THE DECISION TREE FRAMEWORK:

BEYOND DOWNSCALING TO CLIMATE INFORMED DECISIONS

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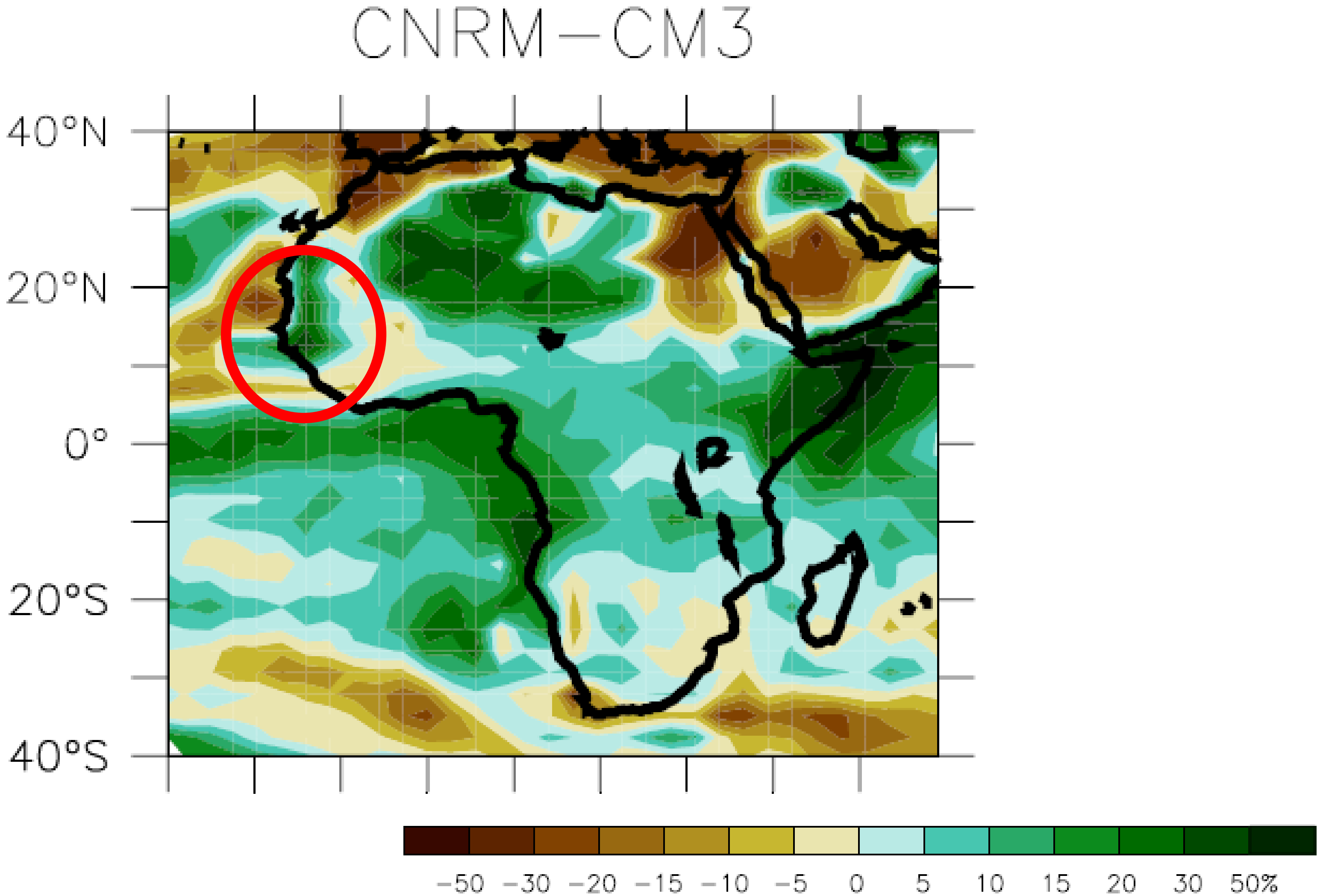
2014-2016: LTHE, University of Grenoble and
Environmental Change Institute, University of Oxford

What is a Water Planner to do?

- Investments in the water sector are potentially significantly impacted by climate change
- Assessment of climate change risks is required
- Climate change may cause the project goals to not be met
- Unclear how to use climate information to aid decisions

A standard process for Project Evaluation for Climate Risk is needed!

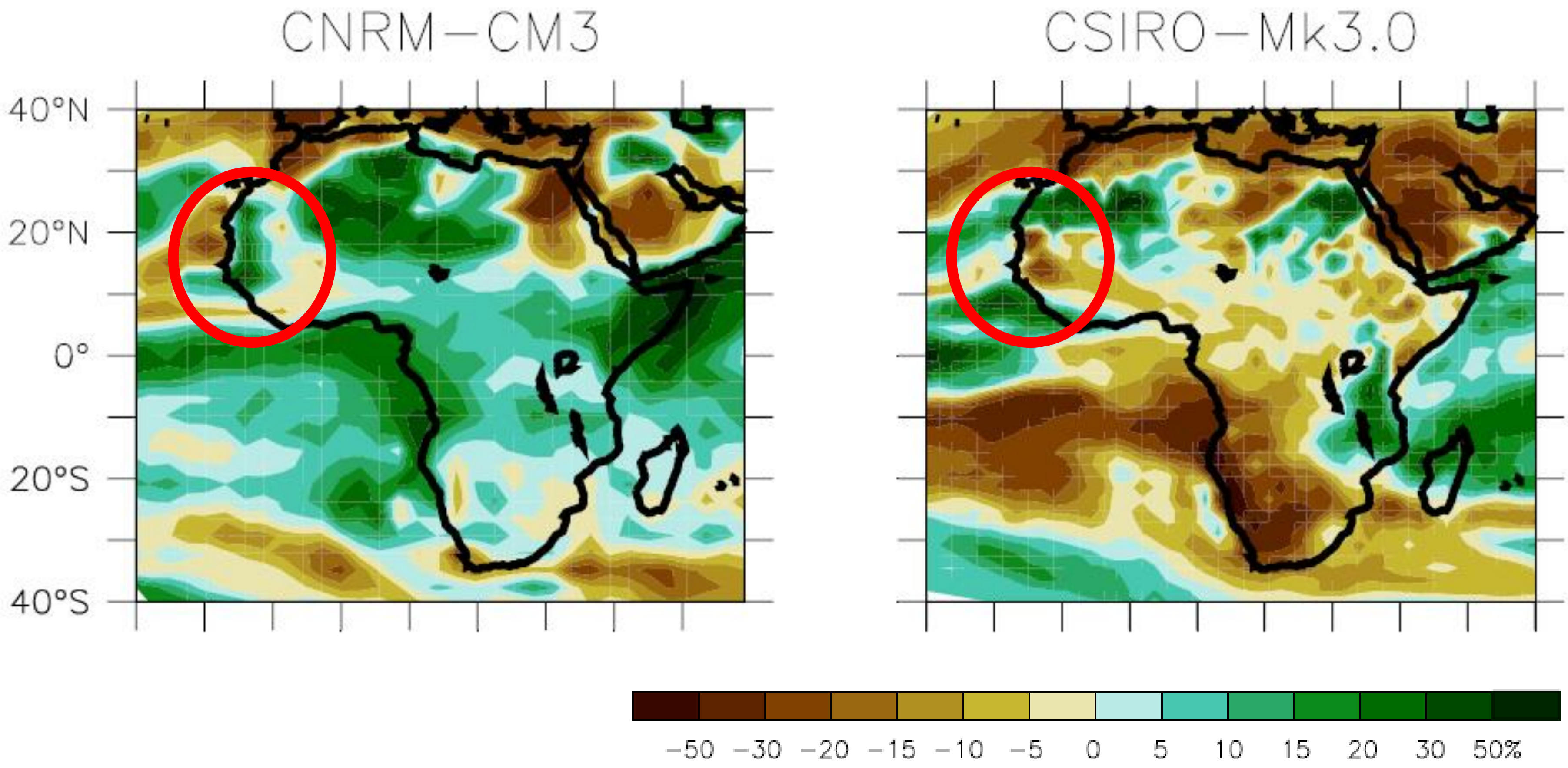
Climate models project future climate



from S. Hallegatte

The Meteo-France model, from IPCC

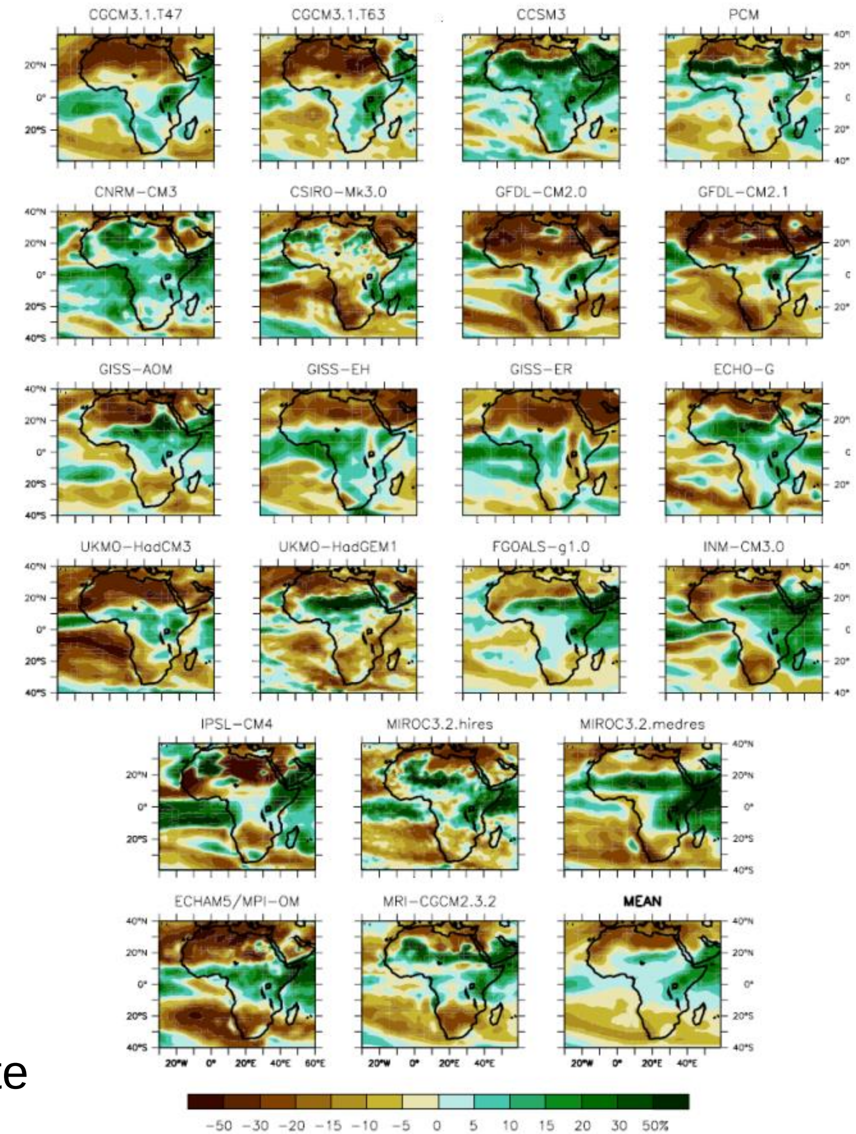
But they disagree with each other



from S. Hallegatte

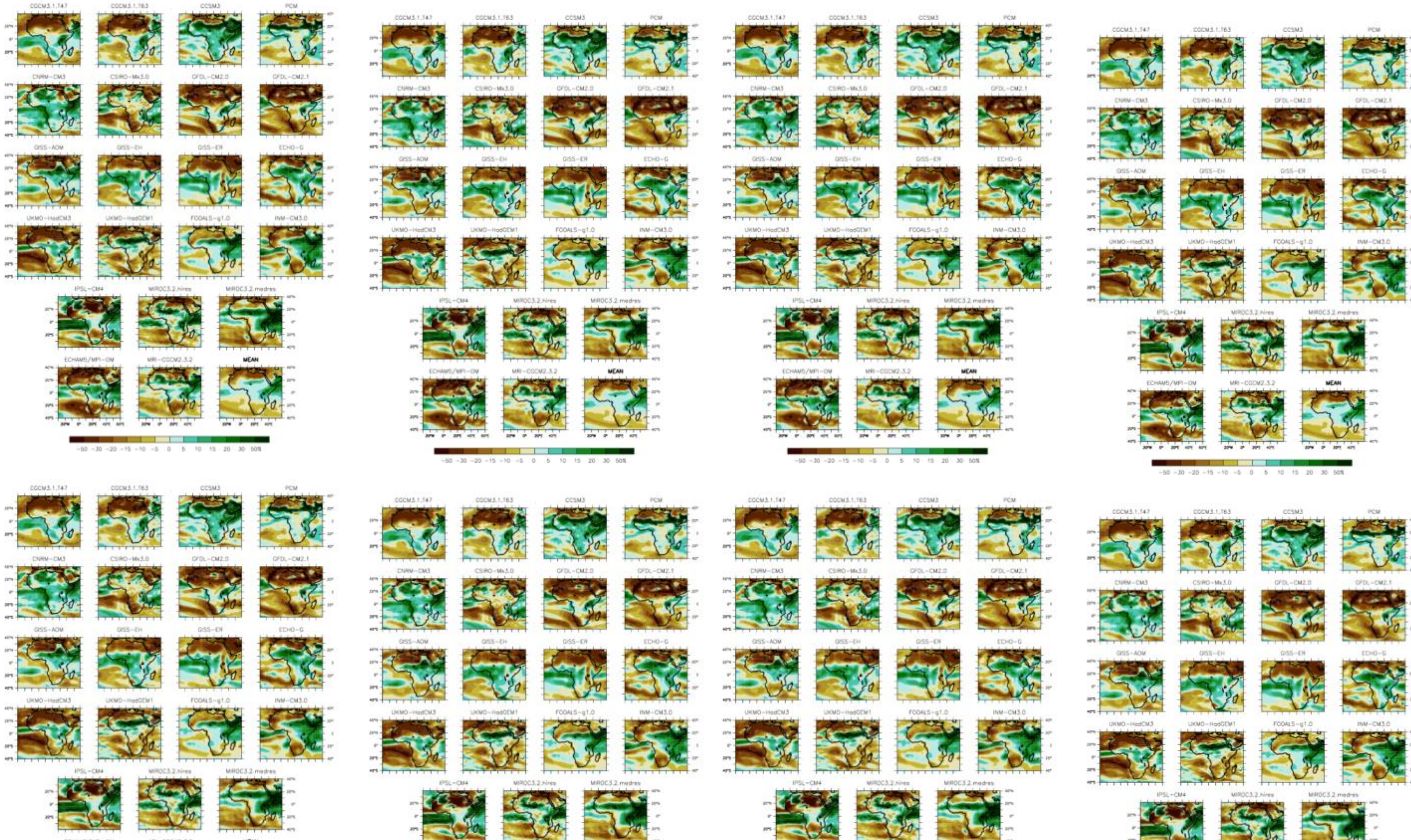
The Meteo-France and the Australian model, from IP

