Accounting for sea-level rise and other climate-related hazards in infrastructure design

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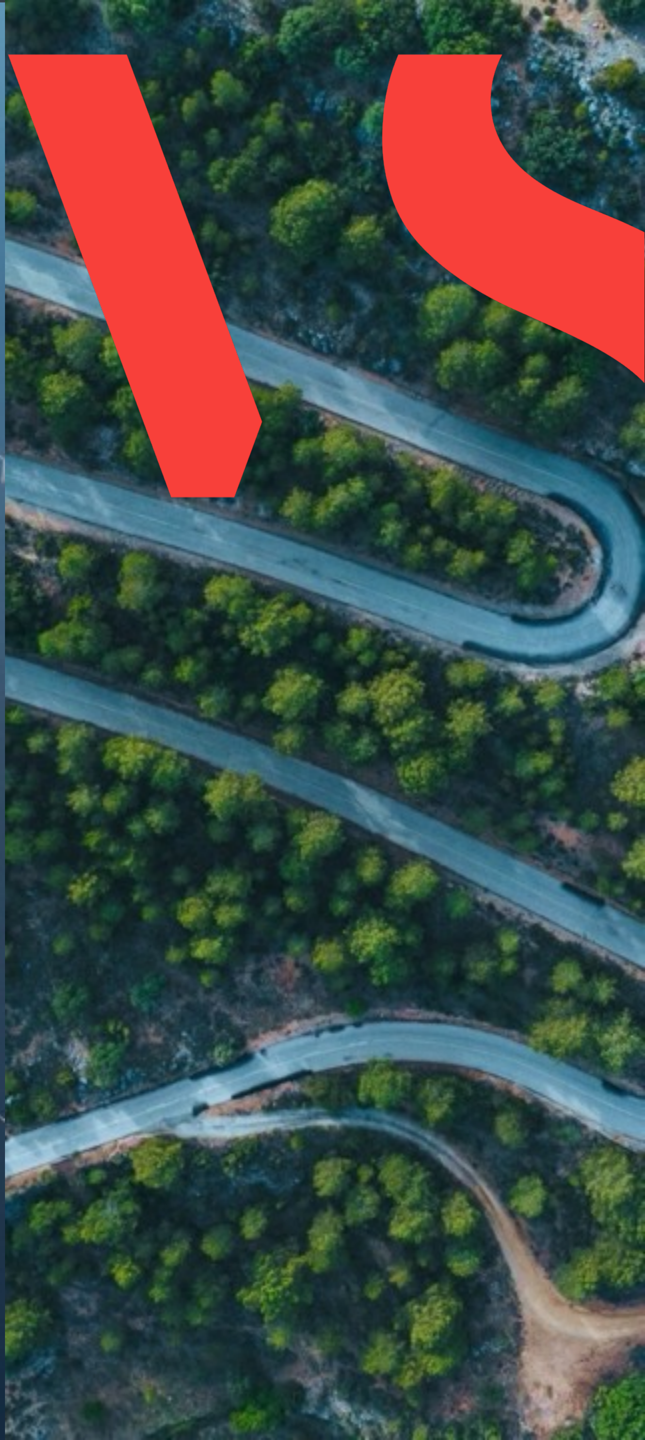
WSP Earth & Environment

NH44A: Climate-Informed Risk Assessment for Extreme Events IV Oral



Motivation: Non-stationarity and civil engineering design

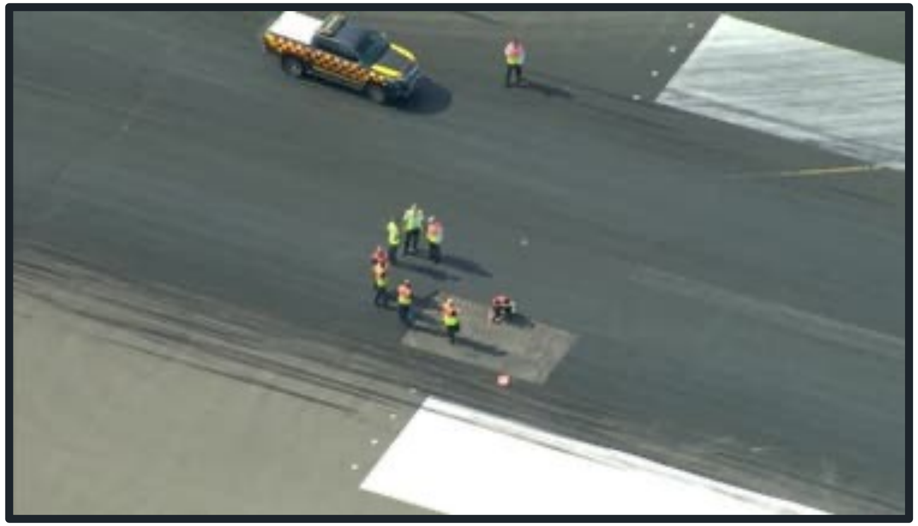
- Stationarity Assumption - “the past is key to the future”
  - i.e., design to historical conditions
- Non-stationarity upends much of traditional civil engineering practice
  - “Stationarity is Dead…” Milly et al. (2008)
  - Historical design criteria are becoming:
    - more likely, more intense, and persisting longer (in some cases)

