Potential Impact of Climate Change on Rare Precipitation

Jan 6, 2014
Geoff Bonnin
National Weather Service
Office of Hydrologic Development

Topics

- Approaches to Hydrologic Design
- National Research Council Concern
- The Semantic Problem
  - Climate community semantics
  - Engineering community semantics
- Trends in Exceedances
  - From an engineering point of view

Approaches to Hydrologic Design

1 Generally too costly to avoid failure always
- Therefore accept chance of failure based on situation
  - *Flood Frequency Estimate*: Peak discharge associated with annual exceedance probability
  - *Precipitation Frequency Estimate*: Precipitation depth or intensity associated with annual exceedance probability <u>for a given duration</u>

1 Sometimes we must avoid failure always
- *Probable Maximum Precipitation*: worst case "perfect storm"
  - Unknown probability

National Research Council Concern

"Management and mission-oriented agencies with public-sector responsibilities have been provided with marginally useful scientific information about the likely manifestations of future climate change."

"There are insufficient interactions and knowledge exchange between climate scientists, water scientists, and engineers and practitioners to solve these challenges."

"Global Change and Extreme Hydrology: Testing Conventional Wisdom"
National Research Council, Water Science and Technology Board, 2011

Climatology Semantics

- "It is likely that the frequency of **heavy** precipitation events … has increased over most areas."

  IPCC AR4, Climate Change 2007: Synthesis Report

- "Groisman et al. (2005) found significant increases in the frequency of **heavy** and **very heavy** (between the 95th and 99.7th percentile of daily precipitation events)"

  IPCC AR4 Working Group I

- These and similar statements in the literature define terms such as
  - "**heavy**", "**very heavy**", and "**extreme**" precipitation
  - Sometimes differently!

For Example

- Groisman et al 2005
  - "… we define a daily precipitation event as **heavy** when it falls into the upper 10% and/or 5% of all precipitation events;

    as **very heavy** when it falls into the upper 1% and/or 0.3% of precipitation events;

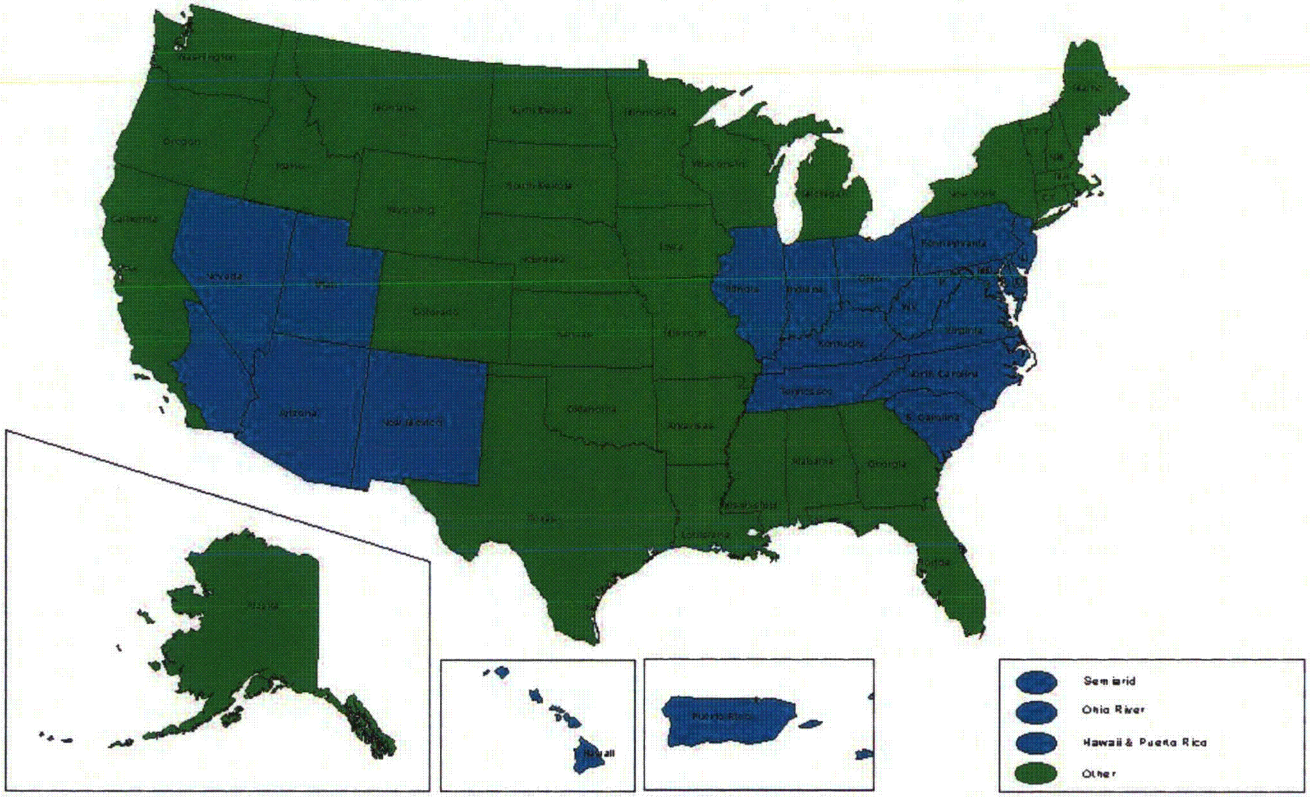
    and **extreme** when it falls into the upper 0.1% of all precipitation events."
  - "The return period for such events … varies, for example, from 3 to 5 yr for … **very heavy** precipitation events."

- Generally consider just daily durations

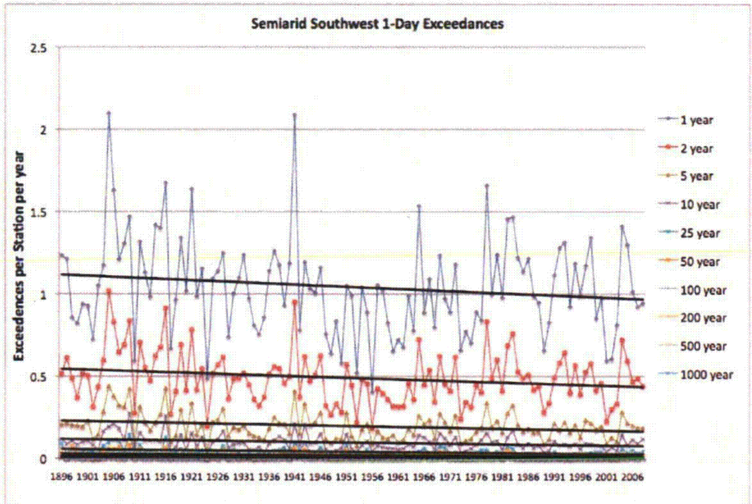
Civil Engineering Semantics

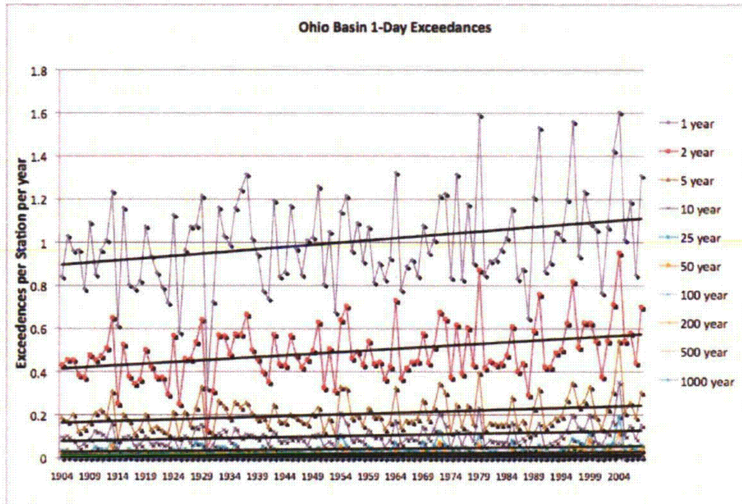
- Use precipitation frequency estimates
  - annual exceedance probability (AEP) or
  - average recurrence interval (ARI)
- Heavy, very heavy, and extreme rainfall:
  - are subjective terms
- Use many durations; not just daily
  - NOAA Atlas 14 provides 5 min through 60 days

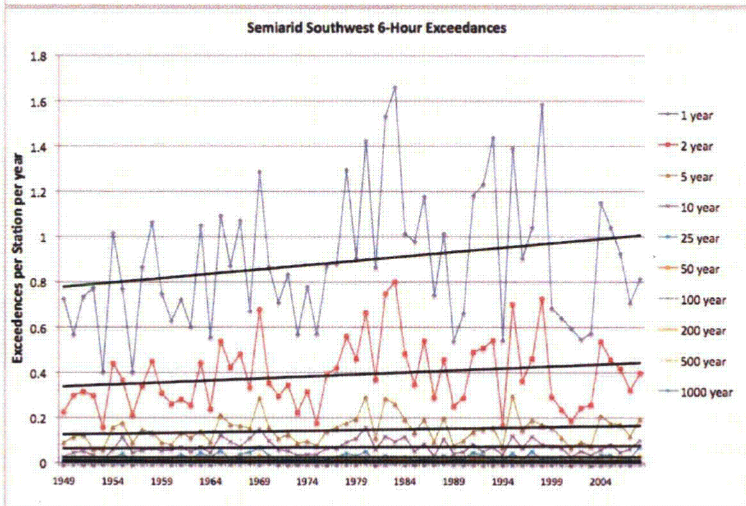
Trends in Exceedances Engineering Perspective

