFHA Gap/Challenge #2

BACKGROUND:

Guidance for screening of upstream dams developed as part of JLD-ISG-2013-01.

- **Figure**: 18,286 dams upstream. Eight of these have a height greater than 250 ft with a max of 491 ft.
- **Figure**: within 500 miles of one NPP (straight line) there are 5,616 dams with a height equal to or greater than 25 ft.



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PFHA Gaps and Challenge #2

- Enhanced Screening of Flood Mechanisms
  - LIP impacts every NPP site (e.g. rain falls on every site). Can it be screened?
  - Regardless, other flood mechanisms can safely be screened given site conditions.
  - Active topic in the PRA Standard-Part 8 (flooding) update group.
  - What guidance should be updated or included in SRP updates and related documents?

External Flooding PRAs: Steps to Support Regulatory Success

NRC Probabilistic Flood Hazard Assessment Workshop

December 5, 2017

Regulatory Application of External Flooding PRAs

- To date, external flooding has generally been addressed in risk informed licensing actions by using bounding assessments
  - Sufficiently supports decision making needs for vast majority of licensing actions
  - Provides assurance that risk estimates are bounded
- While full External Flooding PRAs can provide more realistic treatment, the methods must be sufficiently developed to support this realism

Fire PRA Lessons Learned

- Modern Fire PRA process developed and piloted in 2005-2008 timeframe
  - Piloting process was piecemeal
  - Framework for Fire PRA development was sound, but individual components retained substantial conservatisms
  - Net effect of individual conservatisms resulted in large, unrealistic results
- Regulatory application of Fire PRAs began prior to addressing issues revealed in pilot process, or full understanding of scope and scale of issues
  - Led to inability to support robust decision making process

Key Sources of Conservatism to Address Prior to Widespread Regulatory Application

- Lack of information regarding initiating event frequencies for the ranges of interest in external flooding PRAs
- Physical behavior of flooding phenomena for extreme events
- Treatment of dam failures, including combinations
- Consideration of warning time for some hazards
- Fragility of SSCs during flooding event

How Do We Know We Are Ready?

- Completion of pilot process
  - More than one pilot, addressing all aspects of External Flooding PRA
  - Ability of framework to support development of realistic results in a variety of scenarios
- Alignment of results with operating experience
  - Review accident sequence precursors and compare External Flooding PRA results
  - Comparison of relative risk from other hazards

ELECTRIC POWER RESEARCH INSTITUTE

External Flooding Probabilistic Risk Assessment

Perspectives on Gaps and Challenges

John E. Weglian
Senior Technical Leader

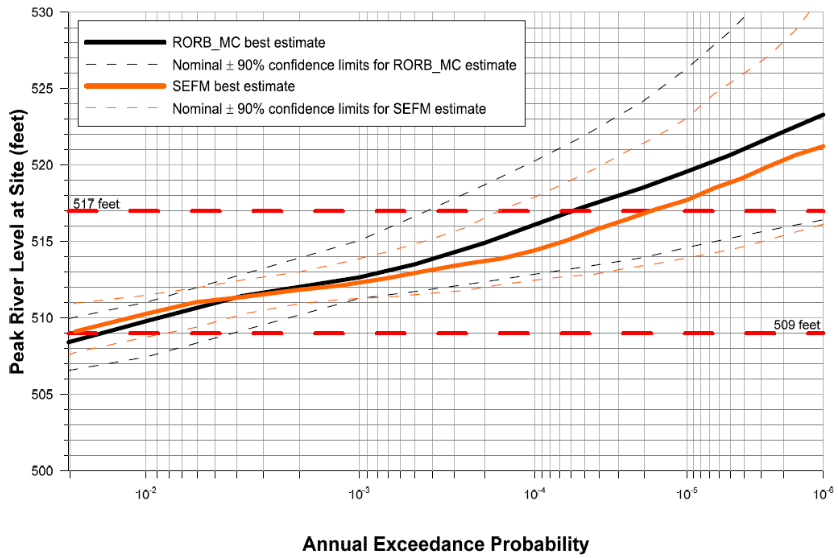
3rd NRC External Flooding Research Workshop
December 4-5, 2017

External Flooding PRA

- Recall, an External Flooding PRA (XFPRA) relies on a number of parts
  - Determine the applicable external flooding hazards to the site
  - Determine the flood parameters for each applicable flood mechanism
  - Develop a flood hazard curve to determine the frequency of the flood parameters
  - Create one or more scenarios that describe relevant portions of the flood hazard curve for each hazard
  - Evaluate the plant response for each scenario with a PRA model and quantify risks associated with each scenario
- So, what gaps and challenges can be found in these steps?