Properly sizing facility cooling towers

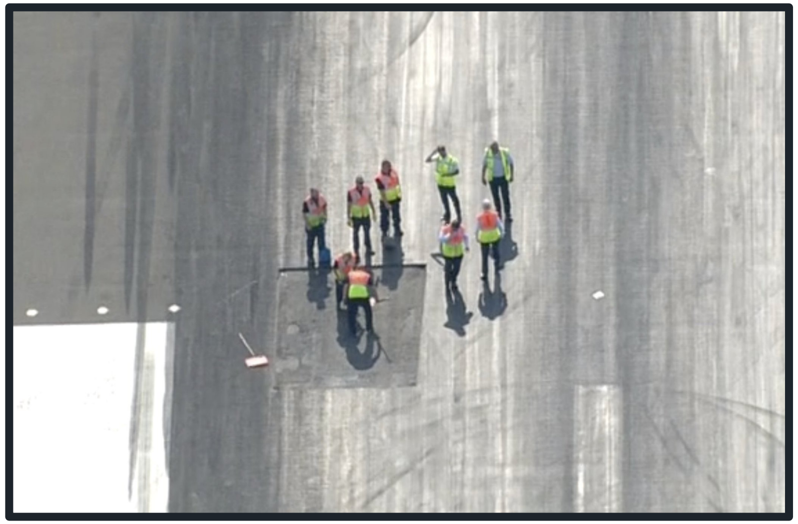
wsp

Selecting heat-tolerant materials

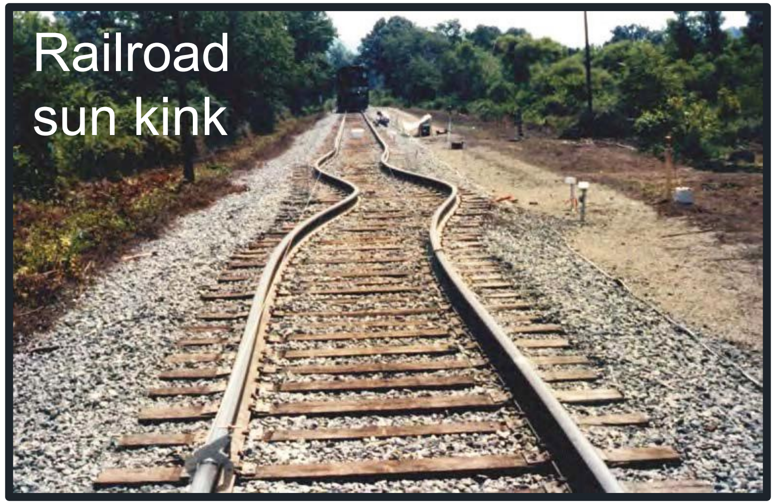
Luton Airport Runway "melt" (London, England)



Reuters



Telegraph (UK)