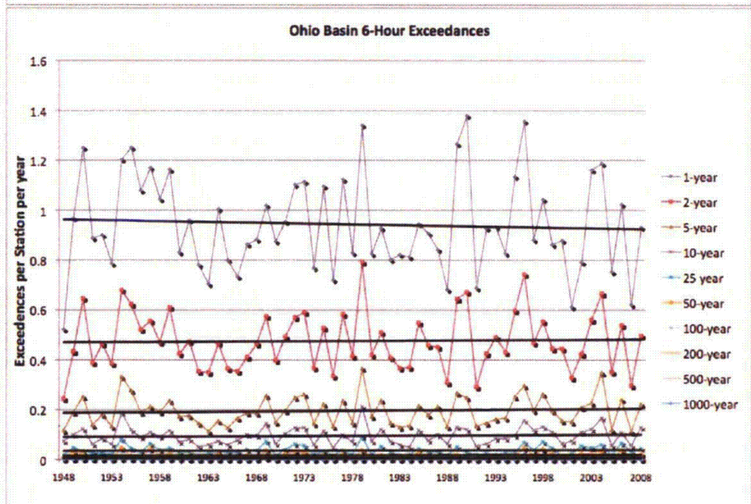


Example Trends in Exceedances







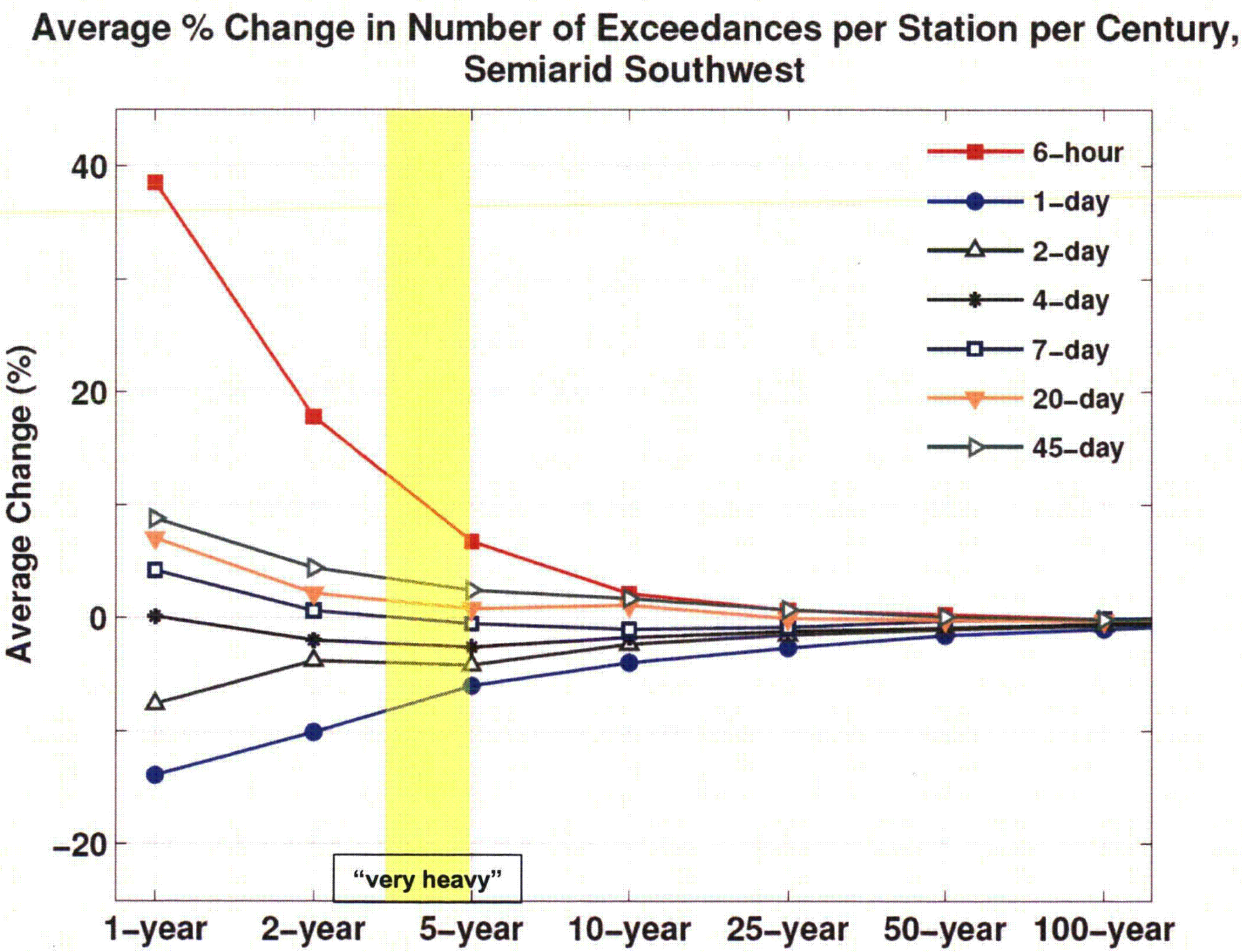


Trends in Exceedances

NA14, 90% confidence intervals

+/- 30% sparsely instrumented, shorter record; to

+/- 10% more densely instrumented, longer record



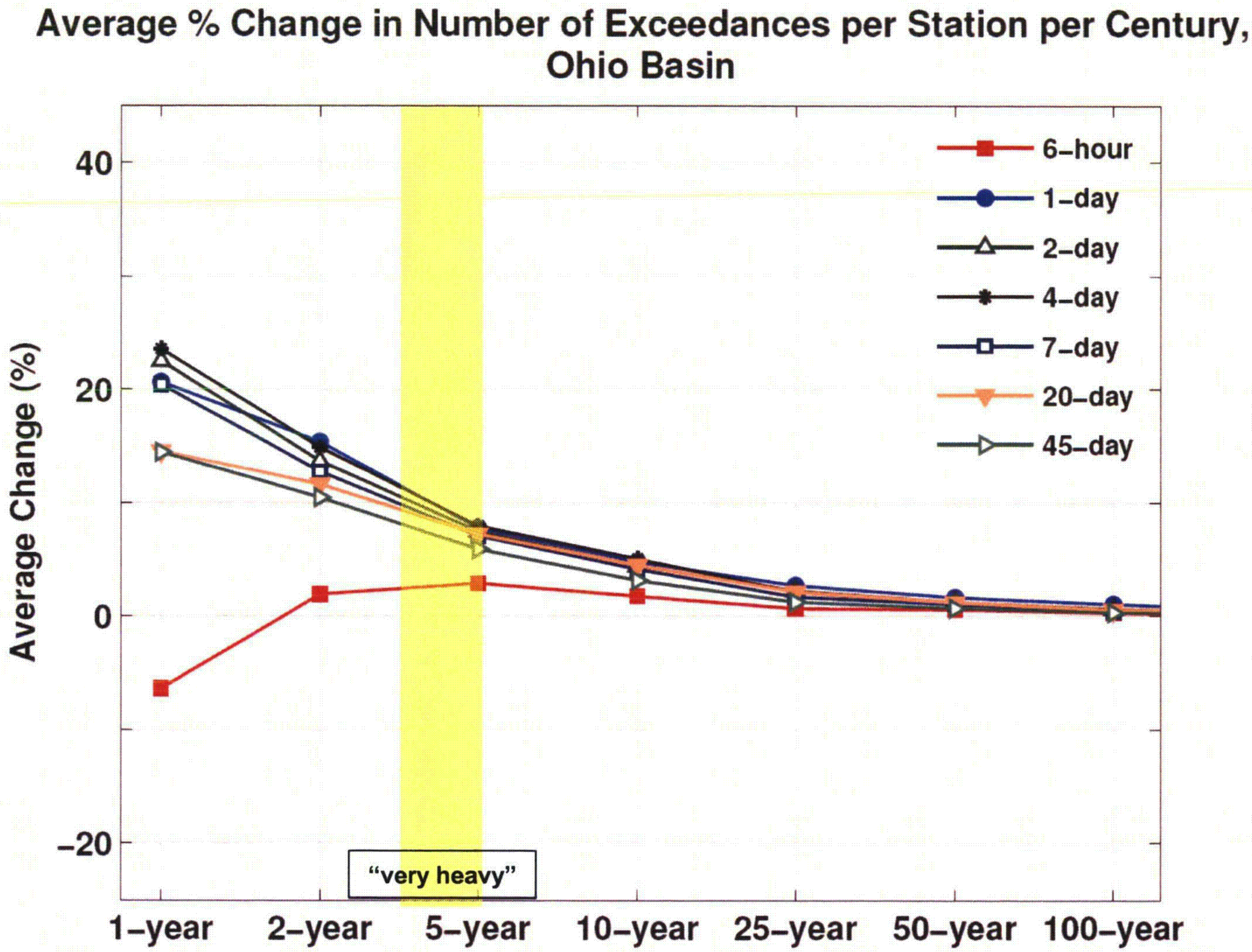
- Generally statistically significant except for 6 hour durations
  - *.05 level, T-test & Mann Kendall*

Trends in Exceedances (continued)

NA14, 90% confidence intervals

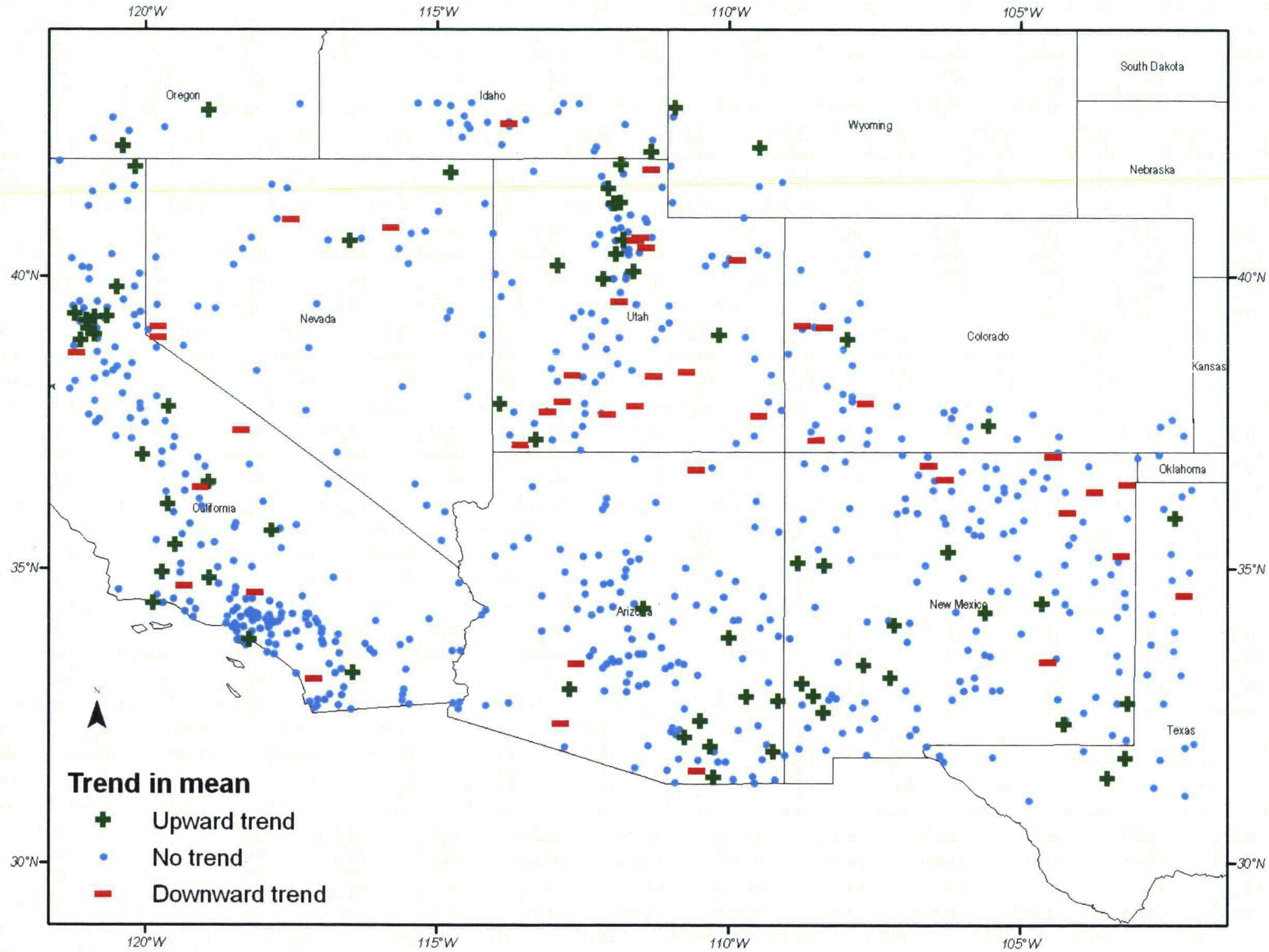
+/- 30% sparsely instrumented, shorter record; to

+/- 10% more densely instrumented, longer record

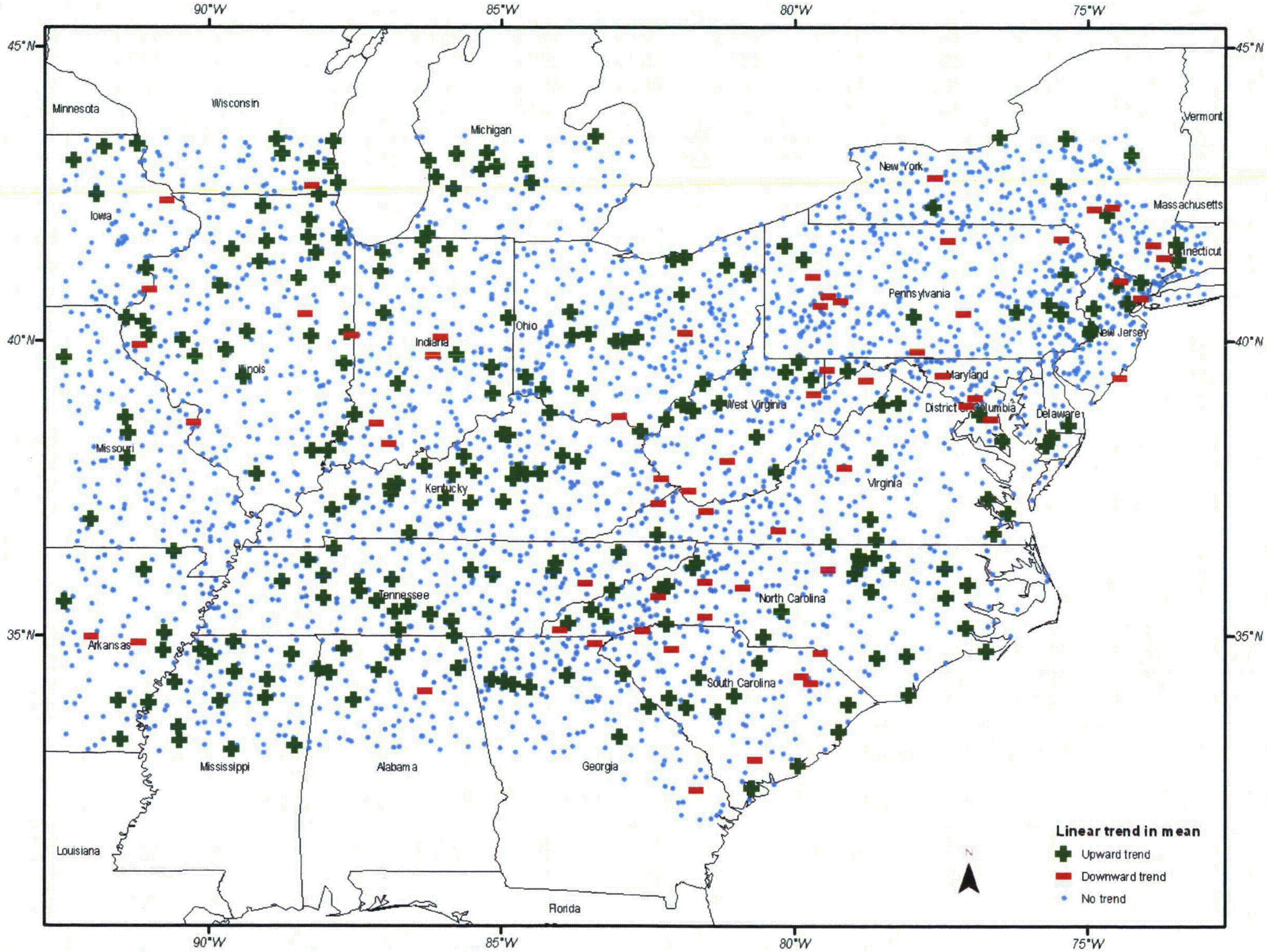


- Generally not statistically significant except for daily durations above 2 yr ARI
  - *.05 level, T-test & Mann Kendall*

