Using Risk Analysis to Inform Levee Investment Priorities in the California and Dutch Deltas

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Larry Roth, GE PE (Arcadis)
How the lowlands 5,000 miles apart left the dark side for a risk-informed approach

Jessica Ludy, CFM;
Larry Roth, GE PE
Dutch lesson

• Hoogwater
• Dijk
• Droge voeten

*Dutch people are direct!*

*Dutch people love football.*

*Dutch people are very proud of their dikes.*
A remarkable paradigm shift
A remarkable paradigm shift

Flood control
“level of protection”
Evolution in thinking

Recognition of unacceptable consequences

Flood control
Evolution in thinking

Recognition of unacceptable consequences

Flood control

Flood risk management
Today’s discussion

Risk & tolerable risk guidelines

A tale of two Deltas

Risk-informed decisions in the Deltas
Risk and Tolerable Risk guidelines
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
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 & communicating risk
- Where are risks the greatest?
- What actions to take?
- Are risks tolerable? Or is more risk reduction warranted?
- Measuring the cost effectiveness of measures
What do we mean by tolerable?
Consider that risk cannot be eliminated.
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
Yet with floods, we focus on levels of protection (LOP)

Probability

“100-yr level of protection”
44 CFR 65.10
Measured with a water level.
Addresses only the hazard.

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

Risk = Probability x Consequences

Image adapted from HR Wallingford and Anna Serra Llobet
Limitations of the LOP approach

- Implies risk can be eliminated
- Focus on 1% water level
  - What if that isn’t safe enough?
- Favors structural options
- Basically an insurance standard

The one-percent annual chance LOP is not a safety standard.
Using LOP ignores residual risk

Residual risk is the flood risk that remains after actions have been taken to reduce that risk.

Adapted from Eisenstein et al (2007)
Principles of Tolerable Risk

- Life safety is paramount
- Risk cannot be ignored (*no matter how small it may seem*)
- Absolute safety cannot be guaranteed
- Equity and efficiency
Where else is tolerable risk used?

- Nuclear Power Plants
- Commercial Aviation
- Dams
- Hazardous Occupations
United Kingdom uses risk to inform priorities
Tolerable Risk Guidance in the U.S.

Best practices identified by USACE and USBR (2015)

USACE Design and Construction of Levees (2016) encourages risk assessment procedures
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 Risk
How safe is safe enough?

• Informed by analysis, risk assessment, and communication

• Considers:
  • Individual risks
  • Societal risks
  • Equity
  - Use F-N plots to inform decisions

A policy decision with expert input
A Tale of Two Deltas
Where are we?
A tale of two Deltas
# A tale of two Deltas

<table>
<thead>
<tr>
<th></th>
<th>Netherlands Delta</th>
<th>California Delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miles of levees*</td>
<td>2,250 (primary)</td>
<td>1,100</td>
</tr>
<tr>
<td>Year reclaimed</td>
<td>1100</td>
<td>1850s</td>
</tr>
<tr>
<td>Land below sea level</td>
<td>Yes (-9 feet-ish)</td>
<td>Yes (-24 feet)</td>
</tr>
<tr>
<td>Population in Delta</td>
<td>9 million</td>
<td>500,000</td>
</tr>
<tr>
<td>Flood of record</td>
<td>1953</td>
<td>1862</td>
</tr>
<tr>
<td>Major concern</td>
<td>Life safety, economic development</td>
<td>Water supply reliability</td>
</tr>
</tbody>
</table>
California Delta

Courtesy: Delta Stewardship Council
Climate and major rivers

Netherlands: Marine

Rhine River
766 mi

California: Mediterranean

Sacramento
400 mi

San Joaquin
365 mi

Water Resources of California
Streams, Lakes, and Reservoirs
Deltas used to be wetlands: “Polderen”
Reclamation in Netherlands

Oldest dike 100-200 BCE
River embankments 1100
Reclamation in California

1850’s Westward movement and gold rush
Levees & Management

2,250 miles primary levees
26 “Waterschappen”
Oldest democratic inst. in EU

http://www.topomania.net/mapinfo/Waterschappen%20van%20Nederland
Levees & Management

1,100 Miles primary levees
65 “islands” or polders
Over 100 Reclamation Districts
Below sea-level

Hoekstra 2006

Ranstad

Public Policy Inst. California
Below sea-level

Ranstad

Stockton

Sacramento

Hoekstra 2006

Public Policy Inst. California

Ludy 2013
Levees are critical for navigation

Netherlands

California

Adrian Mendoza © 2009
The Sacramento Deep Water Ship Channel in the California Delta
www.amendozo.com
Levees are critical for agriculture