National Railroad Museum

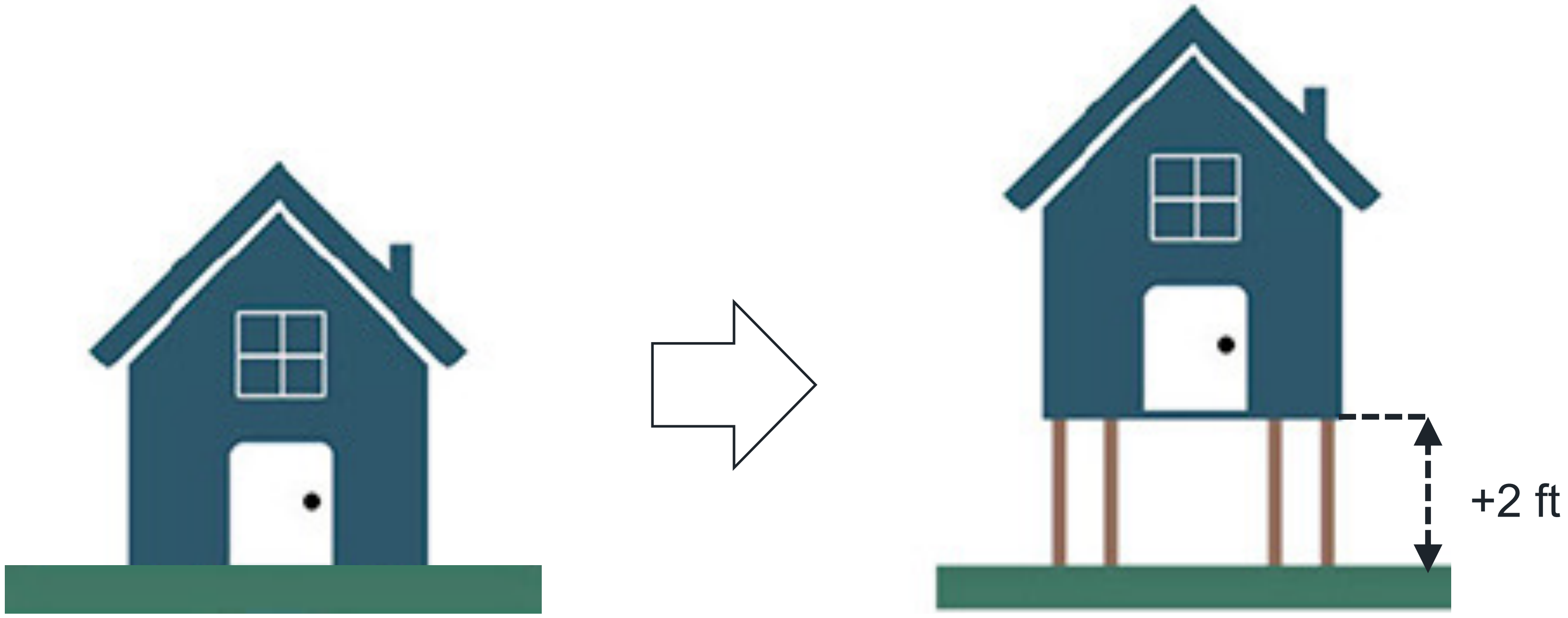
Selecting coastal facility flood design elevations

Hurricane Sandy, Lower Manhattan

Christos Pathiakis/ Getty Images

Problem: +2 Feet of sea-level rise by 2075

Solution: Elevate +2 feet?