Spatial Coherence of Trends in AMS Means



Spatial Coherence of Trends in AMS Means



Conclusions

- Climate community statements on trends in rainfall exceedances
  - *Do not address frequencies and durations required for civil infrastructure*
- Climate community statements are being misinterpreted
  - *by Civil Engineers and probably the public*
- Historical trends in exceedances
  - *Are small compared to uncertainty of IFD values*
- We need better guidance on potential impact of climate change on IFD curves
  - *In range relevant to civil infrastructure*

Discussion

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NRC Commission Meeting on Flooding and Other Extreme Weather

FLOODING

Presenter

Pacific Northwest
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Lance W Vail

- Senior Research Engineer
- Hydrology Group
- Pacific Northwest National Laboratory (33 years)
- Richland, Washington

Research Focus

- Water and Energy Nexus
- Water Resource Systems
- Advanced Hydrologic Models
- Climate Impacts on Water Resources

Projects

- Department of Energy
- Environmental Protection Agency
- NOAA
- NASA
- Nuclear Regulatory Commission

Yakima River

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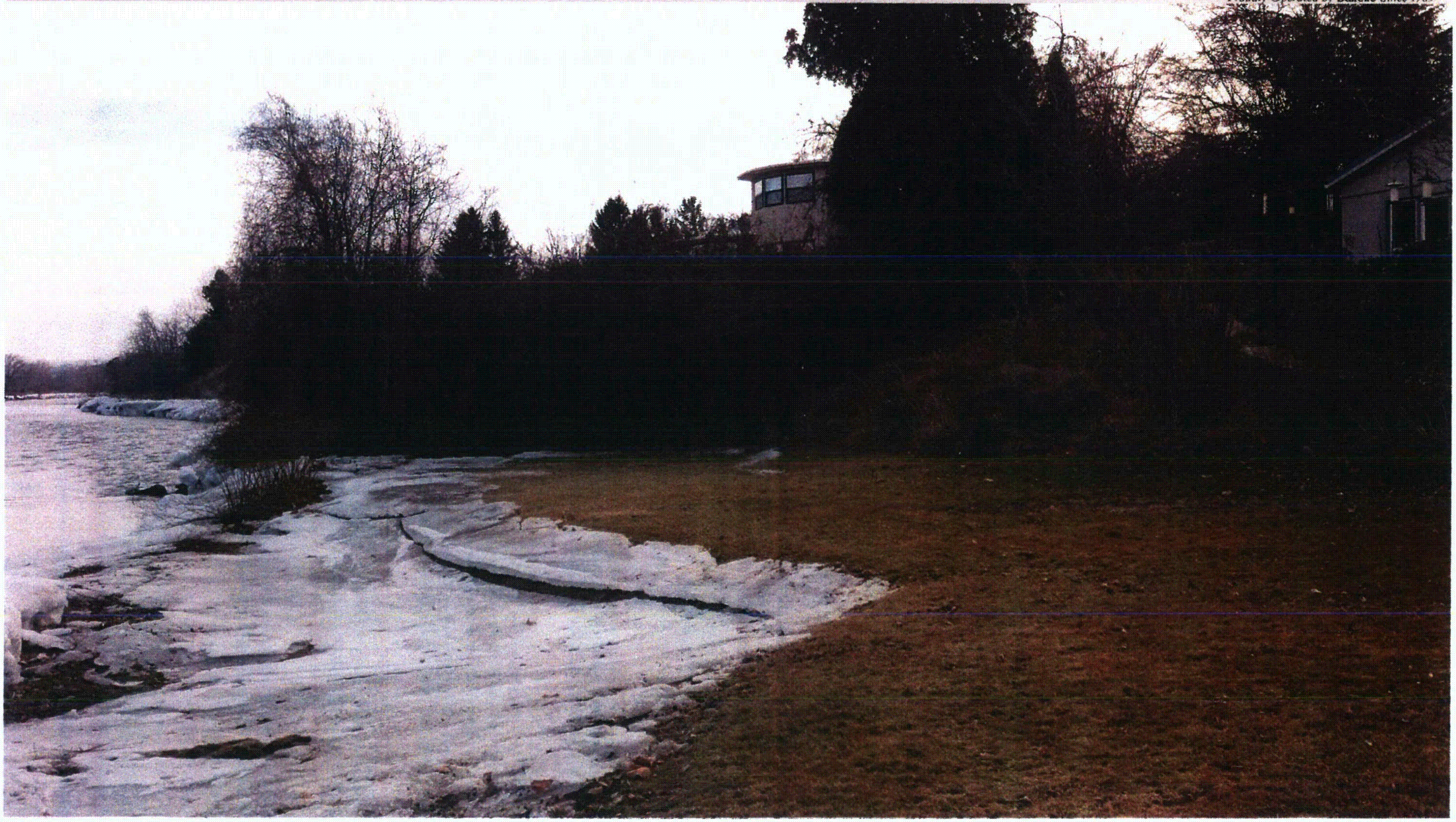

Presentation Outline

- Lessons Learned
- Flooding (Tale of Tails)
- Flooding with Climate Change (Tale of Moving Tails)
- Extreme Floods
- Probable Maximum Precipitation
- Sea Level Rise and Coastal Flooding
- Conclusions

Tails and Sigmas

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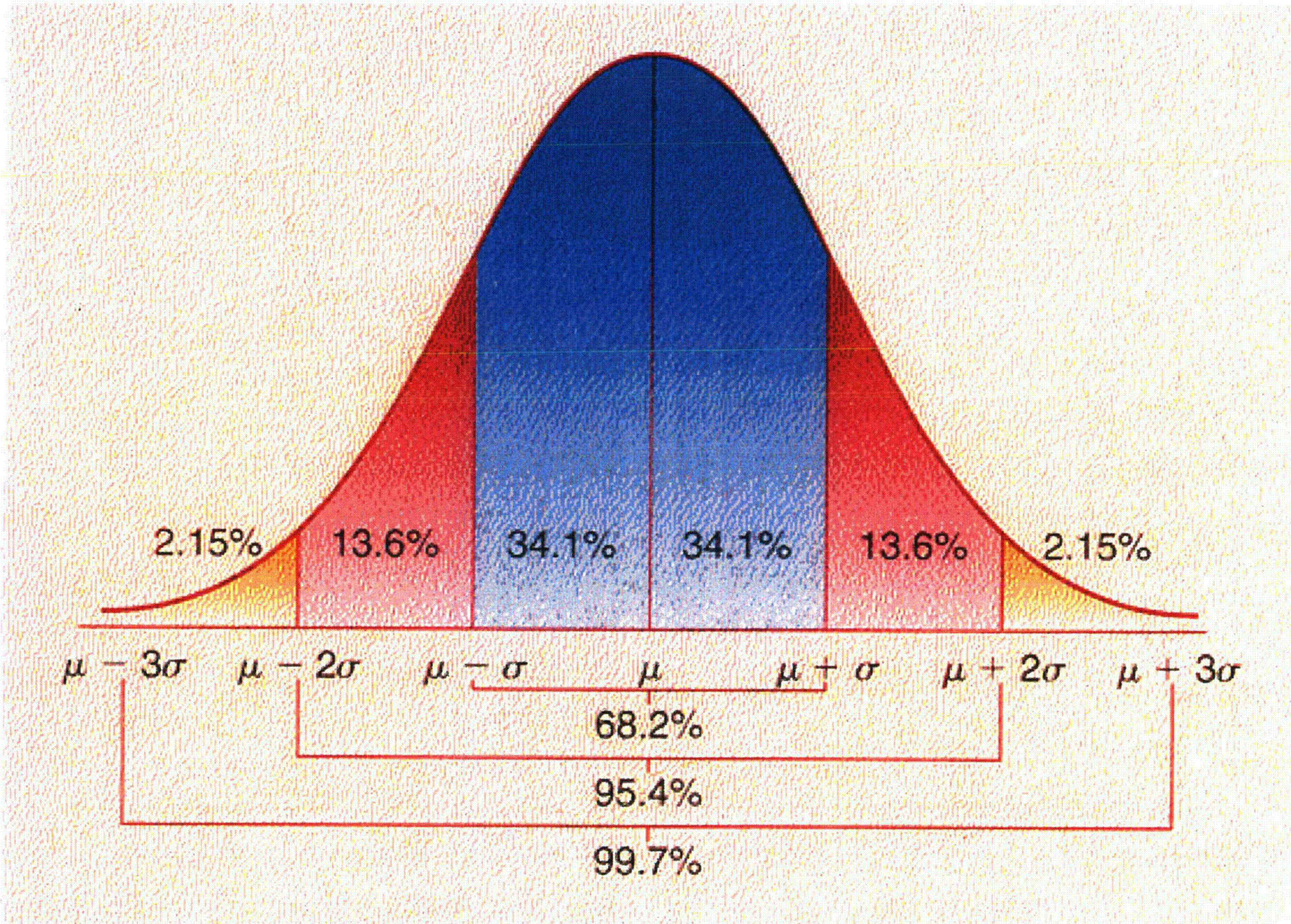

Lessons Learned
American River Watershed Climate Study

Pacific Northwest NATIONAL LABORATORY

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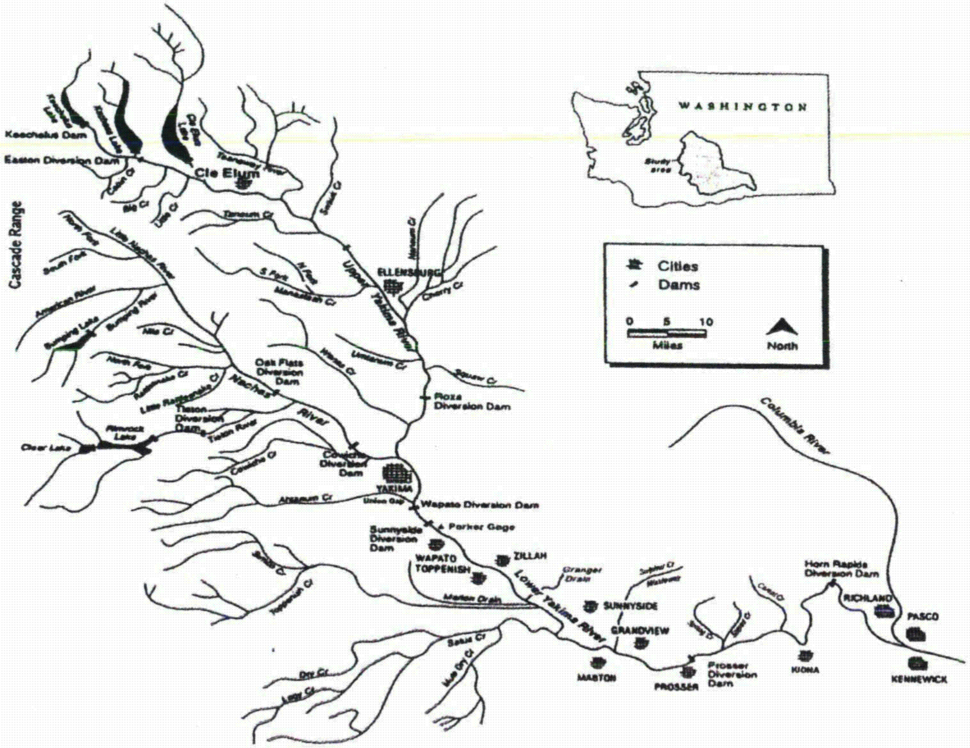
- Changes in tails are more meaningful than changes in means
- Tails (flood and drought) are meaningful
- Limited period of future records limits consideration of even 1-sigma levels
- Patterns in climate systems are crucial



