Dynamically Resilient Water Resources Systems in an Environment of a Nonstationary Climate

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April 23, 2025
GEER 2025

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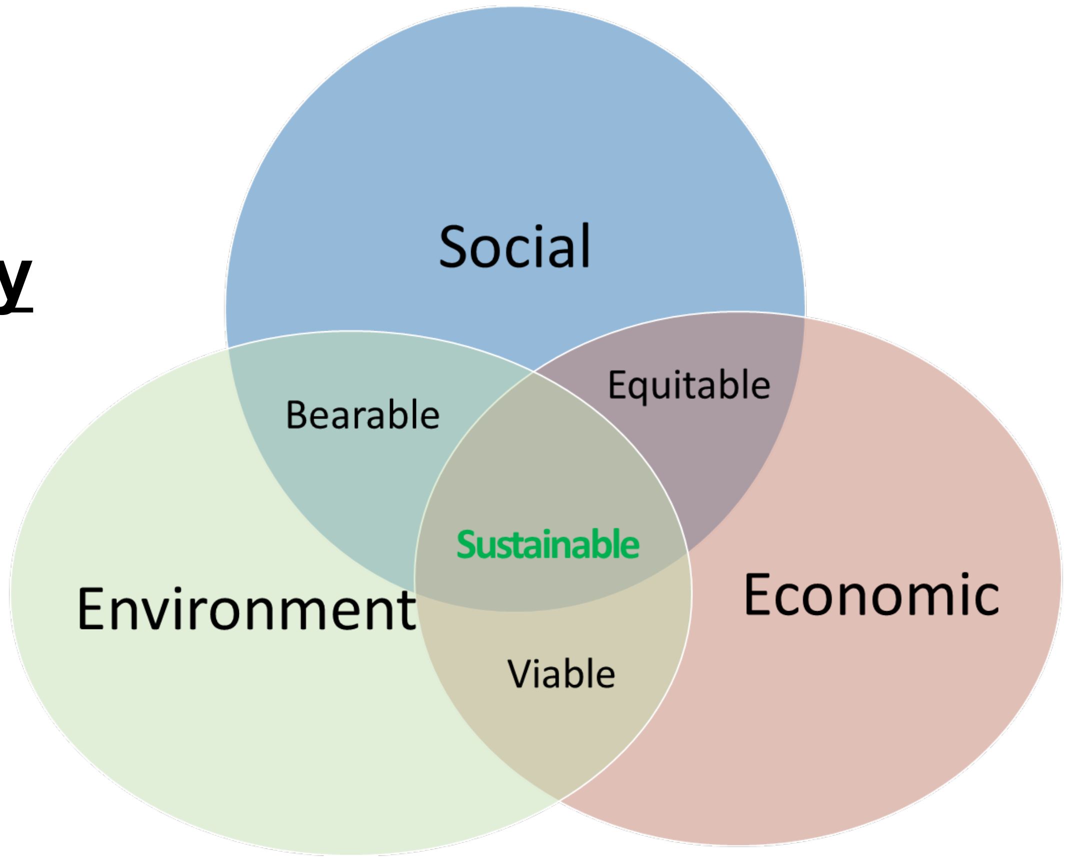
Science Informed Public Policy: New Paradigm

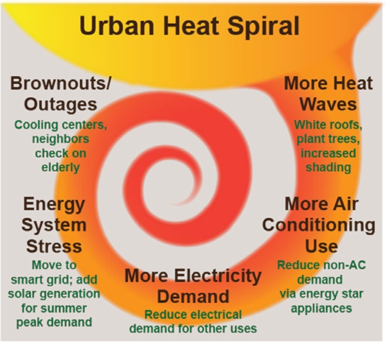
- Complexity of climate change -> multidimensional approach that encompasses environmental considerations, social, economic, and often political factors in a **<u>nonstationary environment</u>**
- Navigating **<u>Deep Uncertainties</u>** is crucial:
  - Decision Making Under Deep Uncertainty (DMDU)
- Need to balance short-term interests with long-term sustainability



Dynamically Evolving

Credit: Adapted from slides by James Mack

Outlook of Future Conditions



Stressors:

- Rising Temperatures
- Sea Level Rise & Storm Surge
- Saltwater intrusion
- Rising groundwater levels
- Changes in rainfall patterns
- Frequency and magnitude Hurricanes

Potential Impacts of Climate Change on Water Resources (Florida)

Quartet of change: Drivers*

- •Rising Sea Levels (& groundwater levels)
- •Increasing Temperature (& ET)
- •Changing Rainfall (both averages & extremes)
- •Tropical Storms & Hurricanes

Water Management Impacts

•<u>Direct landscap</u>
<u>impacts</u> (e.g.
surge)
•<u>Water</u>
(e.g
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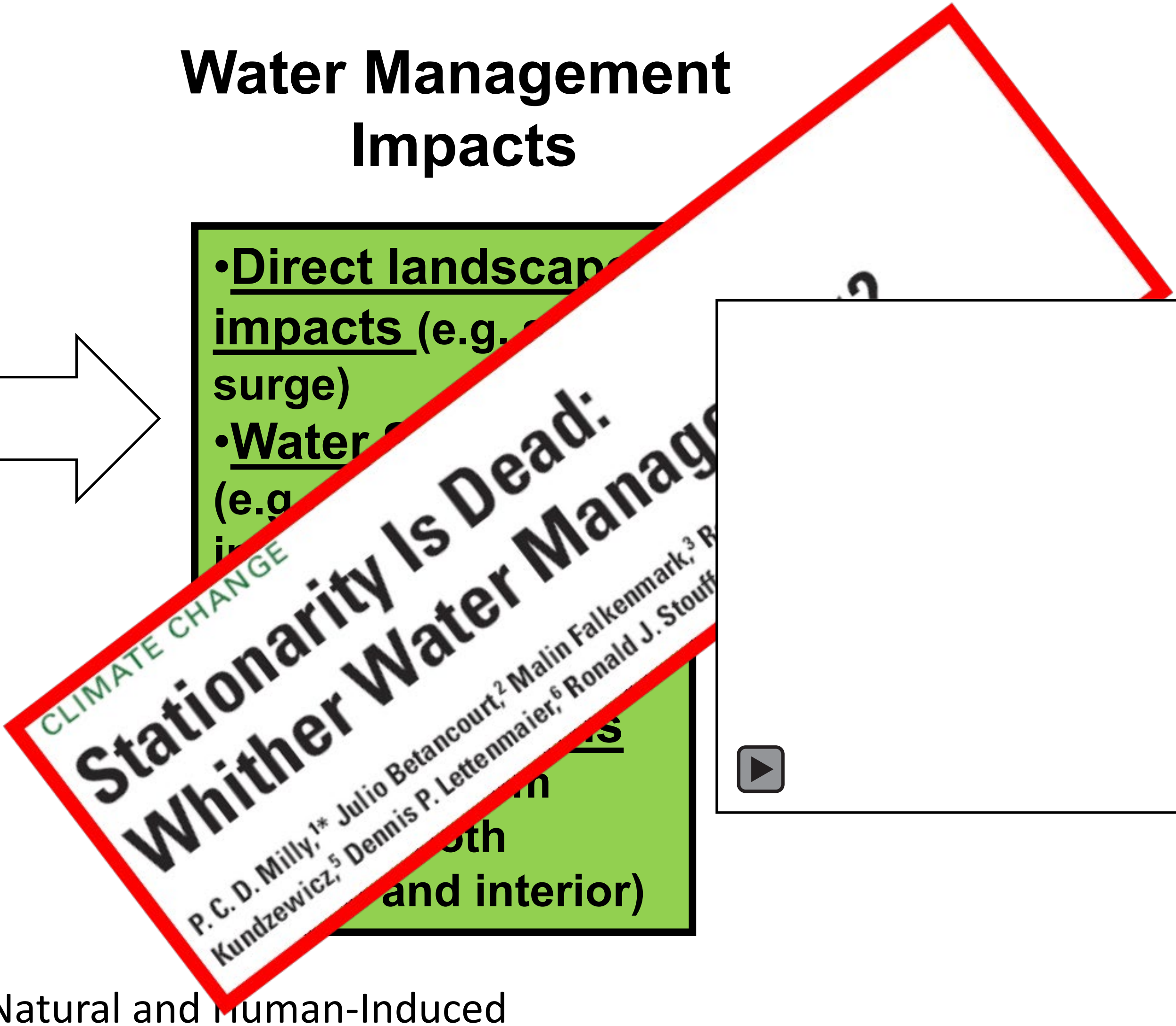
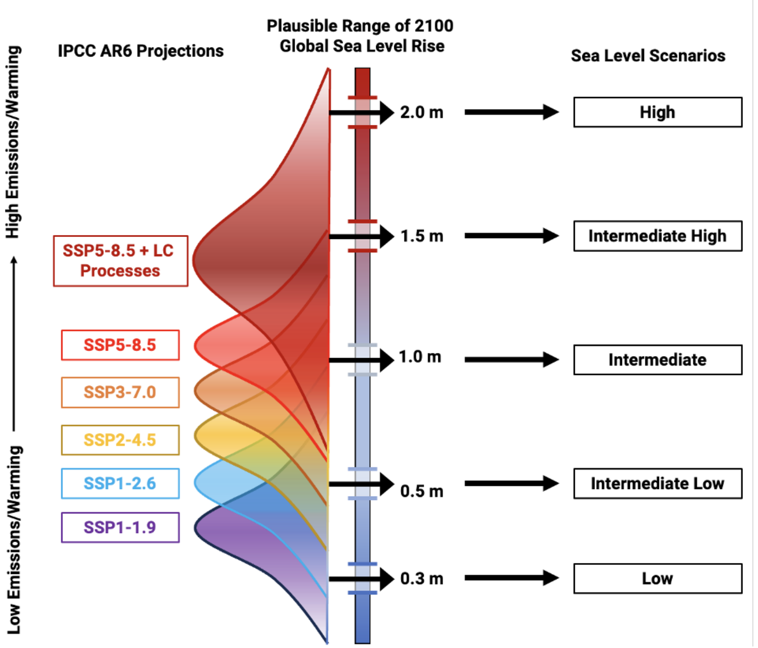
and interior)



