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Risk Based Approaches for Levees in the U.S. and Abroad: Lessons for the NFIP

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“NFIP should move to a modern risk analysis that makes use of modern methods and computational mapping capacity to produce state-of-the-art risk estimates for all areas that are vulnerable to flooding”

-National Research Council 2013

What is Risk Based Analysis?

- Probability x Consequence = Risk
- *The portion of the process in which potential failure modes, structural performance, and adverse consequences are identified. It is also the process during which a quantitative and qualitative estimate of the likelihood of occurrence and magnitude of consequence of these potential events is made. (FEMA, 2015)*
- Considers a full range of events (not simply the 1%-annual-chance)
- Considers failure probabilities for structural features, including levees and floodwalls
- Factors in consequence modeling

Risk Based Analysis for Levees

- Risk Based Analysis currently being performed for levees by USACE and by other agencies internationally
- TMAC recommends that the NFIP
 - Move away from the “base flood” to ratings by multiple flood events
 - Structure-specific consequences
- Would be consistent with Biggert Waters 2012 and Homeowner Flood Insurance Affordability Act
- Natural floodplains may achieve TMAC objectives without fundamental changes to modelling approaches.
- Levee risk based analysis would need to consider failure mechanisms and scenarios for multiple flood events.



Source
River or sea

Pathway
e.g. beach,
defence, floodplain

Receptor
e.g. property, agriculture,
infrastructure, people in the floodplain



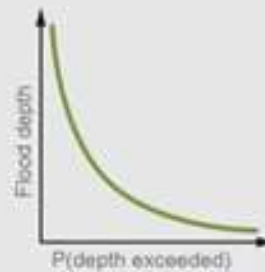
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Source
Extreme distribution
of in-channel water
levels or coastal
overtopping



Pathway
Reliability analysis of
assets e.g. defences
(load dependent)



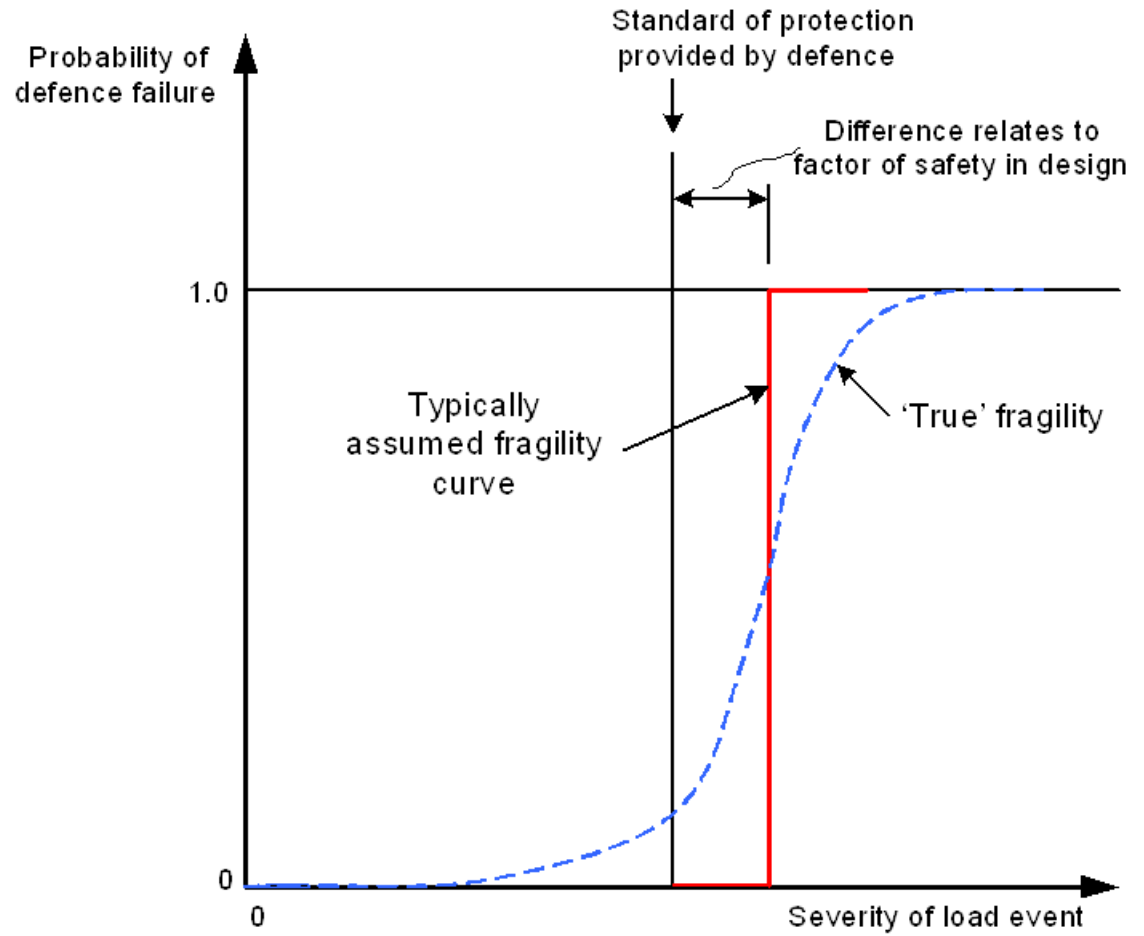
Pathway
Flood probability,
flood extent and
depth, reflecting
asset performance
and source terms.



Consequences
Flood damage or harm
related to depth. Risk is
assessed by the probability
that particular damage
values are exceeded.

