Adaptive infrastructure planning in a non-stationary uncertain environment

Dr Rob Bell
NIWA, Hamilton
New Zealand

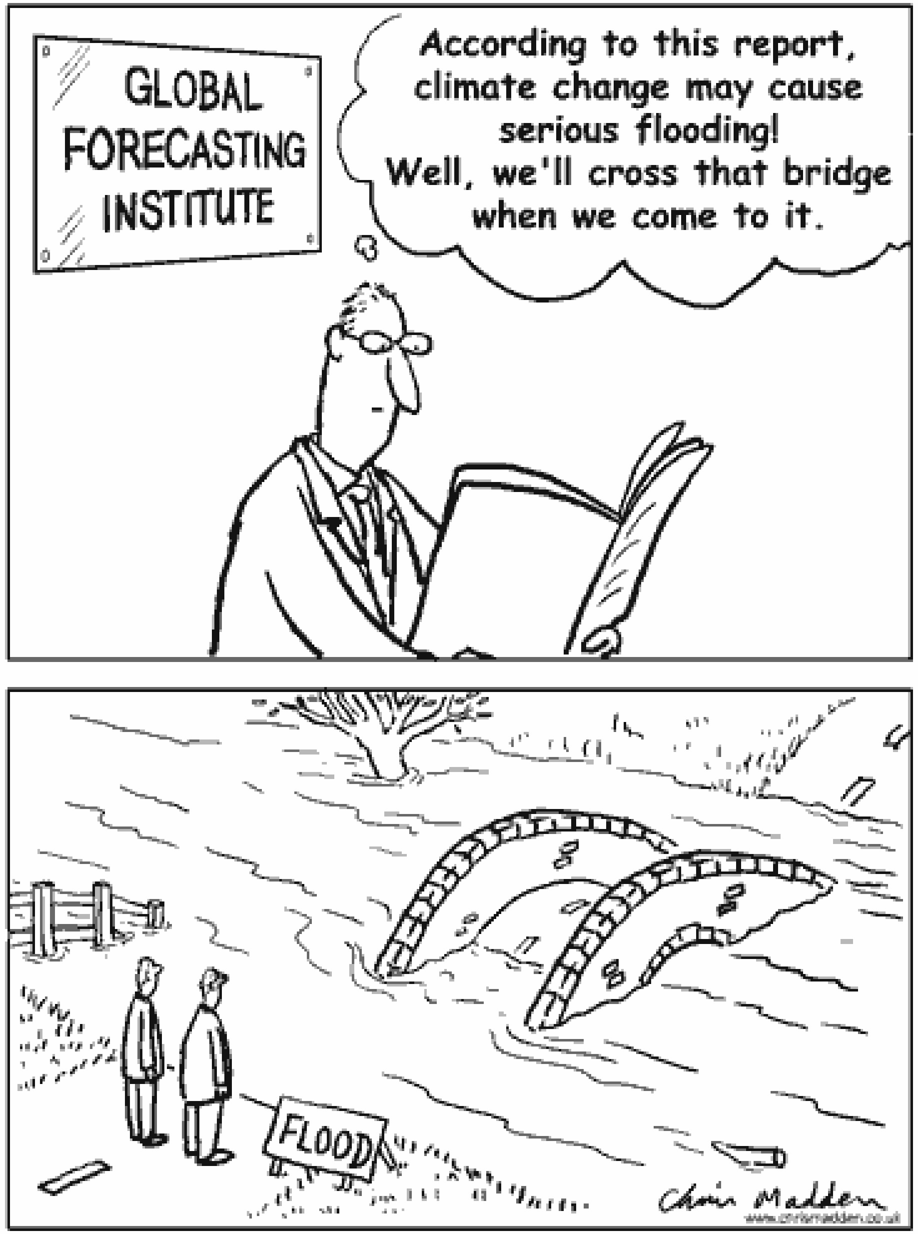
How adaptive is our “long-lived” infrastructure?