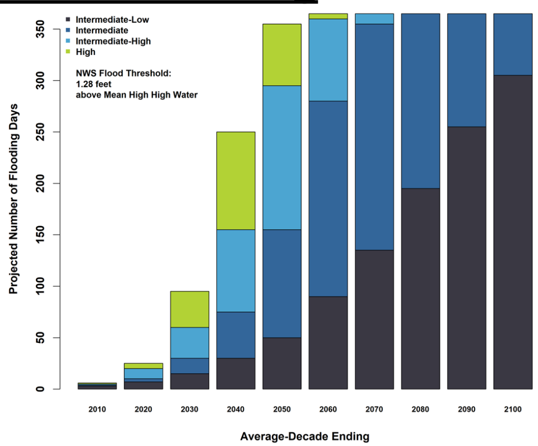
* Natural and Human-Induced

Future Conditions

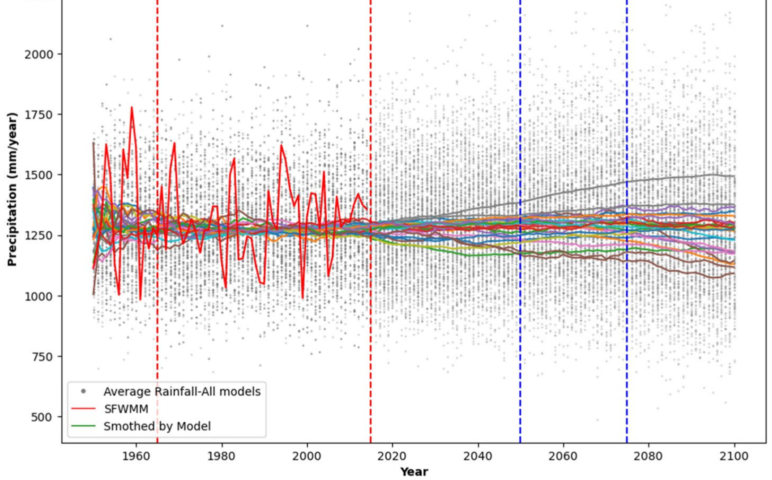
Sea Level Rise



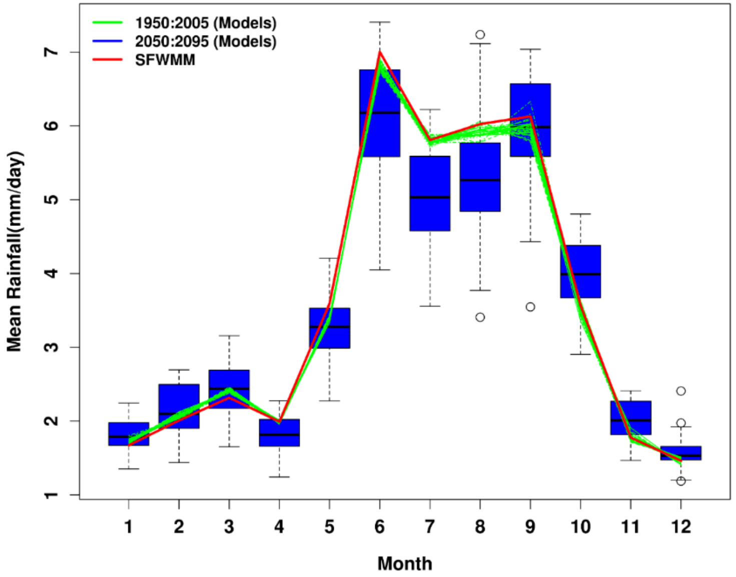
High Tide Flooding



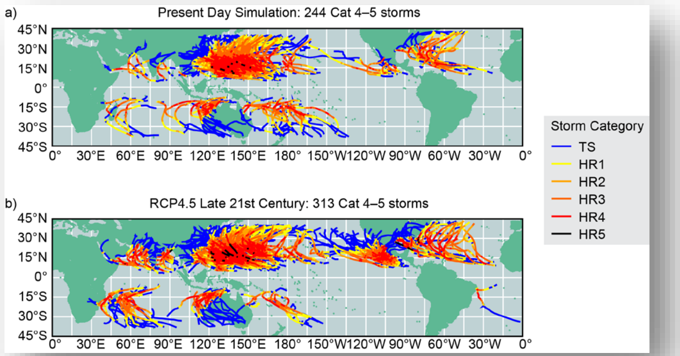
Annual Rainfall



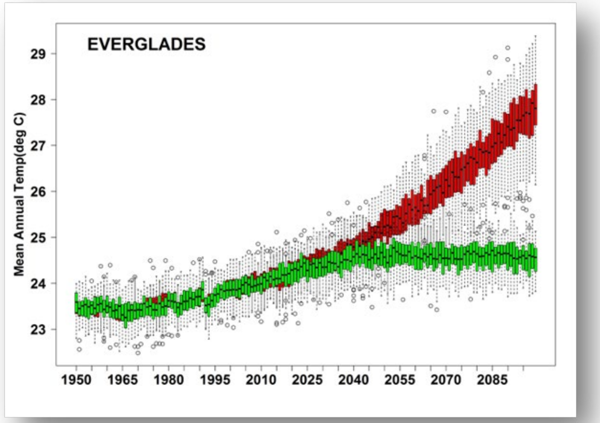
Seasonality



Tropical Systems

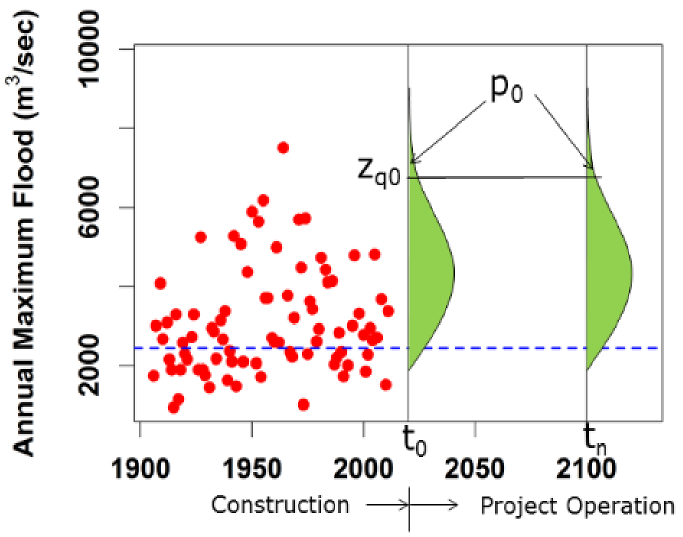


Temperature



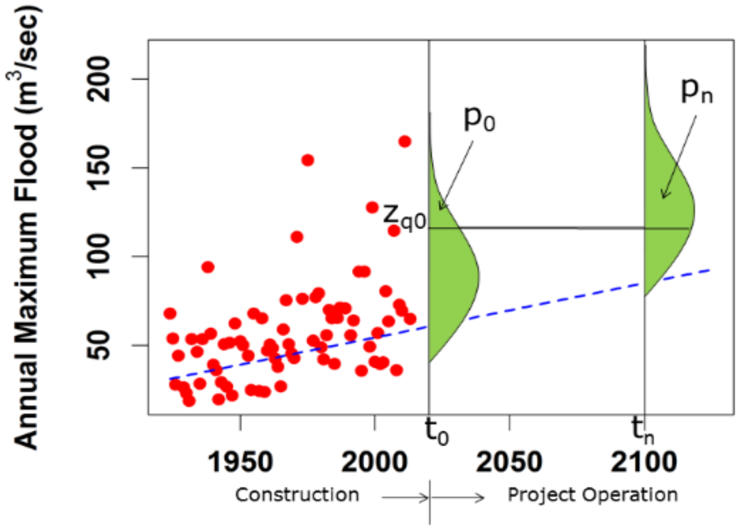
Stationarity vs. Nonstationarity