Uncertainty

- Wide uncertainties exist when estimating very low hazard frequencies
  - Paleo data may be helpful in reducing the uncertainty, especially in the 10^{-2}/yr to 10^{-4}/yr range
  - Uncertainties below 10^{-4}/yr will still be large



- Uncertainty combined with cliff-edge effects has the potential to hide significant risk
  - Sensitivity studies can be used to determine if the model results are sensitive to particular aspects of the model, including cliff-edge effects
  - Careful use of scenarios can be used to ensure cliff-edge effects are considered

Hazard Assessment – Dam Failure

- Most dams of interest are regulated by the U.S. Army Corps of Engineers, FERC, or the Bureau of Reclamation
- Up to now, utilities have requested deterministic information from the regulator via the NRC
- Performing a risk assessment for dams not under the control of the utility is challenging
  - The relevant information is not available
  - The government agencies that regulate dams have an agreement that only they will assess the risk of their dams
- A PRA is not treated as security-related information and any risk information from a dam regulator needs to be provided in a form that isn't tightly controlled
- Potential Solution: partnership with NRC and dam regulators to decide what data can be shared, how to generate it, and how to share it

Human Reliability Analysis (HRA) for XFPRA

- We have an existing framework for HRA for external events, and, in general, this can be applied to external flooding
- External flooding has specific challenges that still need to be addressed (e.g., for actions that take place prior to the arrival of the floodwaters during the warning time)
  - How is the decision made to initiate actions to prepare for the flood (e.g., are the cues subject to interpretation)?
  - What are the failure modes involved in performing the actions (e.g., what are the failure modes of building a sandbag wall)?
  - Under what conditions would Operations not allow personnel to work outside due to personal safety concerns?
- Need to collect operating experience to inform our methods and identify gaps
- Need to understand how the HRA picture might change with correlated hazards (e.g., concurrent high winds and flooding)

Together…Shaping the Future of Electricity

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External Flood Risk Analysis -- From Probabilistic to Computational Risk Assessment

Zhegang Ma, Ph.D., P.E.

3rd Annual NRC PFHA Research Workshop
Washington DC, December 4-5, 2017

Idaho National Laboratory

External Flood Risk Analysis – the Need

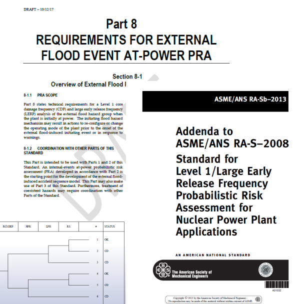
- External flooding risks are real and could be significant
  - Interrupt offsite power
  - Threaten plant structures and mitigating components
  - Limit plant access
  - Potential for either safety or economic impacts

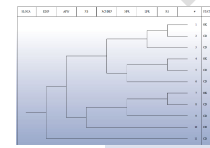
- External flood risk analysis could be used to
  - Identify plant flood vulnerabilities
  - Provide inputs to risk-informed decision making
  - Evaluate event/condition significance

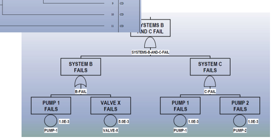
  AND
  - Protect Public Health and Safety

External Flood Risk Analysis – What We Have and What are Challenges

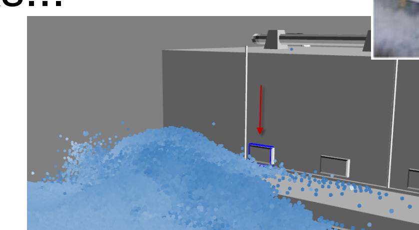
- What Do We Have?
  - Revised ASME/ANS external flooding PRA standard
  - Existing PRA methodologies (classical ET/FT but adequate)
  - Existing PRA models (internal event, internal flooding...)





