

Modeling Uncertainty in IAV:

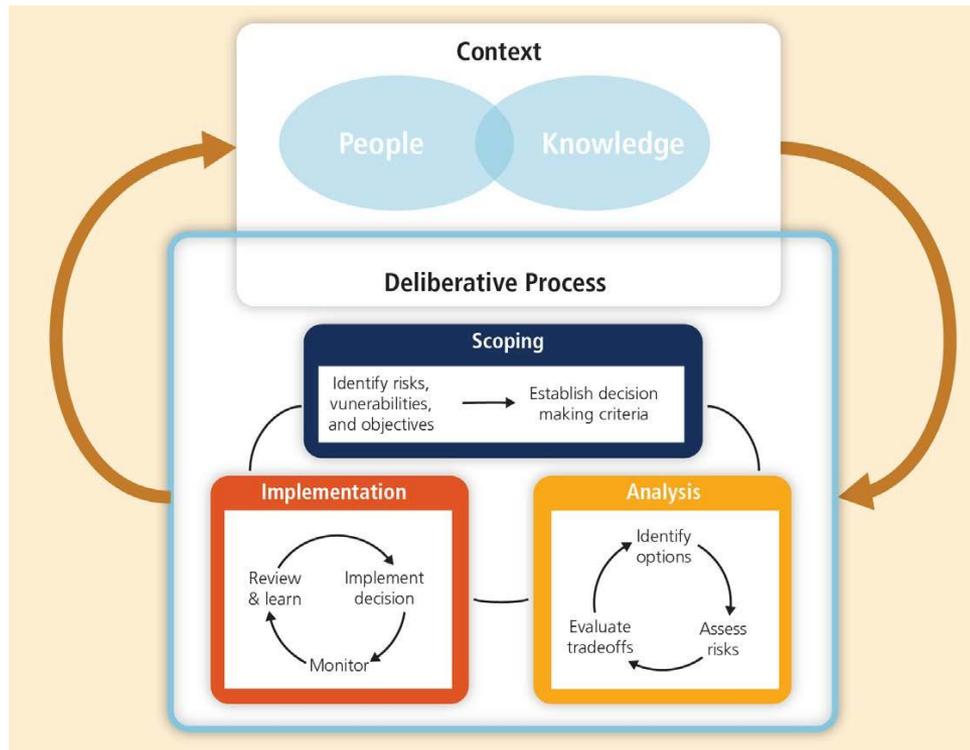
(Emerging decision support toolkit for wicked problems, and some implications for IAV modeling)

Robert Lempert

Snowmass

July 26, 2016

Iterative Risk Management Can Address Uncertainty Through Choice of Strategy



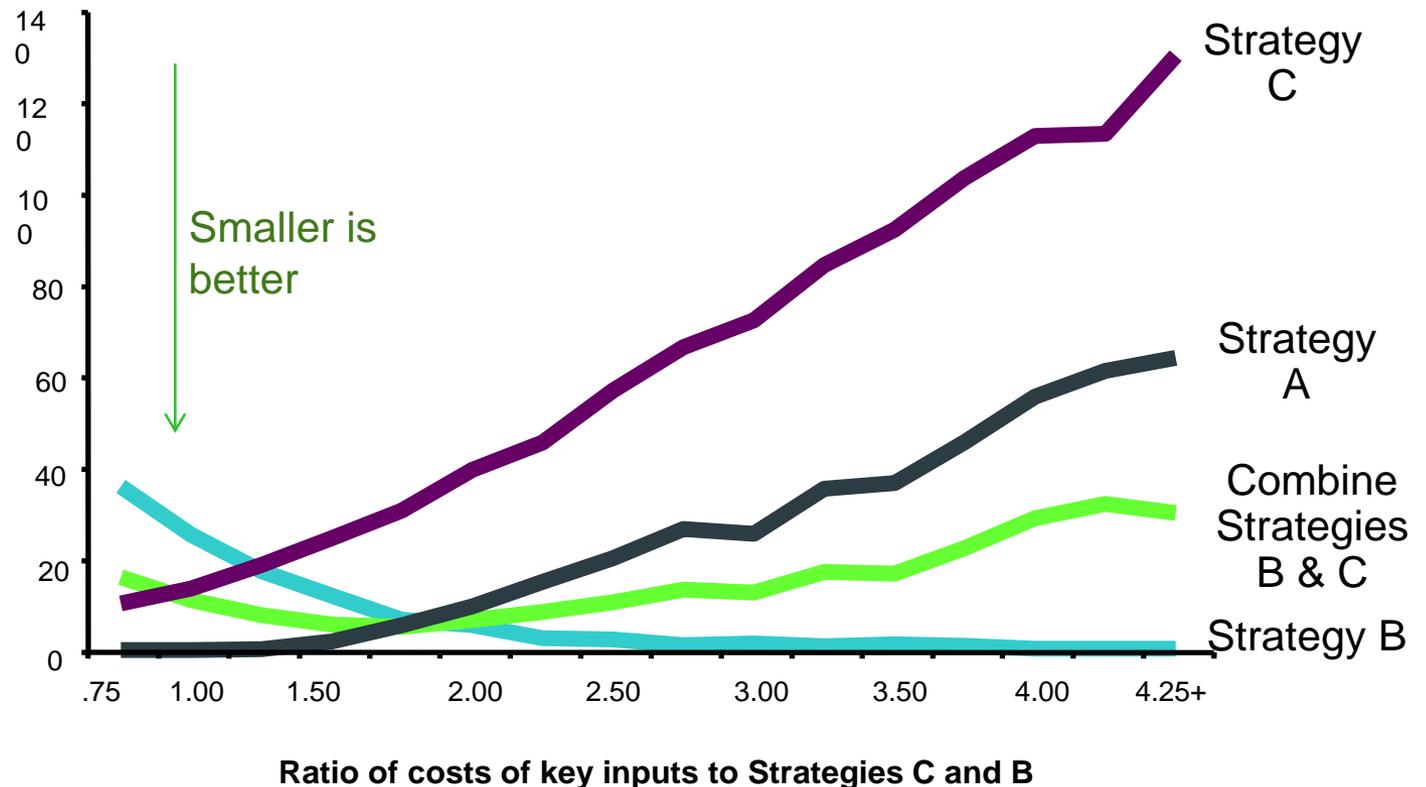
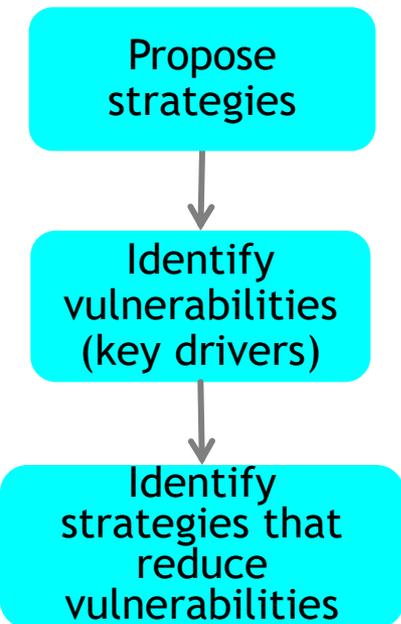
AR5, WGII, Chap 2

When asked in a public meeting whether he trusted the climate models they were using, the director of the Metropolitan Water District of Southern California's planning staff replied he did not necessarily trust the models, but he did trust the agency's contingency plans.

