Using Tolerable Risk Guidelines to Manage Flood Risk

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Today’s discussion

- What is Risk?
- US Flood Policy, “Levels of Protection”
- Tolerable Risk Guidelines
- Using Risk Analysis
- Case Study: the California Delta
- Conclusions and other Applications
What is Risk?
What is Risk?

What is the hazard and how likely is it to occur?

How will infrastructure perform?

Who and what are in harm’s way?

How much harm will be caused?
What is Risk?

Risk = Probability x Consequences

Image adapted from HR Wallingford and Anna Serra Llobet
We tend to focus on the hazard

Risk = **Probability** × Consequences

Image adapted from HR Wallingford and Anna Serra Llobet
And often ignore consequences

Risk = Probability × Consequences

Image adapted from HR Wallingford and Anna Serra Llobet
Risk cannot be ignored
How do we measure risk?

Loss of life:

*Expected Annual Fatalities (EAF)*

- Considers the probability of flooding
- Number of individuals exposed to floodwaters
- Affected by warning time, water depth and velocity, rate of rise, water temperature, etc.
How do we measure risk?

Damage to property and infrastructure:

*Expected Annual Damages (EAD)*

- Probability of flooding
- Depth Damage curves
- Integrates the product of these over all flood levels
Quantifying risk enables

- Understanding and communicating risk
- Where risks are greatest?
- What actions to take?
- Are risks tolerable? Is more risk reduction warranted?
US Flood Policy and Levels of Protection
When it comes to levees, there are two types:

Those that have been overtopped by floodwaters

And those that will be overtopped by floodwaters

William Hammond Hall, 1895
When it comes to levees, there are two types:

“It should be fully understood then, that floods will occasionally come which must be allowed to spread…”

William Hammond Hall, 1895
And now, for an oversimplification of U.S. flood policy
And now, for an oversimplification of U.S. flood policy

Began in 1968 as a way to:

• Reduce federal losses in disaster liability
• Identify floodplains and discourage development therein
• Offer flood insurance to those unable to acquire it due to adverse selection
And now, for an oversimplification of U.S. flood policy

Three components:

• Floodplain mapping
• Floodplain management
• Flood insurance
And now, for an oversimplification of U.S. flood policy

Based on the 1%, or “100 year Level of Protection”
(44 CFR 65.10)
1% Level of Protection Approach

Out of the floodplain
No insurance required
No building requirements

In the floodplain
No new development
Insurance required
Floodproof houses

Special Flood Hazard Area
(1% annual chance floodplain)
How do we measure achieving 1%?

It doesn’t tell us anything about risk or residual risk. It focuses on the hazard, implies risk can be eliminated.

Has 1% LOP

Does not have 1% LOP

How high is the (base) flood elevation?
What is a 100-year flood anyway?

A “100 year flood” is a flood with a 1% (1 in 100) chance of occurring or being exceeded in any year.

“The last flood came in 1950—I guess the next one will be in 2050.”

“A major flood that comes every 100 years—it’s a worst-case scenario.”

“The Army Corps of Engineers built our levees to last 100 years.”

These are real answers from a 2009 survey.
Using LOP ignores residual risk

Residual risk is the flood risk that remains \textit{after actions have been taken} to reduce that risk

\textit{Adapted from Eisenstein et al (2007)}
Ignoring residual risk has adverse consequences

- Public safety
- Land use
- Infrastructure investment
- Preparedness
Limitations of the LOP approach

• Insurance standard
• Focuses on the hazard, ignores the consequence
• Implies risk can be eliminated
• Favors structural solutions
• Hard to measure
  – Risk reduction
  – Cost-effectiveness
Is there a better approach?
Guidance from other settings

Nuclear Power Plants

Commercial Aviation

Dams

Hazardous Occupations
Risk cannot be eliminated

What level of risk is tolerable?
Risk cannot be eliminated

What level of risk is tolerable?

Chemical Plant in Crosby, TX, flooded during hurricane Harvey.
What do we mean by tolerable risk?

**Tolerable Risk** is the level of risk that people are willing to live with in order to secure certain benefits.
We make decisions everyday on what level of risk is tolerable to us
Principles of Tolerable Risk

Life safety is paramount
Risk cannot be ignored
Absolute safety cannot be guaranteed
Equity and efficiency

ALARP: As Low As Reasonably Practicable
How to use risk analysis and TRG?