Lessons Learned
EPA STAR Grant – Yakima Basin

- Address conceptual model uncertainty explicity
  - Climate change
  - Land use change
  - Water control infrastructure changes
  - Water use change
  - Hydrological and meteorological uncertainties
- Large ensemble simulation of multiple plausible conditions

Lessons Learned
Accelerated Climate Prediction Initiative

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- Bias correction needed to future meteorological record
- Relatively short period of climate simulations limits consideration extreme events of even 1-sigma level
- Forecasts can reduce impacts up to 1-sigma level

Lessons Learned
Flood Assessment Methodologies

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- Revisiting required
  - Bulletin 17B
    - "This generalized skew map was original prepared for Bulletin 17 published in 1976. It has not been revised utilizing the techniques recommended in Bulletin 17B"
  - HMRs (1970-2013)
- More data but fewer streamflow measurement stations
- Changes in land cover and water control infrastructure

Flooding
Tale of Tails

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- Floods
  - 5, 10, 20 year floods
  - 100 year floods
  - Probable Maximum Flood (PMF)
  - Paleofloods
- Hydrological statistics based on stable environment
- It is well established that climate "changes irregularly, for unknown reasons, on all timescales" National Research Council – 1991
  - El Nino Southern Oscillation (ENSO) 5 year
  - Pacific Decadal Oscillation (PDO) 20-30 year
  - North Atlantic Oscillation (NAO)
- Hurst phenomena (1951)

Flooding and Climate Change
Tale of Moving Tails

- Additional factors of uncertainty
  - Less representative record
  - Nonstationarity
  - Uncertainty in future
- Can extreme event hydrological statistics be adapted to consider climate changes?
  - Long-term climate modeling linked with hydrological simulation to generate long-term streamflow records to estimate extreme event probability
  - Classify historical large-scale climate patterns associated with historical extreme events and adapt frequency estimate based on large-scale climate patterns in climate models
  - Identify ‘new’ climate patterns

Extreme Floods

- Flood Frequency Analysis
  - Log-Pearson Type III
  - Skew and Outliers Issues
  - Empirical with Stationarity Assumption
- Probable Maximum Flood
  - Deterministic
  - Flood resulting from Probable Maximum Precipitation

Probable Maximum Precipitation

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- Definition
- Maximum?
  - Truncated Distribution
  - Physical Limits
- Deterministic Approach
- Hydrometeorological Reports (HMR 51 – 1978 ➔)
- Revising for climate change?

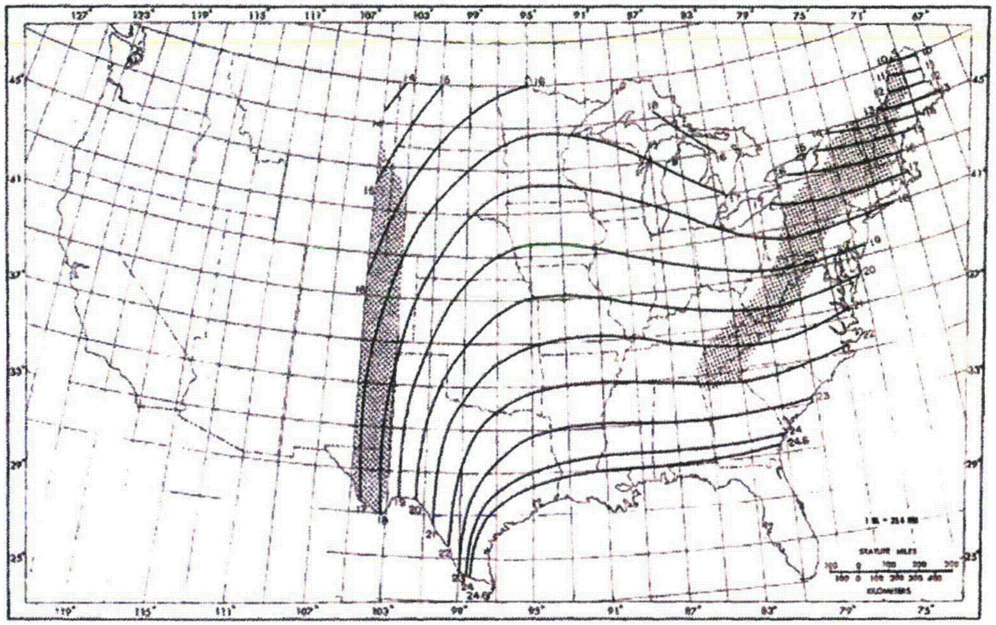
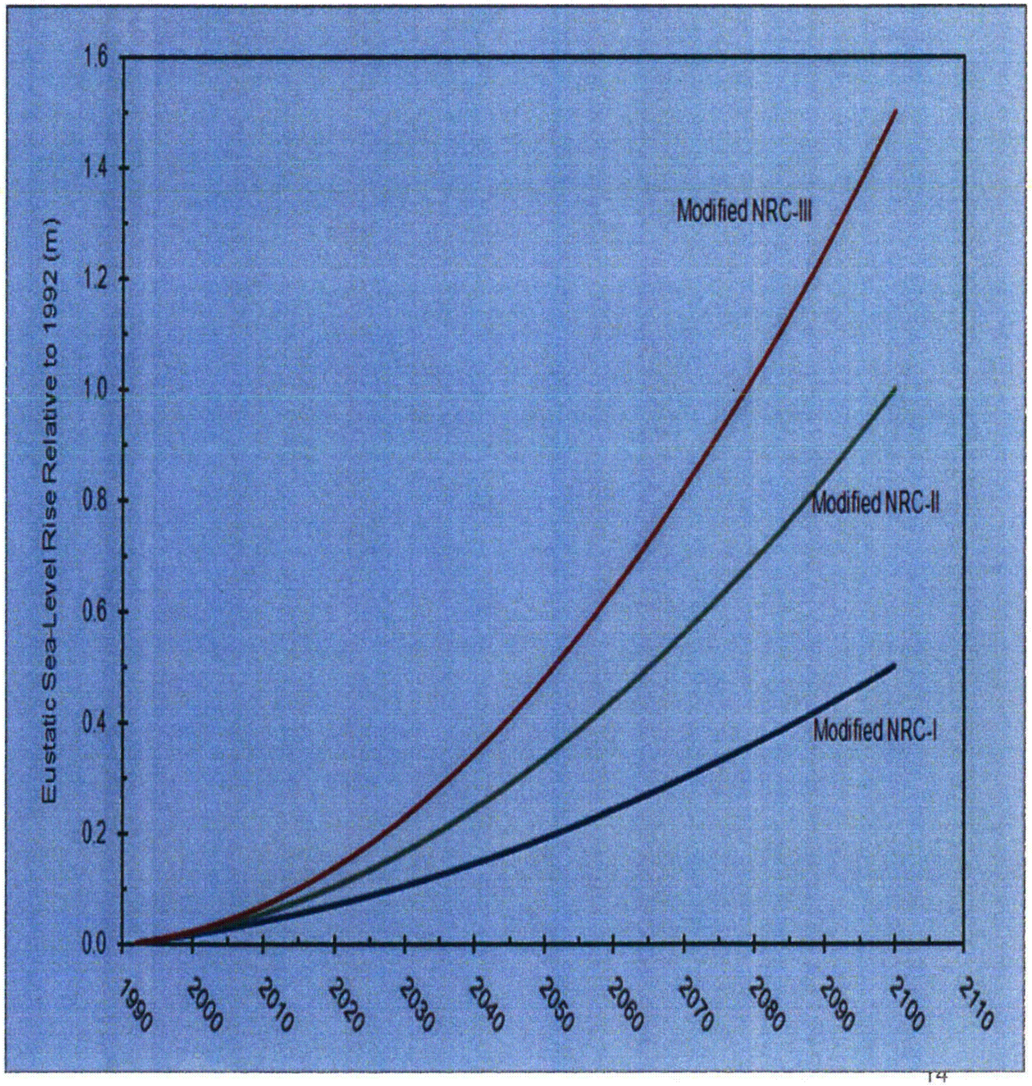


Figure 23.--All-season PMP (in.) for 6 hr 200 mi^2 (518 km^2).

Sea Level Rise

- "… it is reasonable to assume that a credible upper-bound for 21st century GMSL (global mean sea level) rise would be about 2 meters. This by no means suggests that 21st century GMSL rise cannot exceed 2 meters, but a maximum of 2 meters is reasonable at this time." Corps Circular 1165-2-212 (1 October 2011)



Conclusions

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- Embrace the Uncertainty
  - Probabilistic Flood Hazard Assessment
  - Future conditions uncertainty
  - Minimize future regrets
  - Increase adaptive capacity
- Trust but Verify Climate Projections
  - Continuous improvement in data and methods

Union of Concerned Scientists

Flooding Hazards

January 6, 2014

David Lochbaum
Director, Nuclear Safety Project
Union of Concerned Scientists
www.ucsusa.org

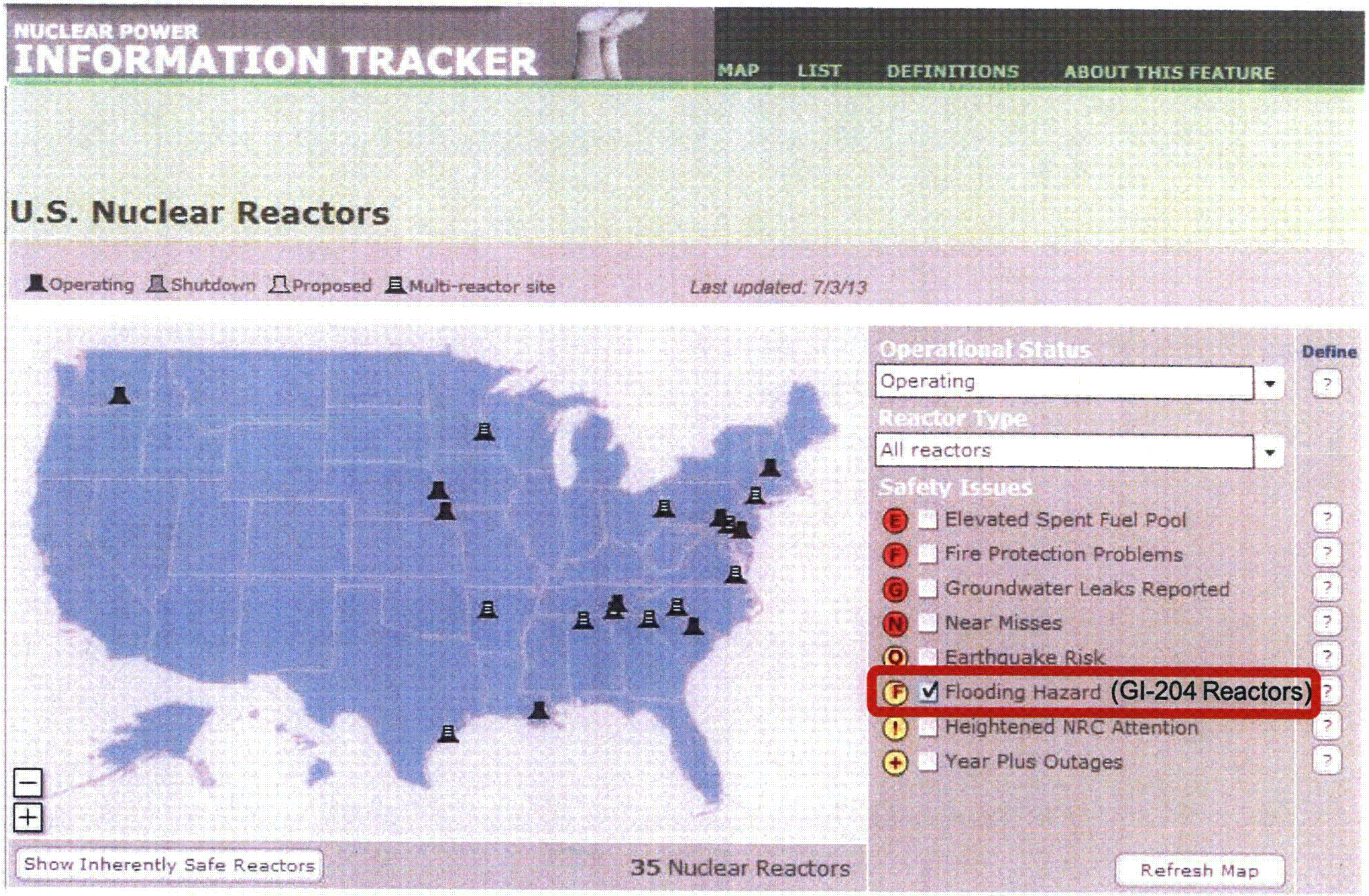
Issues

- Risk integration vs. isolation
- Cart before the horse
- Inconsistent oversight