Robust Strategies Help to Manage the Cascade of Uncertainties

Robust strategies perform well, compared to the alternatives, over a wide range of uncertainties

Expected costs above least cost over many scenarios (%)

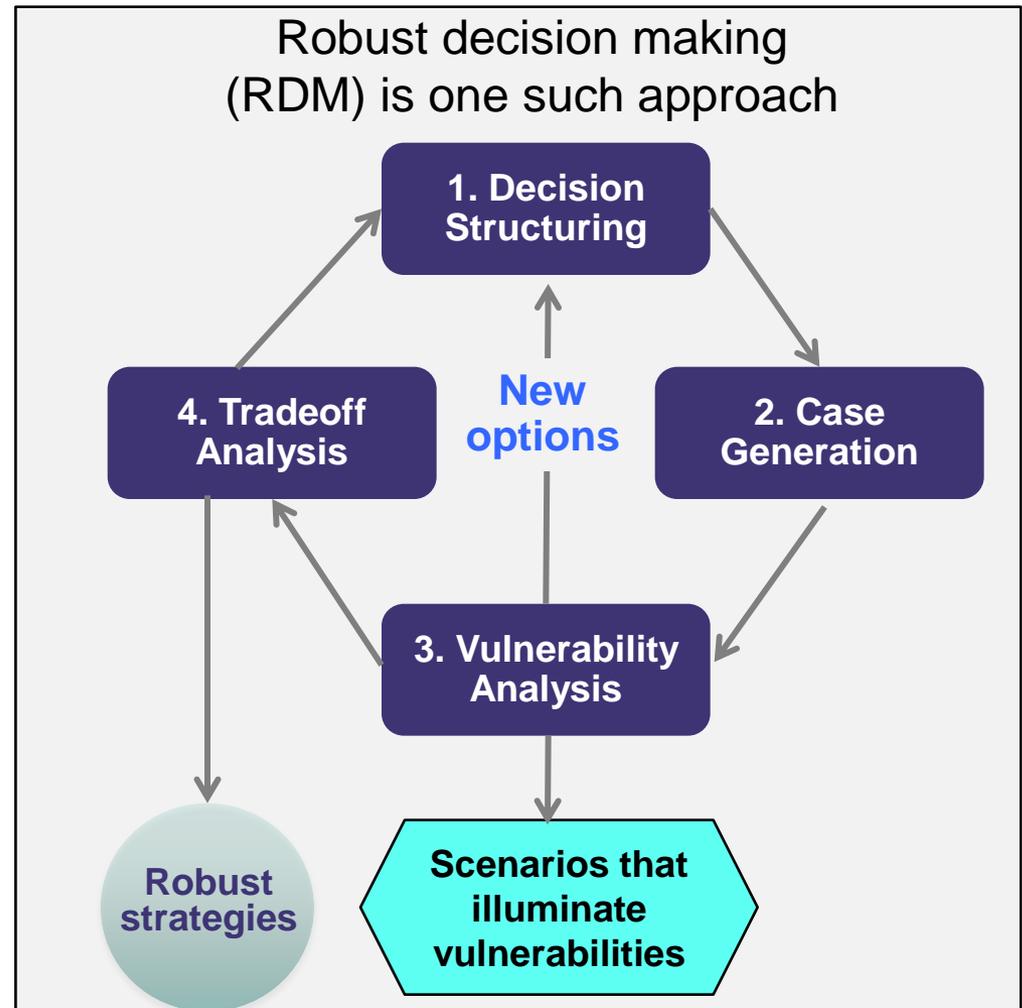


Popper, S. et. al. (2009). Natural gas and Israel's energy future: Near-term decisions from a strategic perspective. RAND

Backwards/Bottom Up Analysis Often Useful for Identifying and Evaluating Robust Strategies

Key idea -- conduct the analysis “backwards”:

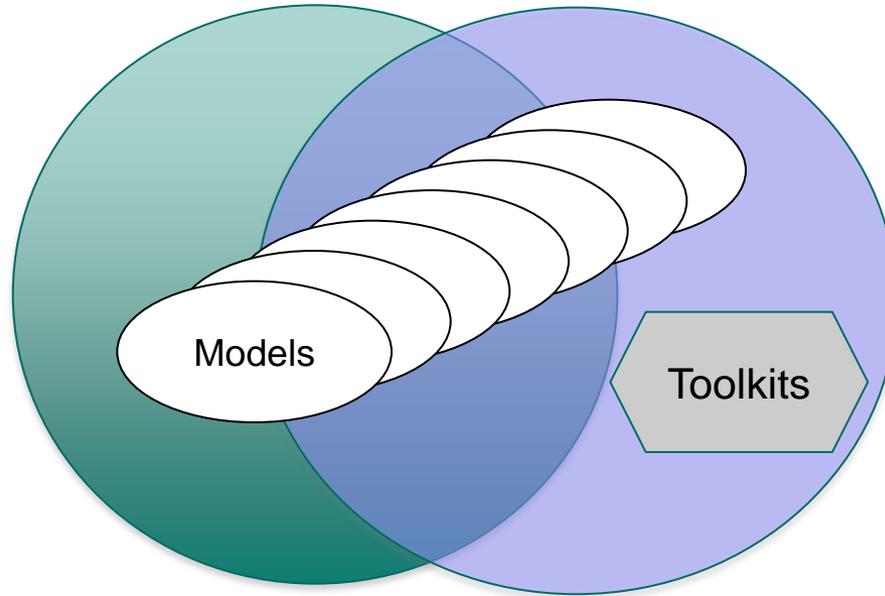
- Start with strategy
- Use analytics to identify scenarios where strategy fails to meet its goals
- Use these scenarios to identify and evaluate robust responses



Two Sciences, Overlapping But Distinct

Science for decision support

Science of decision support



Goal:

- Understanding
- Truth

Criteria for analysis:

- Able to answer well-posed scientific questions

Goal:

- Better decisions

Criteria for analysis:

- Salience
- Legitimacy
- Credibility

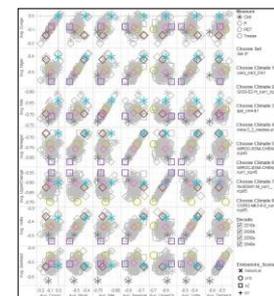
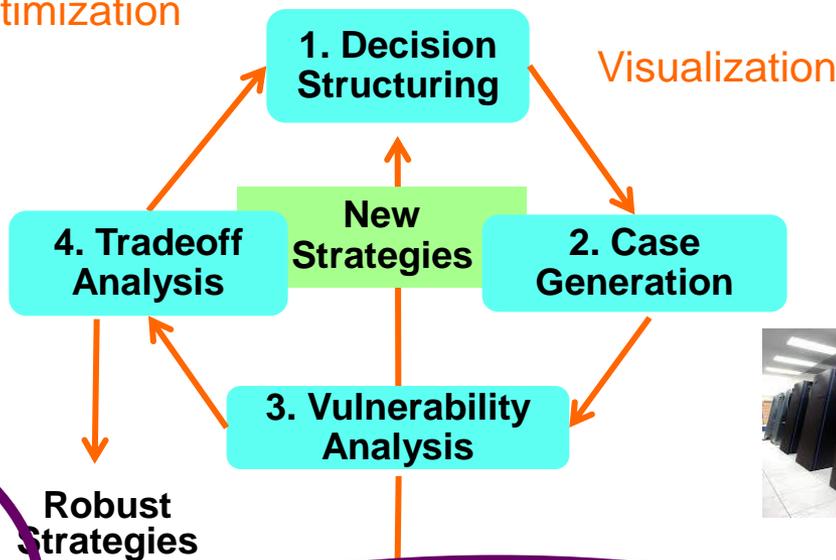
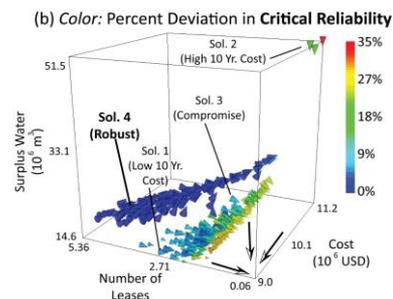
Each role, and each stage, places different requirements on models and how we use them

Key Stages

- Pre-framing
- Framing
- Options analysis
- Justifying the decision

Tools for Multi-Objective, Robust Decision Making Becoming Sufficiently Capable to Use in Deliberative Policy Environments for Wicked Problems

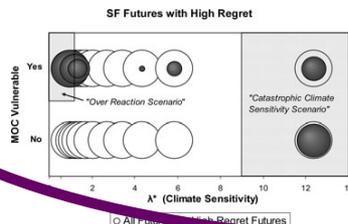
Multi-objective (robust) optimization



High performance computation



Scenarios that Illuminate Vulnerabilities

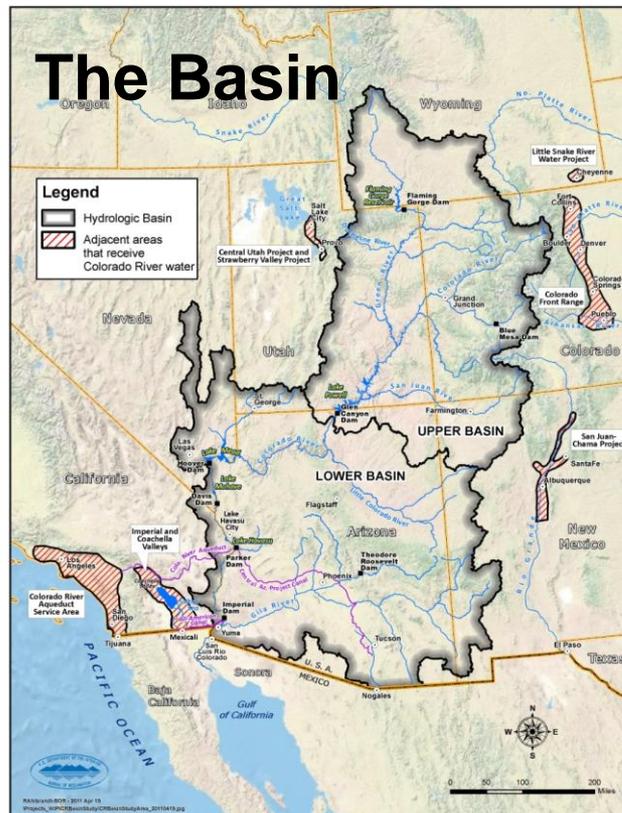
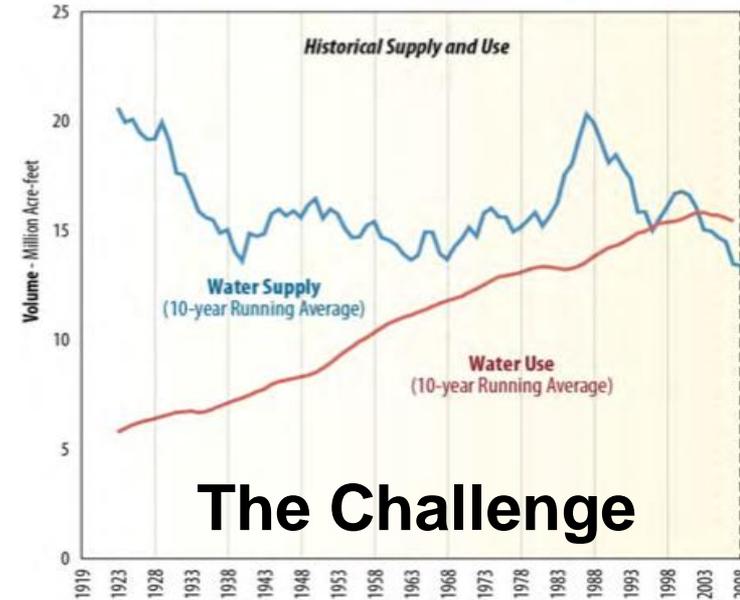


- Analytic methods to suggest scenarios
- Scenario discovery
 - Scenario diversity

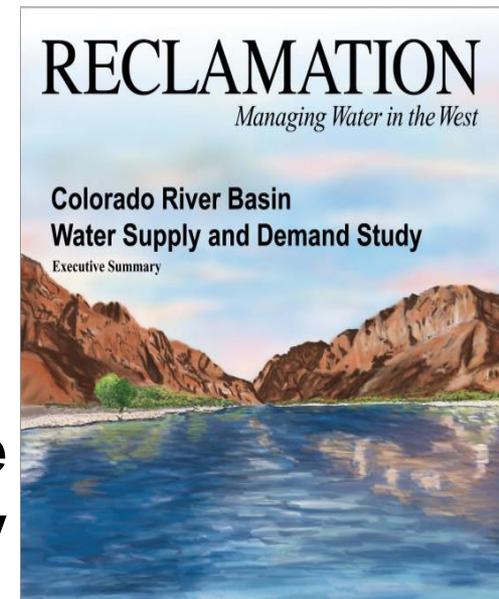
Colorado Basin Supply & Demand Study Demonstrates These Tools

In collaboration with seven states and other users, Bureau of Reclamation:

- Assessed future water supply and demand imbalances over the next 50 years
- Developed and evaluated opportunities for resolving imbalances