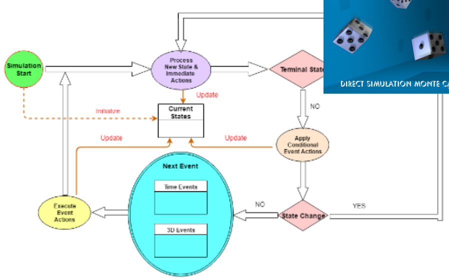


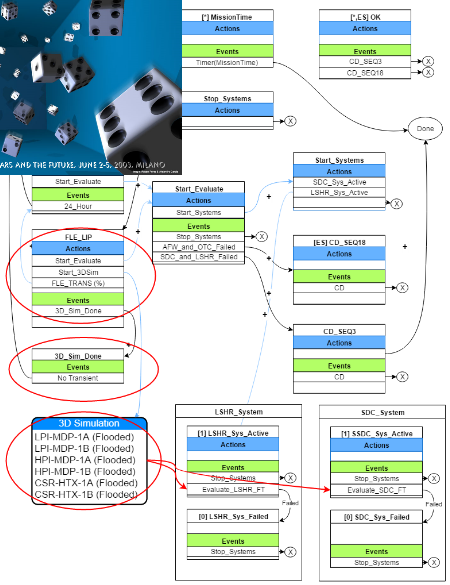
- What are Challenges?
  - Hazard analysis: IE frequency, concurrent hazards...
  - Fragility analysis: component failure probabilities with different flood height
  - Plant response modeling:
    - Spatial: location, location, location...
    - Temporal: sequence/human action are time-dependent...
    - Mechanics: flooding effect, multi-physics phenomena...
    - Topology: multi-state vs yes/no, causal links...



External Flood Risk Analysis – From Probabilistic to Computational

- Advancing Probabilistic RA to Computational RA
  - Improve state-of-art PRA model from classic ET/FT model to integrated simulation-based dynamic PRA (or CRA)
  - Enhanced computation capabilities
  - Static -> Dynamic: by adding time element into PRA explicitly
  - Integrated PRA: through simulations
    - Monte Carlo simulation
    - 3-D physical simulations
    - Mechanical simulations

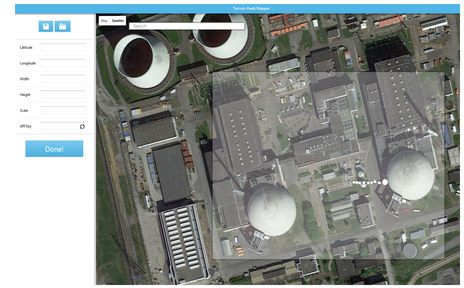




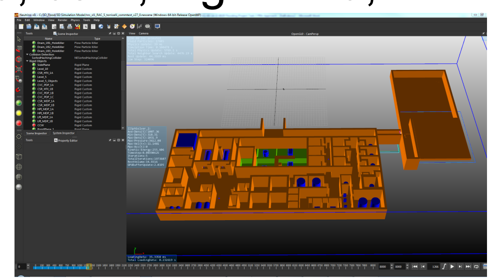
- Potential Roles
  - Stand along analysis tool
  - Supplemental role to support traditional approach

External Flood Risk Analysis – the Path Forward

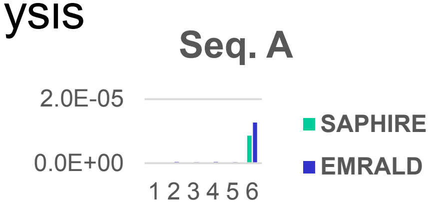
- Challenges
  - Methodologies (site simulation, 3-D flood simulation, “smart” Monte Carlo simulation for extremely low probability...)
  - Resource (3-D plant modeling and beyond)
  - Uncertainties



- The Road
  - NRC project: local intense precipitation case study
  - DOE/RISMC projects: case studies on external flood, dam, high wind, seismic hazards



  - Selected scenarios -> full PRA model
  - Other external flood mechanisms
  - Concurrent external hazards
  - Able to address multi-unit risks in one integrated analysis



Perspectives on External Flooding Probabilistic Risk Assessment: Gaps and Challenges

Risk Analyst Perspective

Ray Schneider

Fellow

Westinghouse Electric Company

NRC 3rd Annual Flood Workshop (2017)

Westinghouse

Considerations for Constructing an External Flood PRA

- Characterizing the Initiating Event
- Fragility of Flood Protection SSCs/Barriers
- Treatment of Preventive actions and organizational behaviors
- Characterizing the Plant Initial State