(a) Stationary



- "The scientific term "stationarity" does not necessarily mean constancy of variables. What it does mean is constancy of laws and patterns".
- Stationarity can be interpreted as the rule "the past is a key to the future."
- Fixed "Return Period"

(b) Nonstationary

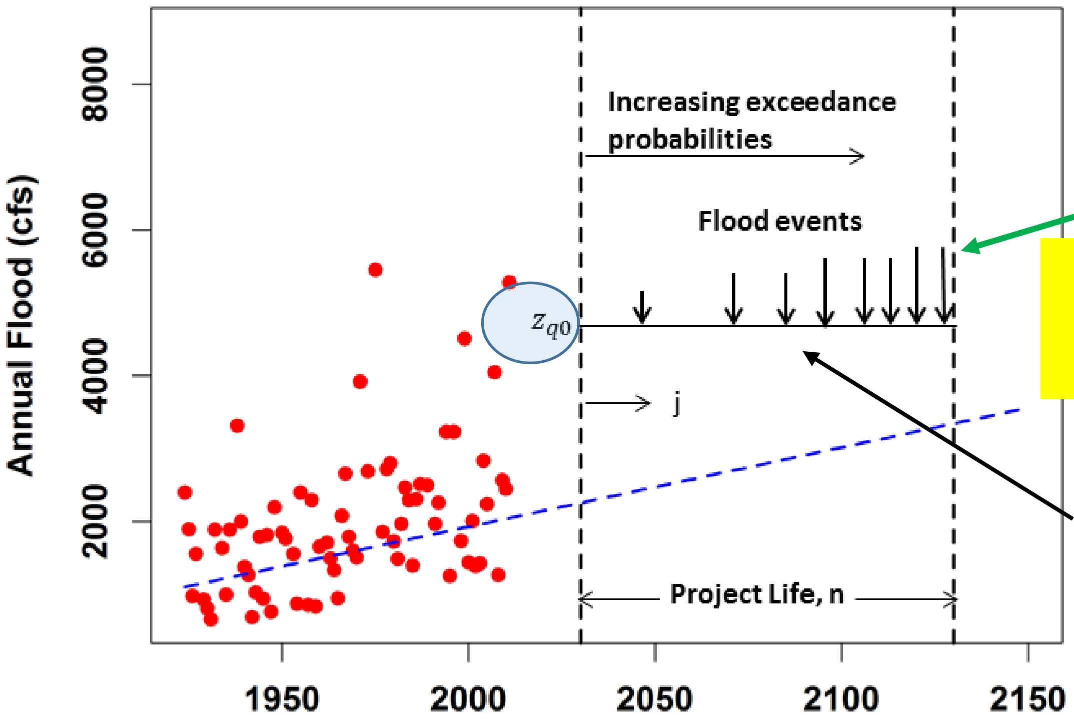


- In nonstationary systems the past is not a key to the future. But, there are useful lessons that can be learnt from the past.
- Dynamic "Return Period"