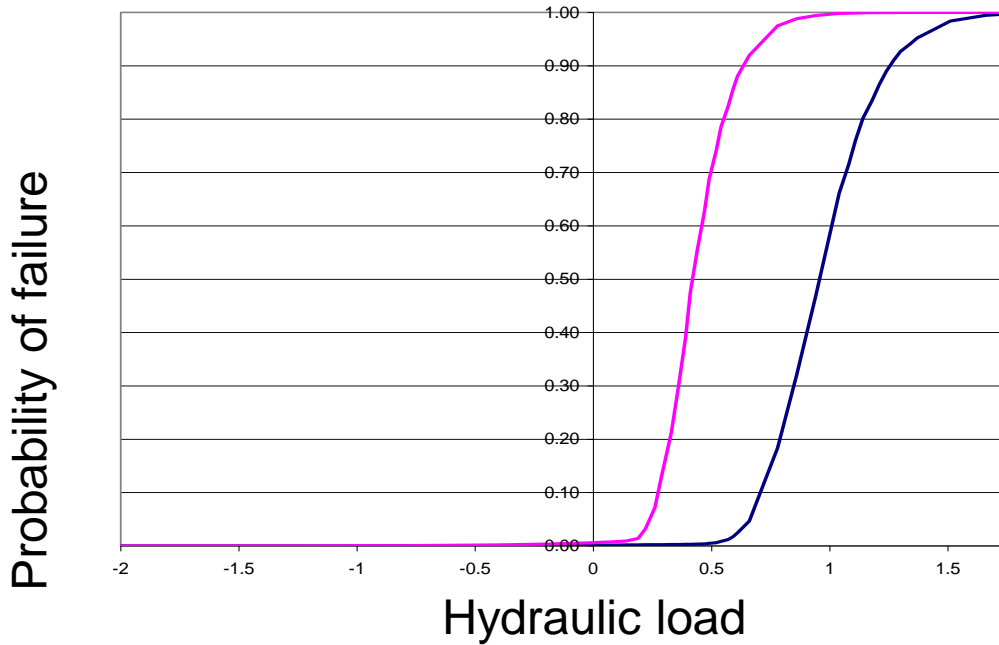
Fragility Curves

- Where levees are present, the fragility curve concept expresses probability of failure given load.
- Fragility concept was developed by USACE 1991-3. Applied by USACE and internationally
- *Key Challenge in U.S.: lack of data availability throughout National levees*

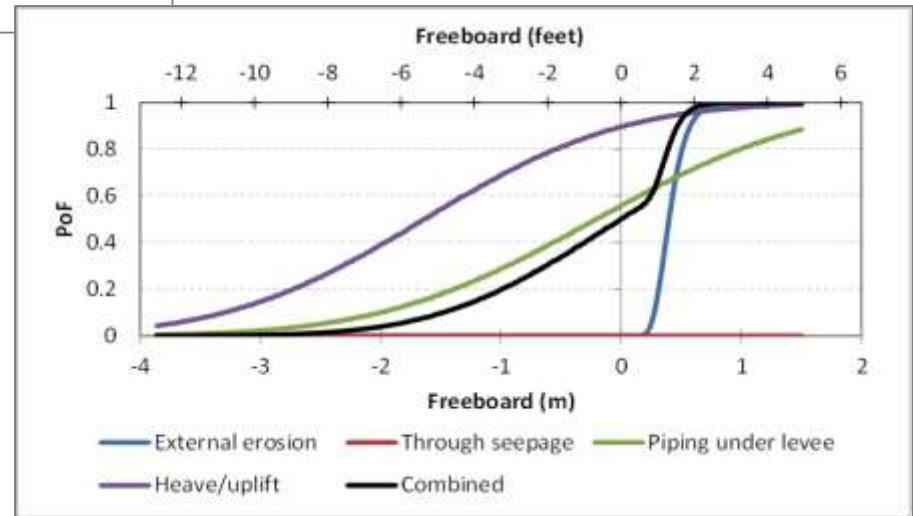
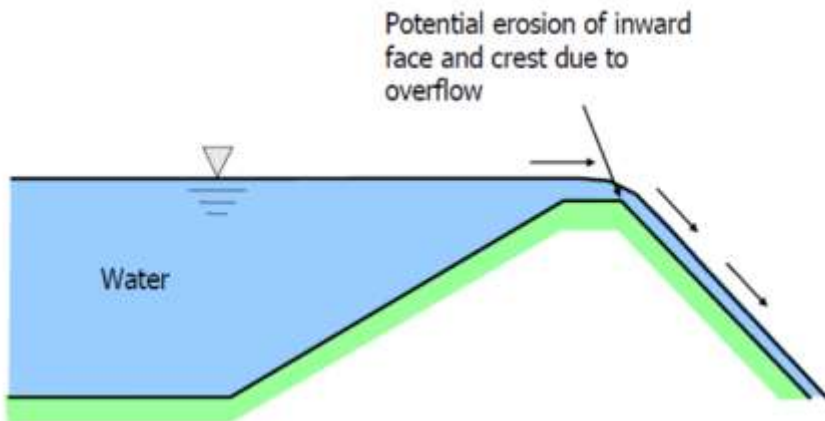
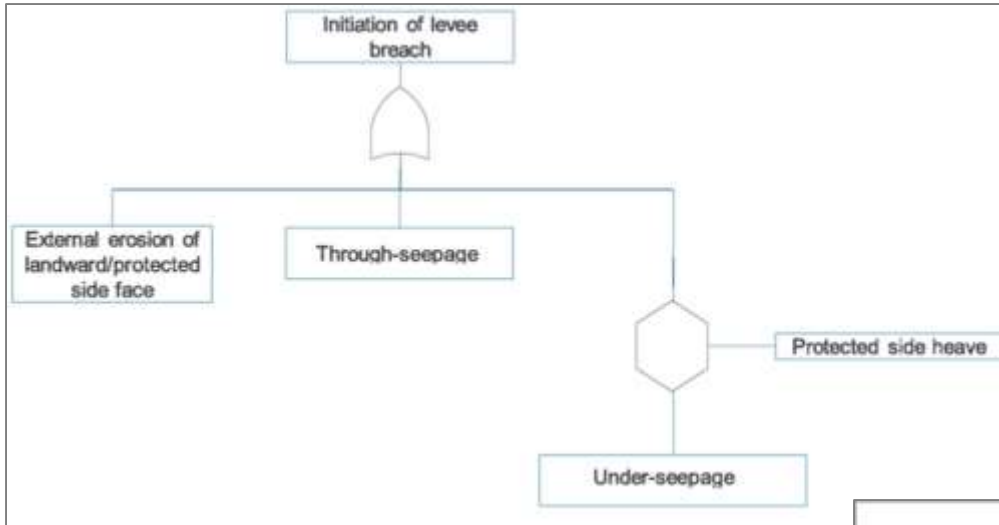