… and we have a lot of models…



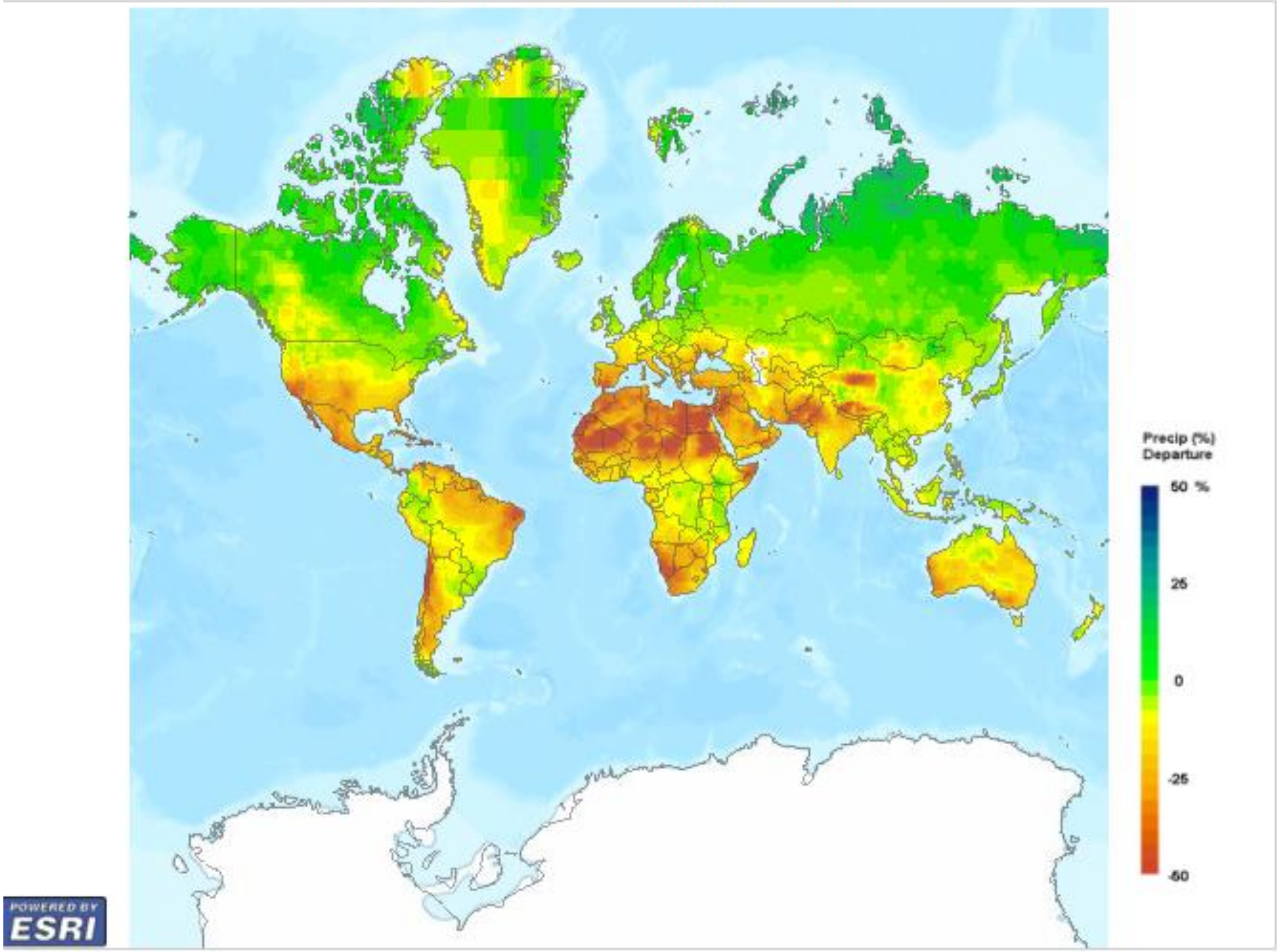
from S. Hallegatte

… and future climates depend on future climate policies and socio-economic trends…



Change in Annual Precipitation by the 2050s

Model: Ensemble Lowest, SRES emission scenario: A2



Map data Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

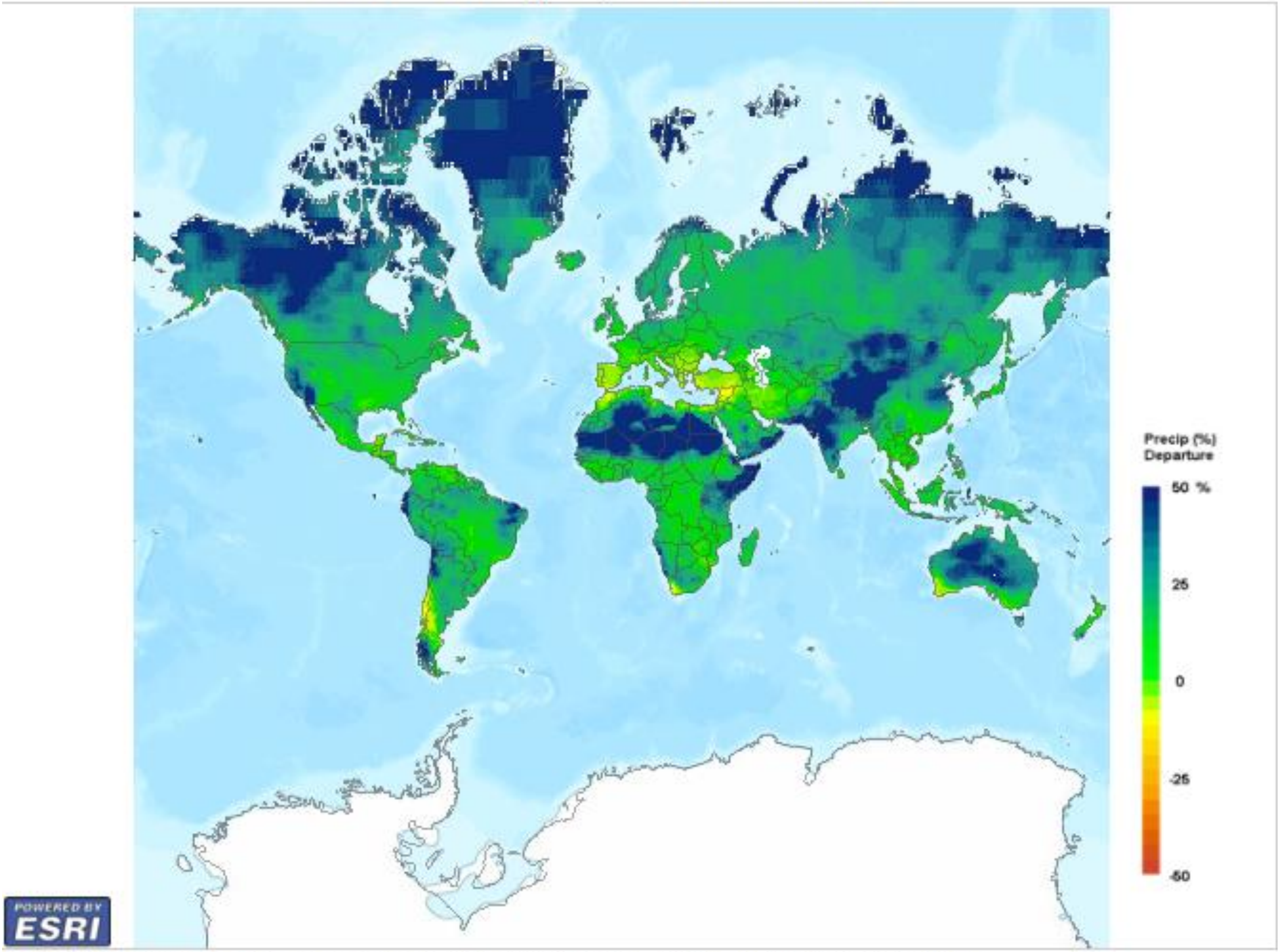
Data Source: Global climate model output, from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset (Meehl et al., 2007), were downscaled as described by Maurer et al. (2009) using the bias-correction/spatial downscaling method (Wood et al., 2004) to a 0.5 degree grid, based on the 1950-1999 gridded observations of Adam and Lettenmaier (2003).

The Nature Conservancy

Protecting nature. Preserving life.

Change in Annual Precipitation by the 2050s

Model: Ensemble Highest, SRES emission scenario: A2



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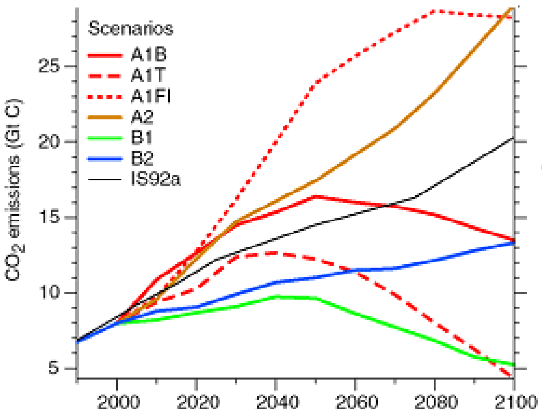
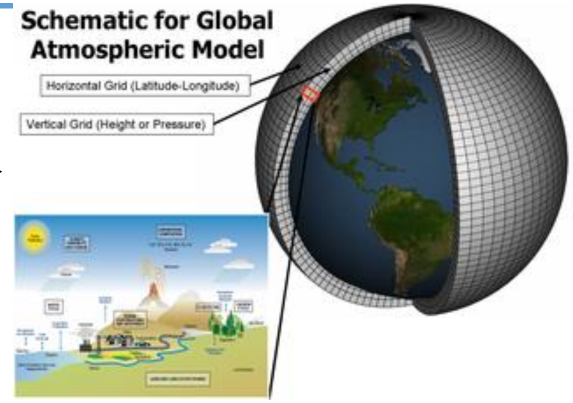
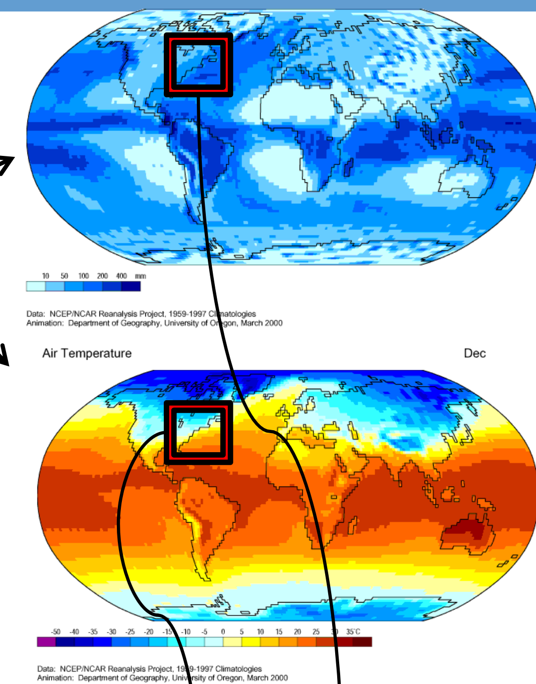
Emission Scenarios



General Circulation Models (GCMs)

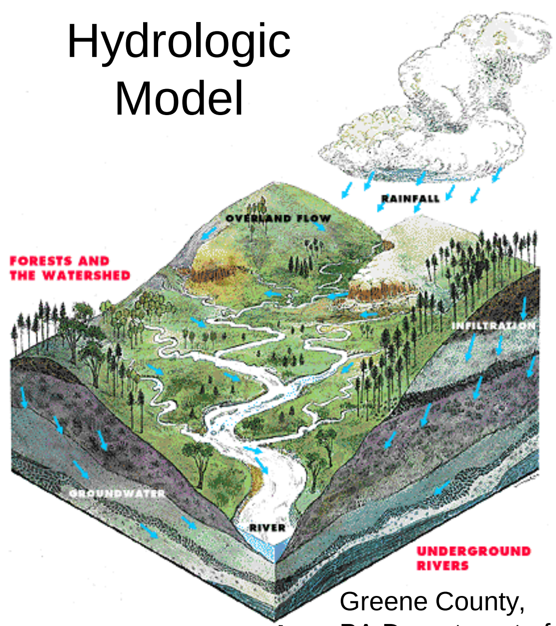


Geography Department, U. Oregon



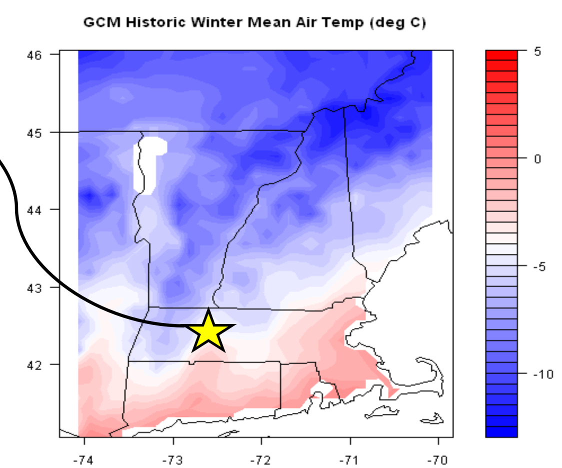
Water System Performance Under Future Climate Scenarios

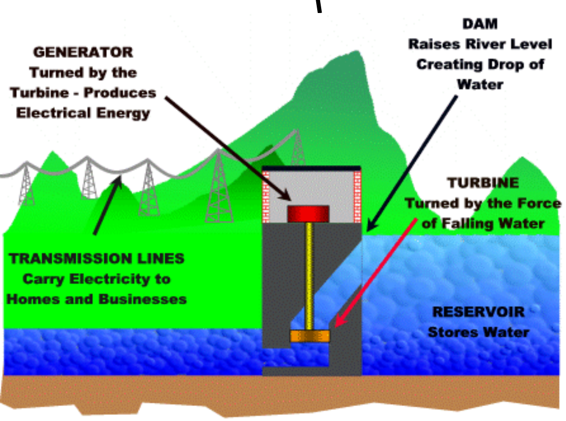
Hydrologic Model



Greene County, PA Department of Econ. Development

Downscaling

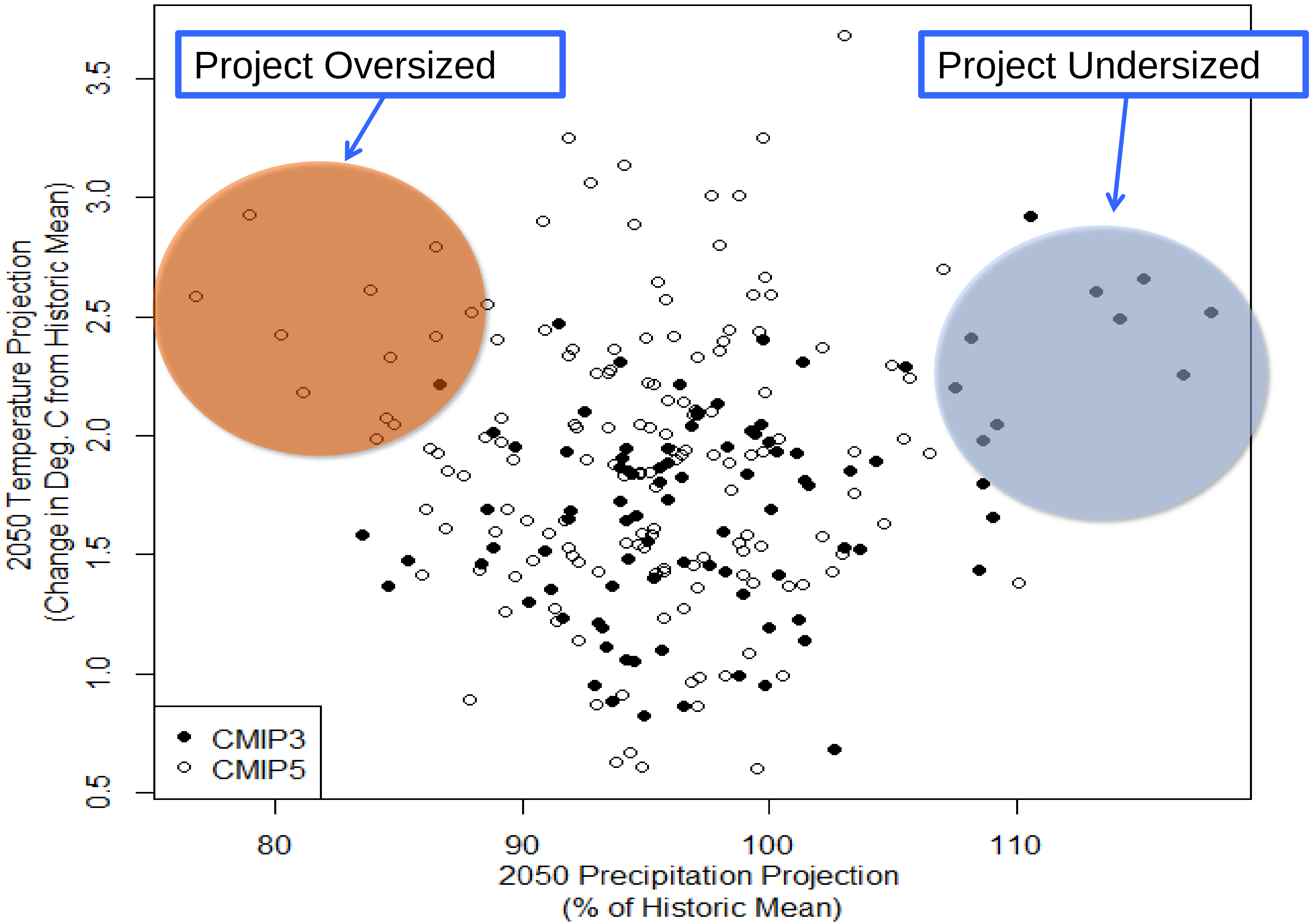




Wisconsin Valley Improvement Company

Water Resources System Model

Now What?