Netherlands  California
Dikes built for one purpose now serve many others.
Dikes built for one purpose now serve many others
Levees disconnect floodplains
## Similar hazards and consequences

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floods</td>
<td>Life</td>
</tr>
<tr>
<td>Earthquakes*</td>
<td>Property</td>
</tr>
<tr>
<td>Subsidence</td>
<td>Infrastructure</td>
</tr>
<tr>
<td>Seepage</td>
<td>Water Supply</td>
</tr>
<tr>
<td>Sea-level rise</td>
<td>Ecosystem</td>
</tr>
</tbody>
</table>

* Earthquakes may cause further hazards and consequences beyond those listed.
Flood of record (California)

1861-1862: Atmospheric River flood

“Inland Sea”
Flood of record (Netherlands)

1953
North Sea Flood
70,000 Evacuated
1,835 casualties
€450-680M damages
How did these floods affect policy?
Levee failures since flood of record?

Netherlands:

Levee failures = World Cup titles
Levee failures since flood of record?

Netherlands:

Levee failures = world cup titles

California:

~ 200
Unacceptable risk: *Never Again!*

The Delta Works (1958-1997)

Designed for Dry Feet, 2006
Unacceptable risk: Never Again!

Consequences-based approach to setting safety standards
California: (after a few more floods)

Developed Sacramento Valley Flood System

Unwritten: let’s just build a little bit higher than the last time.

Until... Katrina
Finally: Where are we today?
Risk-informed decision making
Recognition of unacceptable and increasing risks

The Delta Plan
Ensuring a reliable water supply for California, a healthy Delta ecosystem, and a place of enduring value

Delta Programme 2015
Working on the delta
The decisions to keep the Netherlands safe and liveable
Delta Levees Investment Strategy

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

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

Scope of work:
Identify priorities and the appropriate level of protection

To assign priorities:
• What is the risk?
• What level of risk is tolerable to key stakeholders?
• Which levees to improve first?
What is the risk?

Probability of flooding
- stage recurrence
- seismic recurrence

Consequences of flooding
- Life
- Property
- Infrastructure
- Ecosystem assets
- Water supply and water quality

Image adapted from HR Wallingford and Anna Serra Llobet
Specific metrics help characterize risk in the Delta

- Expected Annual Damage (EAD)
- Expected Annual Fatalities (EAF)
- Damage to Delta as a place
- Water Supply Disruption
- Harm to the Ecosystem
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
• Complimentary risk management measures
• Open and transparent basis for prioritizing investments
• Amending the Delta Plan recommendations
The Dutch Approach

Characterize risk of flooding

Expected Annual Damage (EAD)

Expected Annual Fatalities (EAF)
Results: Dutch approach more comprehensive

- Life-risk safety standard: 1/100,000 chance of dying from a flood per year
- Additional, higher safety standards in areas of great “societal risk”
- Investment priorities determined by economic efficiency
- “Multi-layered safety” where levee investment cannot be justified
- Benefit-cost determines levee height
Using risk analysis is important in informing flood management decisions!

- What is the risk?
- Recognize intolerable risks
- Allocate scarce resources
- Life safety
- Communicate Residual risk
- What actions to take?

Flood risk management of the hazard and the consequences
For more information

*Geostrata, March, 2016*


*Civil Engineering, September 2016*

For more information

Exploration of Tolerable Risk Guidelines

HSE Reducing Risks, Protecting People
For more information

Delta Levees Investment Strategy

http://deltacouncil.ca.gov/delta-levees-investment-strategy
Thank you!

Jludy@esassoc.com
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Probability of flooding

Hydrologic
Seismic
Expected Annual Fatalities
Expected Annual Damages
Water supply risk

The Delta supplies water to 25 million people and 4 million acres farmland.
F-N PLOTS

FREQUENCY OF AN ADVERSE EVENT

CONSEQUENCES
F-N PLOTS

FREQUENCY OF AN ADVERSE EVENT

CONSEQUENCES

NOT TOLERABLE
F-N PLOTS

FREQUENCY OF AN ADVERSE EVENT

CONSEQUENCES

NOT TOLERABLE

TOLERABLE

Limit of Tolerable Risk (judgement)
F-N PLOTS

FREQUENCY OF AN ADVERSE EVENT

CONSEQUENCES

CURRENT RISK
F-N PLOTS

- Frequency of an adverse event
- Consequences

- Levees deteriorate
- Population grows

Current risk
F-N PLOTS

- **CURRENT RISK**
  - IMPROVE LEVEES
  - IMPROVE EVACUATION
  - LEVEES DETERIORATE
  - POPULATION GROWS

- **FREQUENCY OF AN ADVERSE EVENT**

- **CONSEQUENCES**

25 September 2017