The Study



Analysis Employed Existing Systems Models

Strategies

- Current management plan
- Adaptive response strategies
 - Hundreds of distinct options
 - Organized as act, monitor, respond adaptive strategies

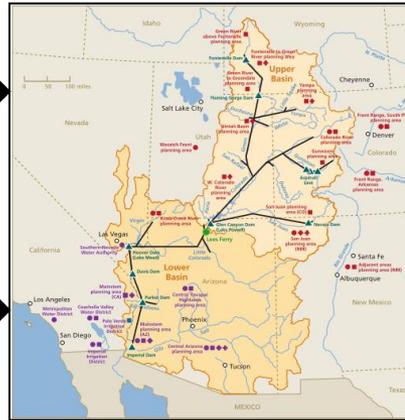
Uncertainties (24,000 futures)

Climate projections (1,000)

- Recent historic
- Paleo records
- Model projections
- Paleo-adjusted model projections

Several demand projections

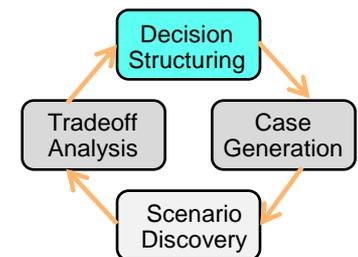
Behavior of future decision makers



Outcomes

- 26 measures of environmental, economic, water supply, energy, and recreational performance

Used the client's existing hydrological simulation model: RiverWare™ (CADSWES)



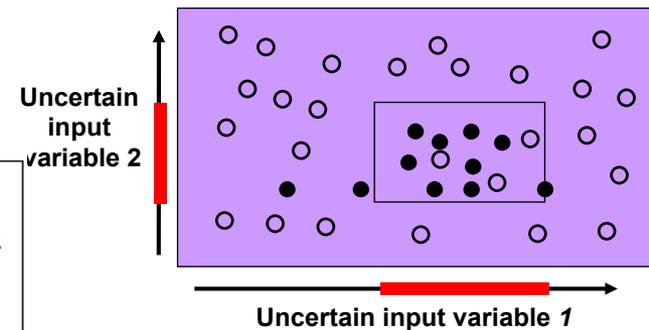
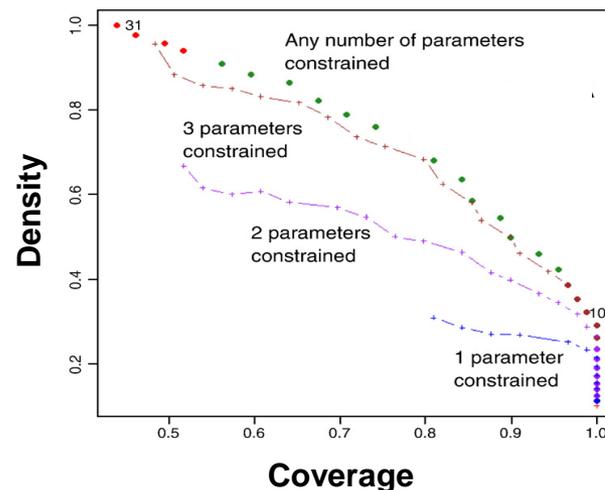
Analysis:

- Stress test strategies over 24,000 alternative paths into the future
- Identifies scenarios that illuminate vulnerabilities of strategies (scenario discovery)
- Suggests portfolios of response options robust over a wide range of futures.

With Scenario Discovery, Policy-Relevant Scenarios Emerge From Analysis

1. Generate large, multi-dimensional database of simulation model runs
2. Use classification algorithms to find interpretable (low dimensional) clusters of policy-relevant cases

Maximize coverage, density, and interpretability

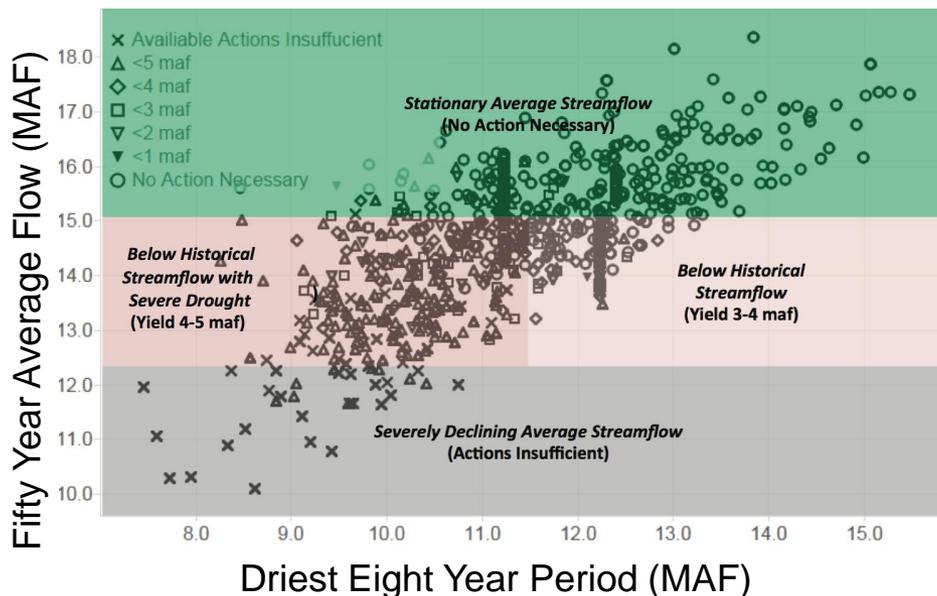


3. Resulting scenarios often provide effective decision support

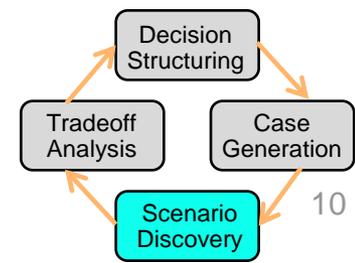
Analysis Illuminated Vulnerabilities of Plans and Helped Identify Responses

Key drivers of vulnerability for current river management plan are both climate-related:

- Fifty year average river flow
- Driest eight year period
- Other uncertainties less important



Bloom, E. (2015). Changing Midstream: Providing Decision Support for Adaptive Strategies Using Robust Decision Making, RAND: RGSD-348