Project Oversized
Project Undersized
2050 Temperature Projection
(Change in Deg. C from Historic Mean)
0.5
1.0
1.5
2.0
2.5
3.0
3.5
80
90
100
110
2050 Precipitation Projection
(% of Historic Mean)
CMIP3
CMIP5

An Alternative Approach

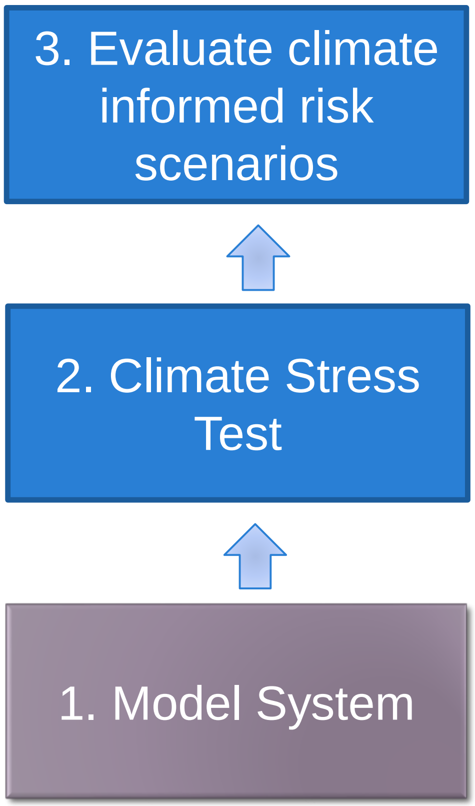
- Assess impacts and identify hazards via systematic sensitivity analysis
  - Identify and explore the uncertain variables that are relevant (HINT: Not emissions scenarios or downscaling methods!)

- "Climate Stress Test"

- Use the best available climate information to inform the level of concern with the risk
  - Subjective Probabilities or prioritization of concerns

Brown and Wilby, *EOS*, 2012; Brown et al., *WRR*, 2012, Poff et al., 2015 *Nature Climate Change*

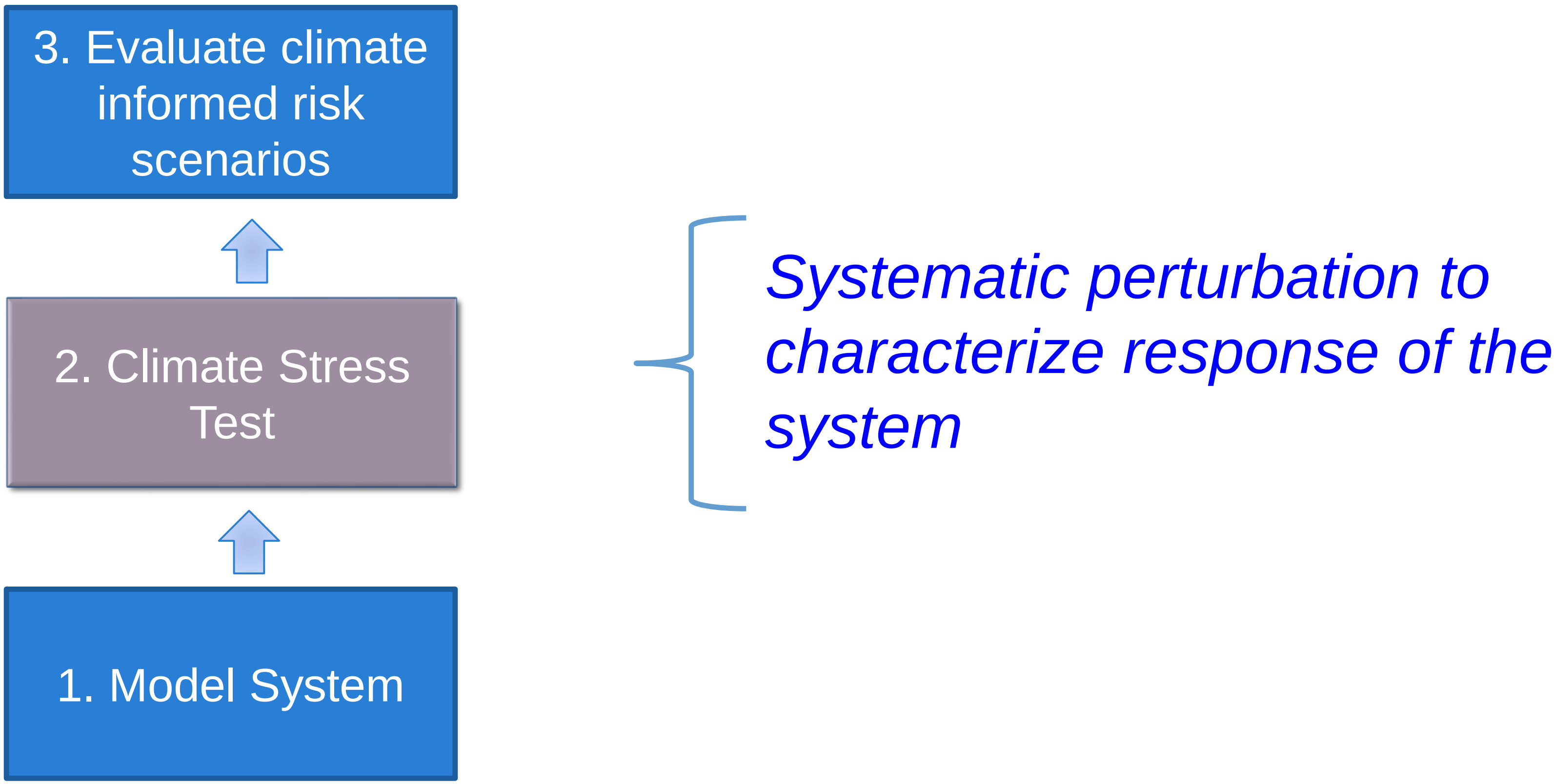
Decision-Scaling for Adaptation to Climate Change



Define link between climate and decisions

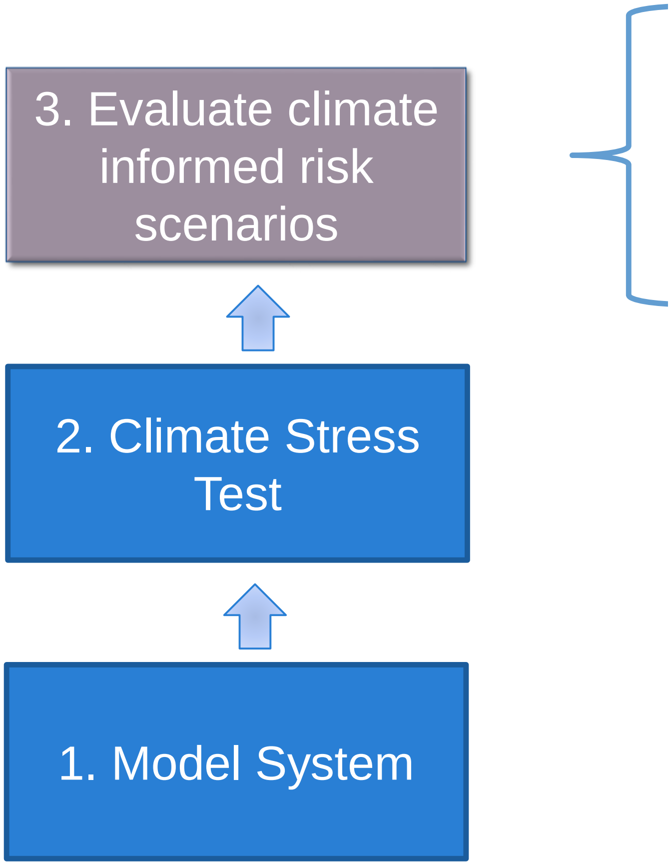
Brown and Wilby, *EOS*, 2012; Brown et al., *WRR*, 2012, Poff et al., 2015 *Nature Climate Change*

Decision-Scaling for Adaptation to Climate Change



Brown and Wilby, *EOS*, 2012; Brown et al., *WRR*, 2012, Poff et al., 2015 *Nature Climate Change*

Decision-Scaling for Adaptation to Climate Change



Data mining to extract "ex post" scenarios for further analysis.

Brown and Wilby, *EOS*, 2012; Brown et al., *WRR*, 2012, Poff et al., 2015 *Nature Climate Change*

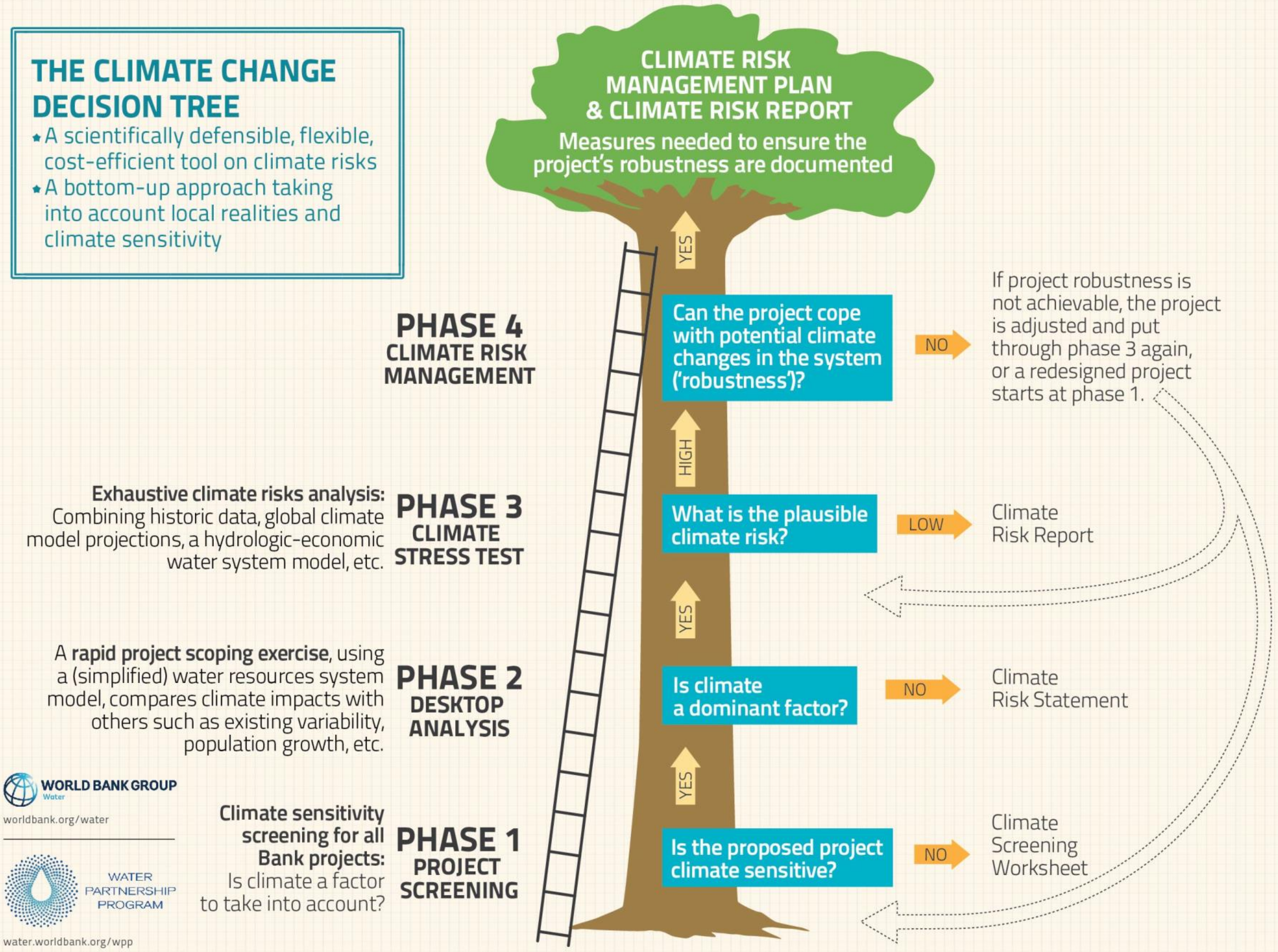
Confronting Climate Uncertainty in Water Resources Planning and Project Design