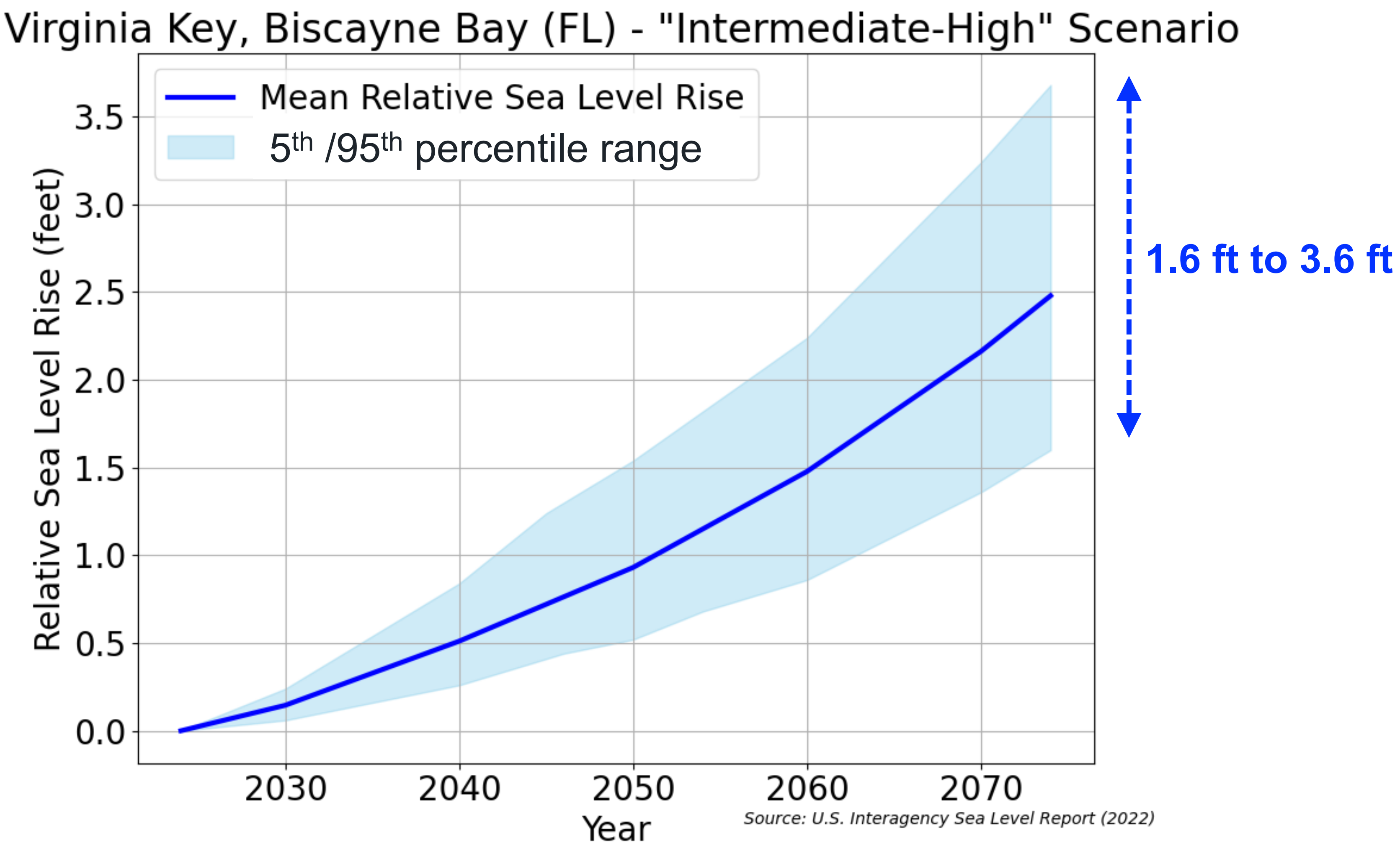


Protected against **current** 1% AEP (11 feet)   Protected against **future** 1% AEP (13 feet)

AEP = Annual Exceedance Probability

Values are illustrative

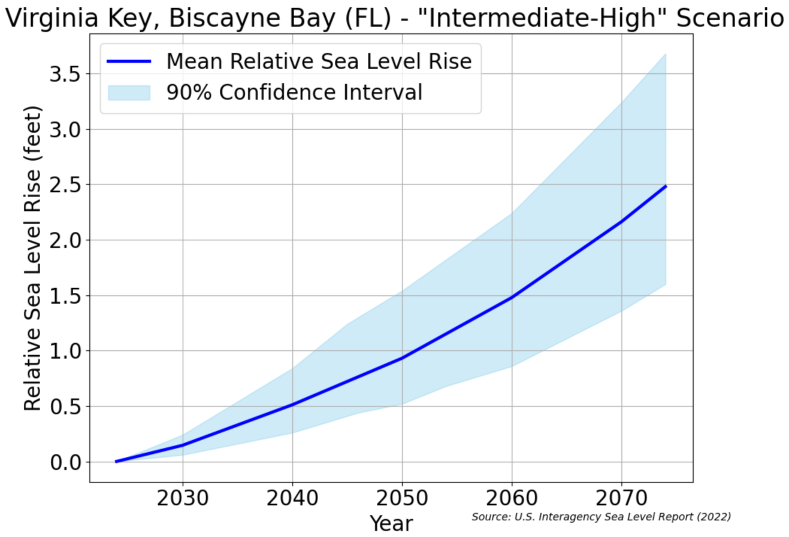
...but sea-level rise and other climate-related hazards are uncertain!



Source: U.S. Interagency Sea Level Report (2022)

Presentation Goals:

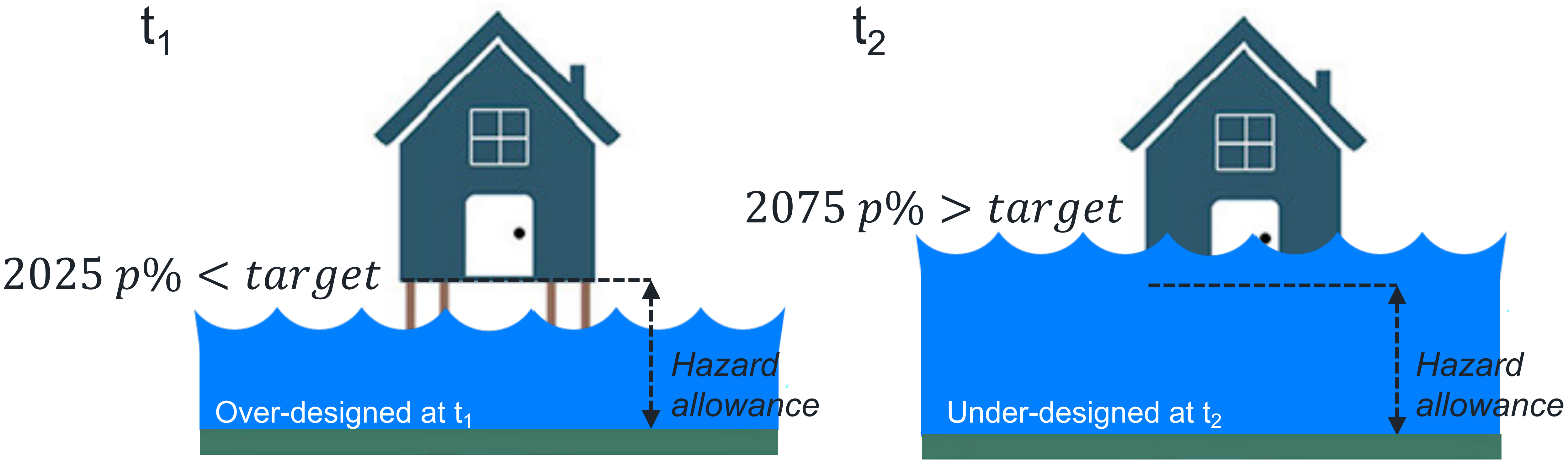
1. How to consider time evolving climate-related hazards that are uncertain?
    - “Allowances”