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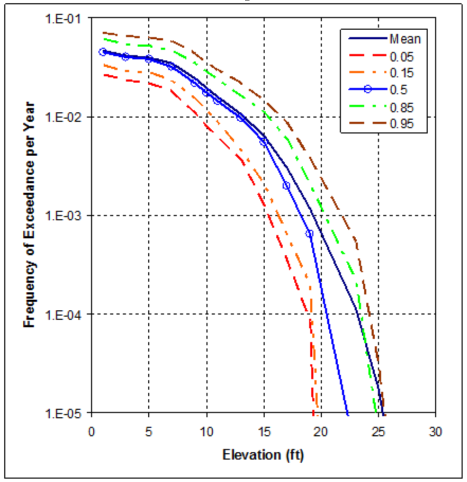
Characterizing the Initiating Event

- A single flood hazard curve may mask PRA important parameters

- Flood Hazard Curve is typically considered a singular relationship relating the frequency of exceedance per year that a site can experience a flood > height/elevation, H.



- Hazard Curve is reasonable simplification for design applications but reflect only one dimension of the cumulative impact of multiple similar but independent hazards if they occur

- Lacks information needed to develop an external flood PRA and to evaluate associated hazard risks

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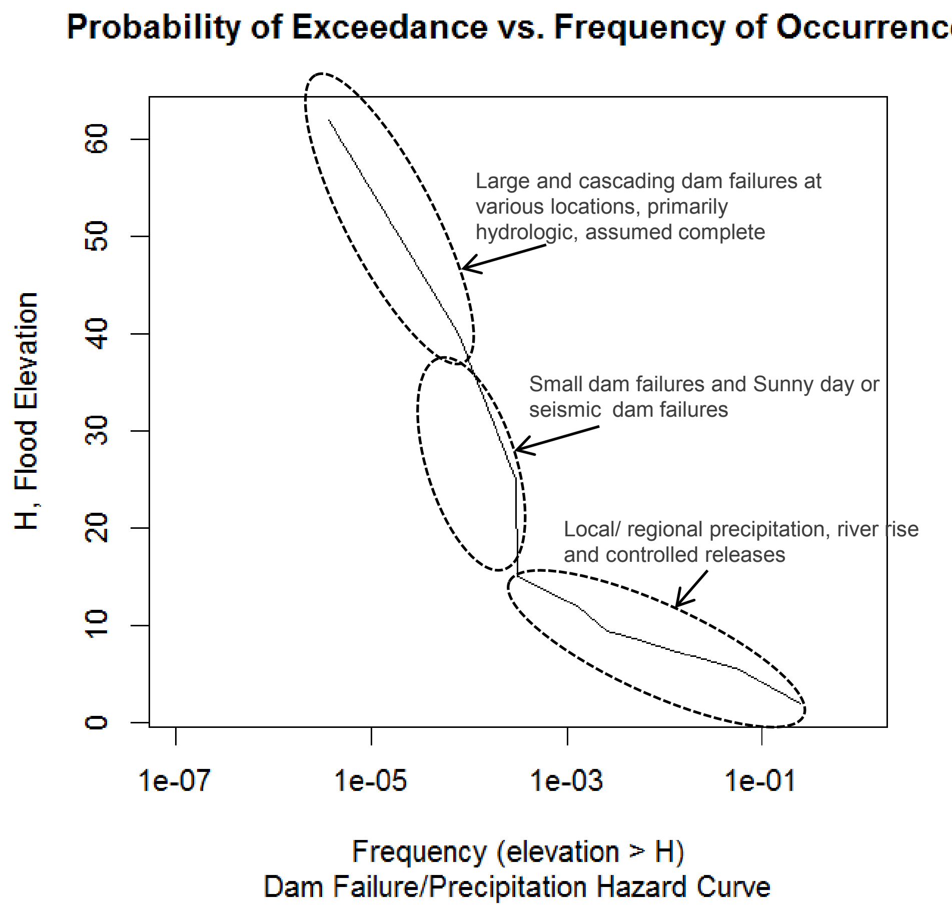
Combined Dam Failure / Precipitation Hazard Curve Developed from Multiple Related Mechanisms

Single curve masks impact of :

- Presence of Pre-Existing Flood Challenges
- Warning Time
- Coexistent Hazards



Need for Disaggregated curves can capture the key characteristics of the hazard event

Impact of Co-existent/correlated Hazards:

- Flood elevation may be impacted by wind induced wave “run-up”;
  - Wind effects may impact human performance.
  - Elevation / run-up effect typically not significant unless associated with hurricane type winds or hazard has cliff edge in vicinity of still water levels.
- Seismic dam failures can have accompanying seismic impact at site:
  - Limit access paths.
  - May impact communication.
  - Reduce equipment availability.
  - Local/on site impact can create distractions.
  - Potential floodwater ingression into structures through damaged penetrations, structural deformations, etc.