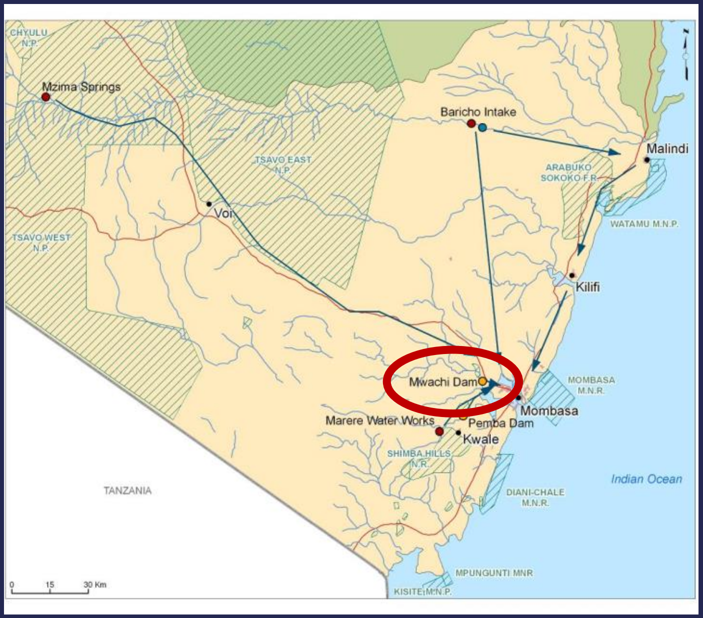
The Decision Tree Framework

Patrick A. Ray
Casey M. Brown

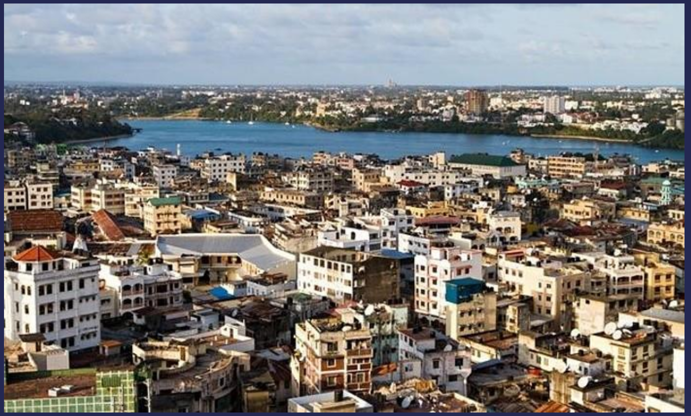
WORLD BANK GROUP

IDENTIFYING AND MANAGING CLIMATE RISKS





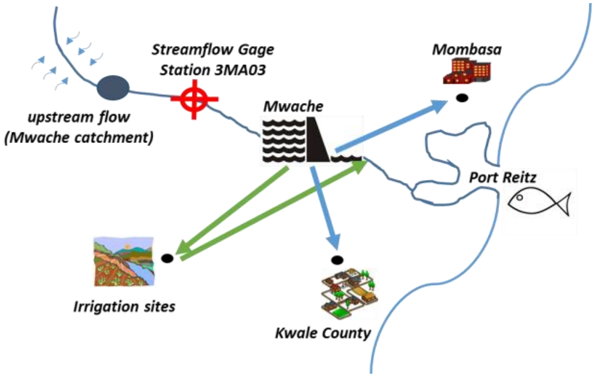
Mombasa city



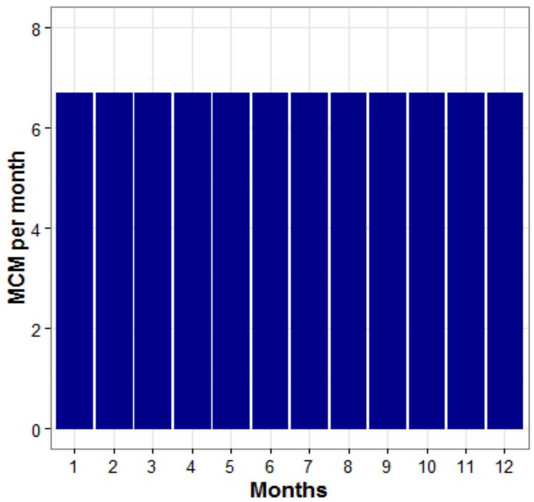
NEW WATER SUPPLY

Mwache Reservoir, Kenya

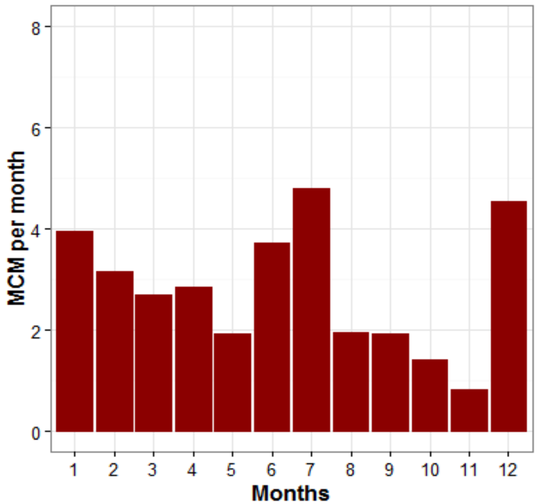
New Water Supply for Mombassa, Kenya - Mwache Dam



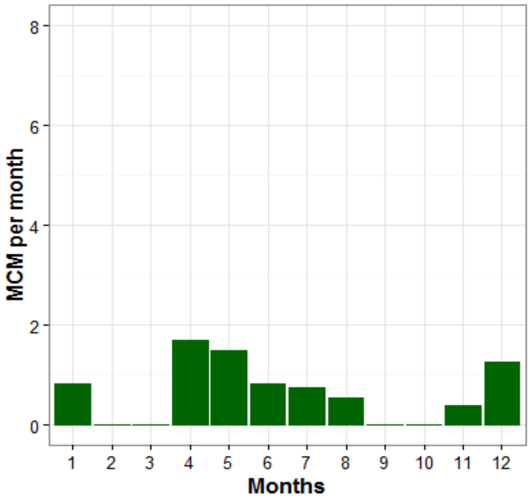
Planned releases for domestic use[1,2] (Mombasa + Kwale)



Planned releases for irrigation[1,2] (for a target of 2800 ha)

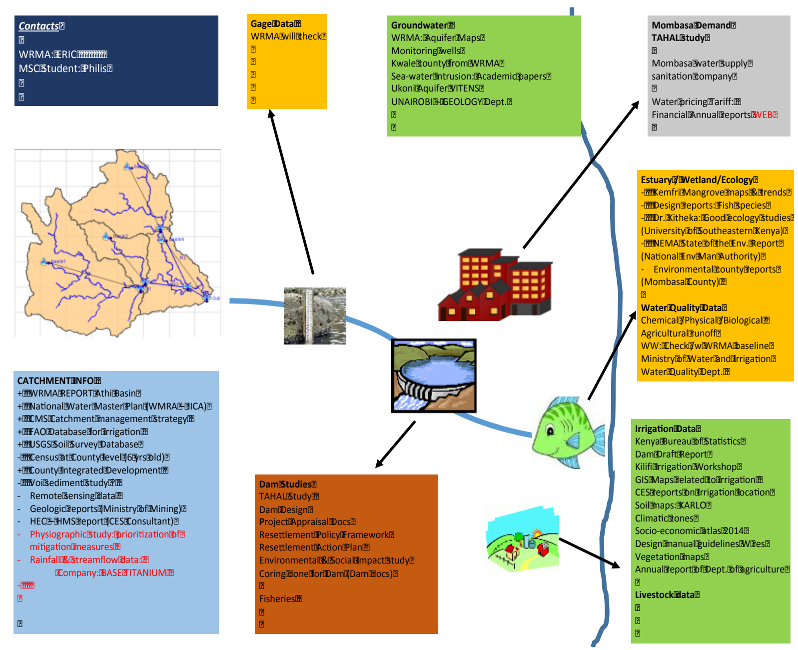


Planned releases for environmental protection[1,2]



Project inception workshop

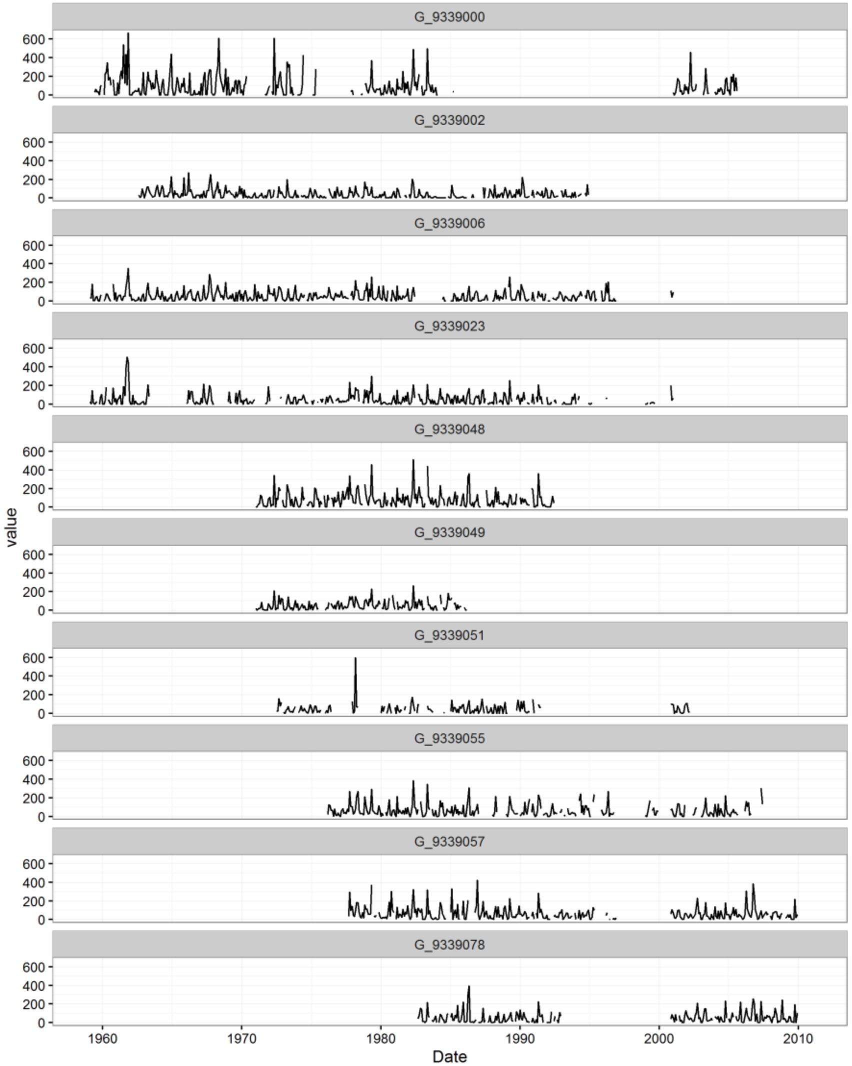
(Kwale, Kenya Aug 10-15, 2015)

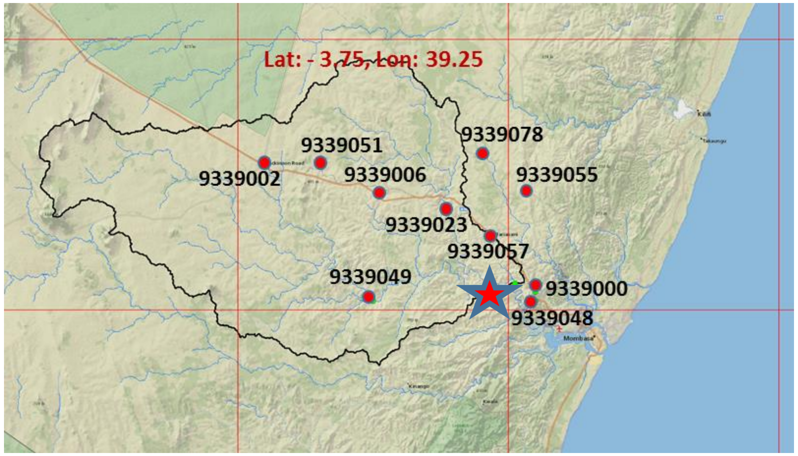


Framing the Analysis – More than Climate

Uncertainties	Investment and Policy Options
Natural Uncertainties Precipitation (intensity, duration, frequency, timing) Temperature (melt/evapotranspiration) Sedimentation Seismic risk and disasters **Nepal Future System and Operations** National markets; International agreements; Prices **Project Variables** Capital costs; Lifetime of the projects; Discount rate	**Upper Arun HP** 335 MW (Q70) – original design 750 MW (Q40) – possible alternative 2000 MW (Q25) – possible alternative
Metrics of Success	**Models and Data**
Hydropower Performance Net Present Value Power generation (Dry season; Wet season; Total Annual)	**Hydrological model** UMass Glacio-Hydrologic Model **Watershed System** Run of River Hydropower in R

Climate context – Historical Observations

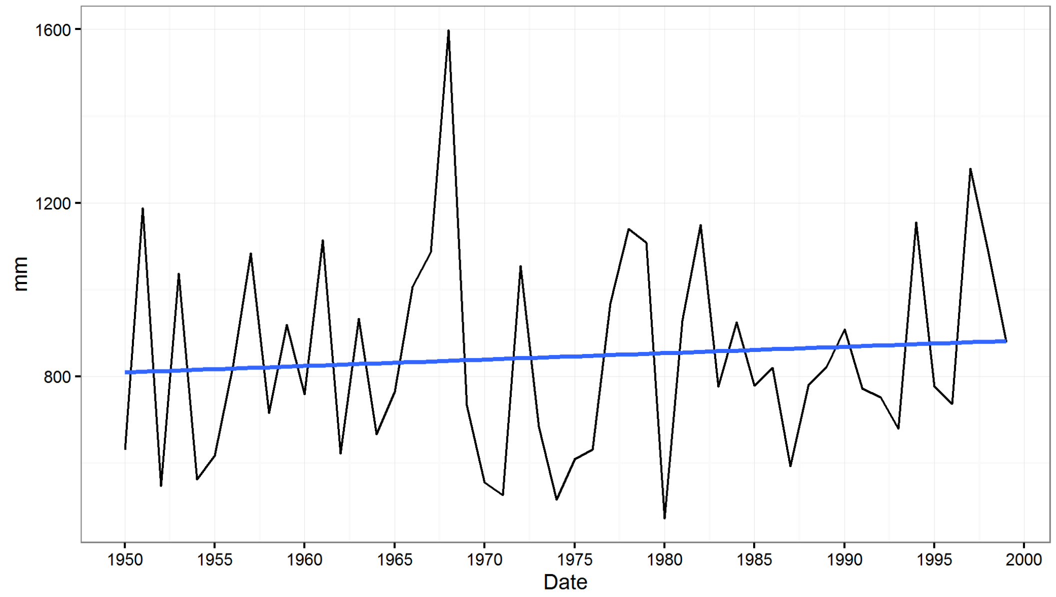


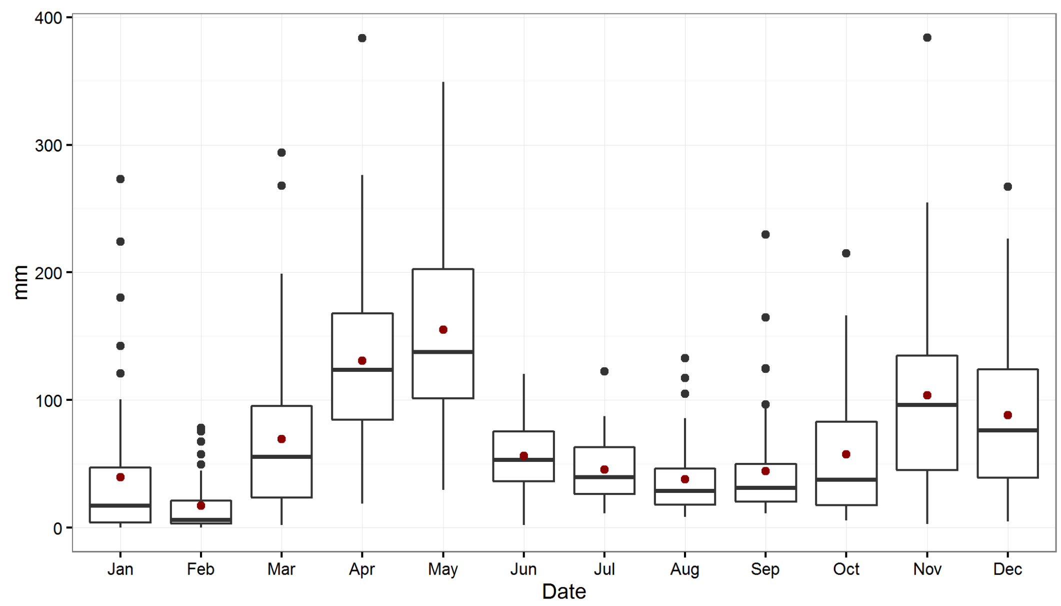


- Inconsistent time-periods
- Missing observations

Historical climate trends?