2. How to consider varying stakeholder risk tolerances?

A **hazard allowance** is a design adjustment needed to ensure that a targeted annual exceedance probability (AEP) $p\%$ is kept constant under evolving and uncertain hazard conditions between t_1 and t_2

Hunter (2012), Rootzén and Katz (2013), Buchanan et al. (2016)



On average, elevation of targeted AEP is below the hazard allowance (e.g., a vertical adjustment)

Hazard allowance math

Buchanan et al. (2016) Climatic Change

$$N_e(z,t) = \mathrm{E}[N(z-\Delta_t)]$$

Expected number of exceedances of *z* in year *t*

Distribution describing frequency of extremes

Climate adjustment
e.g., Monte Carlo samples generated from a climate projection distribution at time t

$$\widetilde{N}_e(z,t_1,t_2) = \frac{1}{t_1 - t_2}\int_{t_1}^{t_2} N_e(z,t)\,dt$$

Expected number of exceedances of *z* in a given year between t_1 and t_2

The hazard allowance is the value of *z* such that $\widetilde{N}_e(z,t_1,t_2) = p\%$

Solve for z numerically

Hazard allowance worked example

User Input

1. Targeted AEP

1 % AEP

Extreme Coastal Water Levels

2. Time Frame

Maintain Acceptable Risk Tolerance over Design Life

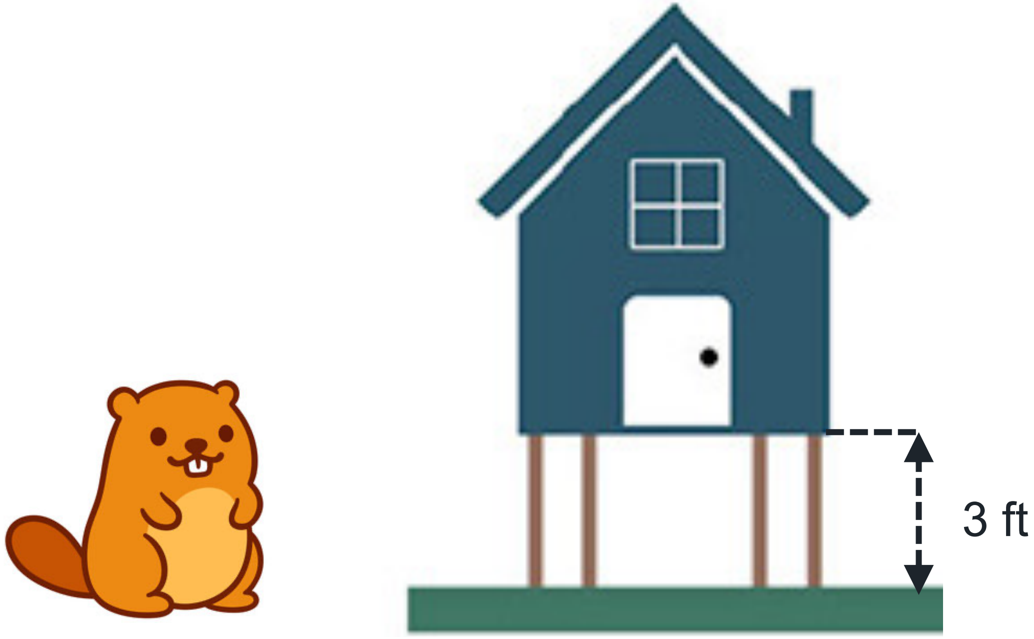
Start Year 2025

End Year 2075

Hazard Allowance

3 feet

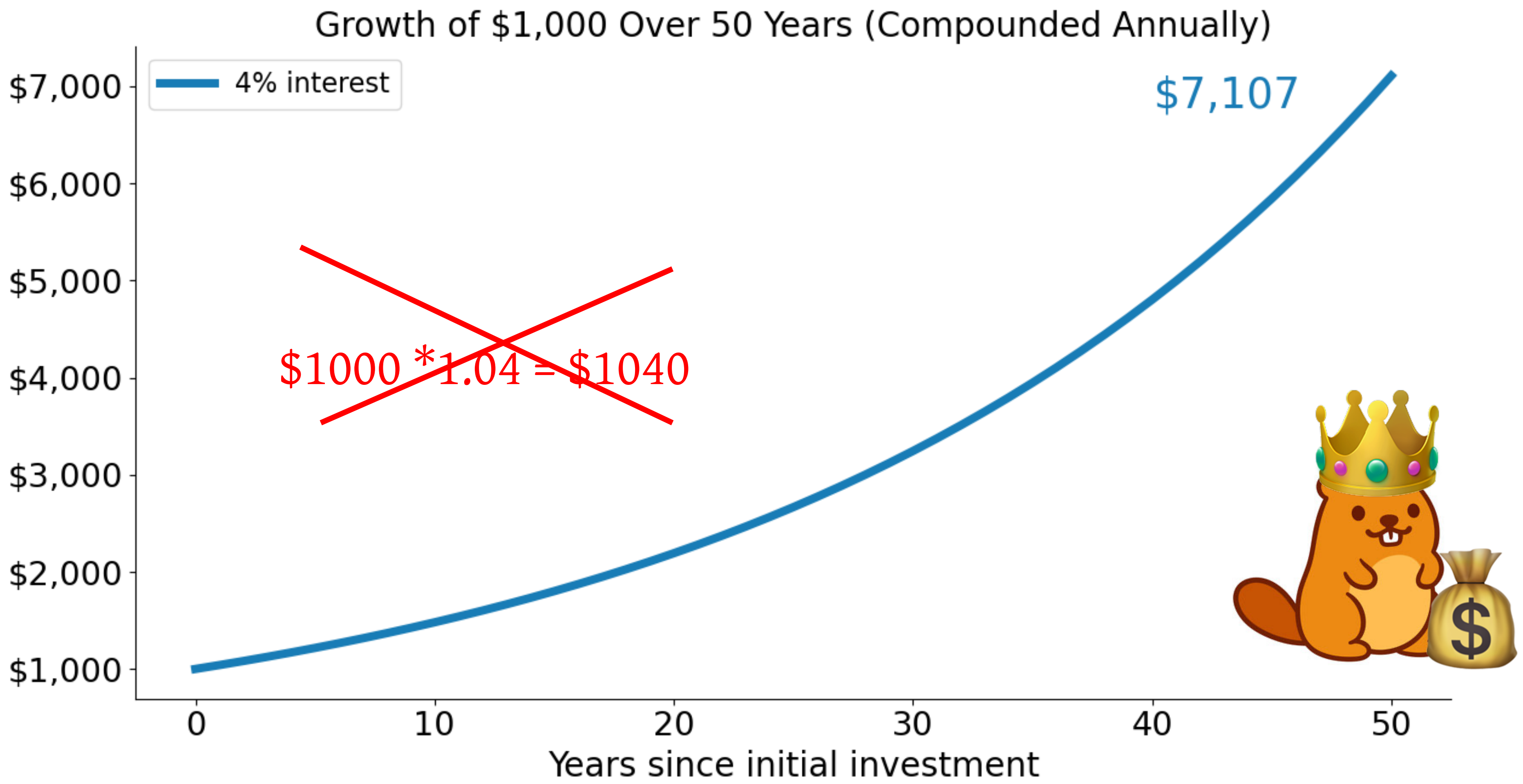
Value is illustrative



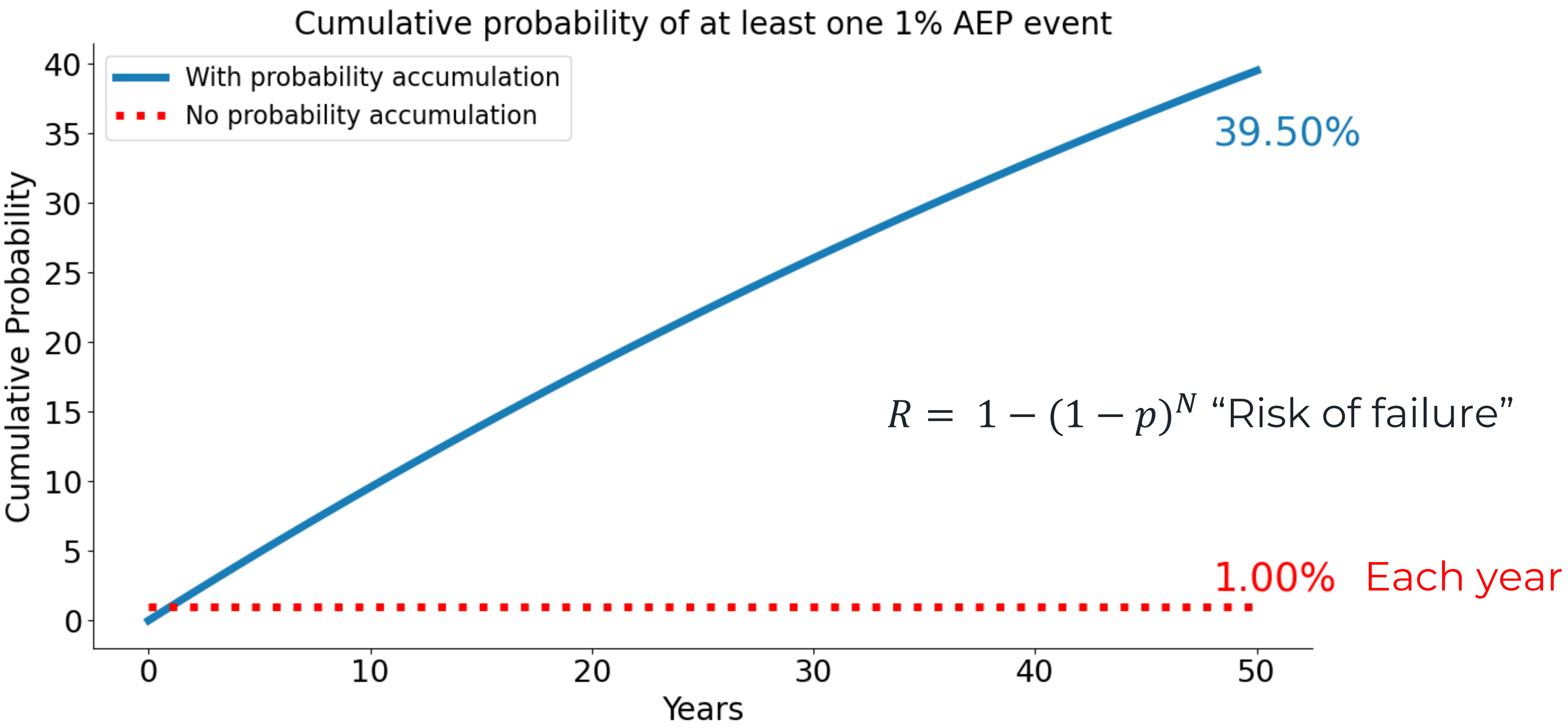
Protected against 1% AEP (average year)

Is the 1% risk of failure each year acceptable?

Consider the growth of $1000 at 4% interest



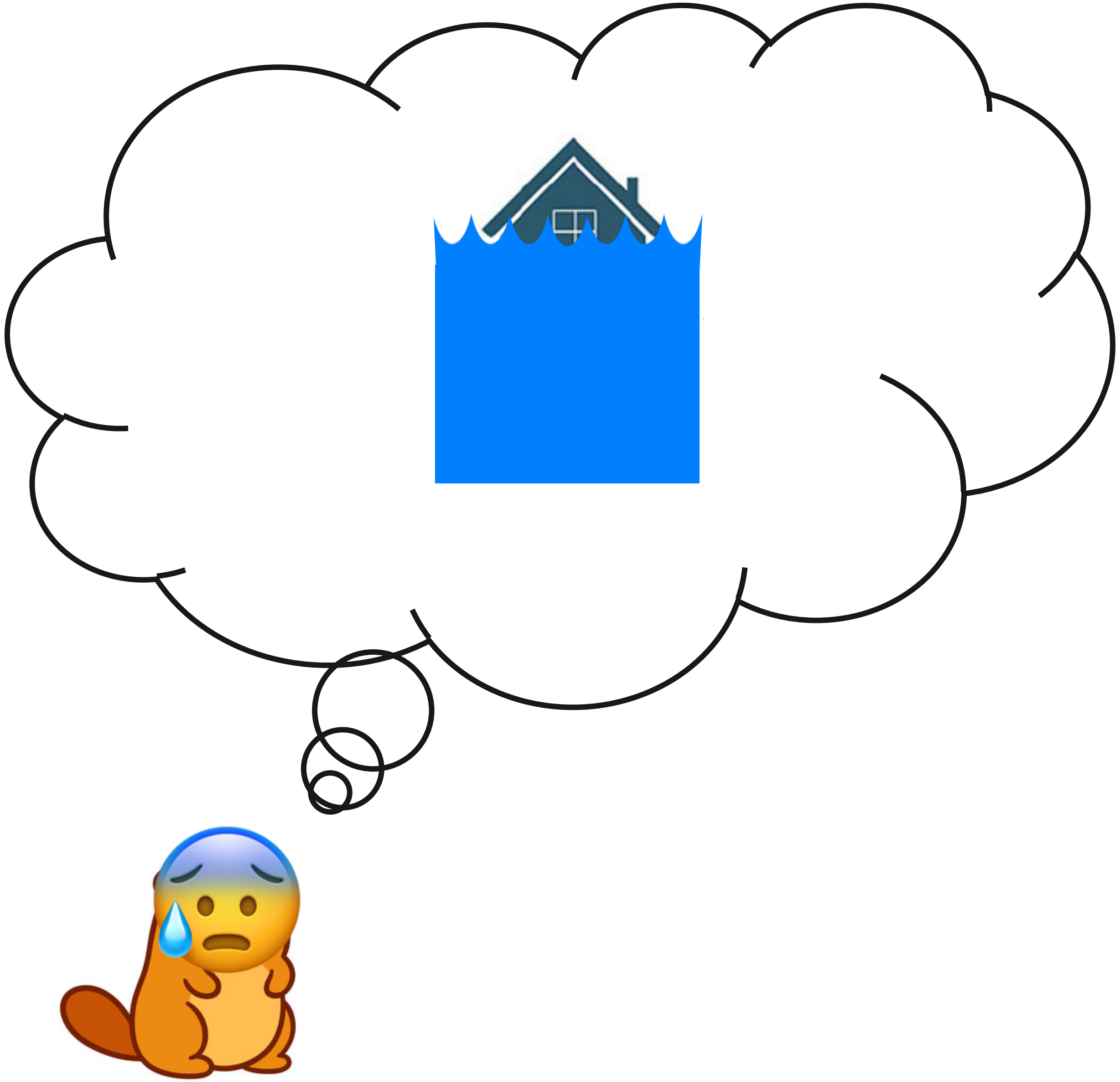
Over a long time horizon, “rare events” are likely to occur at least once