Stellar Regulatory Performance

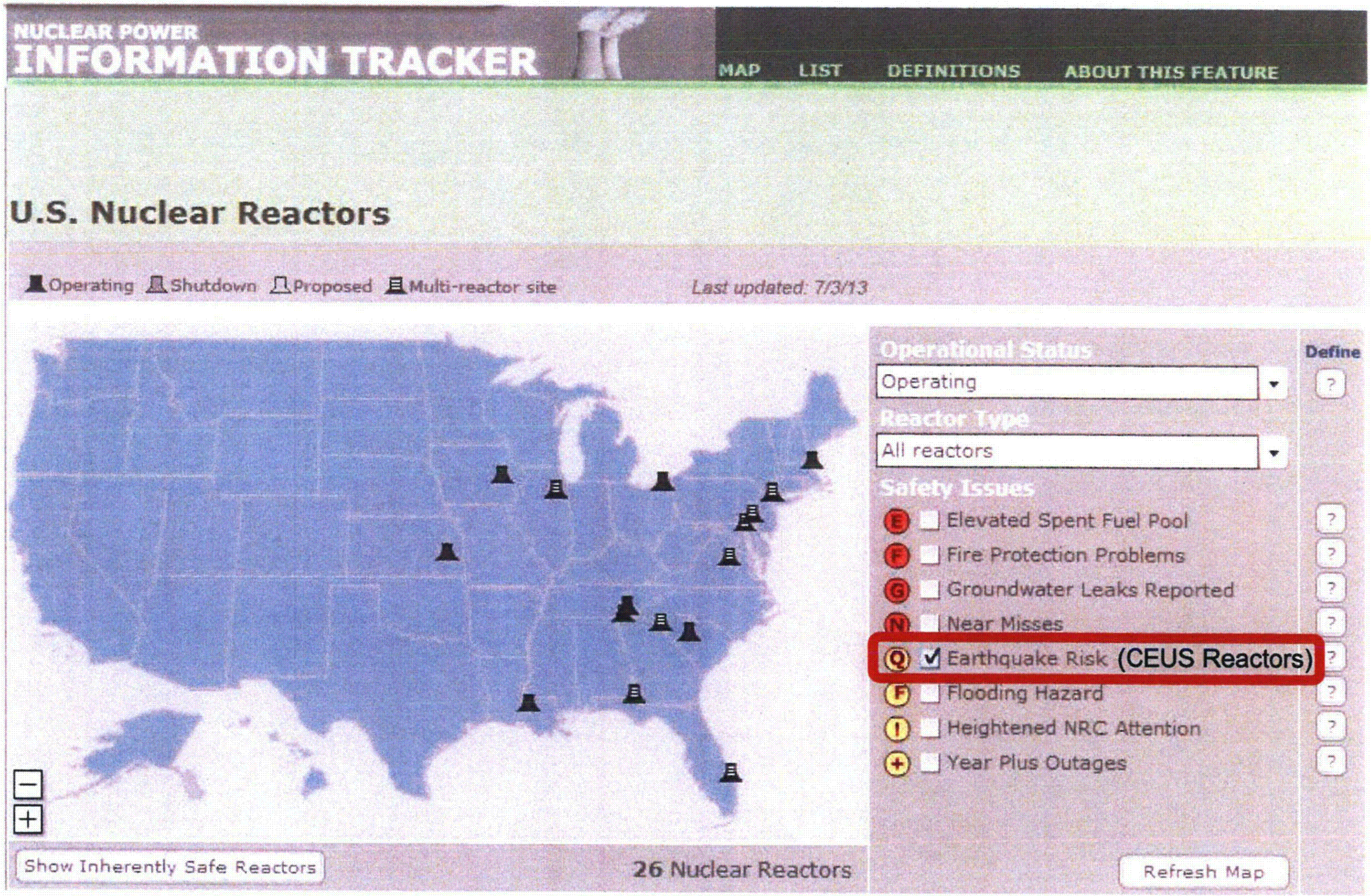
Source: ML120400493

Flood of Known Safety Issues

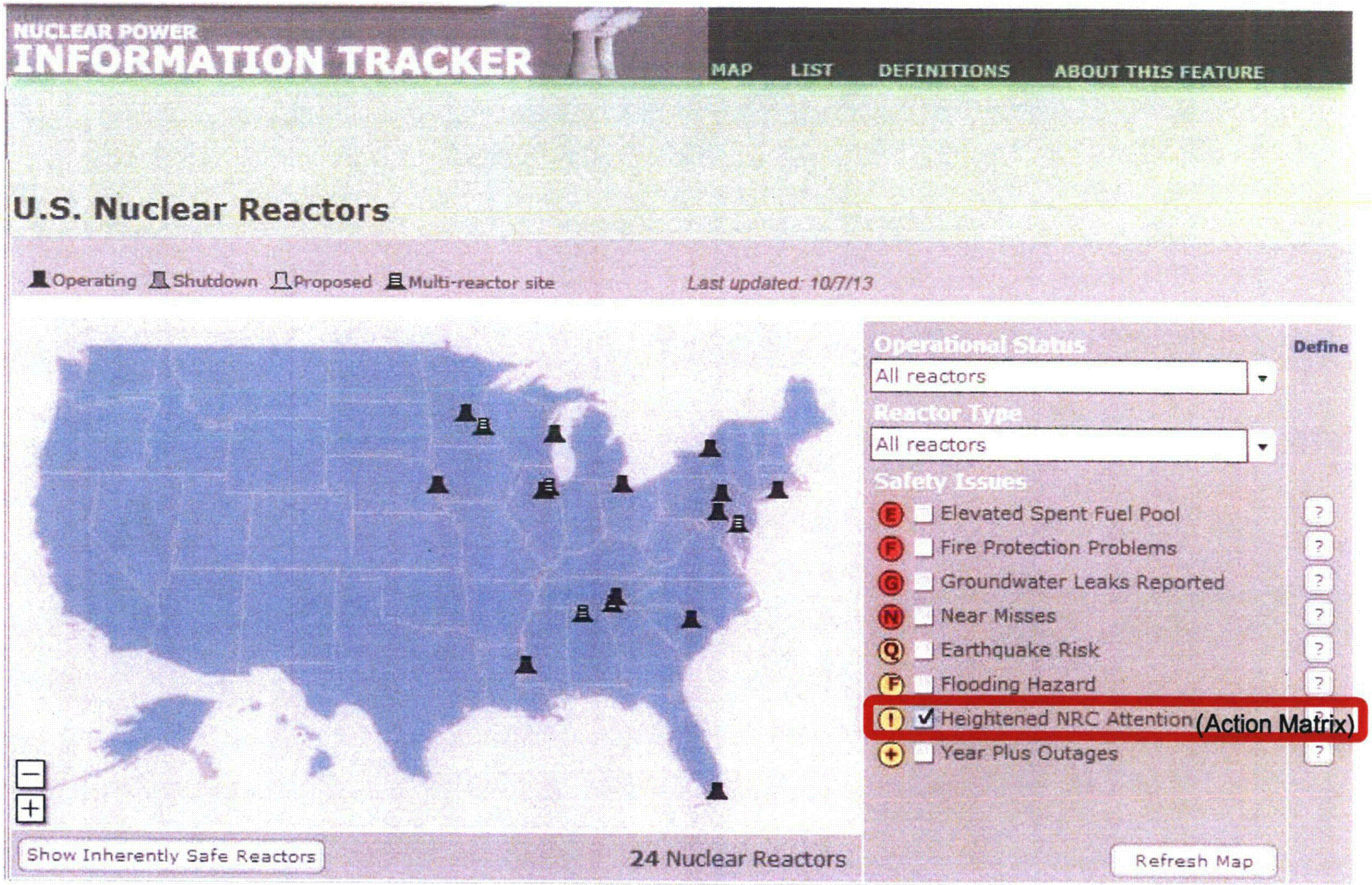


Source: http://www.ucsusa.org/nuclear_power/reactor-map/embedded-flash-map.html

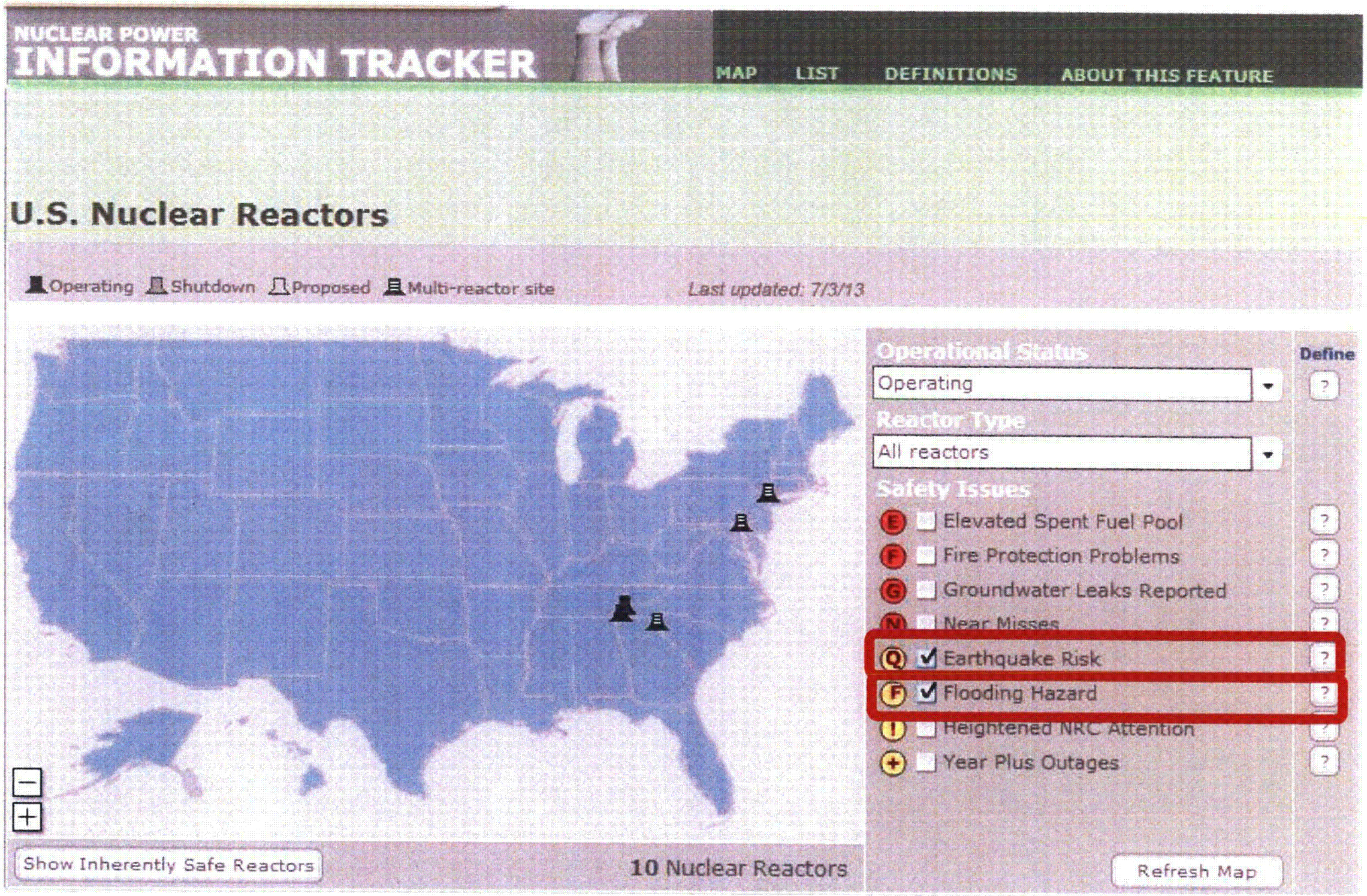
Another Drop in the Flood



Another Drop in the Flood



Flood is More Than One Drop



But NRC Only Sees a Drop

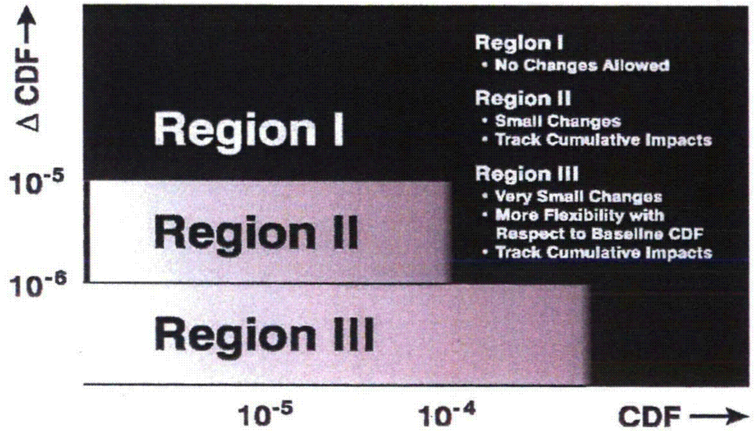


Figure 4 Acceptance guidelines* for core damage frequency

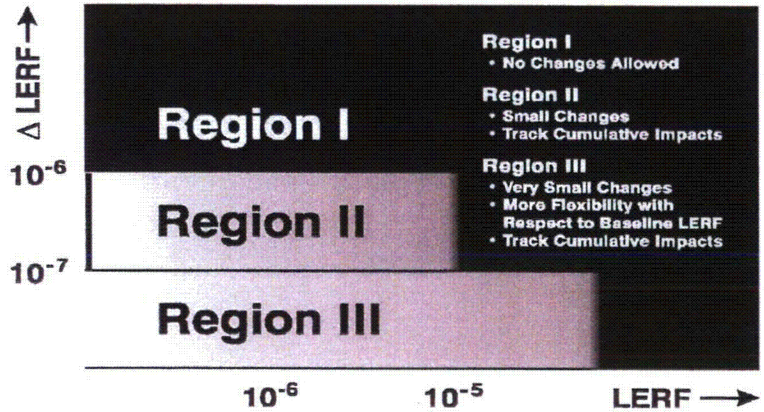
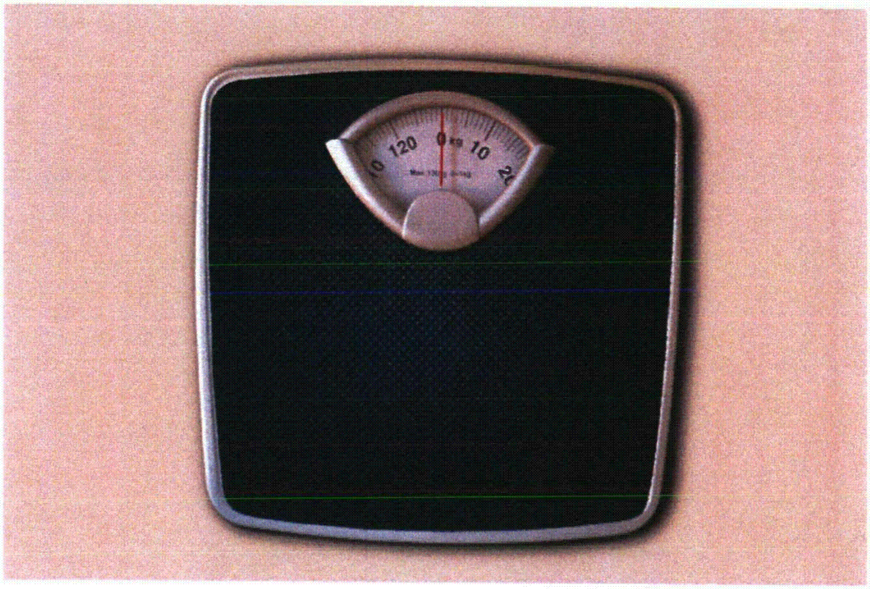
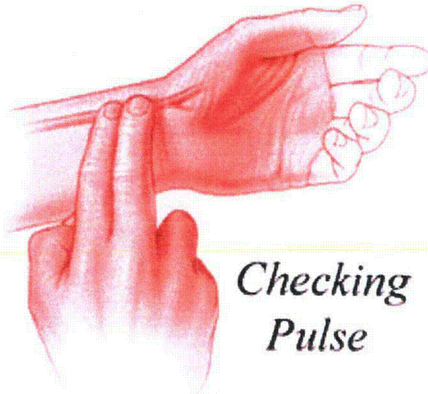


Figure 5 Acceptance guidelines* for large early release frequency

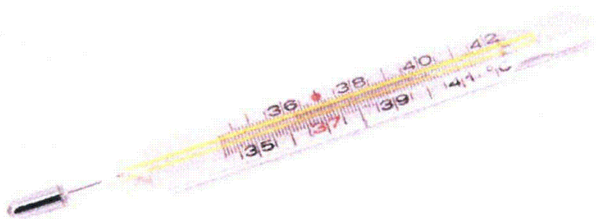
NRC's decision-making processes, such as this one from RG 1.174, are largely made without formally considering other known risks.

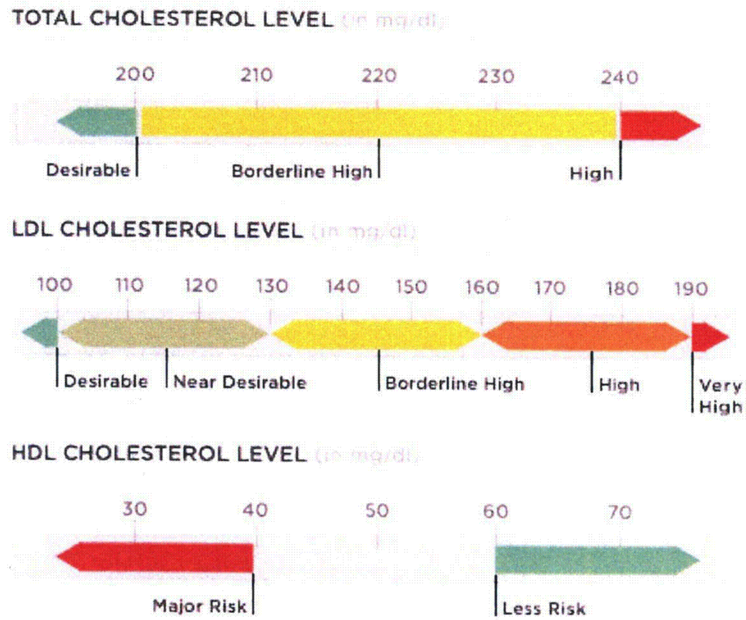
Connect-the-Dot?





Checking Pulse





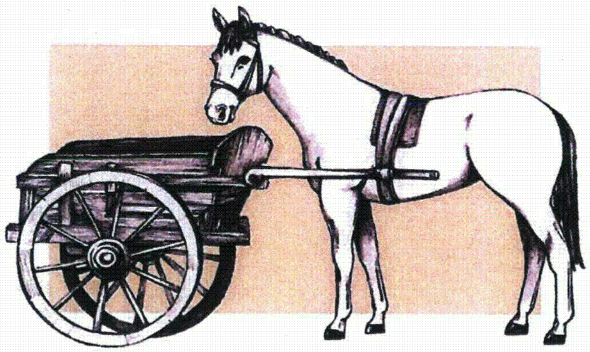
Connect-the-Dot?

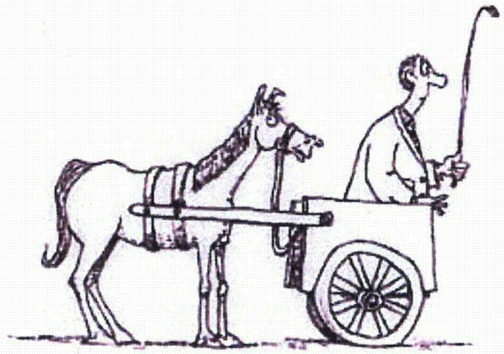
If Reactors A and B each had flooding protection issues, NRC's processes would treat each equally in terms of urgency, etc.

But what if Reactor B also had seismic and fire issues and was in Action Matrix column 4 while Reactor A had no other issues and was in column 1?

Cart Before Horse