- Emerging & future changes:
  - technology (smarts, materials, modes)
  - social licence
  - funding models
  - population (rural/urban)
  - de-carbonising the economy
  - climate + environmental change (e.g. water use, water quality)

- If the <u>rate of change</u> (demands, risk exposure) <u>outstrips</u> cycle time & inertia for infrastructure renewal

  ⇒ decouples from the socio-environment system it serves

Fordham Law

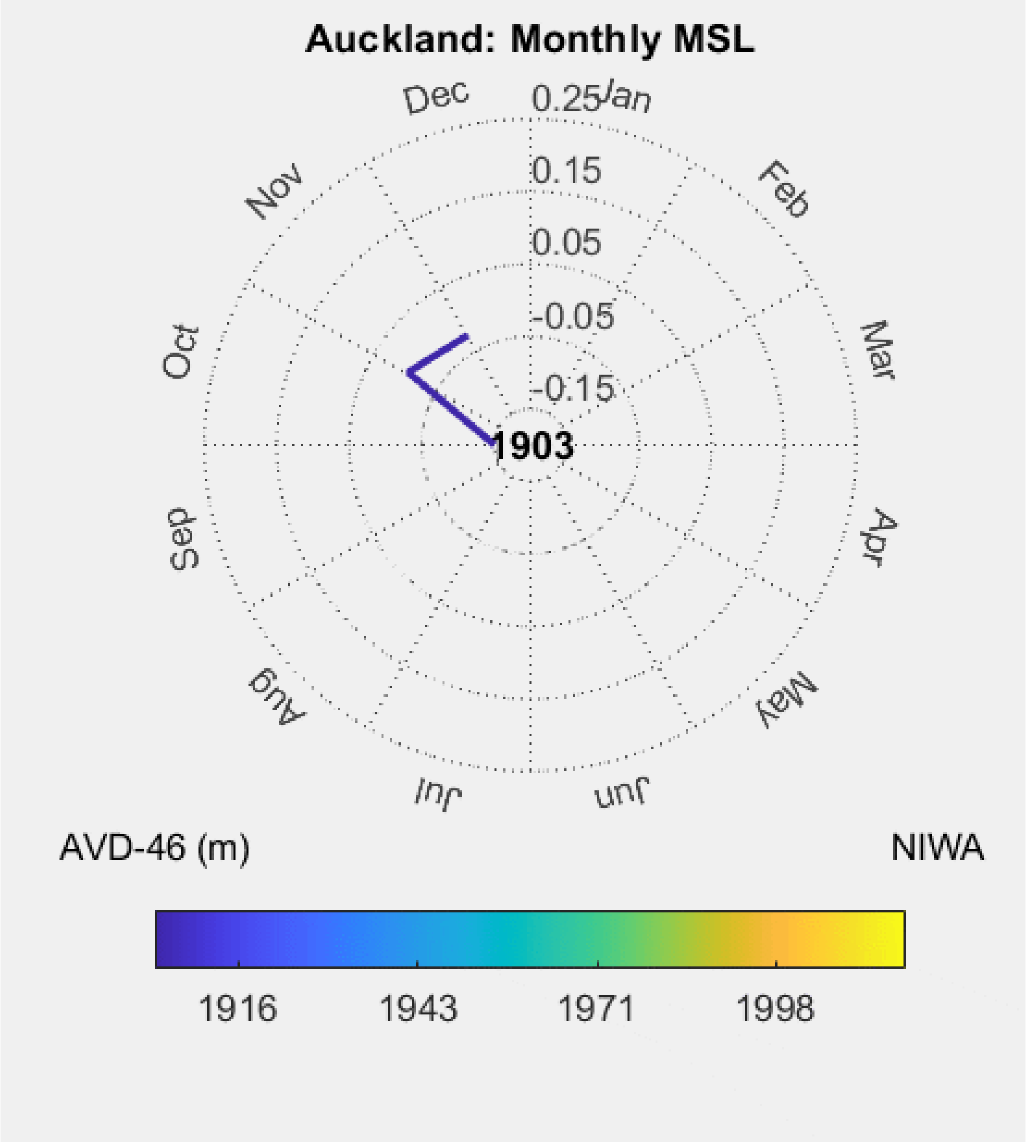


Climate change is one of the rapid changes we're confronting

Coventional risk management & design focused on reducing risk from high-impact hazard events