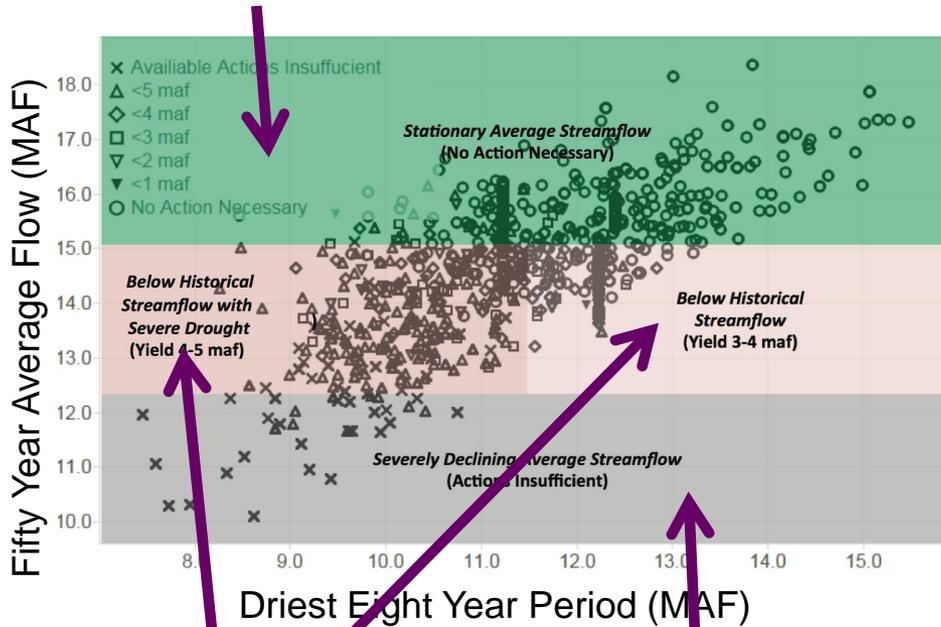


Analysis Illuminated Vulnerabilities of Plans and Helped Identify Responses

Optimization over futures in Adaptive Scenarios suggests rule-based adaptive strategies, which include:

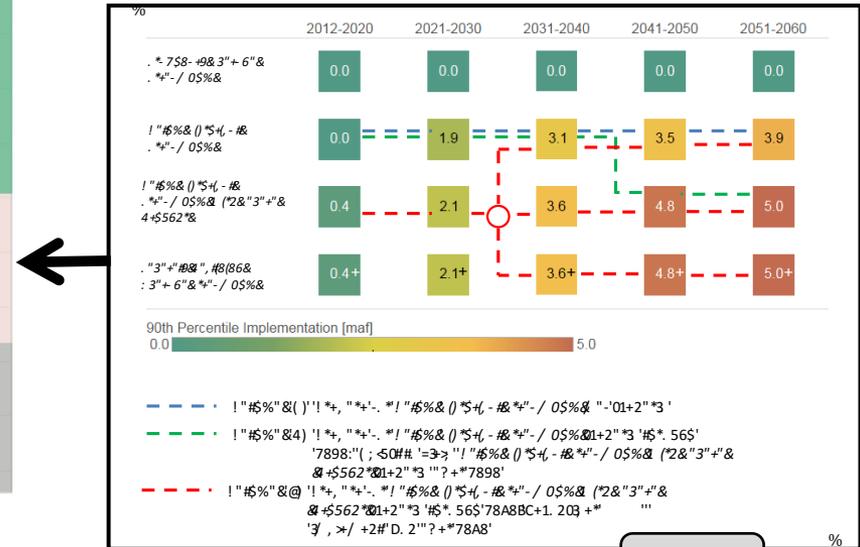
- Near-term actions
- Trends to monitor
- Contingency actions

Business as Usual



Two Adaptive

Transformative



Decision Structuring

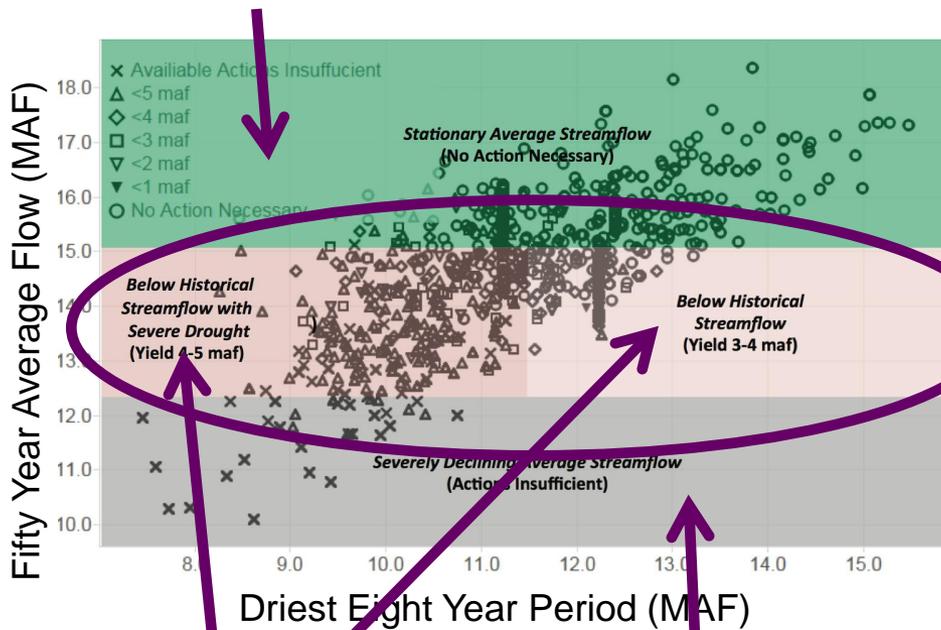
Tradeoff Analysis

Case Generation

Scenario Discovery

Analysis Illuminated Vulnerabilities of Plans and Helped Identify Responses

Business as Usual

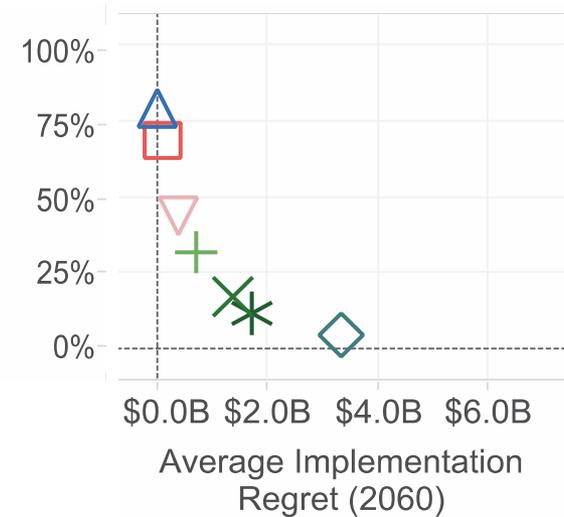


Two Adaptive

Transformative

The set of adaptive strategies lie on a Pareto tradeoff curve for decision makers