Fragility Curves

- Fragility needs to be representative of levee by segment

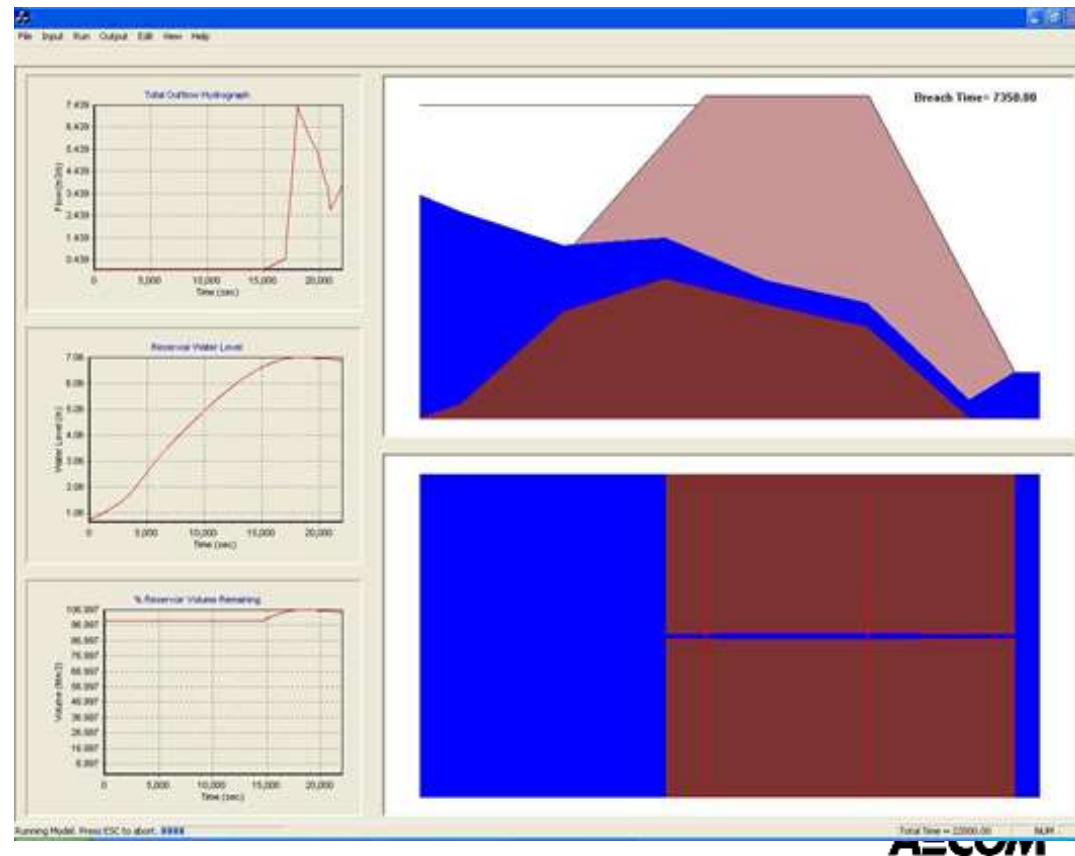


Tools for Generating Site Specific Fragility Curves: RELIABLE (U.K.)



Existing Breach Software: EMBREA

- Breaches in levees have a strong influence on flood extents and impacts
- Inherent complexity and uncertainty
- Numerical models and software that simulate these processes
- Examples of these models include EMBREA (HR Wallingford), SIMBA (USDA ARS), and existing US software such as NWS BREACH (NOAA NWS)



RISK BASED ANALYSIS (FRE MODEL)

Hydraulic loading:
Full distribution of loads



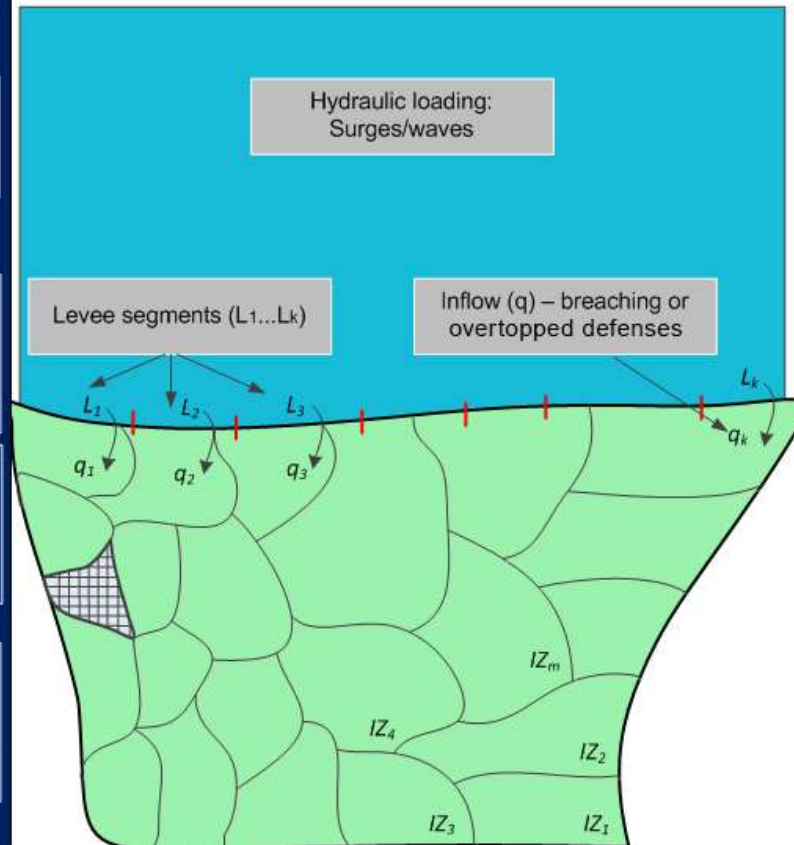
Levee Performance:
Full fragility curve for each defense segment