Hydrologic Design considering Nonstationarity

Expected Waiting Time

$$T = E[X] = 1 + \sum_{x=1}^{\infty} \prod_{t=1}^{x} (1 - p_t)$$

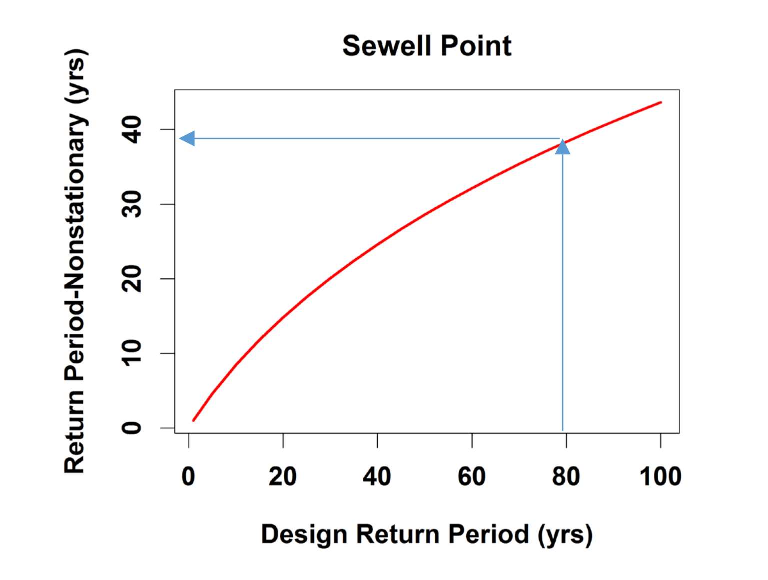


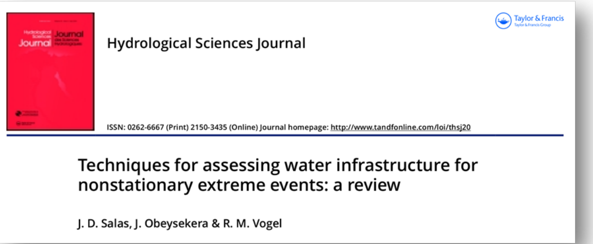
Risk-Based Design

$$R = 1 - \prod_{t=1}^{n} (1 - p_t)$$

Recurrent Flood Frequency

$$E(N(t)) = \sum_{j=1}^{t} p_j$$





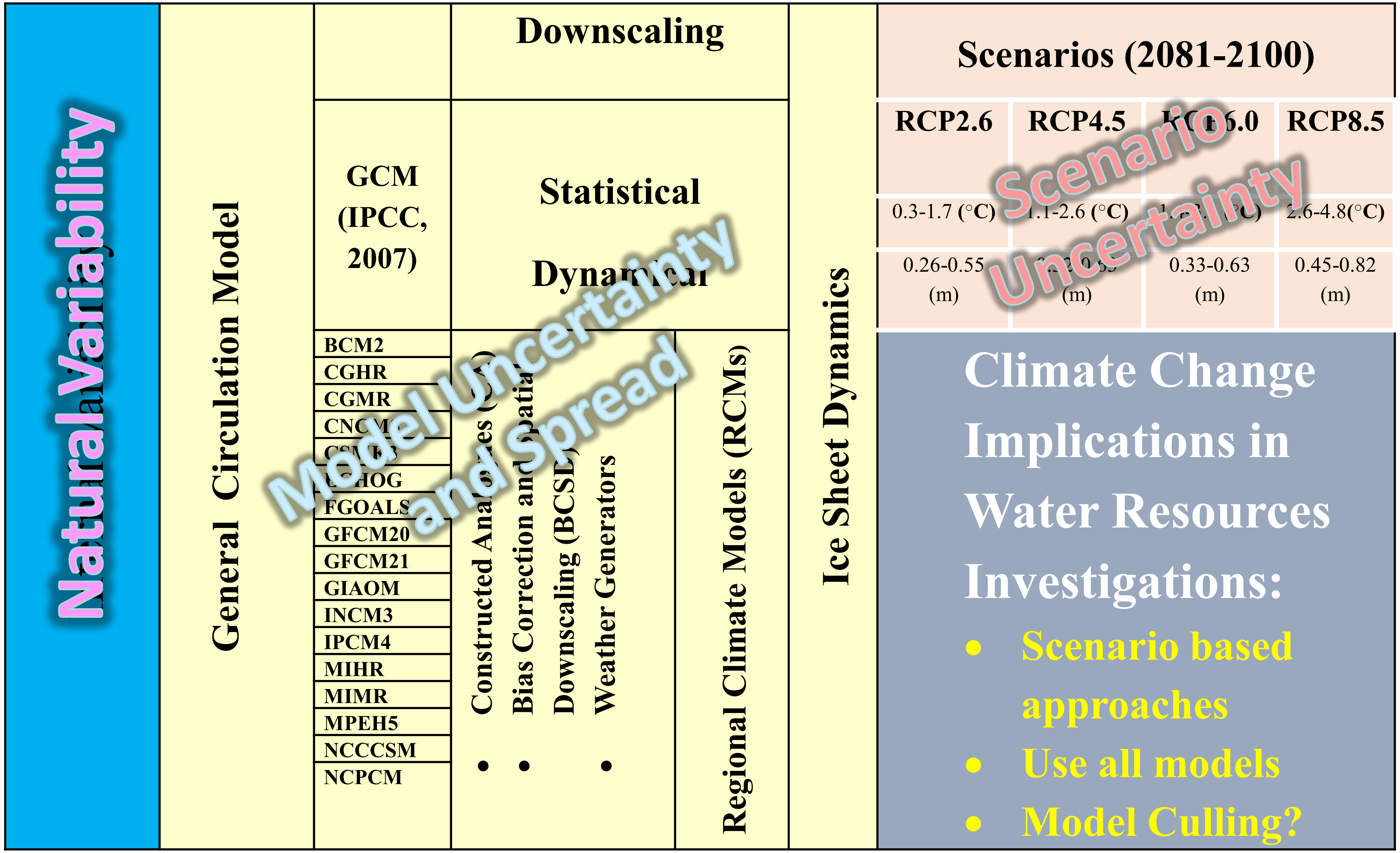
Hydrological Sciences Journal

ISSN: 0262-6667 (Print) 2150-3435 (Online) Journal homepage: http://www.tandfonline.com/loi/thsj20

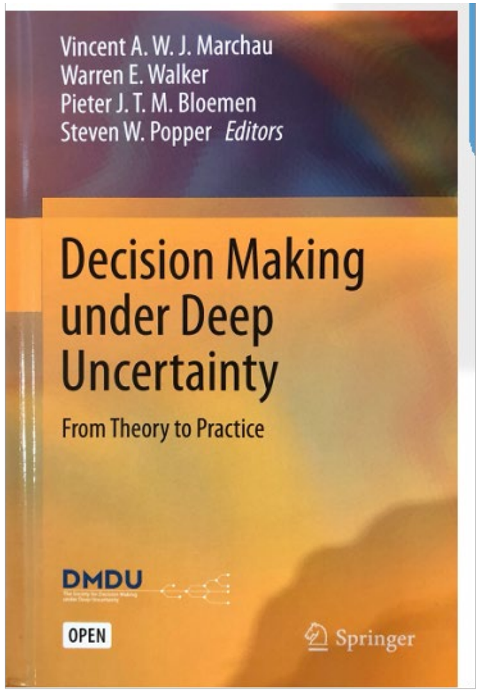
Techniques for assessing water infrastructure for nonstationary extreme events: a review