The NRC mandated that walkdowns and assessments be performed BEFORE it clearly articulated its expectations and appropriate standards.





Cart Before Horse

08-09-2010: **NRC accepted upstream dam failure issue in its generic issue program**

03-11-2011: **Fukushima Daiichi experienced earthquake and tsunami**

03-23-2011: **NRC began walkdowns per Temporary Inspection 2515/183**

07-12-2011: **Near-Term Task Force issued report and recommends external flooding walkdowns**

Cart Before Horse

02-29-2012: NRC approved upstream dam failure issue as Generic Issue 204

03-12-2012: NRC mandated walkdowns and reevaluations of flooding hazards

05-31-2012: NRC endorsed NEI flooding walkdown guidance

11-30-2012: NRC issues flooding assessment guidance

01-04-2013: NRC issues tsunami, surge, seiche hazard assessment guidance

Cart Before Horse

Draft 18; January 17, 2013

Program

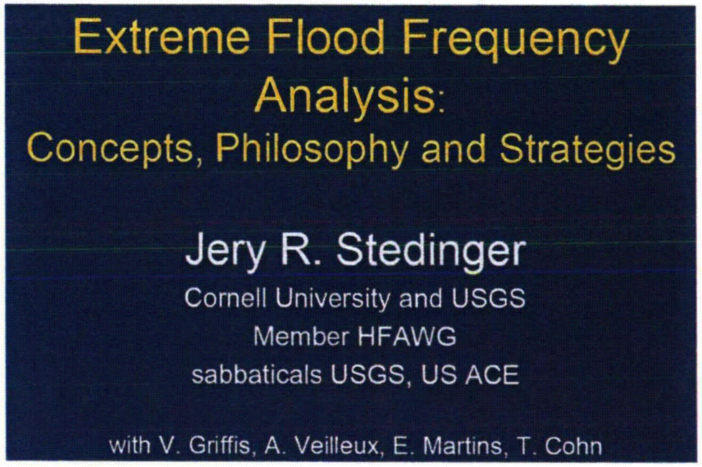
Workshop on
Probabilistic Flood Hazard Assessment
(PFHA)

January 29 - 31, 2013, 8:30 a.m. – 6:00 p.m. (EST)
U.S. NRC Headquarters Auditorium
11555 Rockville Pike, Rockville, MD 20852

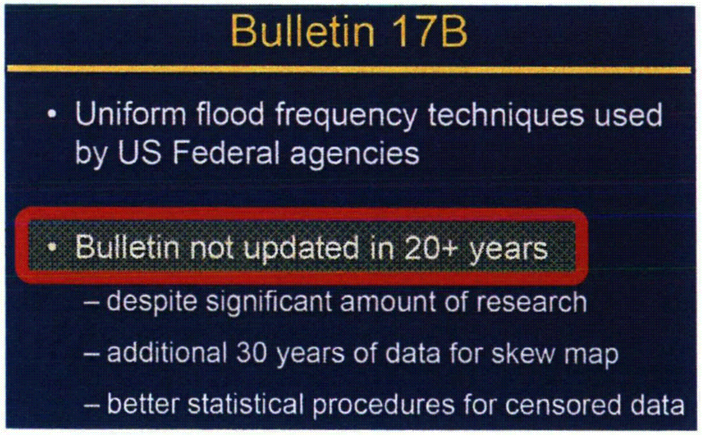
Federal Agency Partners

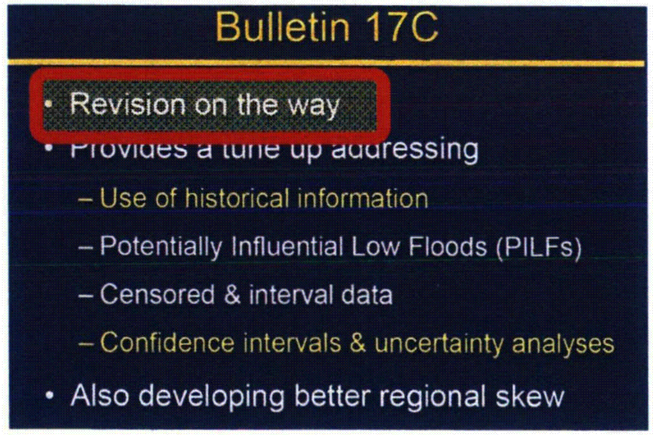
More than 10 months AFTER the walkdown directive, NRC hosted a flooding assessment workshop.

Cart Before Horse



More than two years later, federal government is playing catch-up.