Breach representation:
Inflow hydrographs for all levee reaches for full distribution of hydraulic loads



Inundation simulation:
Simulations of simultaneously modeled breach scenarios and full distribution of hydraulic loads



LAMP

Hydraulic loading:
1% loading level



Levee Performance
Selection of breach failure locations/parameters for levee segments with structural deficiencies to 44CFR65.10. Overtopping of the 1-percent-annual-chance event

Breach representation
Inflow hydrographs 1% hydraulic load (+ sensitivity)



Inundation simulation:
Simulations of multiple, independent breach scenarios for the 1-percent-annual-chance, composited during mapping

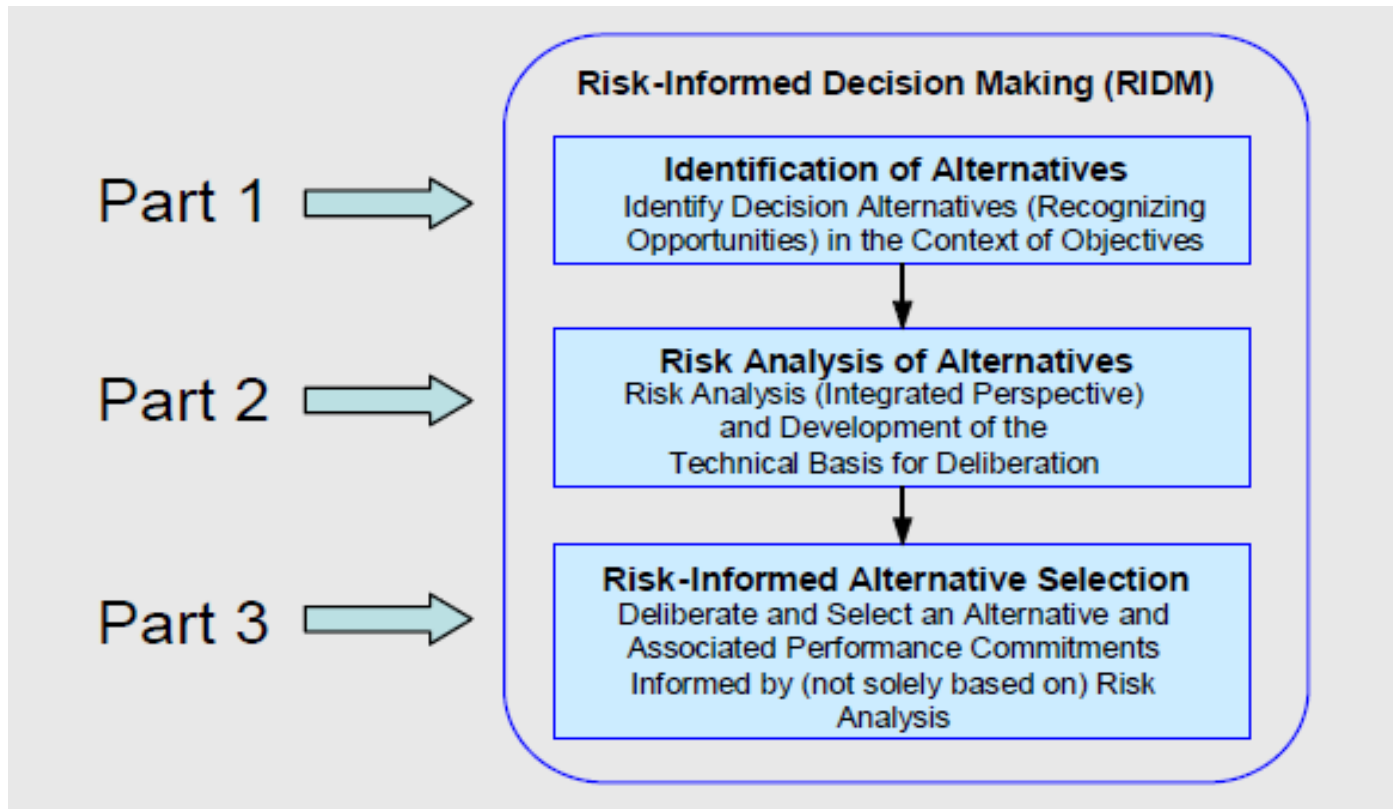
Current Applications

U.S. and International Examples

Applications in Risk Based Approaches

- Many U.S. agencies use risk based approaches in some way for applications *other* than flooding and levees
- U.S. Federal agencies using risk based approaches include:
 - NASA (early application)
 - USACE
 - FERC
 - U.S. Bureau of Reclamation
 - USGS
 - Nuclear Regulatory Commission
- Many countries use risk based approaches for flood evaluation, including:
 - Netherlands
 - UK
 - Japan

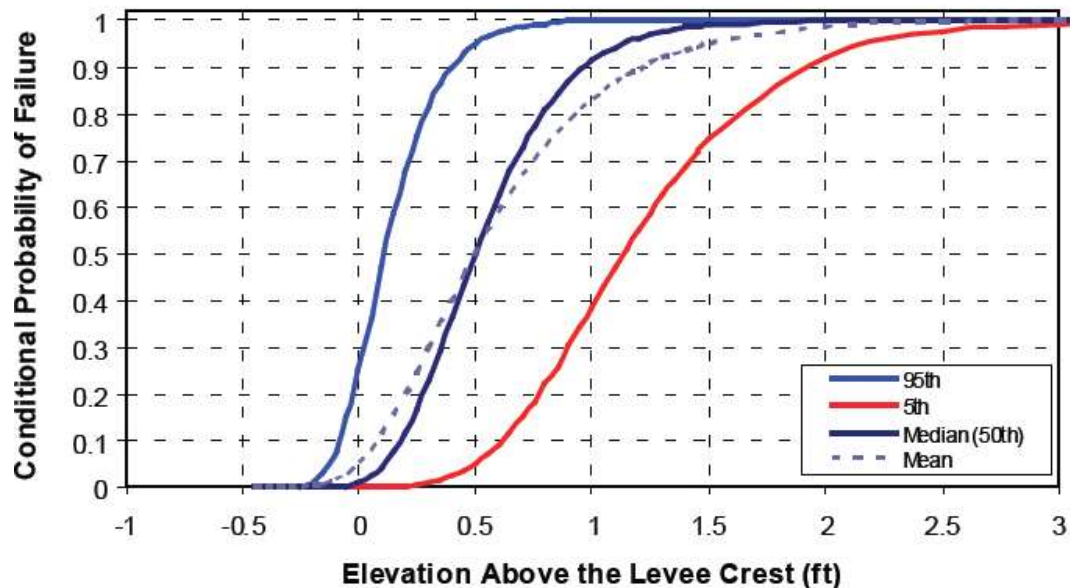
NASA



- Early in the Apollo program, application of Probabilistic Risk Analysis (PRA) on roundtrip missions.