Percent of Futures that Fail to Meet Objectives

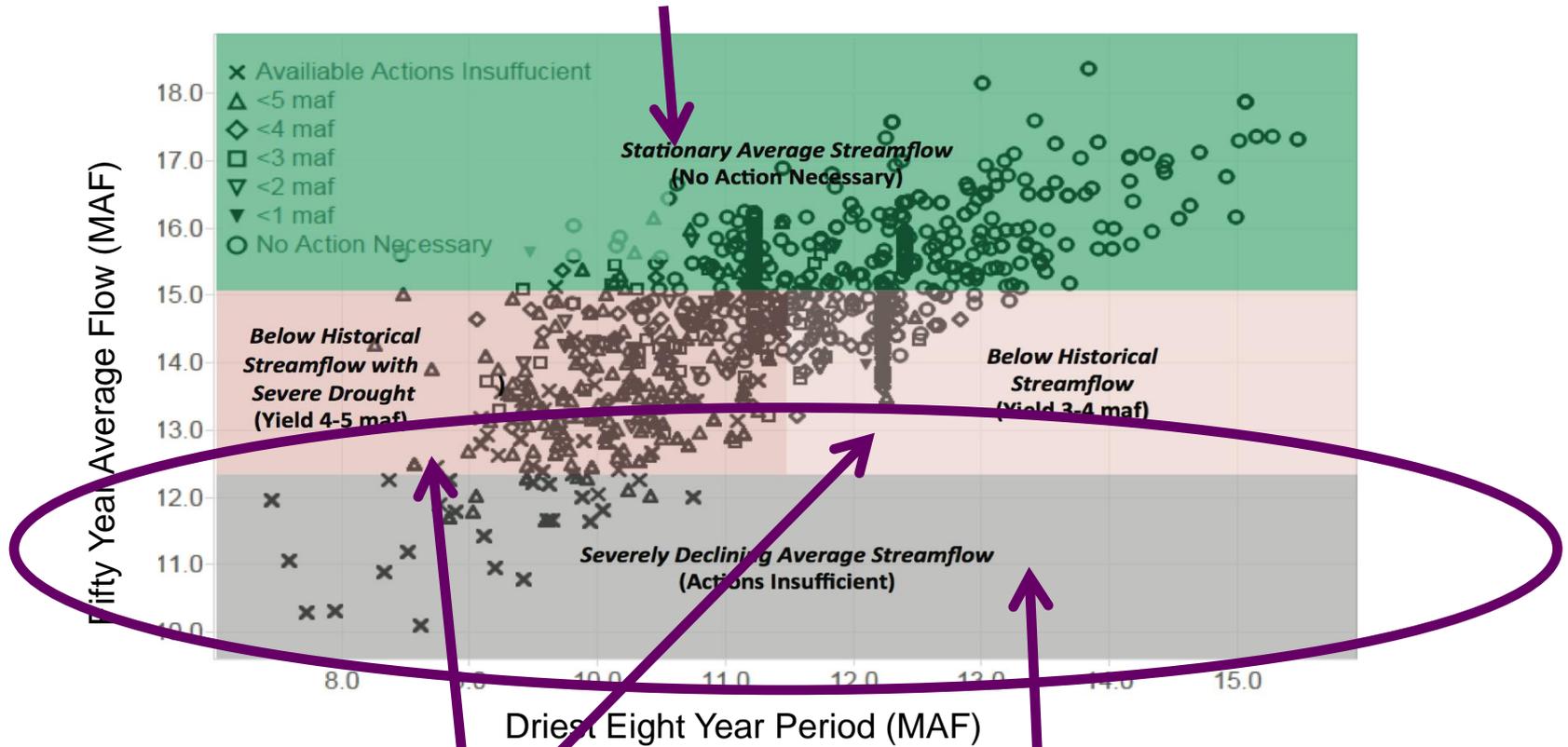


- ▲ Current Management
- Baseline
- ▼ Moderate
- + Moderately Aggressive

- × Aggressive
- * Very Aggressive
- ◇ Static Implement-All-Actions

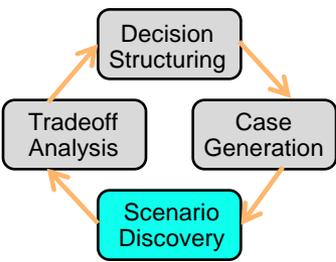
But These Adaptive Strategies Fail in Transformative Scenario

Business as Usual



Two Adaptive

Transformative

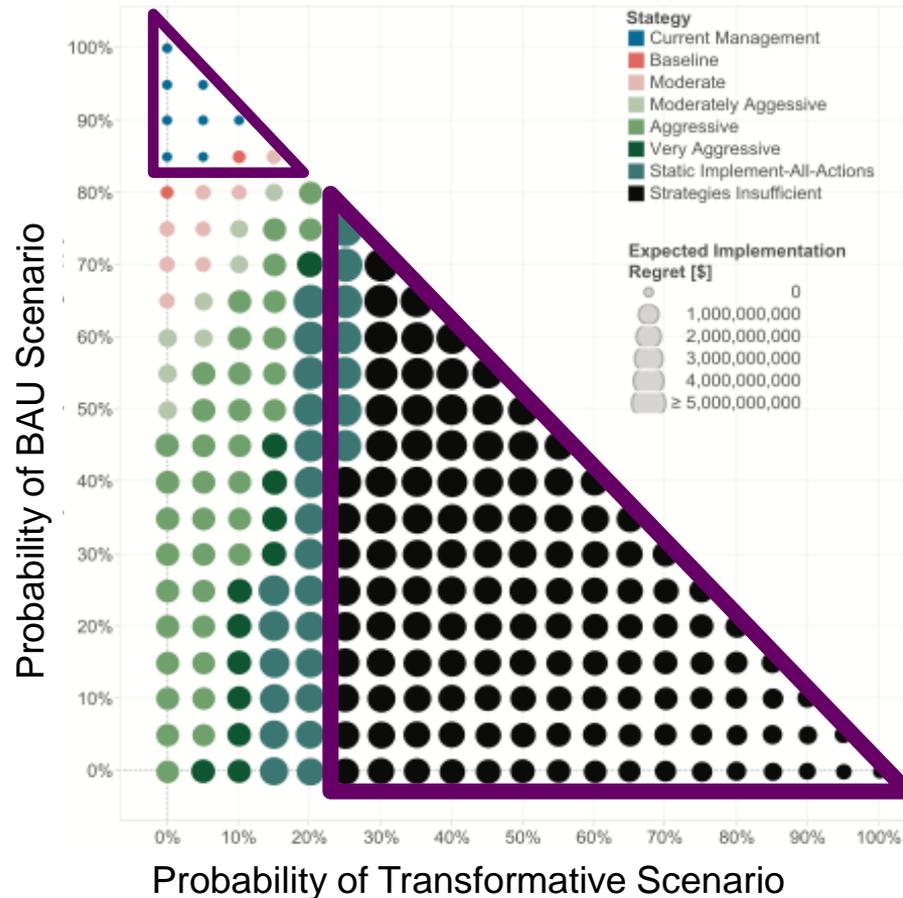


Analysis Suggests Probability Thresholds That Distinguish Alternative Strategies

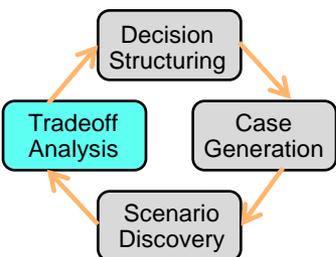
Map shows probabilistic expectations about the future that favor alternative strategies

Management best here

Transformative policies may be needed here



This has some interesting implications for coupling this analysis to other models

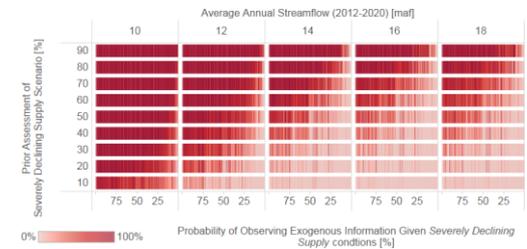


Where Might Additional Coupling Help This Analysis?