Cart Before Horse

Some unanswered questions:

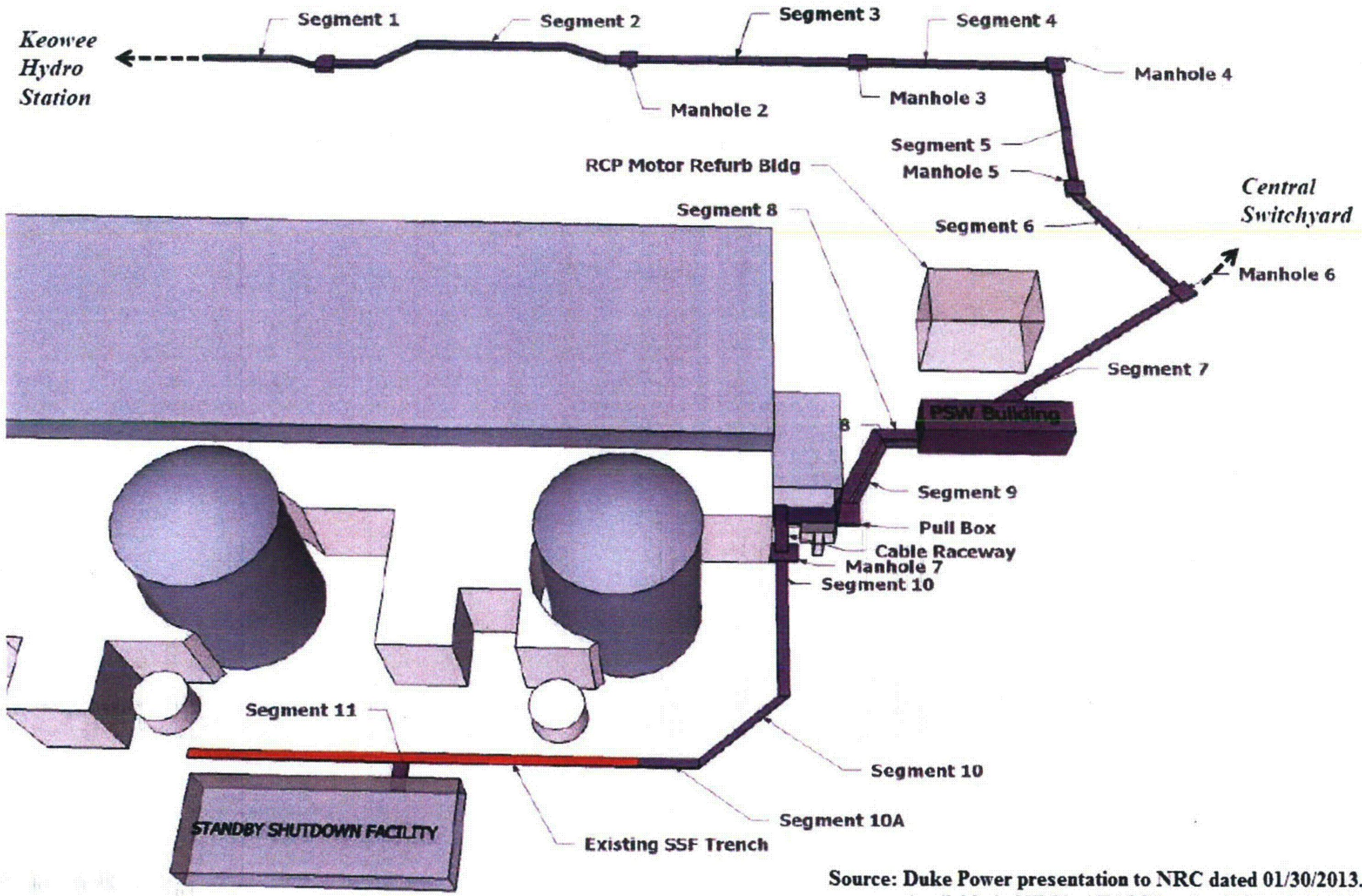
1) Should dam failures be postulated concurrent with heavy rainfall, or should the current "sunny day" practice continue?

Cart Before Horse

Some unanswered questions:

2) When assessing flooding above design basis levels, should factors like weight of water affecting structures be considered, or totally ignored as is the current practice?

Cart Before Horse



Source: Duke Power presentation to NRC dated 01/30/2013.
Available in NRC's ADAMS under ML13035A233

Cart Before Horse

Some unanswered questions:

3) When assessing flooding below design basis levels, should manual actions being impaired by flood water be considered, or totally ignored as is the current practice?

Cart Before Horse

Had they been completed at Fukushima Daiichi before March 10, 2011, would the NRC-mandated flooding walkdowns and assessments have prevented the three reactor meltdowns?

Cart Before Horse

Near Term Task Force recommendation 2.2:

Initiate rulemaking to require licensees to confirm seismic hazards and flooding hazards every 10 years and address any new and significant information. If necessary, update the design basis for SSCs important to protect against the updated hazards.

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Flood Hazard Reevaluations: Categories

Category 1 Due 03/12/2013		Category 2 Due 03/12/2014		Category 3 Due 03/12/2015	
Callaway	Quad Cities	Arkansas Nuclear One	Fort Calhoun	~~Bellefonte~~	Perry
Calvert Cliffs	Salem 03/2014	Beaver Valley	Robinson	Brunswick	Pilgrim
Comanche Peak	Sequoyah 03/2015	Braidwood	Farley	Crystal River	Point Beach
Dresden 05/2013	Shearon Harris	Browns Ferry	~~Kewaunee~~	Diablo Canyon	Ginna
Fermi	South Texas	Byron	LaSalle	DC Cook	~~San Onofre~~
Grand Gulf	Three Mile Island	Catawba	Monticello	FitzPatrick	Seabrook
Hope Creek 03/2014	Turkey Point	Clinton	Palo Verde	Limerick	St. Lucie
Indian Point 12/2013	Vermont Yankee	Columbia	Peach Bottom	Millstone	Surry
Nine Mile Point	Summer	Cooper	Prairie Island	Oyster Creek	Susquehanna
North Anna	Vogtle	Davis-Besse	River Bend	Palisades	Waterford
Oconee	Watts Bar 03/2015	Duane Arnold	McGuire		
delayed		Hatch	Wolf Creek		
COUNT= ~~22~~ 18		COUNT= ~~24~~ 26		COUNT= ~~20~~ 22	

Source: NRC slides 11/12/2013 (ML13311A268)

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Protecting People and the Environment

Observations from Walkdown Reports

- Approximately 90% of licensees entered an issue into its Corrective Actions Program
- Common issues identified include:
  - Inadequate procedures
  - Flood protection features that may not perform as planned
  - Degraded or missing seals

Source: NRC slides 11/12/2013 (ML13311A268)

Duck and Uncover

06/22/2010 – Secret confirmatory action letter for Oconee flood protection shortcoming

10/08/2010 – Public yellow finding for Fort Calhoun flood protection shortcoming

06/18/2013 – Public yellow finding for Point Beach flood protection shortcoming

08/28/2013 – Public yellow finding for Monticello flood protection problem

Issues

- **Risk integration vs. isolation**
- **Cart before the horse**
- **[redacted] oversight**

Acronym List

CEUS – Central and Eastern United States
GI – Generic issue
NEI – Nuclear Energy Institute
NRC – Nuclear Regulatory Commission
RG – Regulatory Guide
SSC – Systems, structures, and components
USGS – United States Geological Survey

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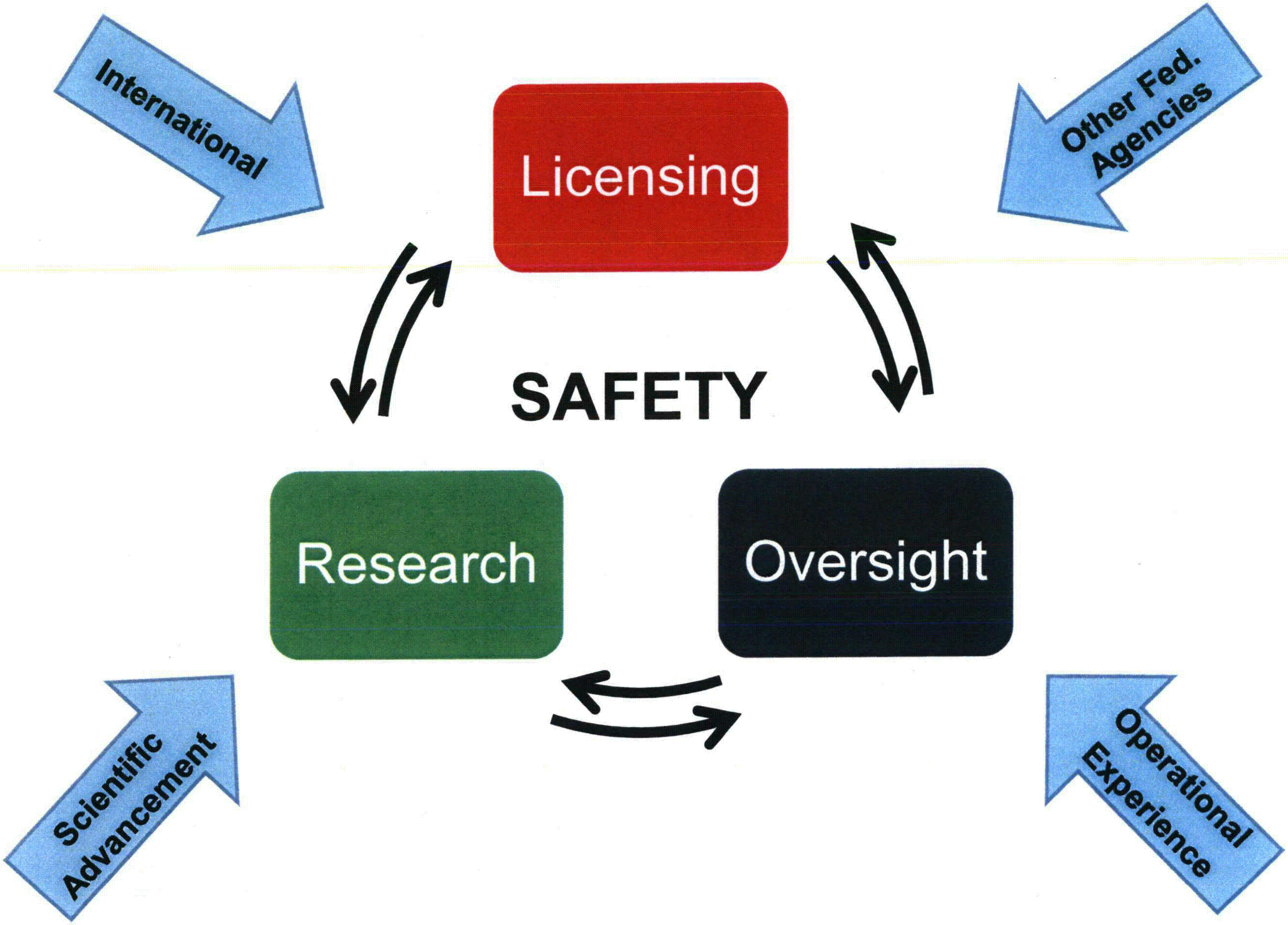
United States Nuclear Regulatory Commission
Protecting People and the Environment

FLOODING AND OTHER EXTREME WEATHER EVENTS

January 6, 2014


International
Other Fed. Agencies
Licensing
SAFETY
Research
Oversight
Scientific Advancement
Operational Experience

Flooding and Severe Storms Lessons Learned

George Wilson, Flooding Lead
Japan Lessons Learned Directorate
Office of Nuclear Reactor Regulation

Overview

- Reactor Oversight Process
- Impacts of Plant Findings and Events
  - Oconee
  - Fort Calhoun
  - Watts Bar
  - Oyster Creek
  - Fukushima

Reactor Oversight

- Specific inspection activities for adverse weather and flooding
- Inspectors have identified flooding and severe weather issues
- Feedback into regulatory process

Oconee

Inadequate maintenance procedure led to developing Generic Issue 204, “Upstream Dam Failures”