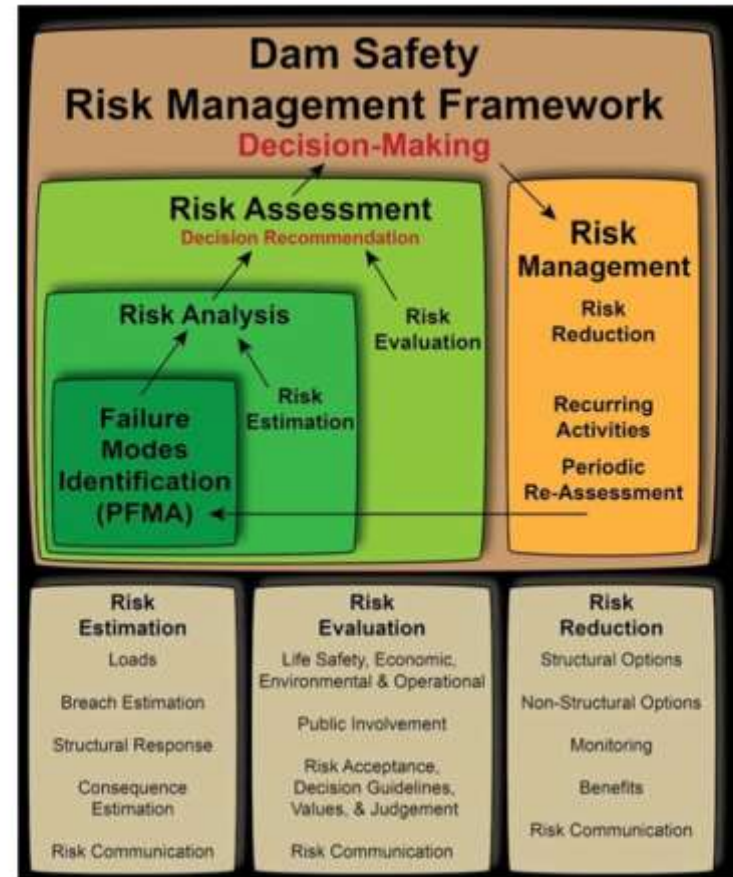
USACE

- Leaders on developing risk based methodologies for levees in the U.S., including fragility curves
- Applying on detailed risk analyses for high consequence levees.



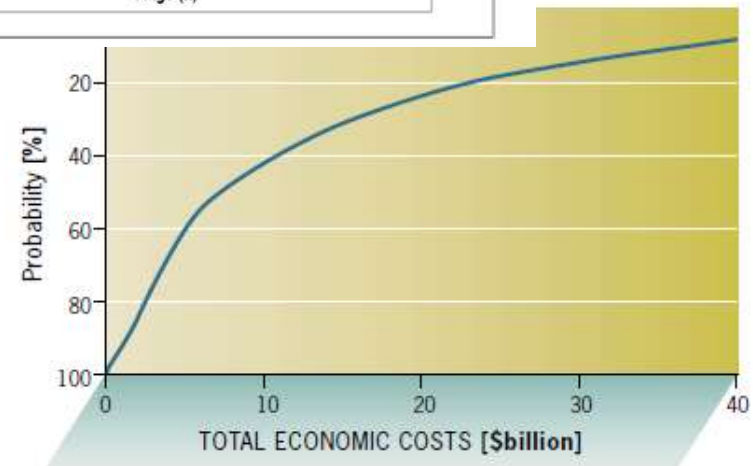
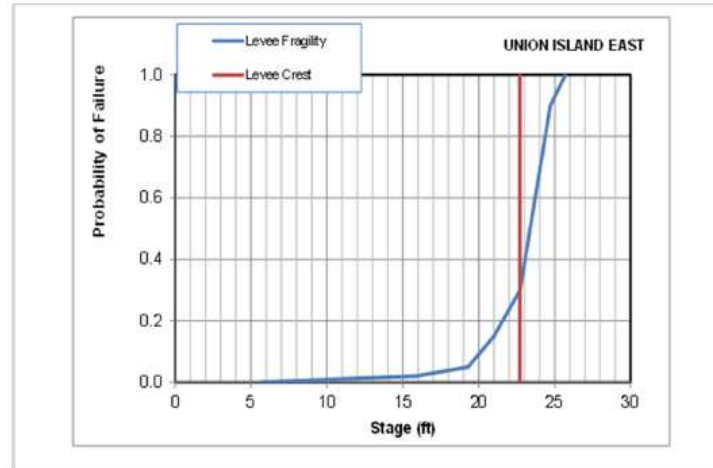
Federal Energy Regulatory Commission

- Evaluates risk analysis and the process and procedures for conducting a risk analysis for FERC-regulated dams
- Concepts of tolerable risk and as-low-as-reasonably-practicable, how risks are to be assessed, and dam safety decision making
- A 2016 report compared two general approaches:
 - standards-based approach (SBA)
 - risk-informed decision making (RIDM) approach



California Department of Water Resources study, based on USACE principles

- 2009 Study on the Sacramento-San Joaquin Delta levee system
- Risk of failure from earthquakes, high water, dry weather, land subsidence, and combined events
- Quantified risk analysis using fully probabilistic methods was implemented for all hazards.
- Resulting output of economic losses or loss of life is defined probabilistically