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Fragility of Flood Protection SSCs

Fragility understanding generally limited to operating equipment and traditional structures

Flood Risk may be dependent on failure/degradation/leakage of atypically analyzed items (e.g.):

- Penetration seals
- Temporary walls/barriers (inflatable barriers, sand bag walls,etc.) (Quality of barrier installation)
- Small portable, commercial equipment (e.g., sump pumps)
- Seismically induced structural degradation (cracks) (?)

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Treatment of Preventive actions and organizational behaviors

Traditional treatment of trained human actions focus on procedural responses with defined cues in an anticipated environment

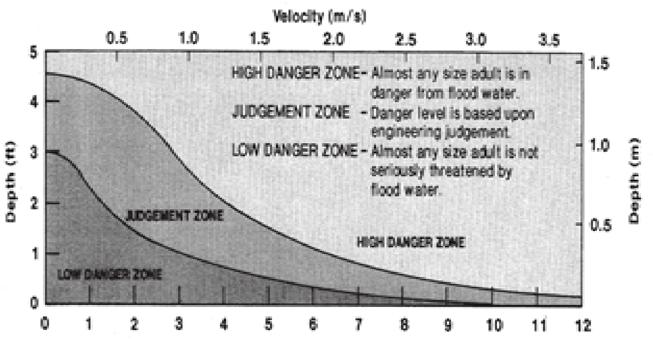
Plant flood responses can include:

- Organizationally driven flood actions with uncertain trigger points and uncertain resource loads, uncertain flood levels, etc.

- Potential for flood induced "cliff edge" dominated actions

- Consideration of actions within complex environments and unique personnel hazards

- Overall actions that look more like complex PERT diagrams resulting with multiple varying probability end states



Considerations in Characterizing the Plant Initial State

Typical plant PRAs occur with a single plant state and defined plant condition. Success is establishing a defined safe shutdown condition.

Initial plant state is known prior to external flood but, flood may dictate alternate shutdown/operational states

- Success of actions to shutdown and re-configure plant for hazard not guaranteed. Leads to multiple shutdown states with differing degrees of flood protection and possible recovery actions
- Duration considerations may complicate definition of mission time.
  - Time to shutdown and re-configure?
  - Time for flood to recede from site
  - Something else?
- Multi-Unit considerations generally apply

Adds complexity and may require additional guidance

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Questions?

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External Flooding PRA: Looking to the Future*

N. Siu
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission

Panel Discussion:
Integrating Flooding Hazard Information Into NPP PRAs

3rd Annual NRC Probabilistic Flood Hazard Assessment (PFHA) Research Workshop
Rockville, MD; December 4-5, 2017

*The views expressed in this presentation are not necessarily those of the U.S. Nuclear Regulatory Commission

Some Technical Challenges

- Discussed
  - Different approaches for spectrum of contributors
    - "Unlikely confluence of likely events"
    - Mega-events
  - Searching for problem scenarios
  - Mechanistic analysis
    - Human and organizational behavior
    - Dynamics
      - Long-term changes in hazard
      - Macro-scenario (warning, plant response, hazard buildup, …)
      - On-site effects (2D time series for elevation)
    - Additional hazards (beyond inundation, beyond flooding)
- In addition…
  - Improved screening
  - Multi-unit, multi-site

An Improving Situation

- Recognition of potential importance
  - "Other" external hazards => full attention
  - PRA standard update
- Broad interest
  - Multiple agencies, international working groups (e.g., OECD/NEA/CSNI Working Group on External Events)
  - Potentially useful methods, models, tools, data, solutions
- Computational technology
  - Scientific simulations including uncertainty: natural language for multidisciplinary analysis, addressing dependencies
  - Knowledge engineering

Cautions/Reminders

- R&D prioritization considerations
  - Need to be purposeful (limited resources) vs. the “Easy Button”
  - Precision of entire risk assessment
  - Balanced use of video
- Limitations of “repurposed” analyses
- PRA uncertainty analysis amplifies typical simulation challenges
  - Input data validity (distributions, correlations)
  - Simulation validity for combinations of parameters
  - Extracting meaning from massive output
  - Treatment of model uncertainty
- “Risk” includes qualitative as well as quantitative information