- year-to-year and within-year variablity
- Upwards trend not significant





Streamflow response

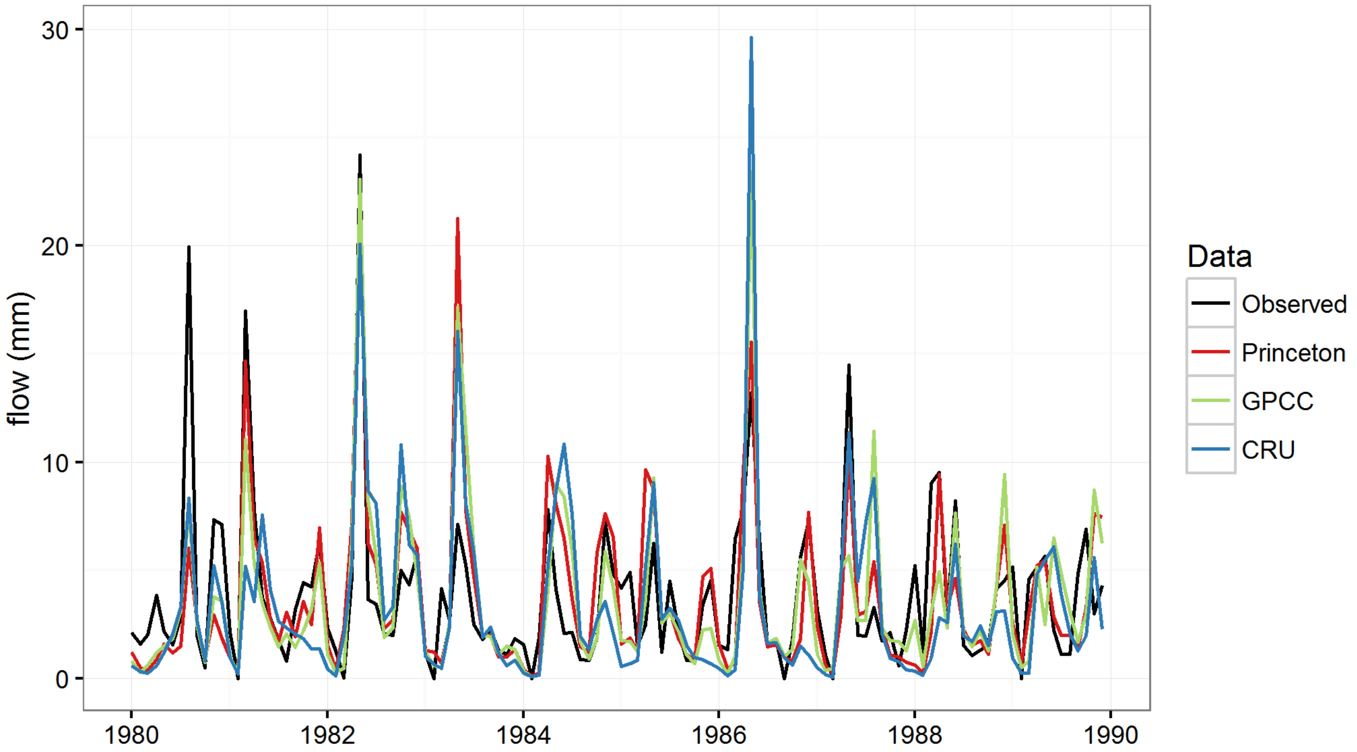
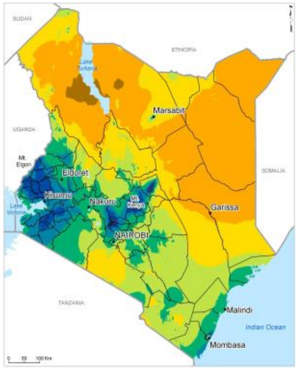


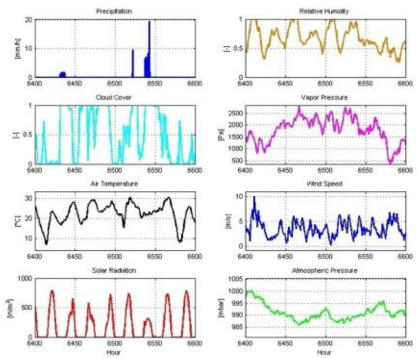
Figure 12 – Observed month flow at Gauge 3MA03 versus simulated model responses with the Princeton, GPCC, and CRU gridded datasets respectively.

Climate Stress test of Reservoir Design

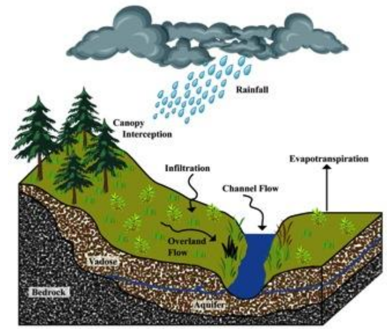
climate dataset
(historical data)



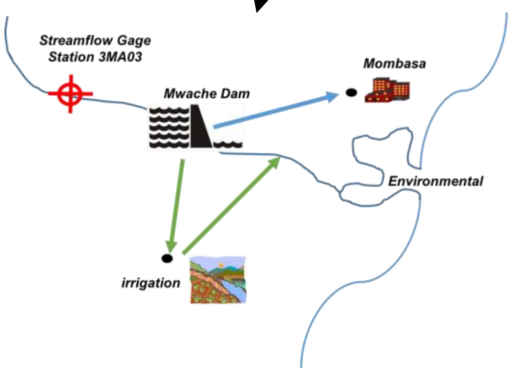
weather generator
(wavelet ar model)

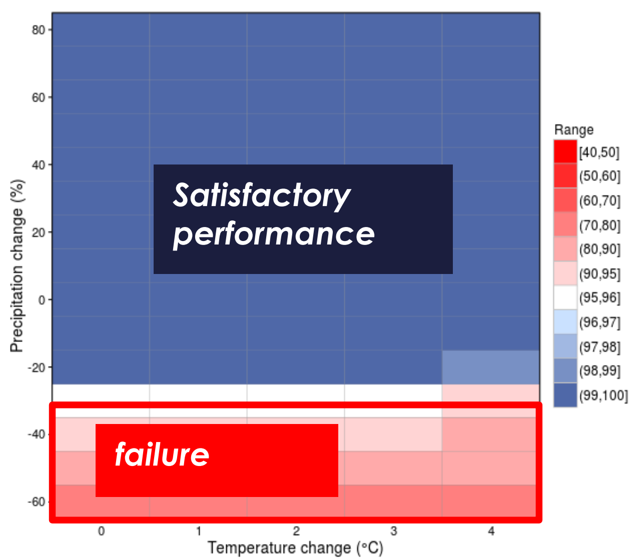


hyrologic response
('abcd' model)



system response
(in R)

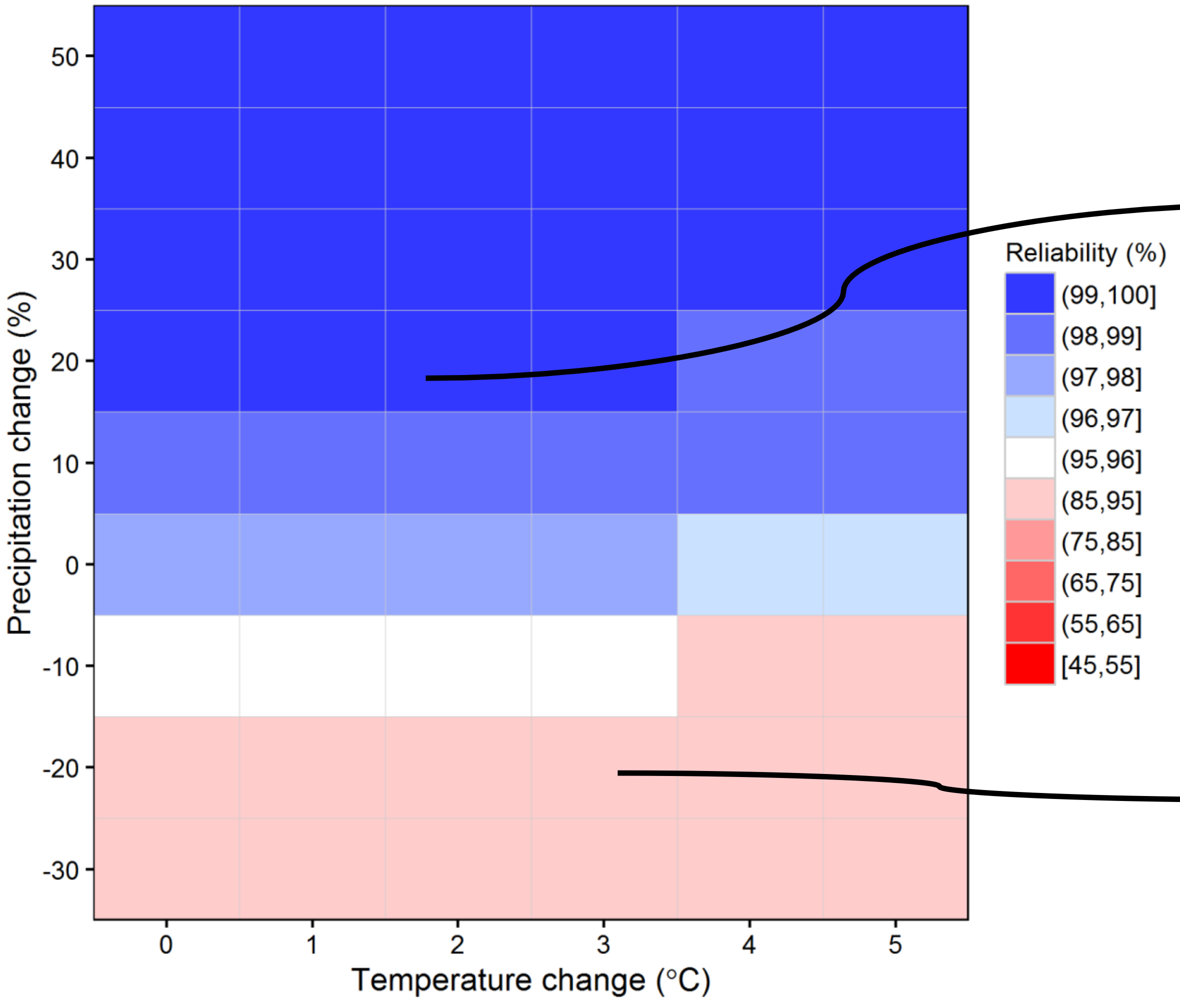




Evaluate robustness across 6500 runs

Water Supply Reliability

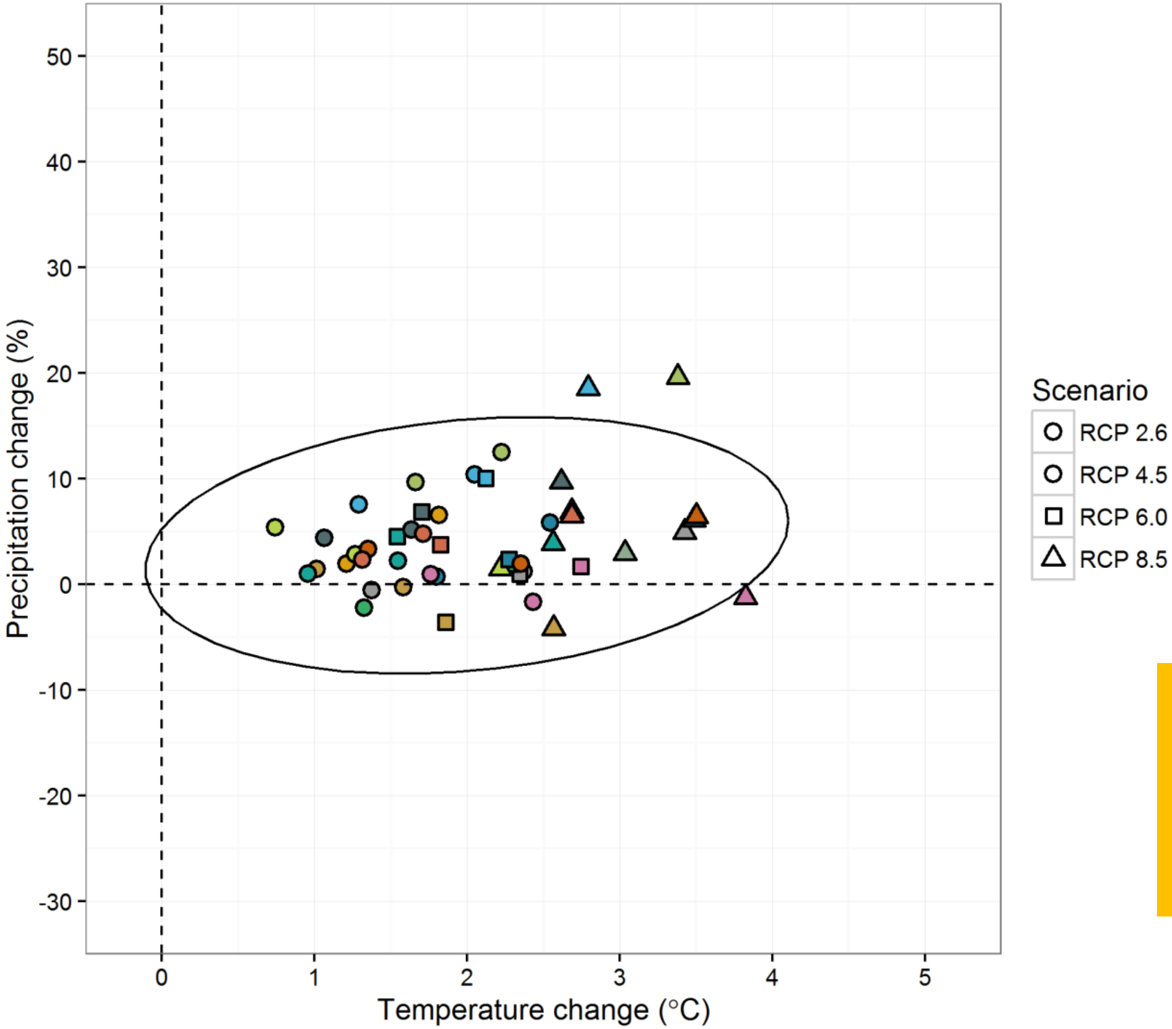
- Demand = 68 MCM



ACCEPTABLE (reliablity > 95)

FAILURE (reliability < 95%)