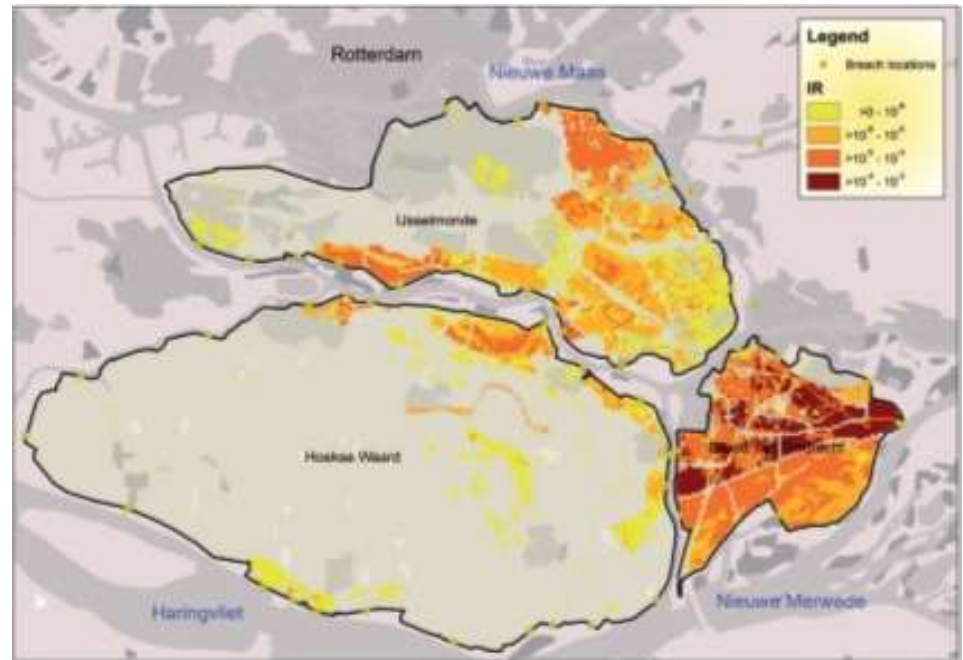


Probability of exceeding an amount in total economic costs due to high water-related levee failures over a 25-year period (2005-2030)

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Netherlands

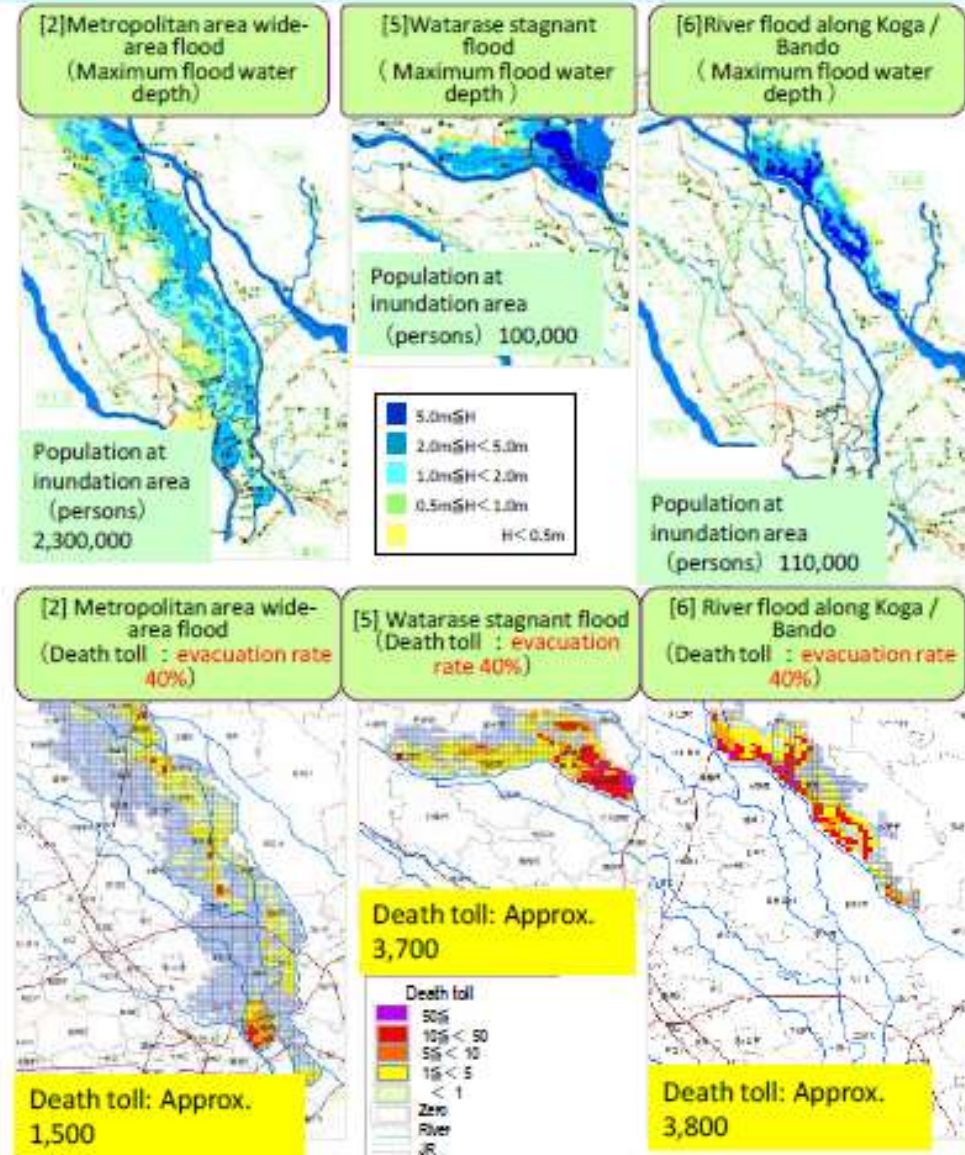
- Computes levee risk of both individual risk and societal risk values for neighborhoods.
- Use of a quantitative risk analysis program for each levee system, considering:
 - failure mechanisms
 - consequences
 - spatial correlations.
- Factors in a ‘length effect’ – the longer the dike section, the higher probability of a weak spot (due to spatial variability of properties).
- Plans for infrastructure expenditures with considerations to climate change scenarios



Japan

- Japan has a tradition of dealing with natural hazards, resulting in policies covering the “safety chain” (i.e. prevention, protection, preparedness, response and recovery).
- Particular interest in addressing preparedness for increases in flood peaks as a result of climate change.
- Evaluates flood consequences including correlations between increased number of deaths and increased flooding.
- Proactive approach for improving the reliability of levees and response in the wake of disasters.