Climate adaptation focused on adapting to gradual change and more frequent events (cumulative risk) over decade scales

Climate norms and extremes (hazards)

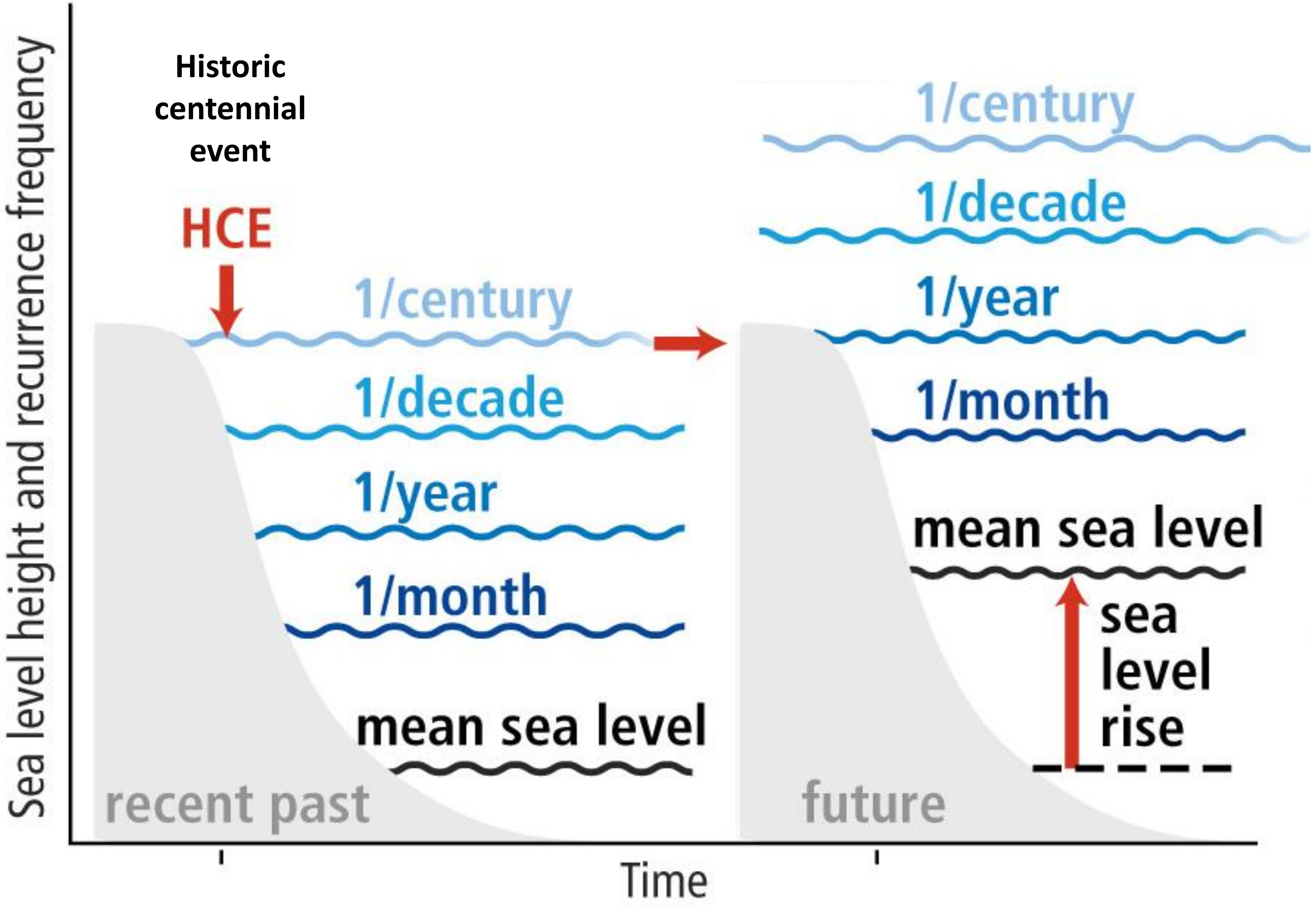


- NZ's built environment has used engineering standards for extreme events assuming **stationarity*** – only uncertainty is "stochastic"
- Need to stop using "black swans" or "perfect storm" as apology for failure of infrastructure
- Trends and changes in variability for weather-related hazards and sea-level rise means statistics of past occurrences cannot be relied on for the future
- Standards, guidance and designs need to be adaptable to accommodate a range of possible futures – "scenario or deep uncertainty"