Two items that emerge from these iterative stress tests:

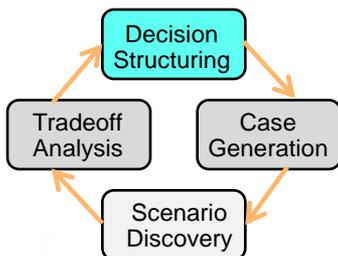
1. Signposts based on out-of-basin observations

- Current signposts based only on observations of in-basin streamflows
- Recent work employs (in a vastly simplified way) information from AOGCM decadal predictions

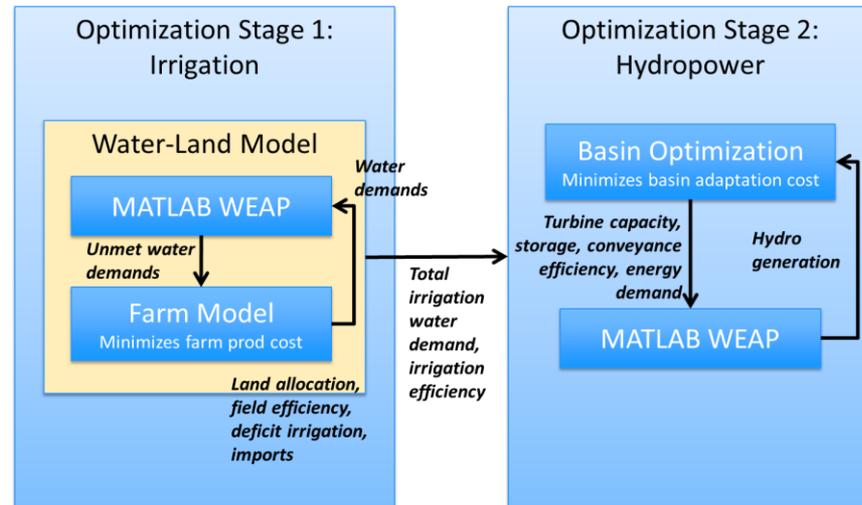
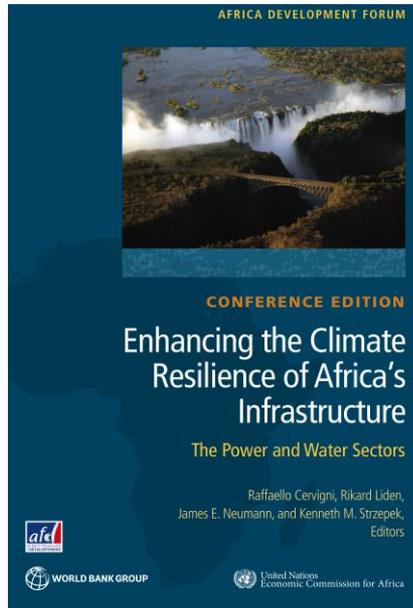


2. Economic models to consider implementation and impacts of more transformative policy options

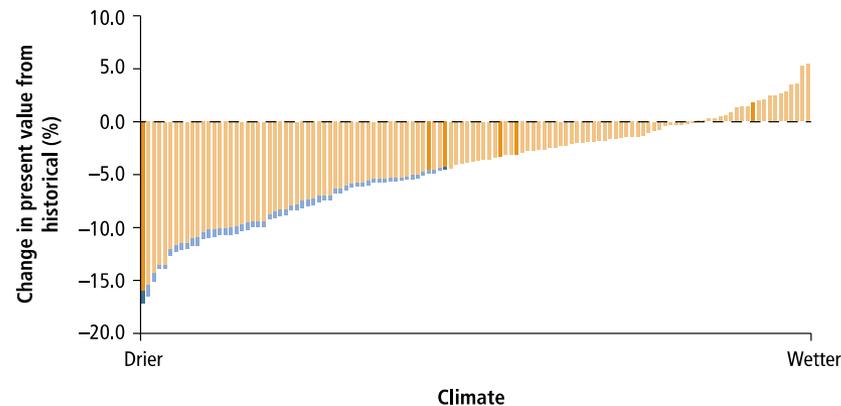
- More extensive use of markets to re-allocated demand represents one obvious example



Enhancing Climate Resilience of African Infrastructure Study Demonstrates Other Tools



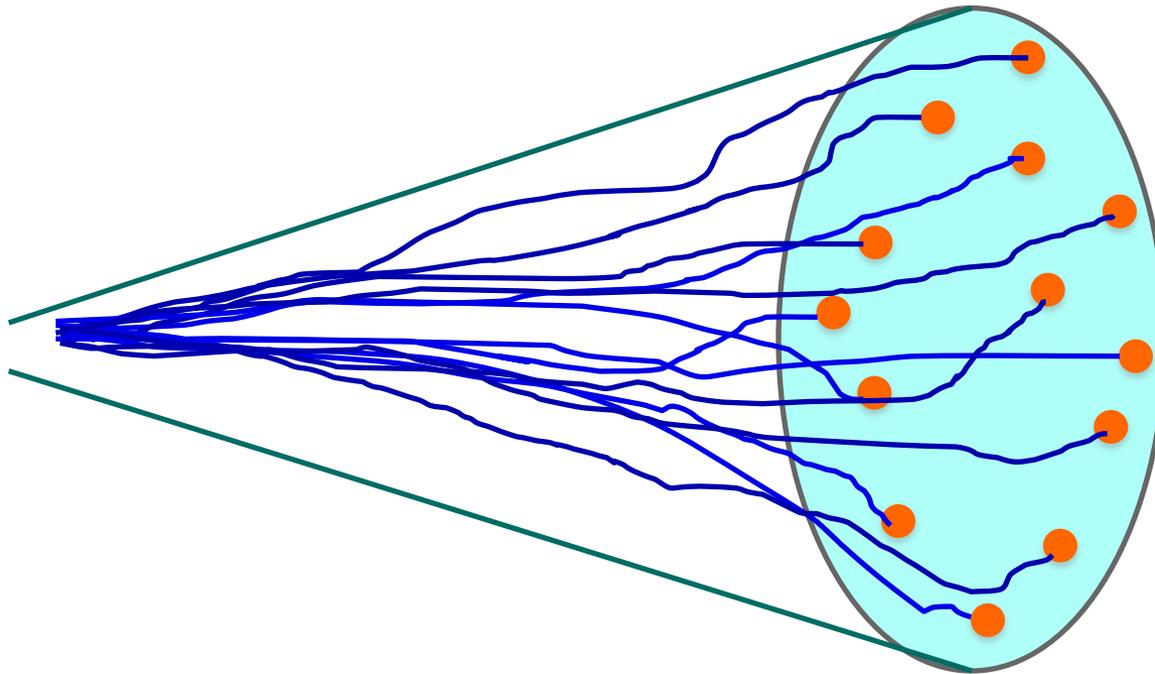
Change in Net Present Value of Hydropower Investments in Southern African Power Pool (2015-2050)