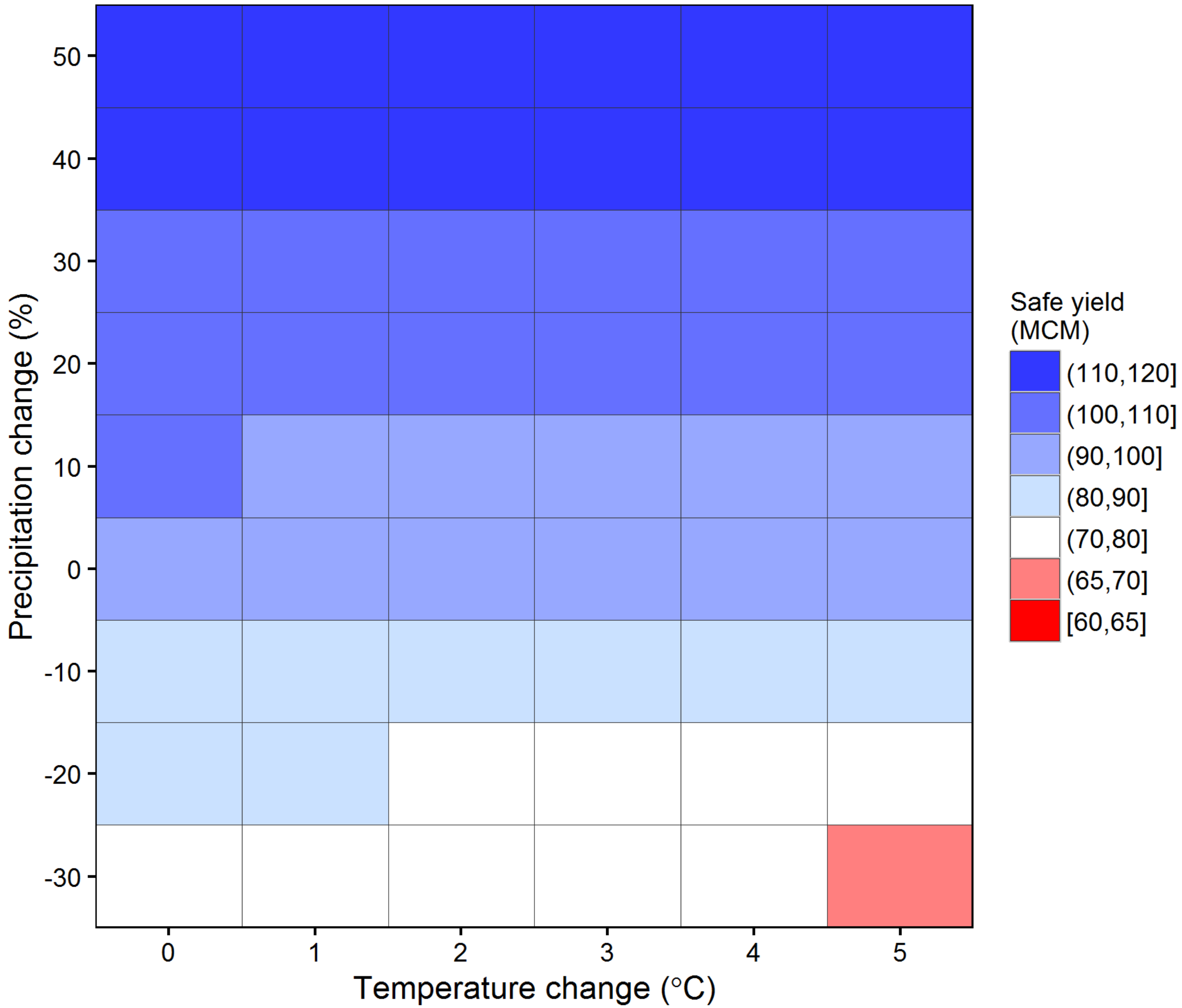
Climate Change Projections



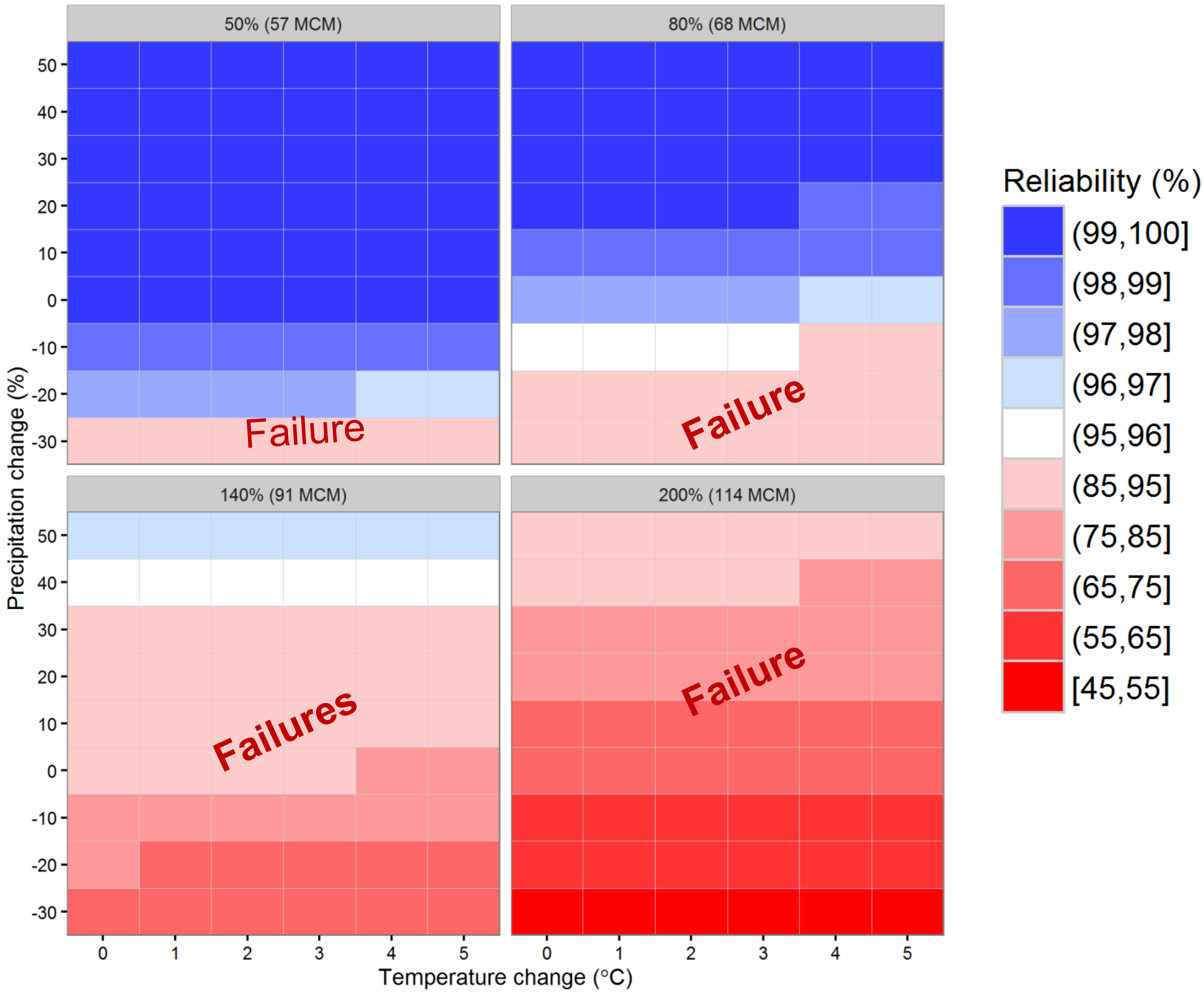
99% confidence level:

- ΔT: 0 to 4℃
- ΔP: -5% to +20%

Safe Yield - MCM

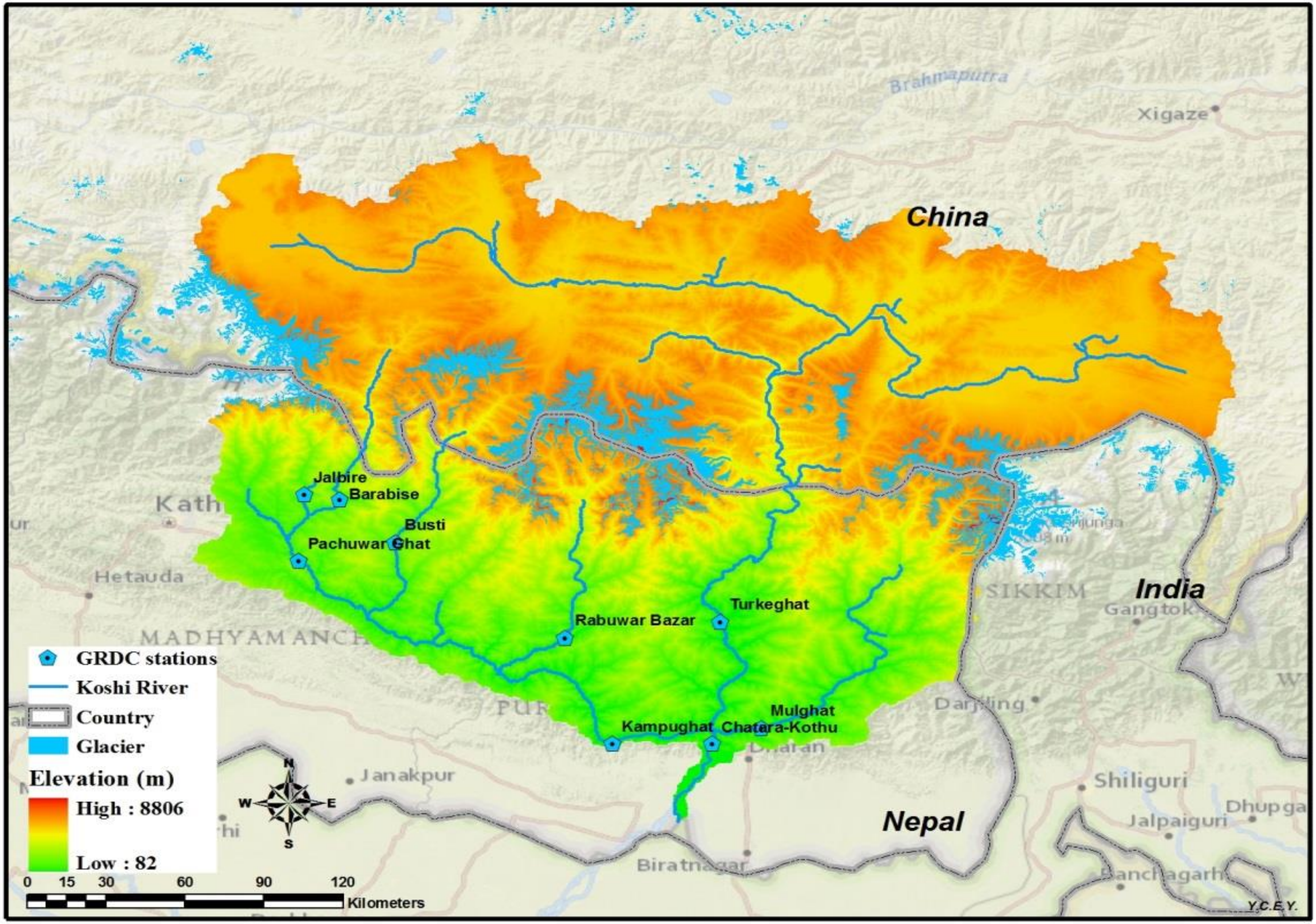


Water Supply Reliability as demand increases

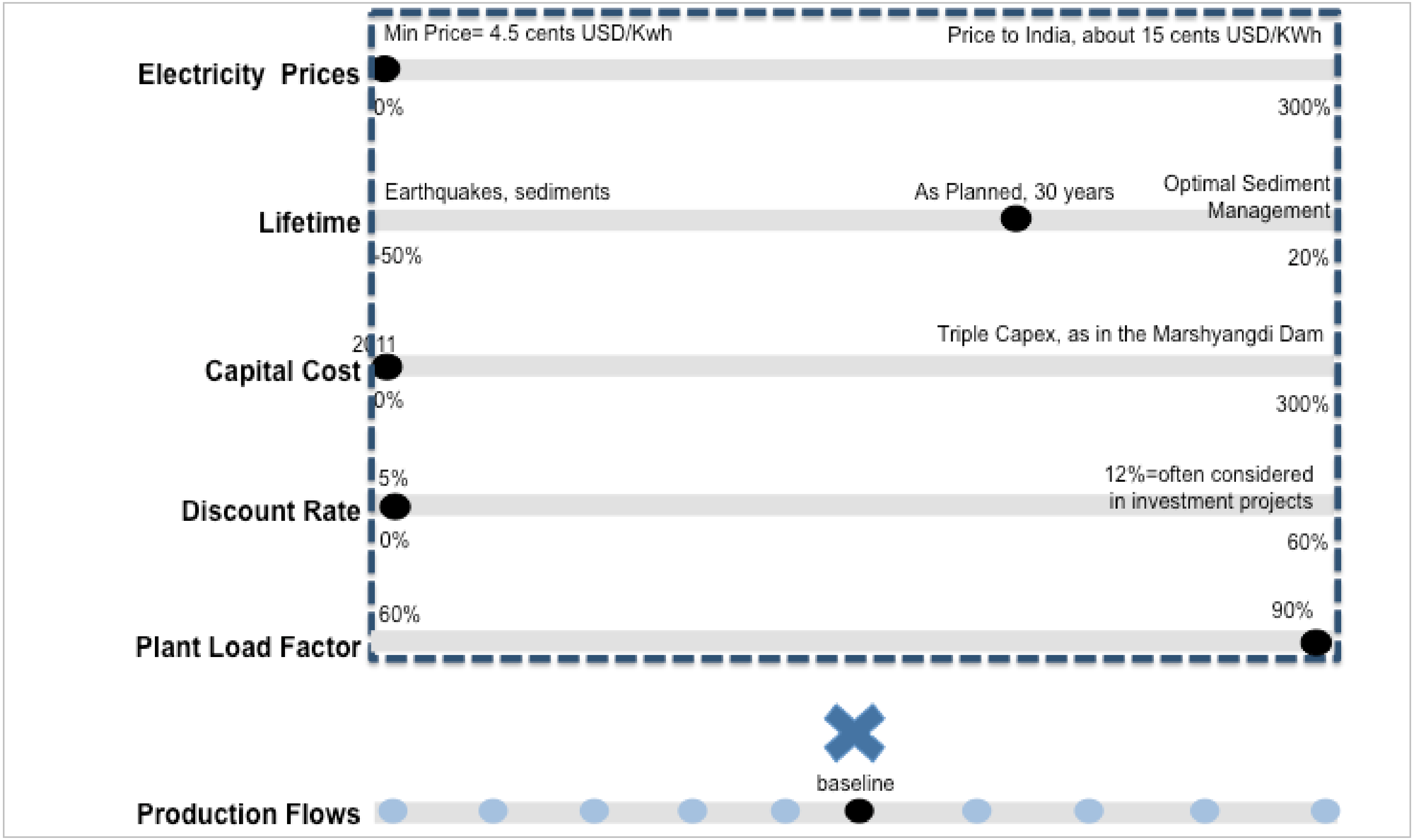


Upper Arun Hydroelectric Plant

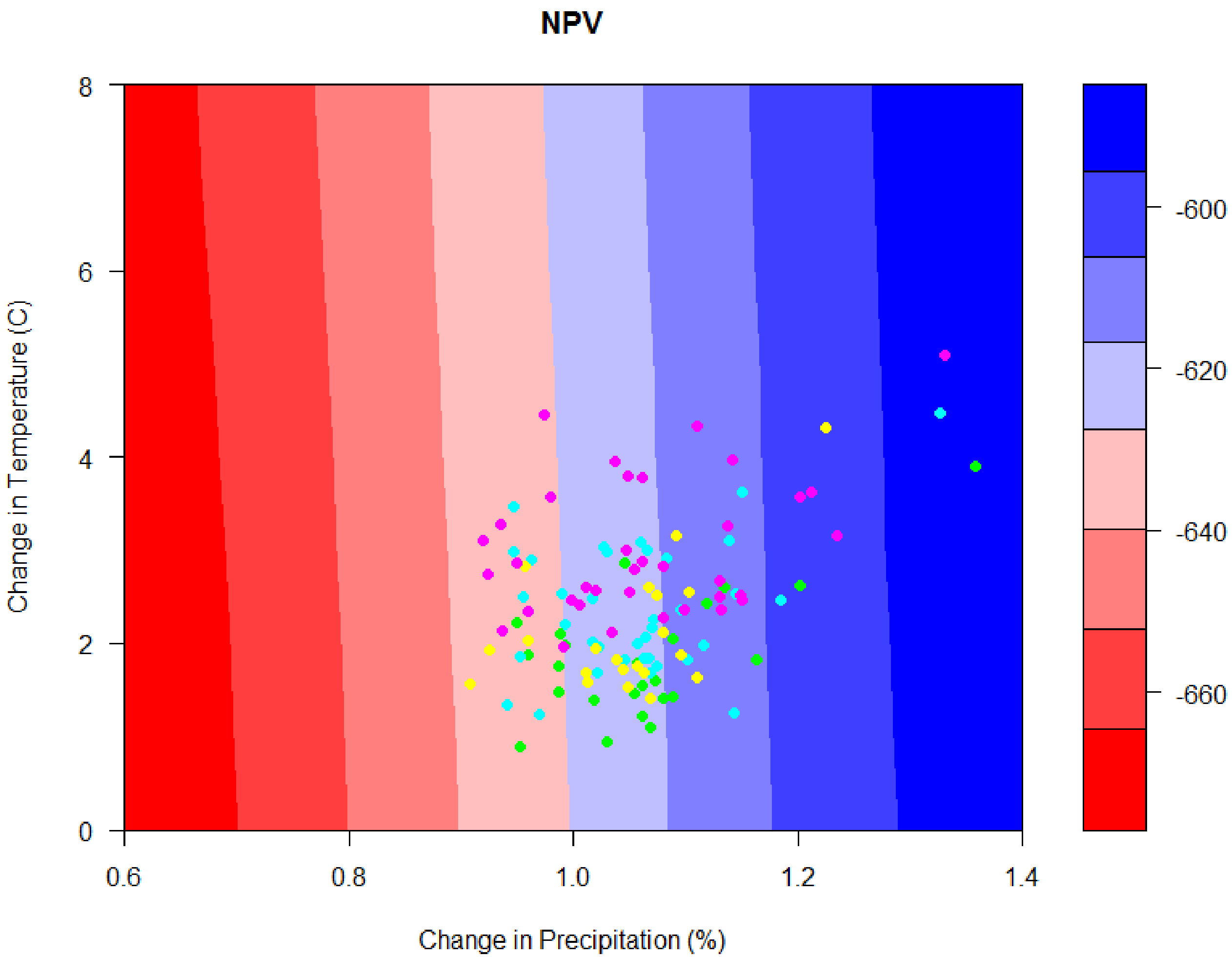
New Hydroelectricity Investment - Koshi Basin