Stationarity is essentially dead

***Stationarity** means that the statistical properties of a process generating a time series **do not change over time**

Changing frequency of exteme coastal flooding



For NZ, change in frequency from 1/century to 1/year:

- after **modest** sea rises of 30-45 cm
- occurs from **2045 onwards**

Special Report: Oceans & Cryosphere-IPCC (Sept 2019)

New “norm”: Changing risk & thresholds

Context

- Legacy of long-lived infrastructure based on stationarity
- More frequent hazard extremes - cumulative consequences (e.g. nuisance <u>and</u> extreme flooding)
- Past events or extreme analysis not a reliable guide for future risks (changes invalidate stationarity)
- <u>Uncertainties mount up</u>: different possible futures, knowledge, models, viability of adaptation options, funding …..
- <u>Standards and design</u>: conventional “*predict & act*” and single-investment approach – need to shift to adaptive approaches

Adaptive design & operation = agility + flexibility

Adaptive paradigm shift needed

Do we continually react, clean up & stay put?

Or do we anticipate and adapt?

- Build back better or somewhere else
- Can we be adaptive and work with future uncertainty
- Timely investment - not too soon, or too late, nor gold plating projects (worst case) taking a single investment perspective
- Reduce or limit land-use & infrastructure development in hazard-prone areas – put brakes on now to stem risk

Pre-conditions for adaptive infrastructure

Flexible: willingness to respond & ability to modify (to changing demands & stressors)

Agile: maintaining functions (physical structure + governance, practice, standards, asset management, 4R's) ahead of ongoing change (decadal now!)

Why do we use adaptive planning/design?

Sven Martin

If we don't, we:

- **perpetuate infrastructure forms despite need to change tack (= path dependency)**
- **raise expectations of 'safety' or LoS with rising residual risk**
- **increase future adjustment costs**

Decisions have to be made under conditions of **uncertainty and changing risk** on actions that persist over long timeframes … across organisations and actors … interdependent scales of governance/funding

This requires processes and practices that **fit the problem space** (uncertainty and changing risk dynamics)

AND

The mediation of different values and preferences **today and for future generations**

When do we use adaptive planning/design?

M Allis- NIWA

- Where there is high uncertainty **and/or** disagreements (experts, stakeholders, community …)
- For existing developments and their intensification (to stress-test options & develop transition pathways)
- For new developments (long lived, high value, and high consequence) – can it be sequenced or switch to alternative?
- To consider LoS and consequences of a range of scenarios
- To build pathways for flexibility and agility

Adaptive approaches to address shallow *vs* deep uncertainty

- **Robust Decision Making (RDM)** → identify alternatives or approaches that are robust under a range of conditions - to **yield better decisions under conditions of deep uncertainty.** [Used for Port of LA - Raise wharves in next upgrade?]

- **Dynamic Adaptive Pathways Planning (DAPP)**: considers a range of short-term actions and long-term options to avoid a pre-agreed Adaptation Threshold (AT) . It produces an overview of alternative pathways into the future and when to switch or sequence.