J. D. Salas, J. Obeysekera & R. M. Vogel

Climate Projection Uncertainties

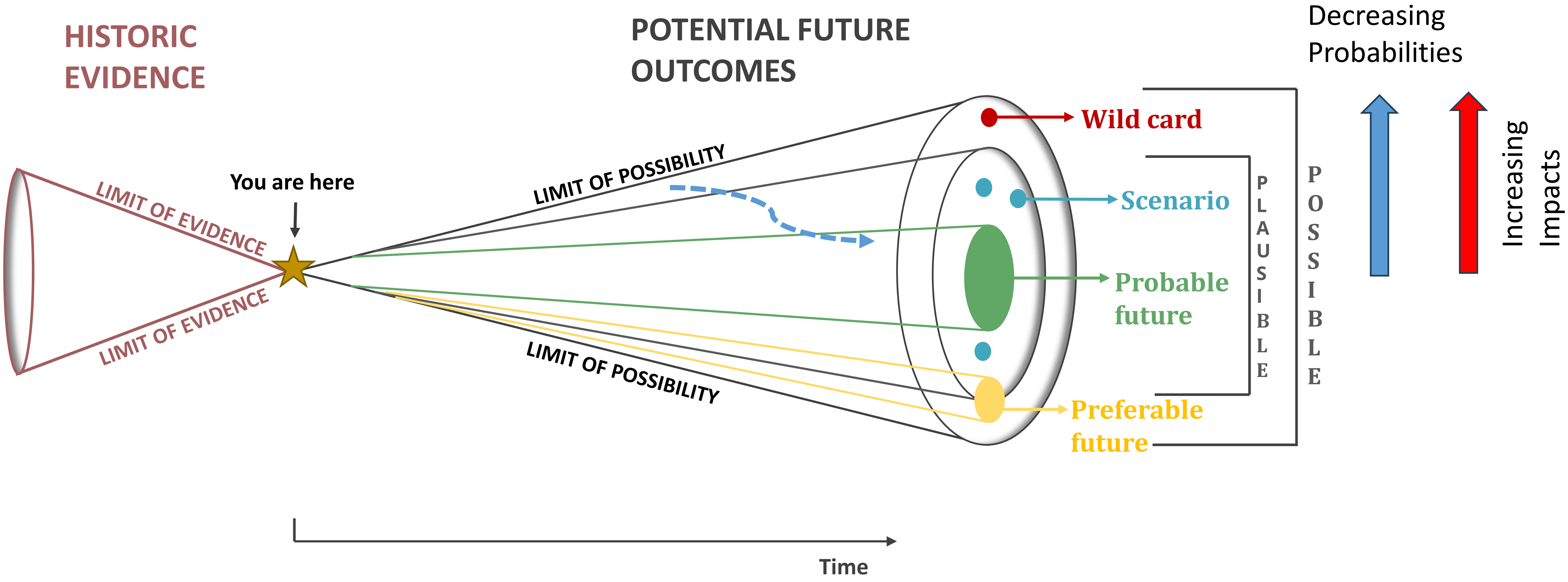


- Case of Deep uncertainty
- DMDU

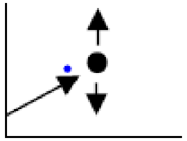
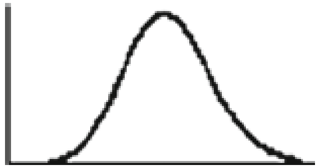
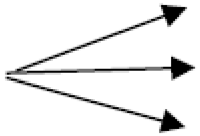
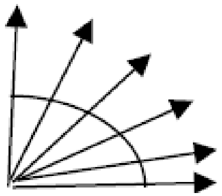
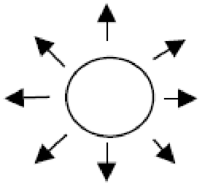


Marchau, V. A. W. J., W. E. Walker, P. J. T. M. Bloemen and S. W. E. Popper (2019). Decision Making under Deep Uncertainty: From Theory to Practice, Springer.

Cone of Uncertainty



Decision Making: Spectrum of Uncertainties

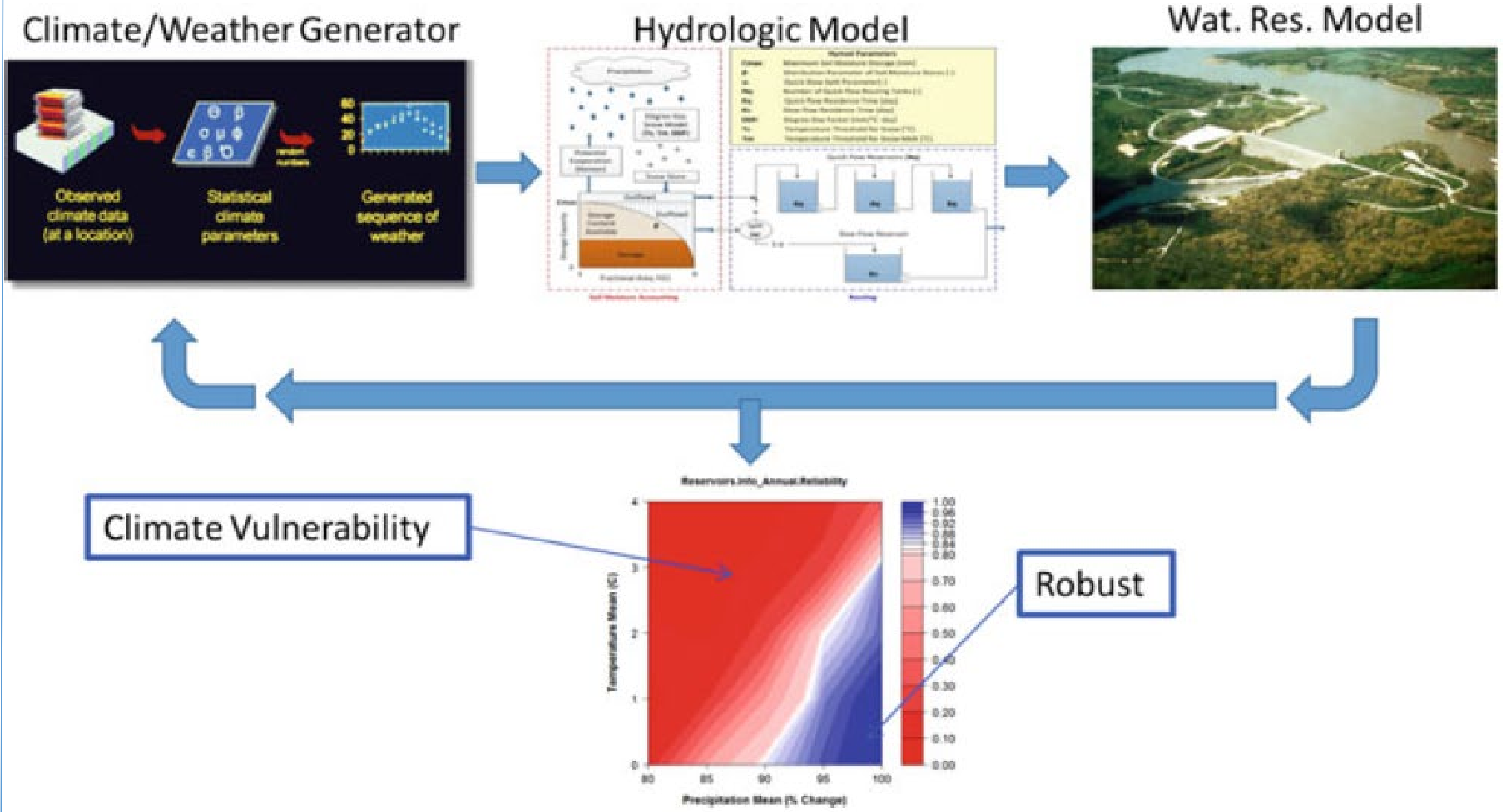
Deterministic	Level-2	Level-2	Level-3	Level-4		Total Ignorance
	Clear enough Future	Alternate Futures (with probs)	Selected plausible futures (Scenarios)	Many plausible futures	Unknown future	
						
	Short-term decisions	Tools of statistics	Few system models	Lack of data; many models	Only know we do not know	
	Simple Sensitivity Analysis	Probability of outcomes	Traditional Scenario Planning	Wide range of outcomes		
Adopted from Marchau et al. (2019)						