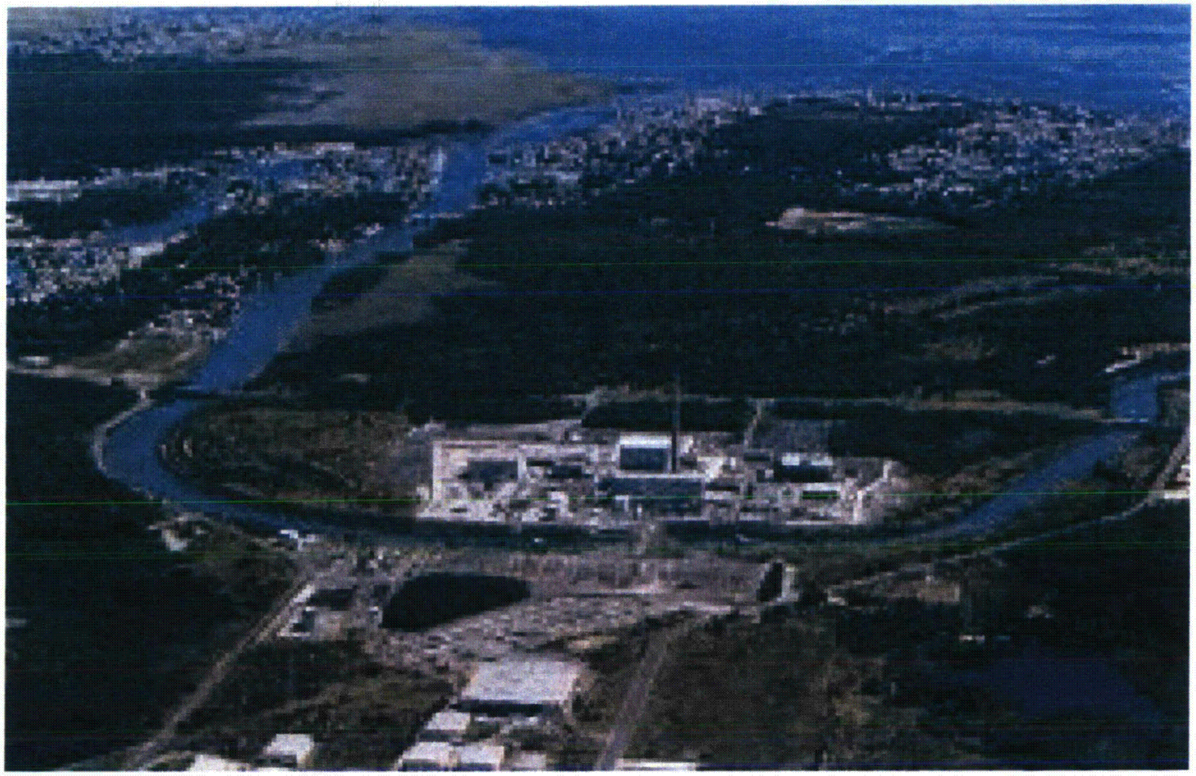
Fort Calhoun

Inadequate flood strategy provided insights for Near-Term Task Force (NTTF) Recommendation 2.3, “Flooding Walkdown,” guidance

Watts Bar

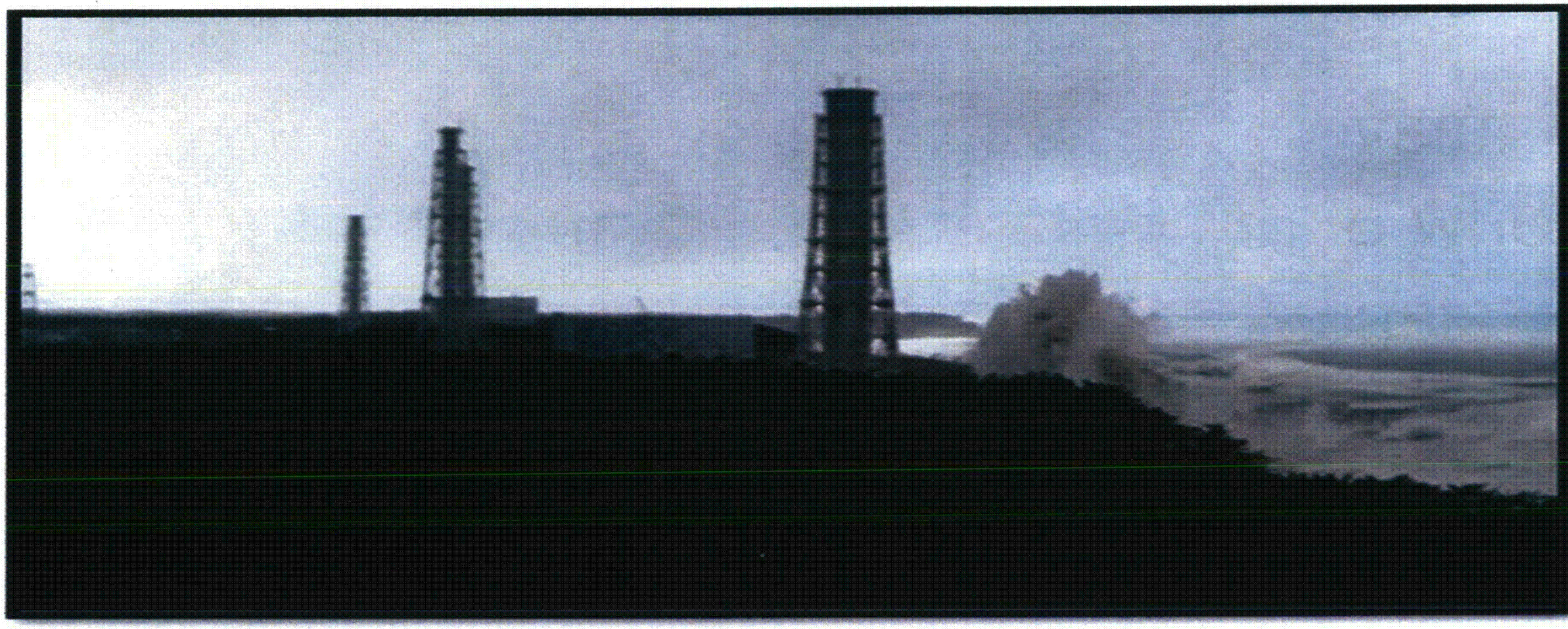
Inspection findings at other sites resulted in greater focus on reasonable simulations at Watts Bar Nuclear Plant

Oyster Creek



Effective contingency planning at Oyster Creek supported the site's response to when Superstorm Sandy exceeded forecasts

Fukushima



Importance of continued vigilance to ensure flood protection measures are adequate and maintained

Evolution of Flooding Hazards

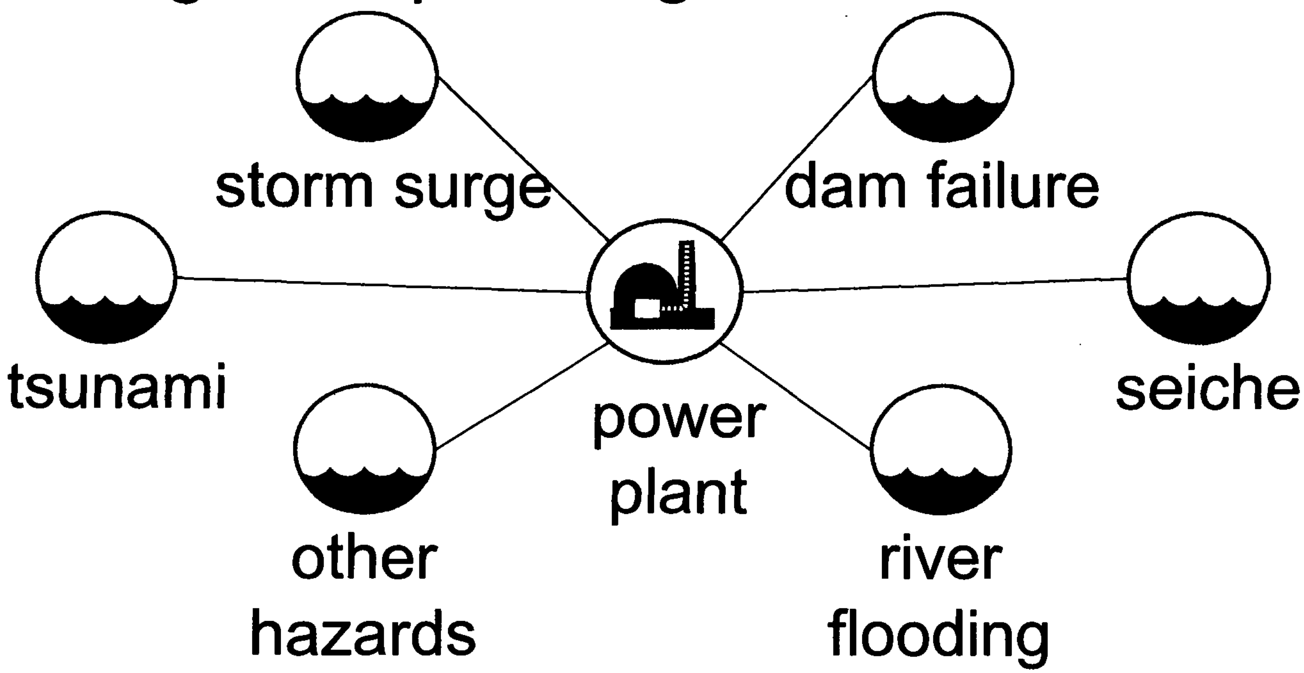
Christopher Cook, Chief
Hydrology and Meteorology Branch
Office of New Reactors

Overview

- Evolution of Design Basis Flooding Hazards
- Post-Licensing External Hazard Reevaluations
- Present-Day Methods
- Motivation for New Guidance
- Continuing Evolution

Evolution of Design Basis Flooding Hazards

- Hazard mechanisms considered today have not changed from those considered when licensing the operating fleet



Evolution of Design Basis Flooding Hazards (cont.)

- What has changed?
  - Increased data record
  - Understanding of flooding hazards
  - Advancements in scientific knowledge and analytical tools

Post-Licensing External Hazard Reevaluations

- Past and present external hazard reevaluations:
  - Systematic Evaluation Program (1977)
  - Individual Plant Evaluation for External Events (1991)
  - NTTF Recommendation 2.1 (2012)

Present-Day Methods for Estimating Design Basis Flooding Hazards

- Based on the historical record for the site and region
- Includes changes to the baseline data (climate change, construction of dams, etc.)
- Predominantly deterministic
- Hybrid deterministic-probabilistic approaches have been submitted for some hazards

Motivation for New Guidance

- Flooding Hazards due to Dam Failure
  - Regulatory reviews demonstrated the need to update and supplement guidance
- Flooding from Tsunami, Storm Surge, or Seiche
  - Incorporate lessons-learned from new reactor reviews and NRC research programs
- Integrated Assessment for Flooding
  - Evaluate total plant response (protection and mitigation) to the reevaluated flooding hazard

Continuing Evolution

- Evolving understanding of flooding hazards
  - Increasing data records
  - Improving scientific knowledge and analytical tools
- Development of probabilistic methods
- Periodic updates of flood hazard evaluations
  - NTTF Recommendation 2.2

Research Activities

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Overview

- Regulatory guidance and supporting technical bases
- Probabilistic flood hazard assessment (PFHA)
- Considering Climate Change
- Conclusion

Updating Regulatory Guidance

- Regulatory Guide 1.59 "Design Basis Floods for Nuclear Power Plants"
  - Issue: Substantial improvement in technology (storm data, computational resources, models)
  - Five published technical reports
  - Draft regulatory guide nearing release

Updating Regulatory Guidance (cont.)

- Regulatory Guide 1.102 “Flood Protection for Nuclear Power Plants”
  - Issue: Lessons learned from domestic and international experience
  - Technical basis project – final report under review
  - Draft revision to regulatory guide under development

Research to Improve Analyses

- Transition from deterministic to more risk-informed framework
  - Probabilistic evaluation of riverine flooding
  - Extension of Probable Maximum Precipitation studies to include transposition and orographic features
  - Use of paleoflood data to inform flooding risks at nuclear power plants
  - Evaluation of dam-breach scenarios
  - PFHA workshop – January 29-31, 2013

Probabilistic Flood Hazard Assessment Research Program Plan

- Outgrowth of (1) new reactor reviews, (2) reactor oversight program needs, (3) PFHA workshop
- Technical Advisory Group on Flooding
- Draft plan developed and under review
- Includes collaboration with domestic and international experts

Considering Climate Change

- Monitor scientific progress
- General guidance in the revision to Regulatory Guide 1.59
  - Site specific estimates based on federal projections from climate models
  - Projections for the life of the plant
- Changes in variability of Great Lakes water levels

Summary

- Substantial work has been completed to support state-of-the-art regulatory guidance
- New research is directed at providing critical information for probabilistic analyses
- A research program plan will guide future activities
- Advances in climate change science will be monitored and given appropriate consideration

Conclusion

- Safety is a continual process
- Our understanding and knowledge continues to evolve
- Lessons learned will be incorporated into the reactor oversight process