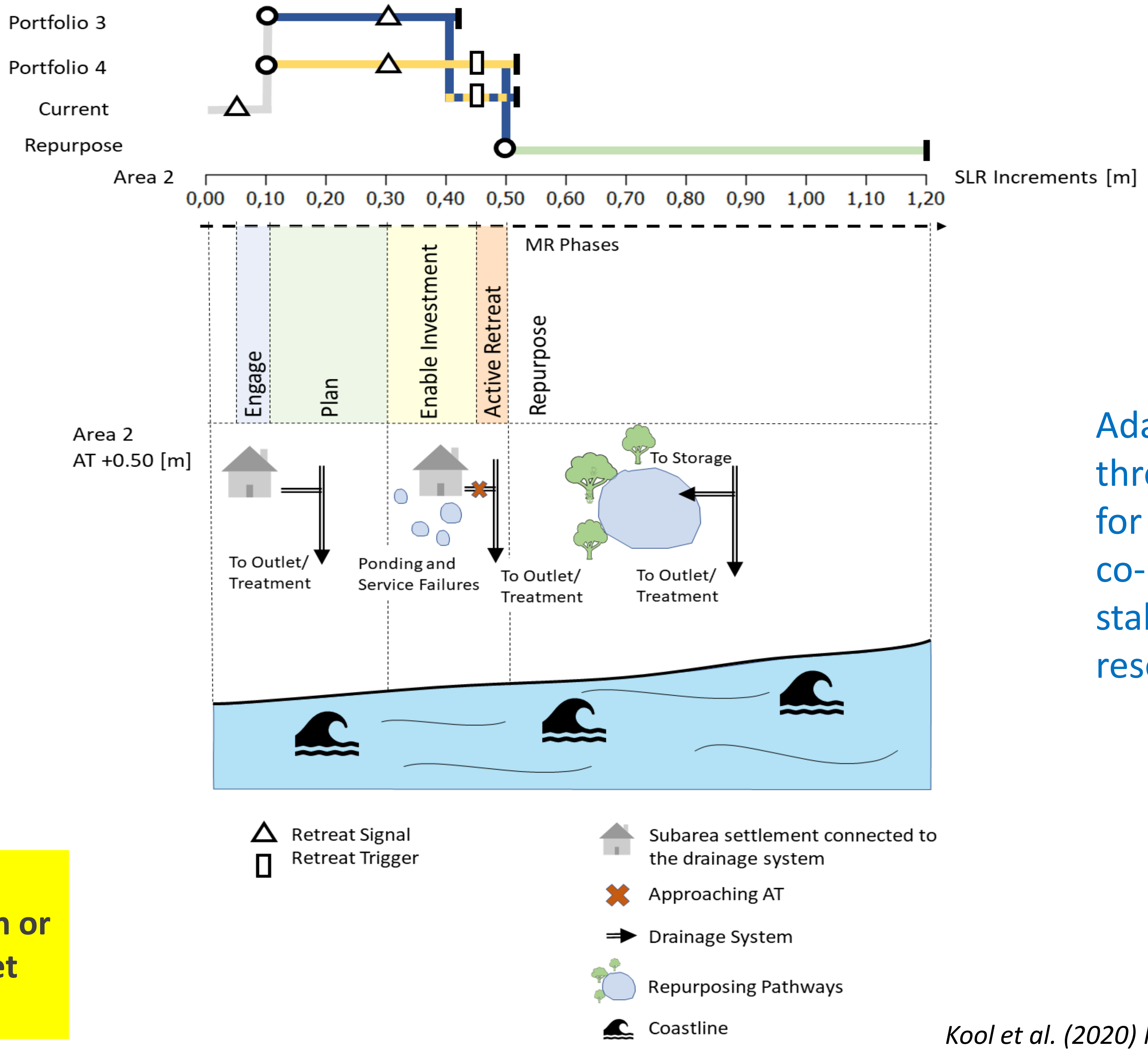
- **Engineering or Real Options Analysis (EOA)**: process of assigning economic value to technical flexibility or the cost of delay e.g. Real Options Analysis economic evaluation. [Used in Hawke's Bay Coastal Strategy and Lower Hutt ("room of the river") with DAPP]

- **Expected Utility Maximization** (risk-based approaches) – identify the adaptation alternative that has the best expected outcome (optimization). Only suitable for stochastic uncertainty, not deep or scenario uncertainty (because what is optimal?)