Deep Uncertainty

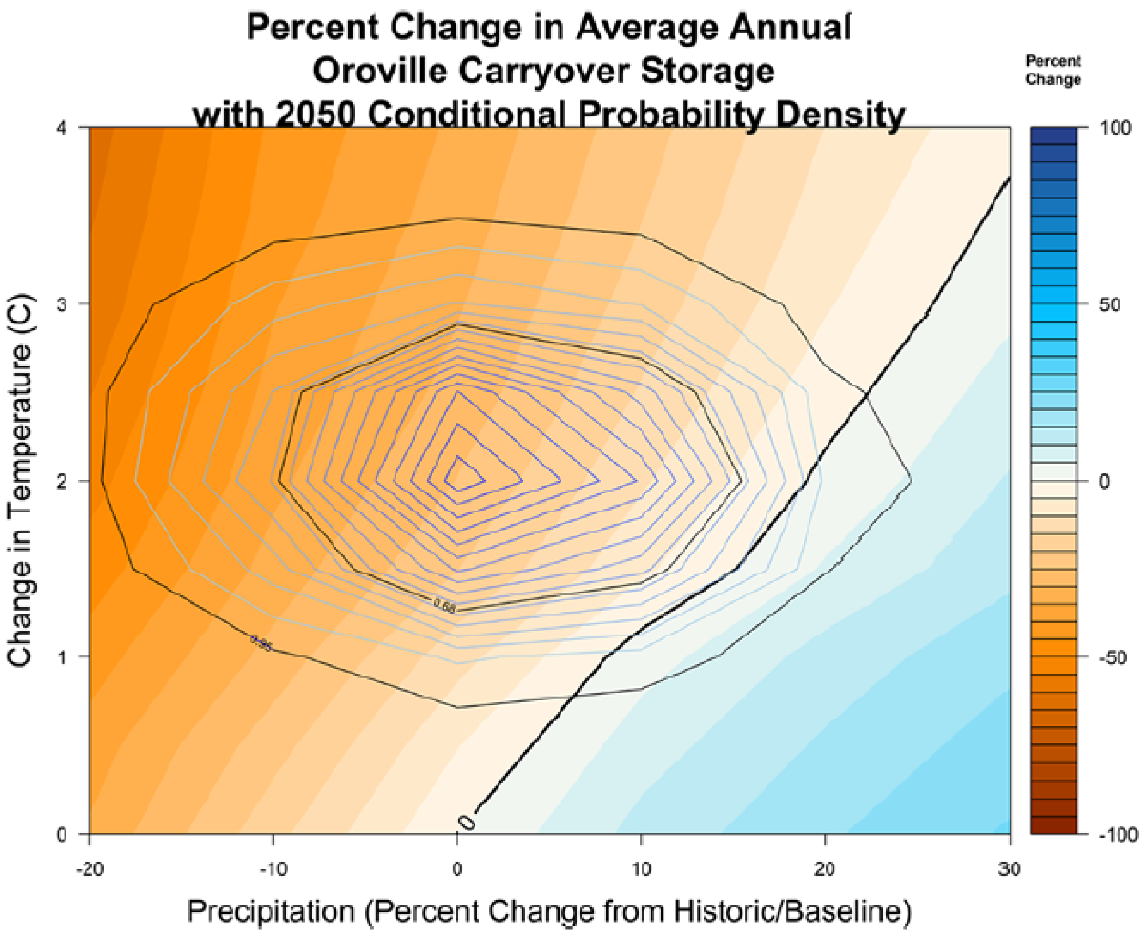
Decision Scaling Concepts

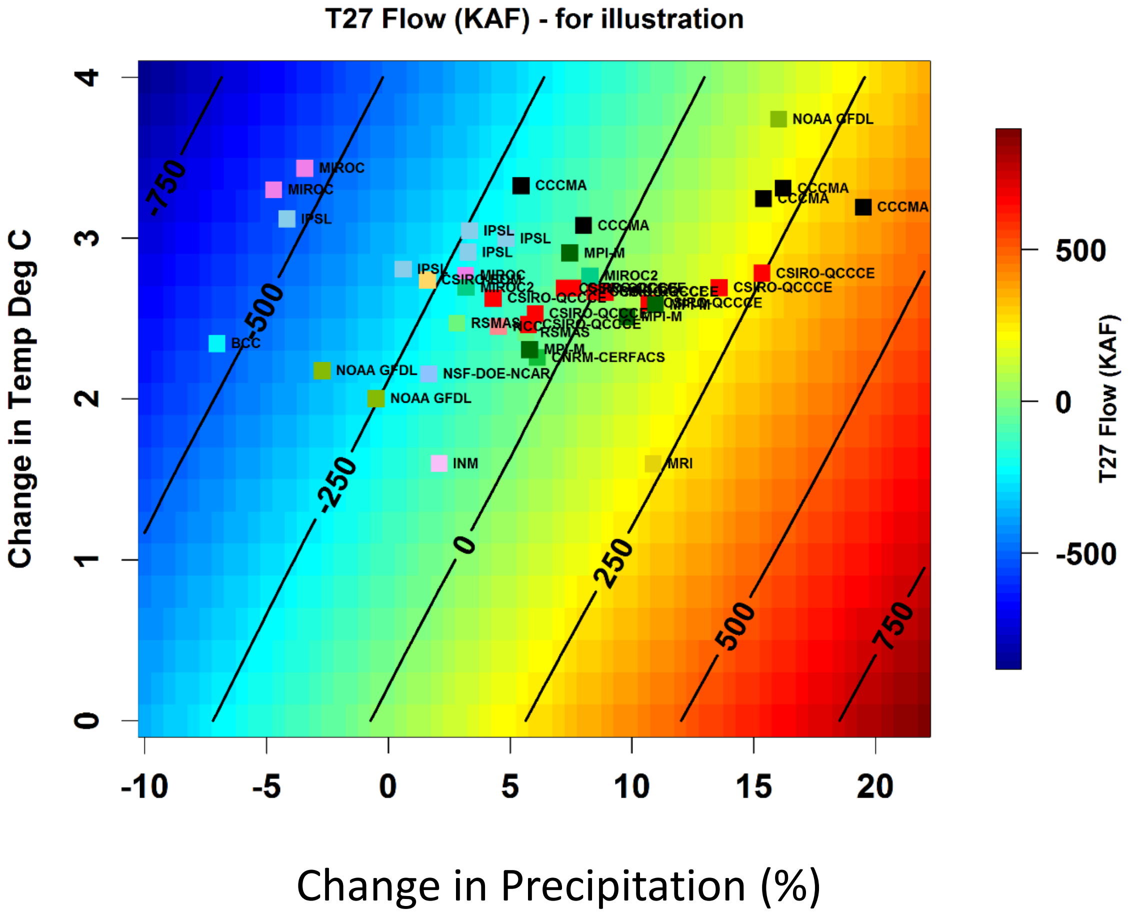
Selected Methods of DMDU

- Robust Decision Making (RBM) pioneered by RAND
- Decision Scaling ("bottom-up approach")-Casey Brown
- Dynamic Adaptive Policy Pathways (DAPP) developed by Deltares, The Netherlands