Testing 6500 Plausible Futures



Net Present Value 335 MW Design



Investment fails if …

335 MW

- **Electricity price** < 5.67 NRs

AND

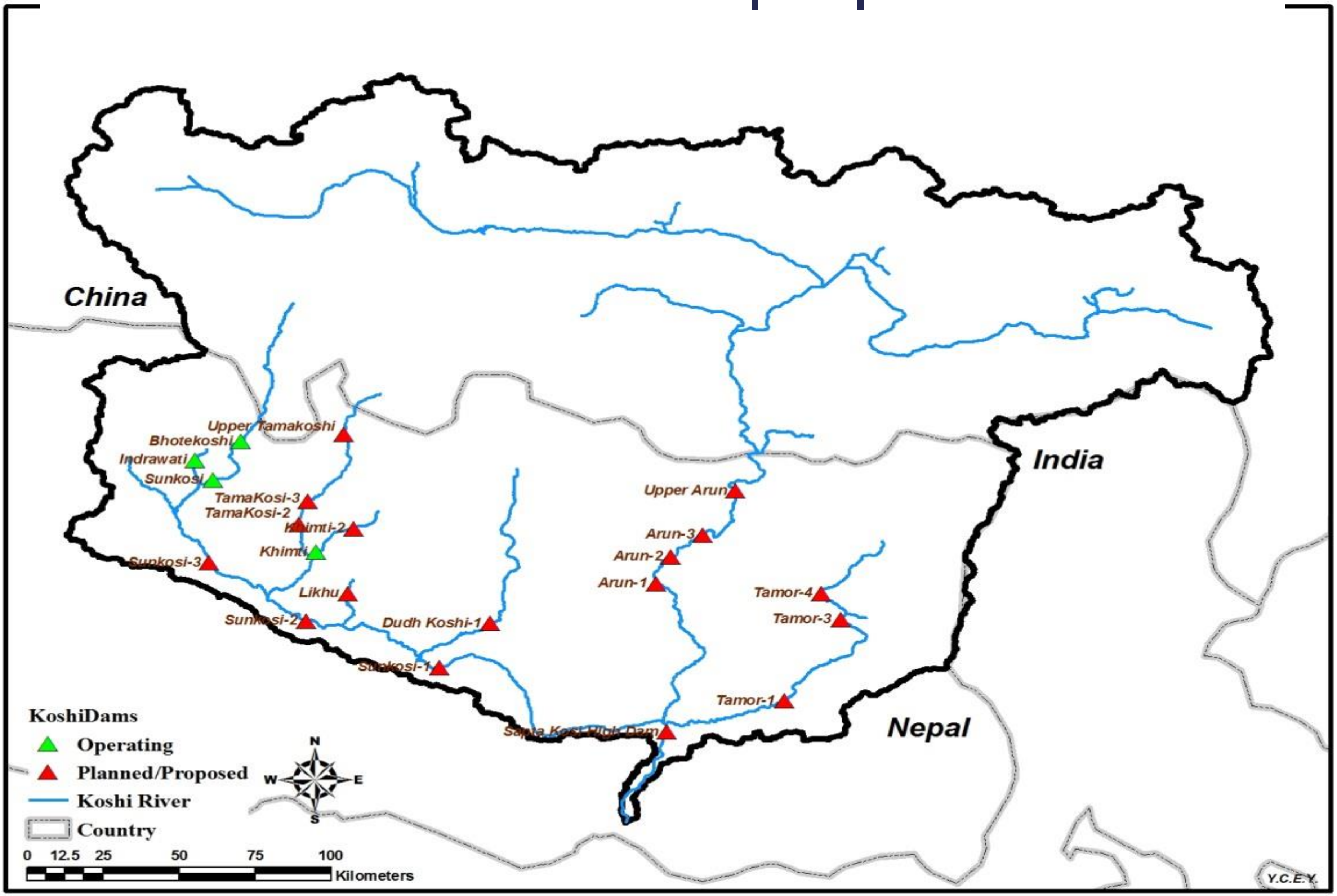
- **Lifetime** of the dam < 15 yrs

AND

- **Discount rate**

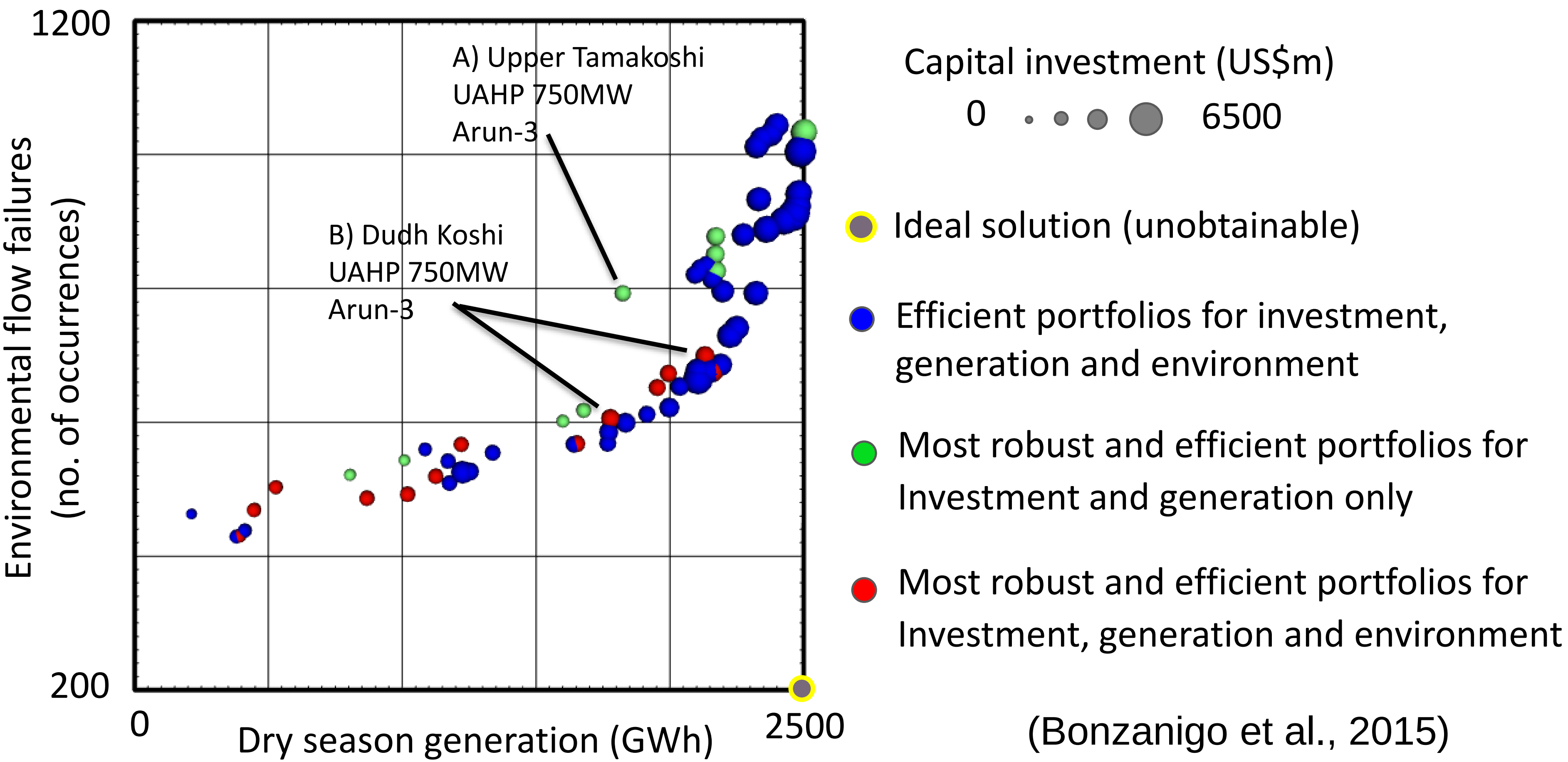
  > 15.6%

The Koshi Basin and proposed dams



Identifying Optimal Investment Portfolios

Explore portfolios for best match with decision maker preferences



(Bonzanigo et al., 2015)

Conclusions

- Current approaches to climate change impact assessment not well designed for risk assessment or aiding decisions
- Decision Making under Uncertainty methods are effective:
  - Identifying Vulnerabilities through “climate stress testing”
  - Assessing Risks
  - Planning Adaptation and identifying robust options
- Decision Tree guides manager to appropriate level of analysis to assess climate risks efficiently and effectively

Research Needs:

1. <u>Adaptation Options and Implementation – </u>Margin of safety; regulatory guidelines; “safe fail”; Endogenous adaptation; etc.
2. <u>Adaptation Planning and Time </u>– planning occurs over time as climate evolves; value of near term climate information; reversible decisions and options based approaches; rule of thumb guidance approaches; dominance of variability in near term.
3. <u>Probabilistic Approaches for Estimating Climate Risk </u>– research effort needed to estimate probabilities of problematic climate change – and risk-based context is critical.

Thanks! Questions: casey@umass.edu

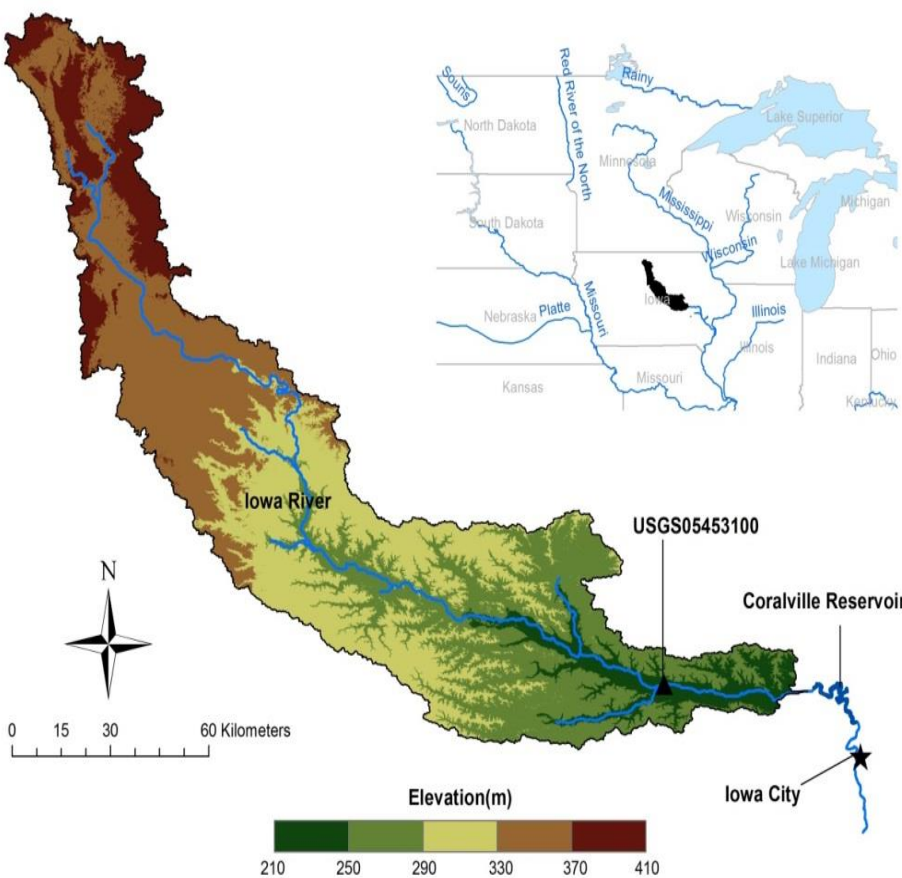
June 2008 Overtopping Event

Iowa River, Iowa, USA

CLIMATE INFORMED FLOOD RISK

SERDP Project# RC 2516 Climate-Informed Estimation of Hydrologic Extremes for Robust Adaptation to Non-Stationary Climate; NSF CAREER: Robust Management of Climate Uncertainty for Ecohydrological Sustainability

Iowa River – Climate Change or Natural Variability?



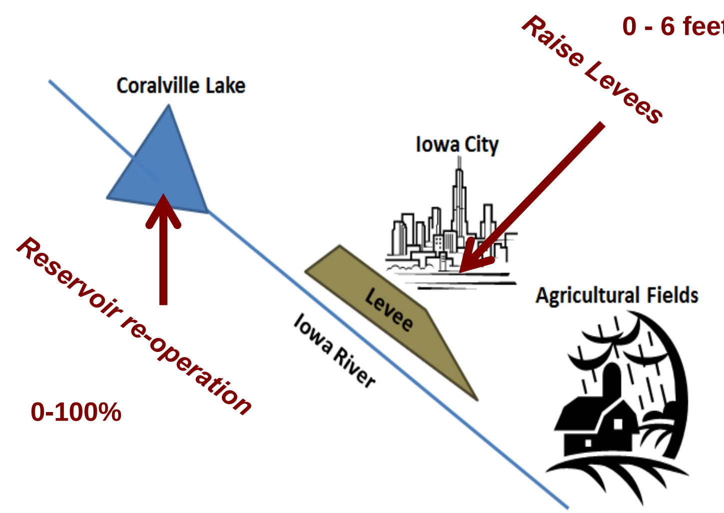
June 2008 floods

Spillway use:

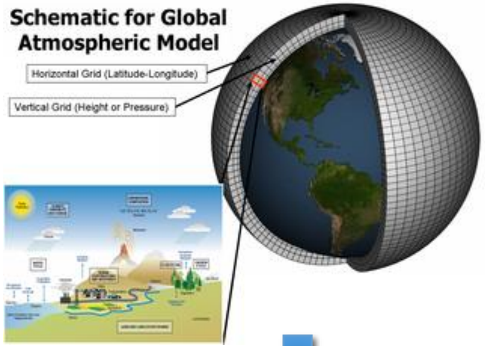
-1993
-2008
-2013

Are floods increasing?