Marchau V., Walker W., Bloemen P., Popper S. (eds) 2019. *Decision Making under Deep Uncertainty.* Springer (FREE)
https://www.springer.com/gp/book/9783030052515

Dynamic adaptive pathways planning (DAPP):

managed retreat: 2-waters network



Adaptation thresholds (AT) for network co-produced by stakeholders and researchers

Underlying Q: Under what conditions or LoS does the plan or portfolio option no longer meet objectives?

Kool et al. (2020) Infrastructures journal

What questions do we ask in DAPP?

R Bell

Storm surge doors: Hamburg (Germany)

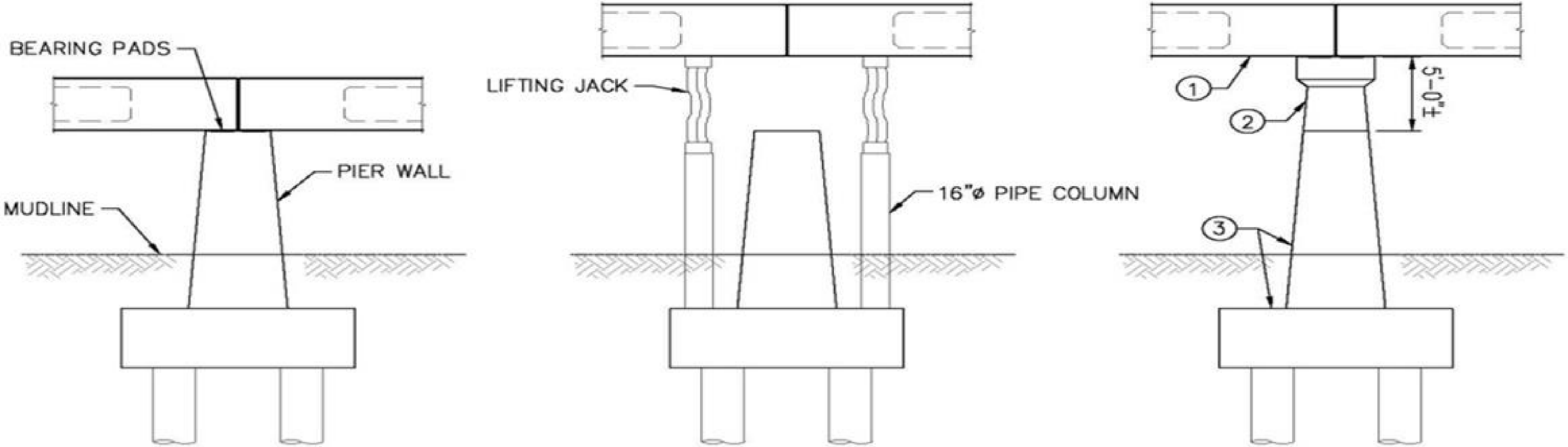
- Will the option meet the long-term objective or Level of Service?
- Will the action/option increase or decrease direct & indirect exposure to the changing risk?
- What combination of options (pathway) provide the greatest flexibility?
- What are the side effects?
- What other measures enable objectives to be met? (e.g. warning signals and decision triggers, planning rules, monitor Levels of Service)