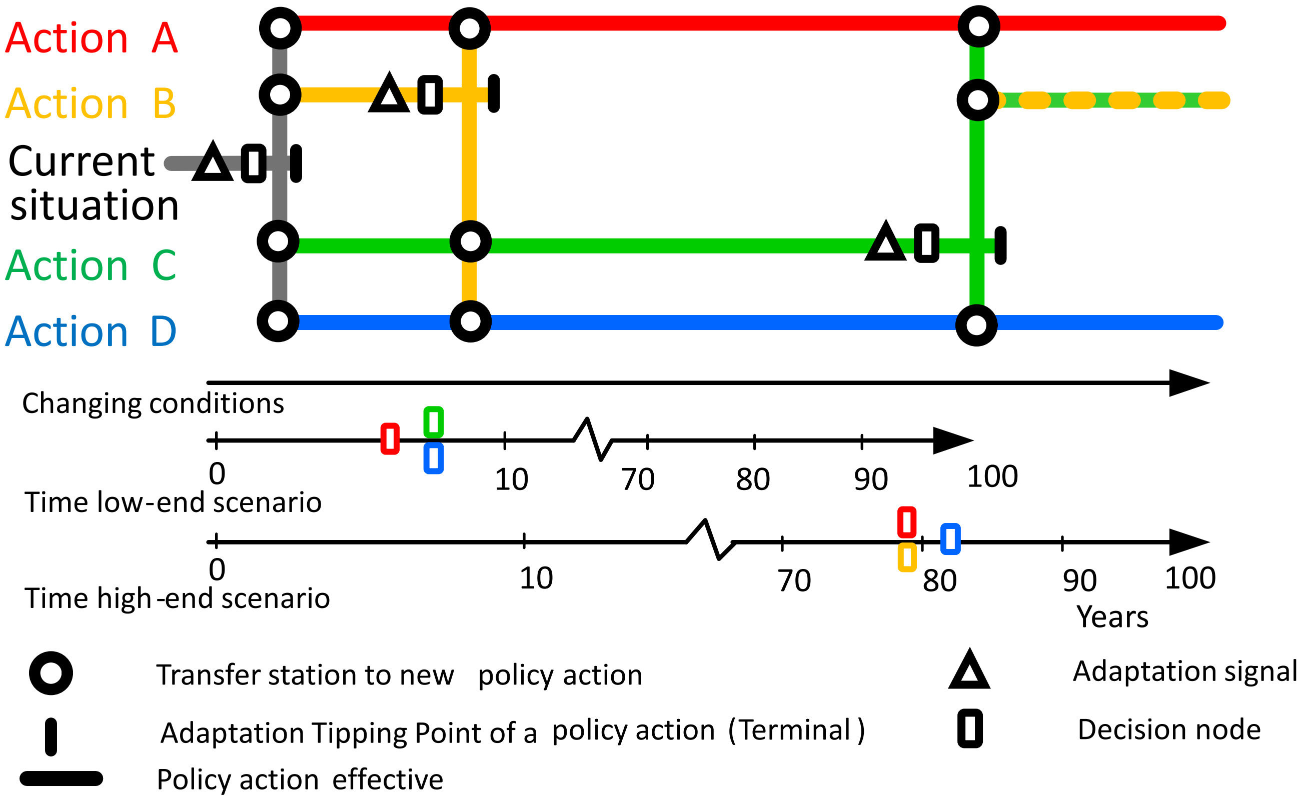


Example: Greater Everglades

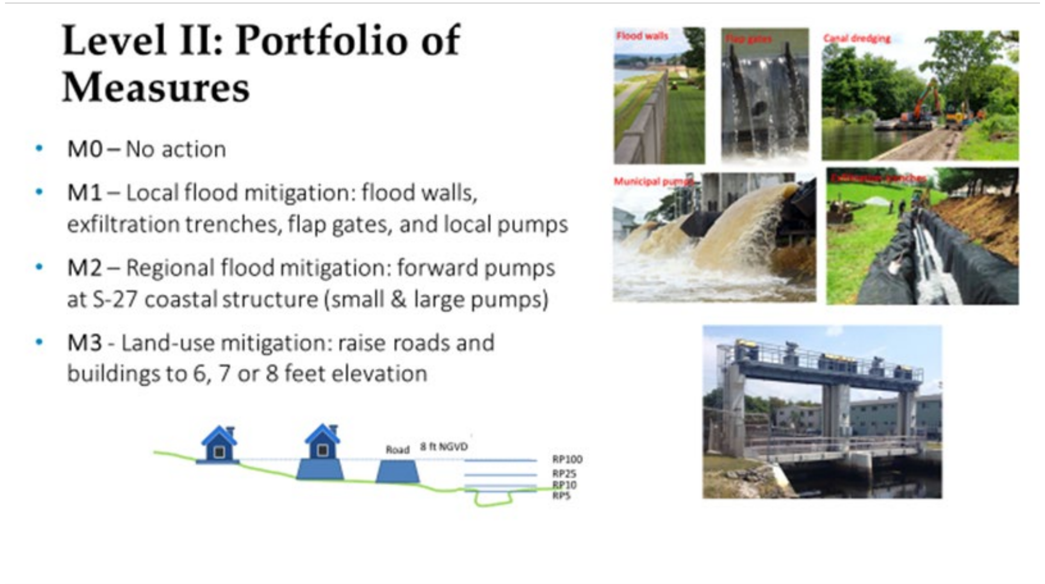




Dynamic Adaptive Pathway Concept (DAPP)