1. Identify Options to Reduce Risk
2. Evaluate Options
3. Implement Options and Continuously Review Risk
4. Characterize and Estimate Risk & Uncertainty
Precedent in the United Kingdom

Humber Estuary
Strategy modelling - Maintain 2115
November 2010

Total Risk (£)
0
- 1 - 100
- 101 - 290
- 291 - 500
- 501 - 900
- 901 - 1900
- 1901 - 2900
- 2901 - 5000
- 5001 - 10000
- 10001 - 20000
- 20001 - 50000
- 50001 - 100000
- 100001 - 200000
- 200001 - 500000
- 500001 - 1000000
- > 1000000

Flood Area

HR Wallingford
Working with water
Precedent in the Netherlands

- Individual life risk safety standard
  - EAF: 1/100,000
- Societal risk safety standard
- Risk-based design standards determine levee heights
- Risk-informed “Multi-layered safety”

How to meet the 1/100,000 EAF standard?
- Levee: 1/100,000 water level
- Levee: 1/10,000 water level + nonstructural measures to reduce life safety risk by additional factor of 10
Tolerable Risk Guidance in the US

Best practices identified by USACE and USBR (2015)

Manual encourages risk assessment procedures (revised 2018)
How safe is safe enough?

Informed by analysis and risk assessment.

Tolerable limits must consider
- Individual risks
- Societal risks
- Equity

A policy decision with expert input
California Delta
California Bay Delta and Suisun Marsh

- 1,100 miles levees
- 60 major islands
- Water supply
  - 27 million people
  - 3 million acres
- Ecosystem
- Agriculture
- 500,000 people
Levees are critical to the state’s water supply

Levees
a) impede brackish water from entering the Delta
b) provide a fresh-water path across the Delta
Water supply functions

Water quality (reduce salinity intrusion)
Water supply functions

Water quality (reduce salinity intrusion)

Freshwater corridor to the CVP and SWP pumps
Water supply functions

Water quality (reduce salinity intrusion)

Freshwater corridor to the CVP and SWP pumps

Water supply infrastructure (such as pump stations and aqueducts)
Pre-1800s Delta

- Over 500mi² freshwater wetlands
- Over 380mi² tidal marsh
- Over 500 species of fish and wildlife
Land below sea level

The Delta’s Primary and Secondary Zones

- **Above sea level**
- Sea level to 10 feet below sea level
- 10 to 15 feet below sea level
- 15 feet or more below sea level

Image: PPIC
Delta levees built for one purpose

...Now serve another
Flood risks - hazards

- Flood (high water)
- Earthquake
- Condition of levees
- Subsidence
- Seepage

158 failures since 1900.

Jones Tract, “Sunny day failure” 2004
Flood risks - consequence
2009 Delta Reform Act

Coequal goals

• Provide a more reliable water supply for California
• Protect, restore, and enhance the Delta ecosystem
• *Protect and enhance the Delta as an evolving place*

The coequal goals help define the state’s interests in improving Delta levees
Delta Levees Investment Strategy

**Charge:** Recommend priorities for state investments in Delta levees to reduce flood risk and advance the coequal goals.

Arcadis  Catalyst Group
ESA        Convey
RAND       Shannon & Wilson
           RiverSmith
From Level of Protection to Risk

**Scope of work:** Identify priorities and the appropriate level of protection for each island

**To assign priorities:**
What level of risk is tolerable to key stakeholders?
Which levees to improve first?
Measuring risk in the Delta

- Expected Annual Damage (EAD)
- Expected Annual Fatalities (EAF)
- Water Supply Disruption
- Harm to the Ecosystem
- Harm to Delta as a place
Probability of flooding

Hydrologic
Seismic

- stage recurrence curves
- seismic recurrence curves
- levee fragility curves
Expected Annual Fatalities
Estimating Composite Risk in California

- LIFE LOSS RISK (EAF)
- FLOOD DAMAGE RISK (EAD)
- WATER SUPPLY DISRUPTION
- ECOSYSTEM HARM
- DAMAGE TO DELTA AS A PLACE
Results

- Identified high risk islands
- Set priorities for investment
- Nonstructural measures recommended in lower risk areas
- Open and transparent basis for prioritizing investments
- Basis for amending the Delta Plan recommendations
Conclusions and other Applications
Why a tolerable risk approach?

• Communicates risk clearly
• *How safe is safe enough?*
• Identifies priorities and what to do first
• Enables evaluation and selection of measures from full suite of options
• Efficient use of public resources
• Promotes equity and transparency
• Recognizes that absolute protection is not possible
Applications in California

- Integrated water management plans
- Floodplain management plans
- Central Valley Flood Protection Plan (updates and programs)
- Small communities flood risk reduction
- Vegetation on levees issues
- Sea level rise adaptation
- Capital improvement planning
- Hazard Mitigation Planning
Thank You!

Image: Jessica Ludy
For more information

**Delta Levees Investment Strategy**
http://deltacouncil.ca.gov/delta-levees-investment-strategy

**Geo Risk 2017: Risk Analysis of Vegetation on Levees**
http://ascelibrary.org/doi/10.1061/9780784480717.018

**Geostrata, March, 2017**

**Civil Engineering, September 2016**
http://cedb.asce.org/CEDBsearch/record.jsp?dockey=0432079
For more information

Best practices identified by USACE and USBR (2015)

Revised EM 1110-2-1913 (forthcoming)
For more information

Exploration of Tolerable Risk Guidelines

HSE Reducing Risks, Protecting People