Adapted from Haasnoot et al. (2013) and MfE coastal guidance

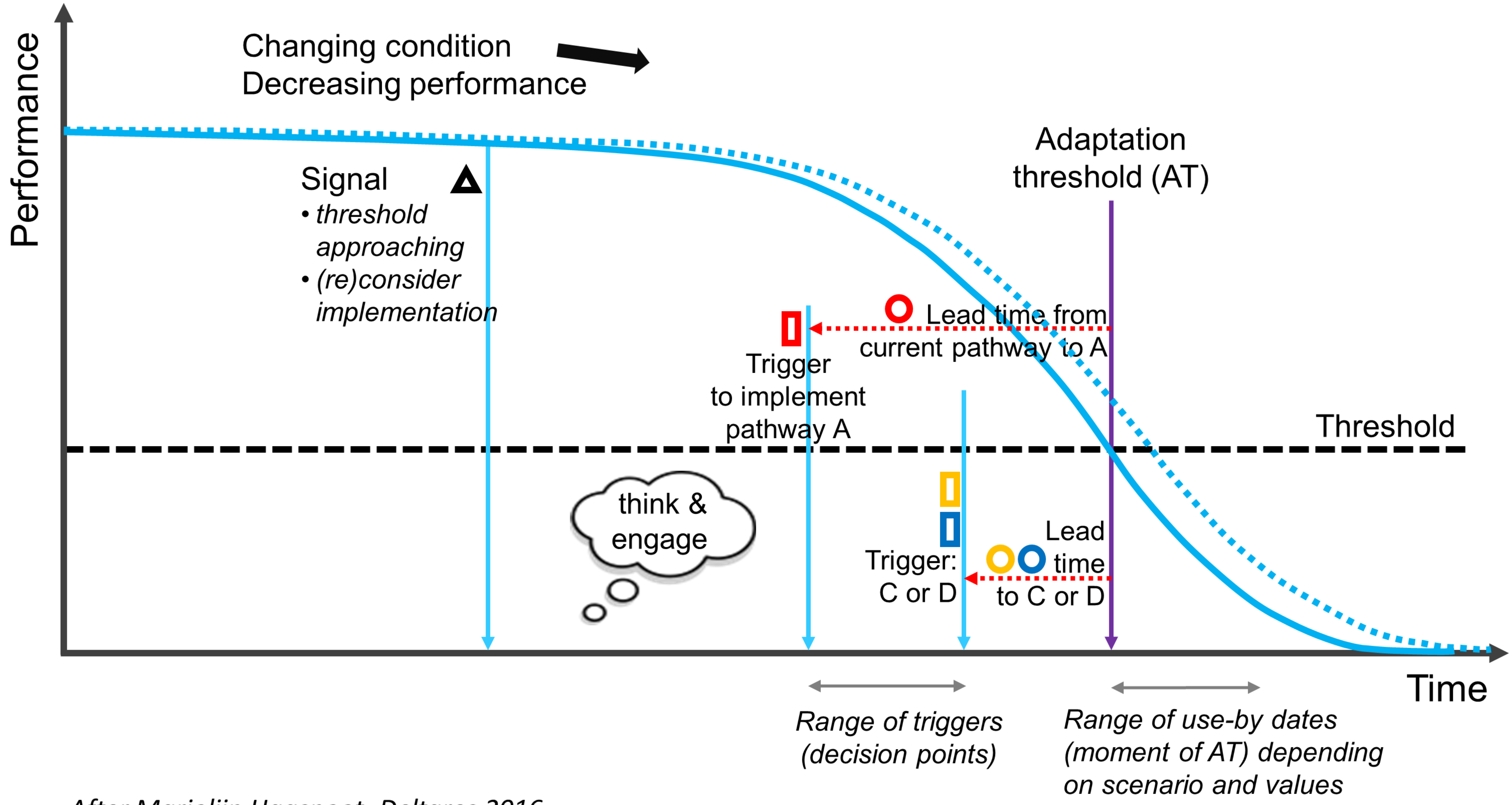
Existing infrastructure: adaptive example

LOSSAN (Los Angeles to San Diego) Rail Corridor

Dial, Smith & Rosca (2014)
Proceedings of the 2014 International Conference on Sustainable Infrastructure, ASCE



Monitoring: Signals, triggers and adaptation thresholds



After Marjolijn Haasnoot: Deltares 2016

Key messages

- Further change ahead … rate of change in risk is rising
- Adaptive or robust-decision approaches best dealing with deepening uncertainty – rather than "predict-and-act" or "single-investment" approaches
- Successful infrastructure provision in the 21st century will need to be *flexible* and *agile.* How do we realize that?
- Consider how incremental asset decisions today affect future adaptation flexibility? Low-regrets, DAPP
- Monitoring for early signals – threshold approaching?
- **Needs systems thinking**: cross-cutting incl. engineering, planning, environmental, social, economic … basis of 2019 *Adaptation to Climate Change Standard ISO 14090*

Sven Martin

Thank you

Rob Bell (PhD, CPEng, FEngNZ)
027 2332324
rob.bell@niwa.co.nz