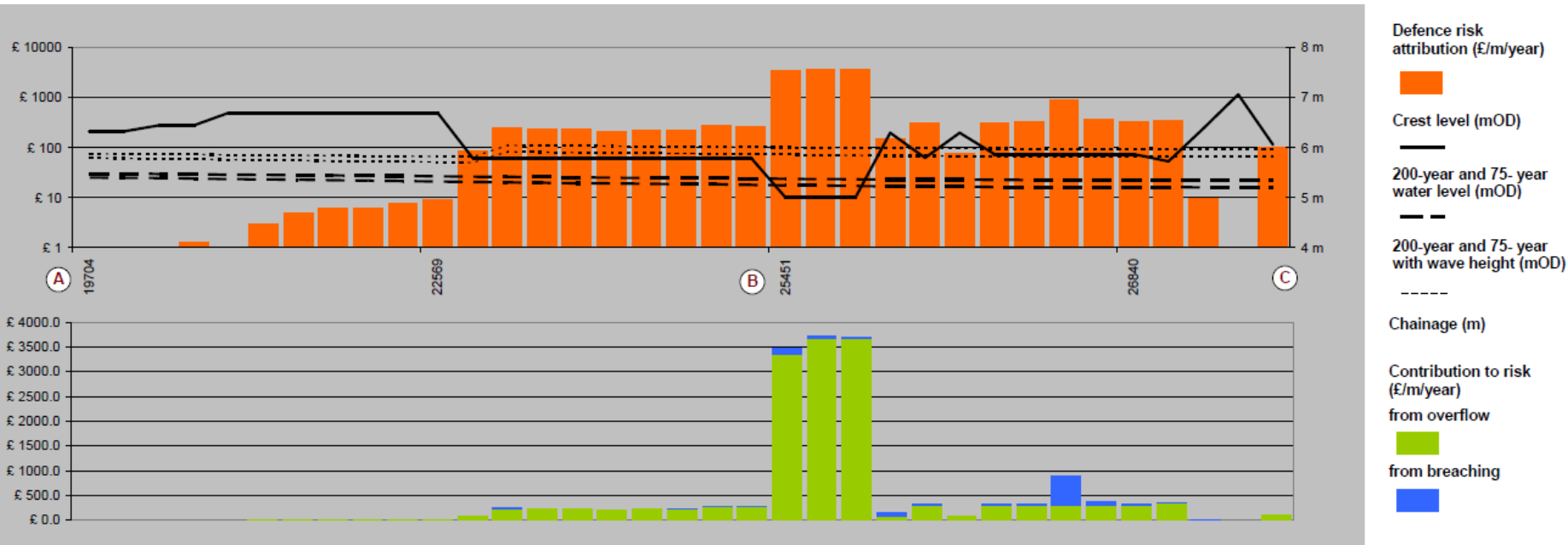
No pump operation; no fuel supply; no floodgate operation; no pumper truck available



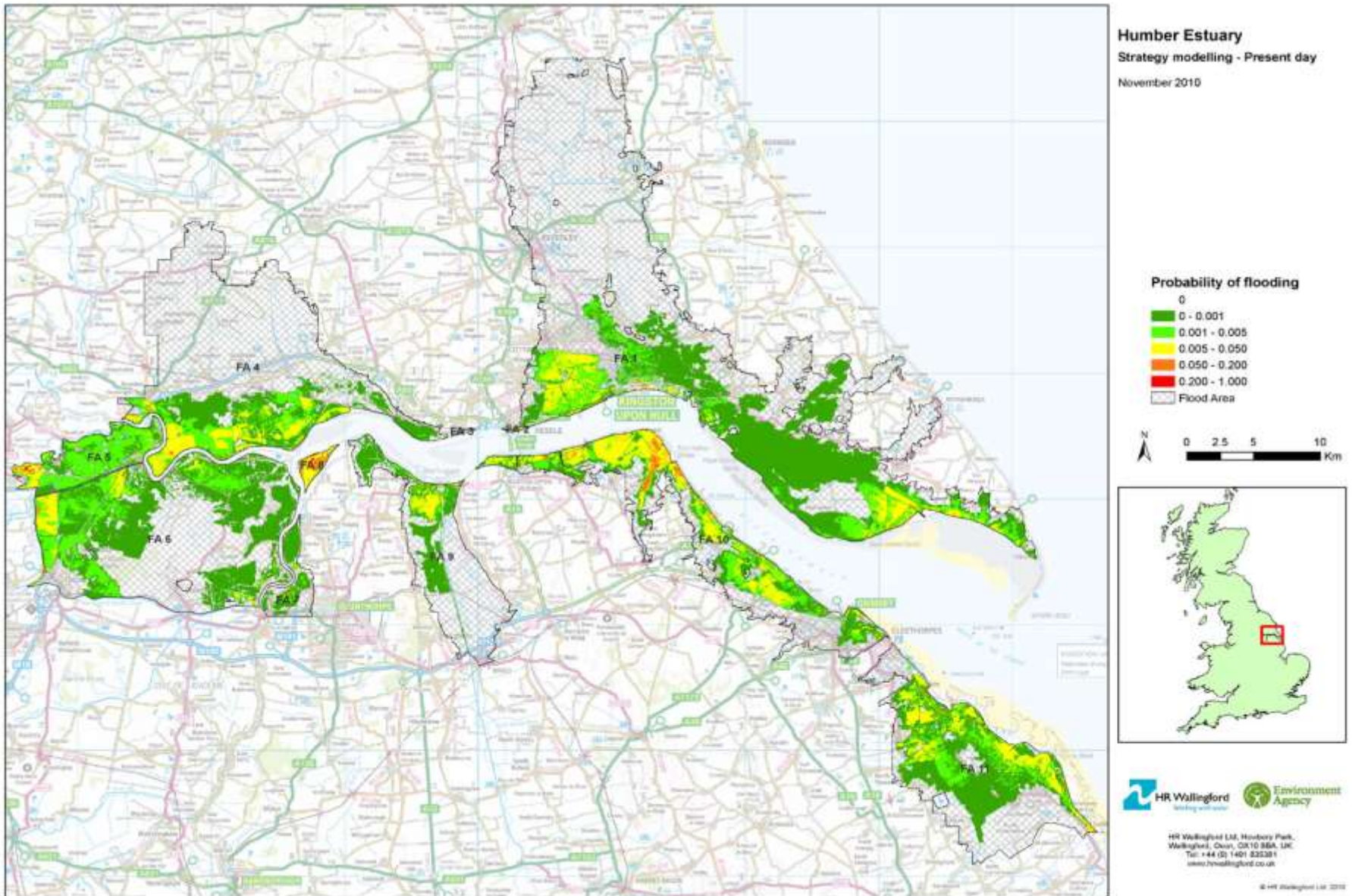
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U.K.