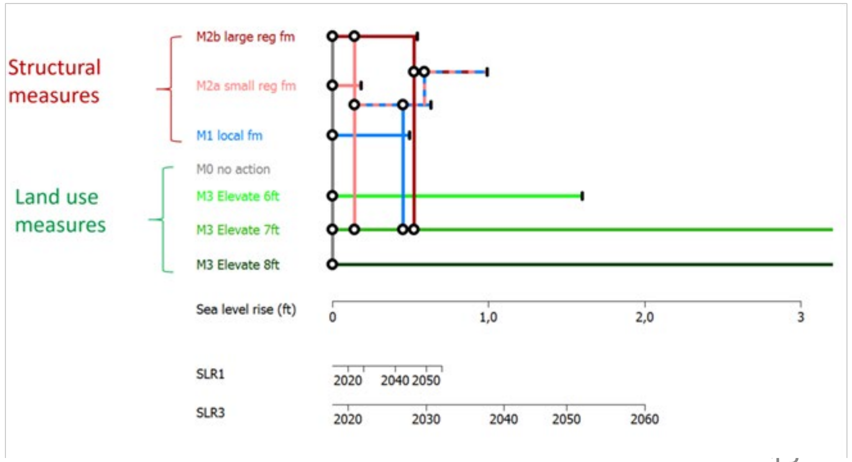


Example: Little River Basin

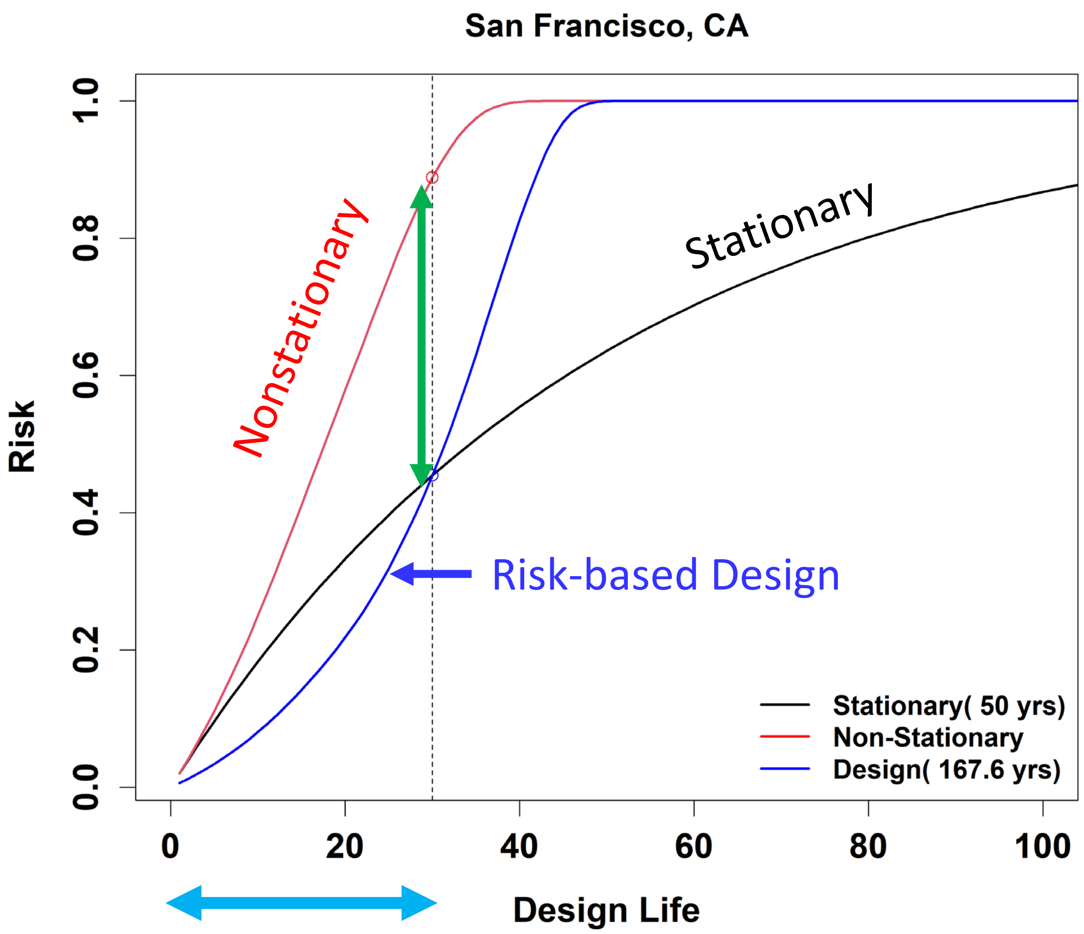


Level II: Portfolio of Measures

- M0 – No action
- M1 – Local flood mitigation: flood walls, exfiltration trenches, flap gates, and local pumps
- M2 – Regional flood mitigation: forward pumps at S-27 coastal structure (small & large pumps)
- M3 - Land-use mitigation: raise roads and buildings to 6, 7 or 8 feet elevation



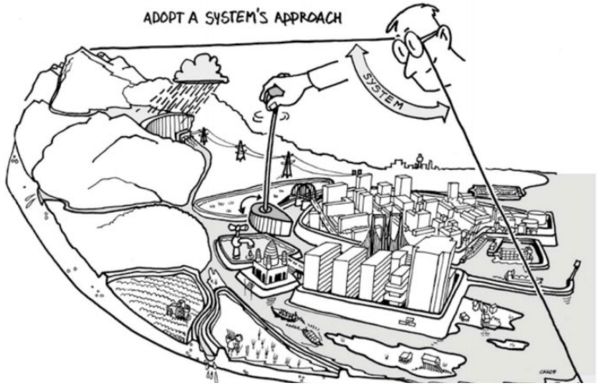
Revisiting Risk Under Nonstationarity

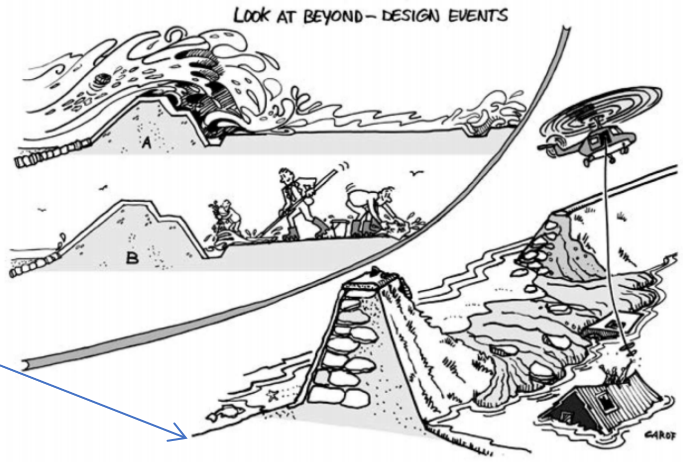


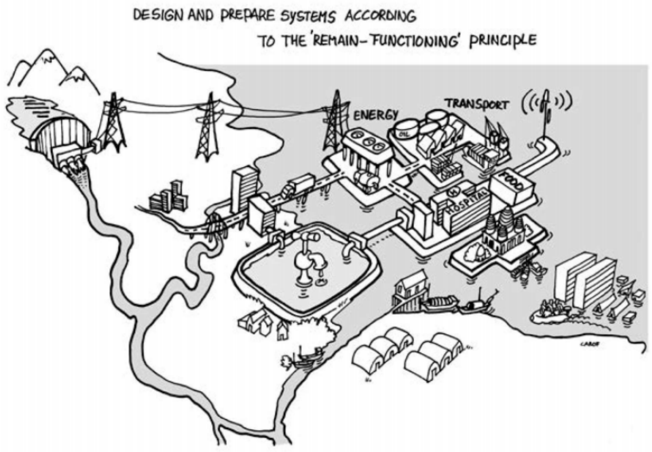
- Under stationarity risks increase with Design Life
- Risks increase faster due to nonstationarity but that depends on the scenario
- Phase in adaptation in stages. In this case, reassess after 30 year. Flexible plan and design

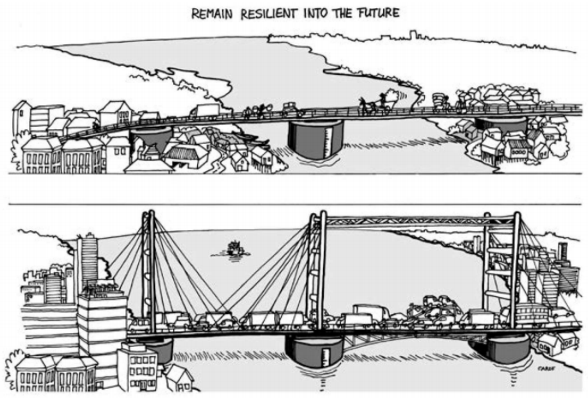
Five Resilience Principles

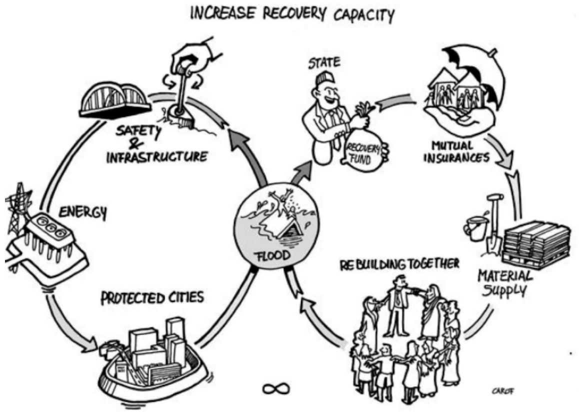
- Adopt a system's approach;
- Look at beyond-design events;
- Build and prepare infrastructure according to 'remain functioning'
- Increase recovery capacity by looking at social and financial capital; and
- Remain resilient into the future











Credit: Bruijn et al. 2017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SEA-DOO

Impacts are already here!

Fort Lauderdale Airport

Key Largo

Heat waves

Rising sea levels

Intensity of precipita

More frequent hurric

structure