$R = 1 - (1 - p)^N$ “Risk of failure”

The 1% AEP has a about a 2-in-5 chance of being exceeded over a period of 50 years!

“A 1% AEP accumulates to a 2-in-5 chance of being exceeded over 50 years”



Compound probability tables communicate the probability of at least one exceedance over N-years

Design Criteria
As Annual Exceedance Probability

Design Criteria (Annual Exceedance Probability)	Design Life (years) 25	50	75	100
20.0%	99.6%	100.0%	100.0%	100.0%
10.0%	92.8%	99.5%	100.0%	100.0%
2.0%	39.7%	63.6%	78.0%	86.7%
1.0%	22.2%	39.5%	52.9%	63.4%
0.2%	4.9%	9.5%	13.9%	18.1%
0.1%	1.2%	2.5%	3.7%	4.9%

Unacceptable Risk?

Acceptable Risk?

1. Targeted AEP

0.2 % AEP

A 1-in-10 chance of being exceeded over 50 years

2. Time Frame

Maintain acceptable risk tolerance over design life

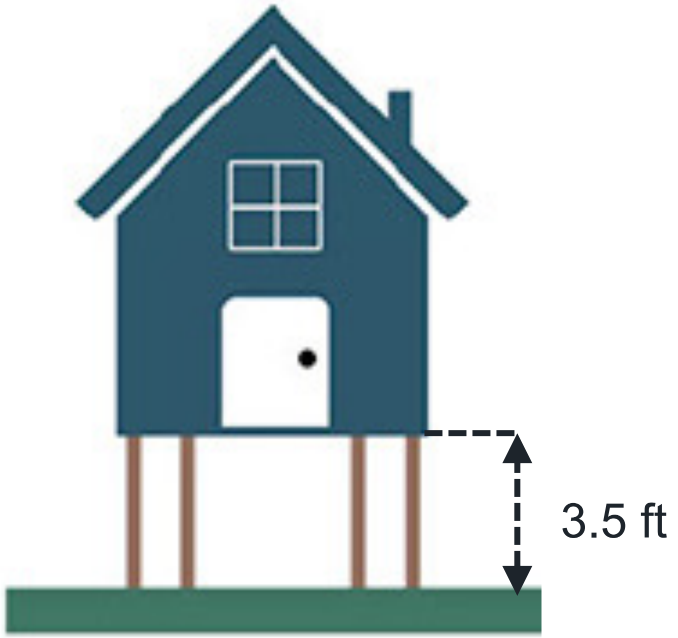
Start Year 2025

End Year 2075

Hazard Allowance

3.5 feet

Value is illustrative



Protected against 0.2% AEP (average year)

Summary

- Non-stationary extremes disrupt traditional engineering practice
- Allowances account for uncertain, evolving climate-related hazard conditions over time
- The compounding of probabilities should be considered when factoring in risk tolerances

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