- NaFRA and Foresight flooding studies for future conditions led to national surface, reservoir and groundwater flood risk maps
- System Asset Management Planning
- Inclusion of probabilistic risk analysis methods at a range of spatial scales using a hierarchical structure
- Attribution of risk to individual levee reaches to aid maintenance prioritization



U.K. Levee Study Example – Probability of Flooding

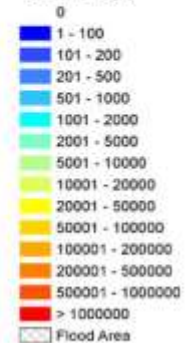


U.K. Levee Study Example – Total Risk

EAD (£K)

Humber Estuary
 Strategy modelling - Maintain 2115
 November 2010

Total Risk (£)



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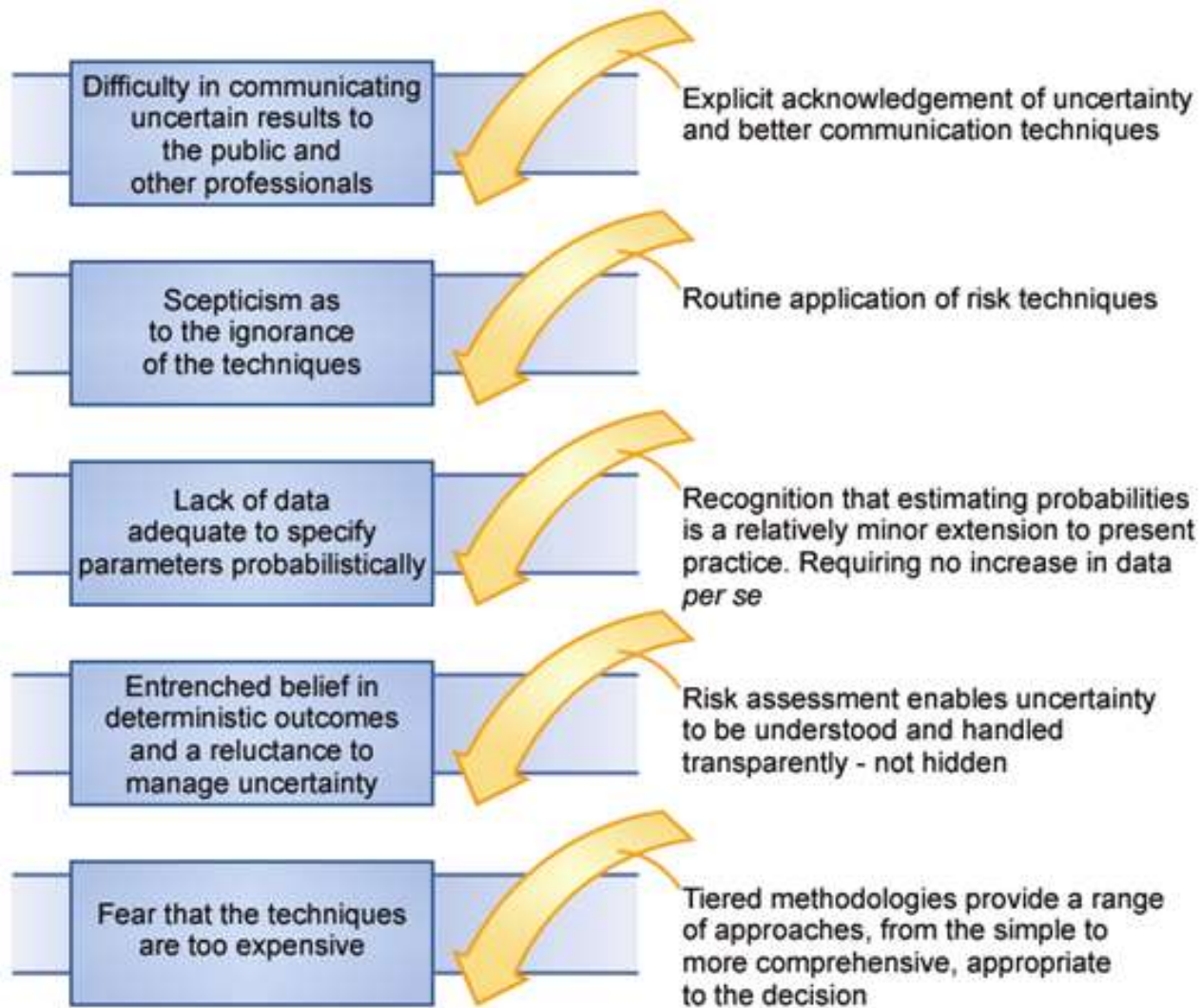
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ingford
 | with water

Potential Application to Flood Insurance Program

U.S. and International Examples



Key

-  Barriers
-  Opportunities

Breaking down the barriers to the update of risk-based methodologies

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