Proposed adaptations:



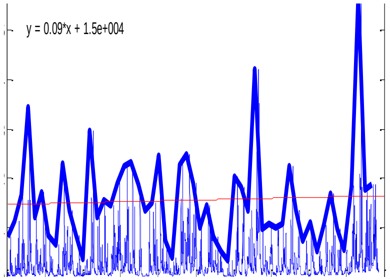
Climate Informed Risk Estimate

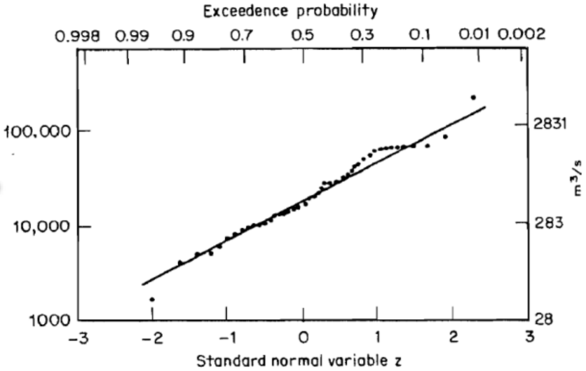


X

Stream gage

Historic record





$LP3[\mu(X),\sigma(X),\xi(X)]$

Climate Informed Risk Estimate

nature climate change

PERSPECTIVE

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Sustainable water management under future uncertainty with eco-engineering decision scaling

N. LeRoy Poff[1]*, Casey M. Brown[2], Theodore E. Grantham[3], John H. Matthews[4], Margaret A. Palmer[5], Caitlin M. Spence[2], Robert L. Wilby[6], Marjolijn Haasnoot[7,8], Guillermo F. Mendoza[9], Kathleen C. Dominique[10] and Andres Baeza[11]

Managing freshwater resources sustainably under future climatic and hydrological uncertainty poses novel challenges. Rehabilitation of ageing infrastructure and construction of new dams are widely viewed as solutions to diminish climate risk, but attaining the broad goal of freshwater sustainability will require expansion of the prevailing water resources management paradigm beyond narrow economic criteria to include socially valued ecosystem functions and services. We introduce a new decision framework, eco-engineering decision scaling (EEDS), that explicitly and quantitatively explores trade-offs in stakeholder-defined engineering and ecological performance metrics across a range of possible management actions under unknown future hydrological and climate states. We illustrate its potential application through a hypothetical case study of the Iowa River, USA. EEDS holds promise as a powerful framework for operationalizing freshwater sustainability under future hydrological uncertainty by fostering collaboration across historically conflicting perspectives of water resource engineering and river conservation ecology to design and operate water infrastructure for social and environmental benefits.

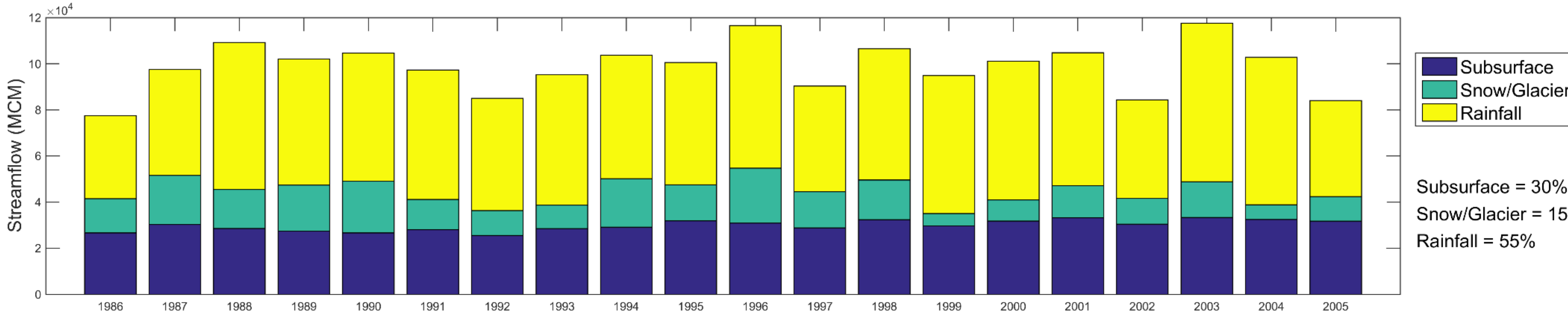
Securing the supply and equitable allocation of fresh water to support human well-being while sustaining healthy, functioning ecosystems is one of the grand environmental challenges of the twenty-first century, particularly in light of accelerating stressors from climate change, population growth and economic development. Rehabilitation of ageing infrastructure and construction of new infrastructure are now widely viewed as engineering solutions to mitigate future climatic uncertainty in the hydrologic cycle[1]. Indeed, the construction of tens of thousands of dams in the twentieth century helped secure water supplies and fuel economic development in industrialized countries, and developing economies are now pursuing massive new infrastructure projects with thousands of new dams proposed for hydropower production and water supply security[2].

Despite the economic stimulus provided by many dams historically, the global experience with dam building warns that traditional approaches to water infrastructure development in a rapidly changing world carry severe risks of economic and environmental failure. First, large water projects are very capital-intensive and long-lived, costing billions of dollars to plan, build and maintain. Yet, they are vulnerable to biased economic analyses[3], cost overruns and construction delays, and changing environmental, economic and social conditions that can diminish projected benefits[4,5]. Under a variable and changing climate, large water infrastructure may even risk becoming stranded assets[6]. Second, the principles of economic efficiency inherent in cost-benefit analysis dominate project design and performance assessment, making integration of social and environmental benefits and costs into a comprehensive economic evaluation a significant challenge[7,8]. These costs can be substantial, as evidenced by human displacement[5,9], local species extinctions[10] and the loss of ecosystem services such as floodplain fisheries and other amenities[11,12].

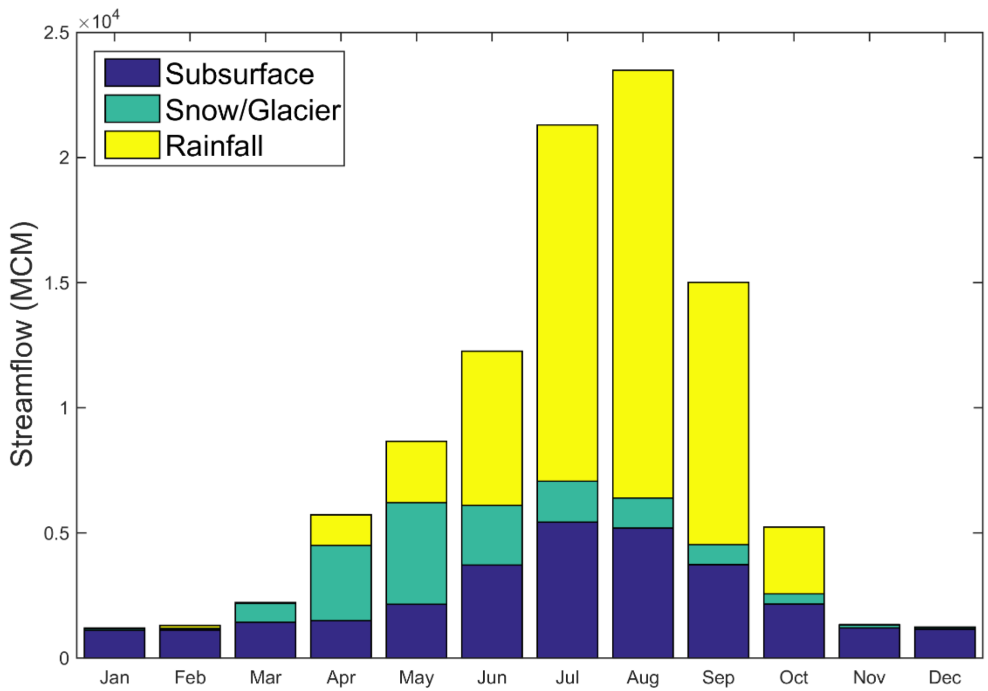
As unanticipated economic, social and environmental costs accumulate with ageing water infrastructure, society is investing in restoration projects to partially undo longstanding environmental degradation, including modifying flow releases from dams[13,14] and, in some cases, dam removal[15]. As global-scale impairment of aquatic ecosystem function becomes increasingly documented and articulated[16,17], there is urgent need for a broader conception of sustainable water resource management that formulates environmental health as a necessary ingredient for water security and the social well-being it supports[18–20]. Notably, new national directives are emerging to develop and manage river ecosystems in more environmentally sustainable ways that retain social benefits, including in the USA[21], Europe[22,23] and Australia[24].

Towards a sustainable water management paradigm

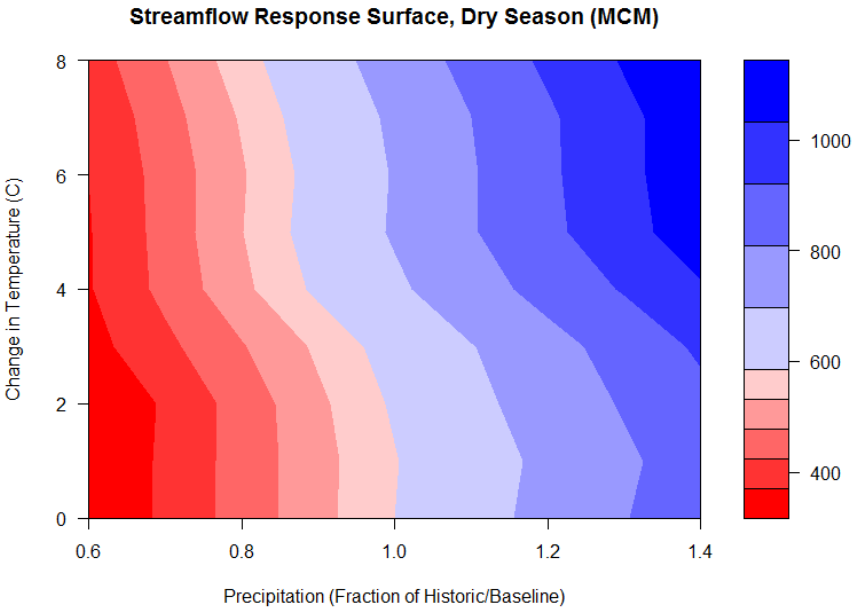
Here, we ask if a more sustainable water management philosophy can be forged to guide investment in, and design of, water infrastructure while avoiding adverse (and sometimes irreversible) social and environmental consequences. We consider 'sustainable water management systems' to be those that meet the needs of society over the lifetime of the infrastructure while also maintaining key ecological functions that support the long-term provision of ecosystem goods, services and values, including biodiversity maintenance. These systems would embrace the principle of resilience, that

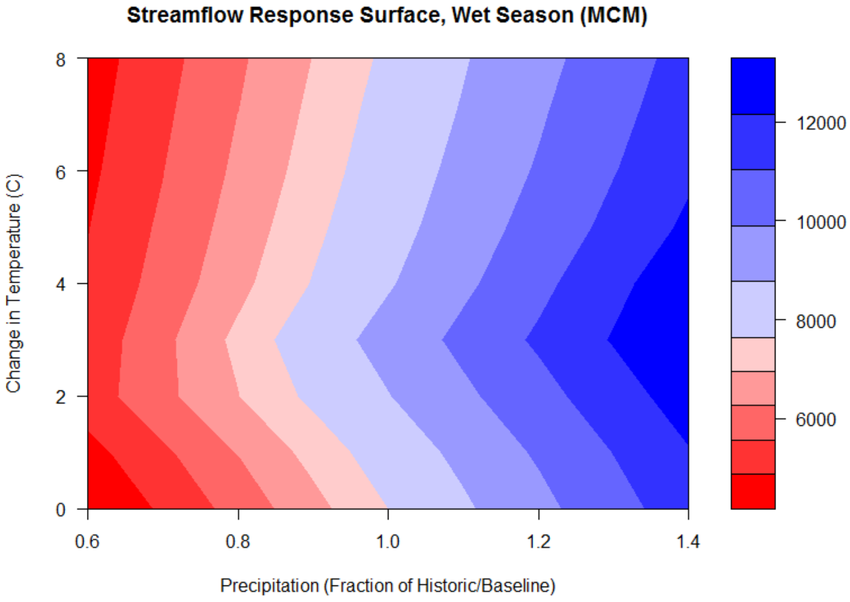


Subsurface = 30%
Snow/Glacier = 15%
Rainfall = 55%

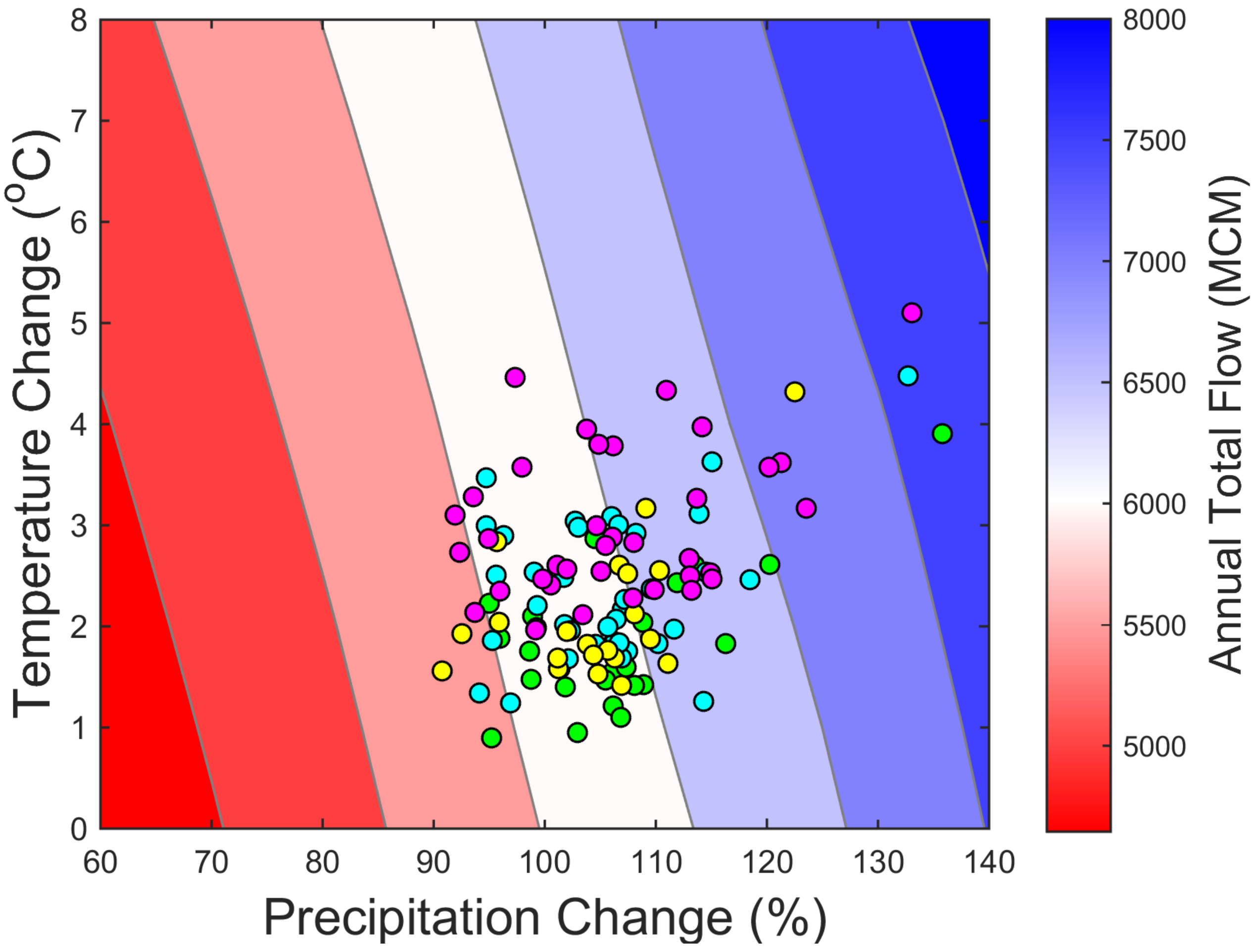


Streamflows sensitivities to changes in precipitation and temperature in the Upper Arun…





Total Annual Flow



Green: RCP 2.6; Blue: RCP 4.5; Yellow: RCP 6.0; Purple: RCP 8.5

Year 2050 Glacier Area

(as % Year 2014 Glacier Area)