Stress test investment plans over 121 CMIP3 and CMIP5 projections for each of seven major river basins

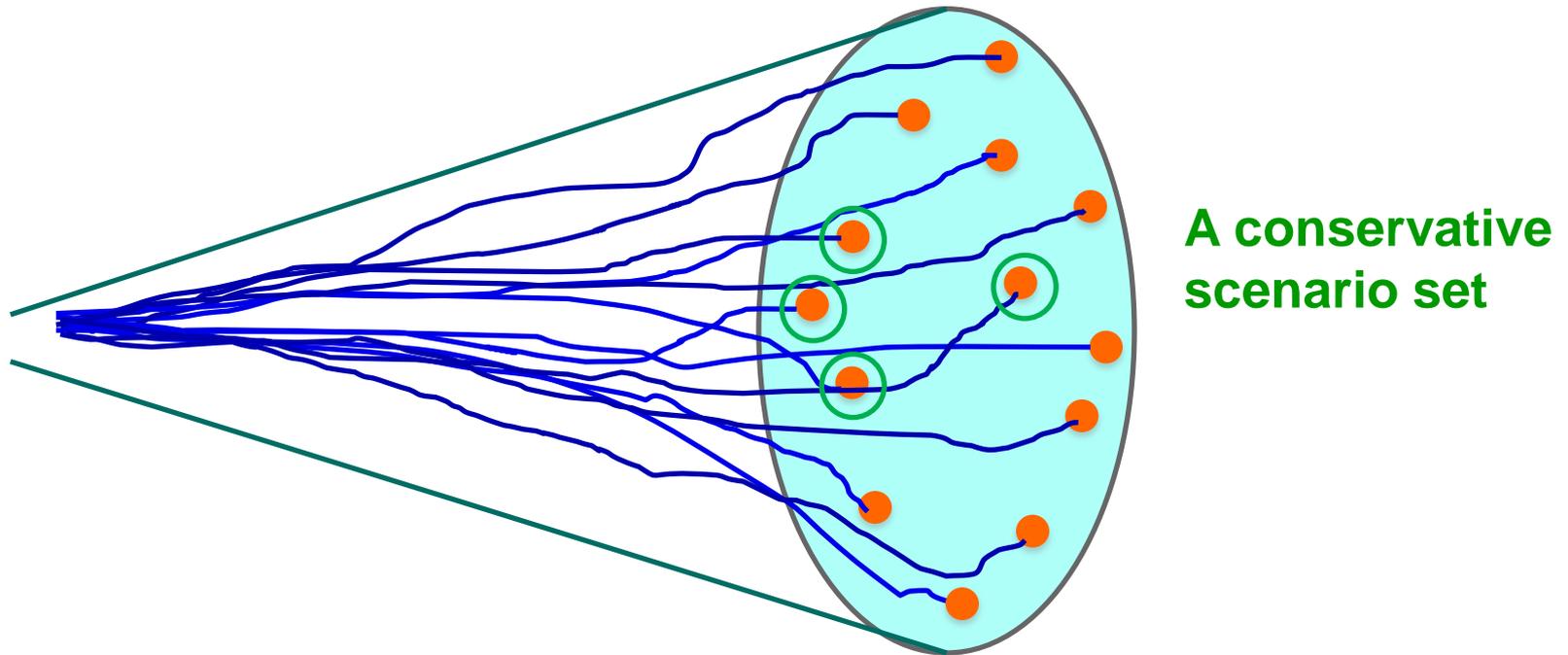
Impacts are significant. Can we adapt?

Use Scenario Diversity Analysis to Find Small Number of Representative Climate Futures to Examine



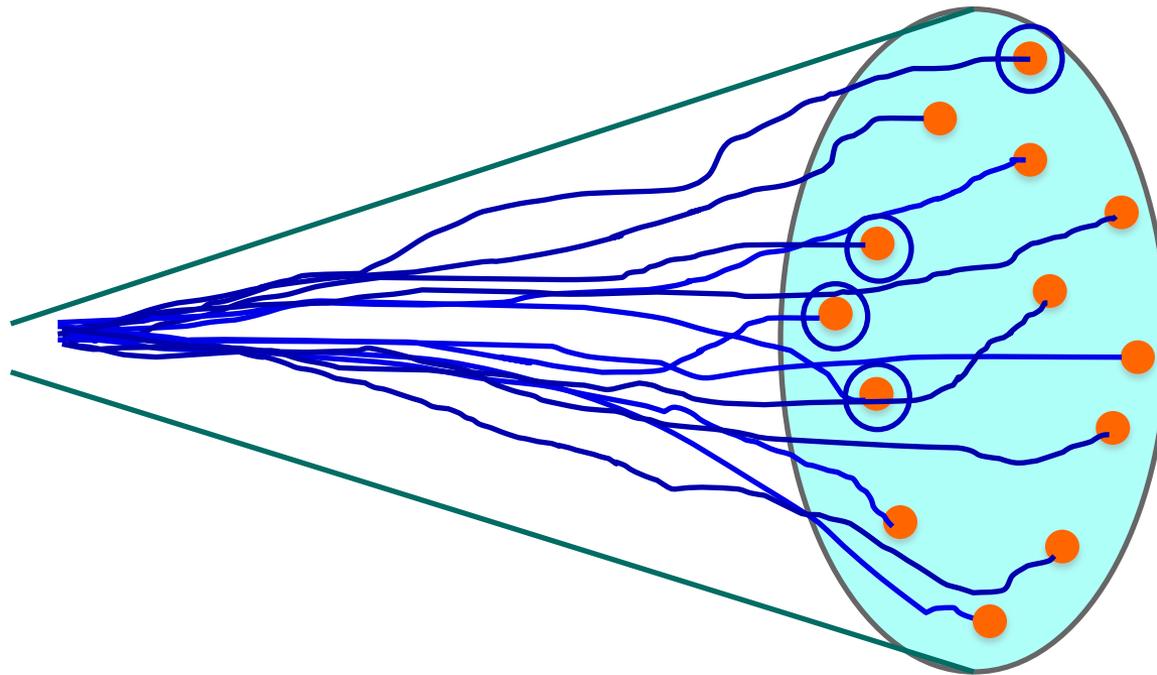
How can one best select a small number of representative scenarios?

Use Scenario Diversity Analysis to Find Small Number of Representative Climate Futures to Examine



How can one best select a small number of representative scenarios?

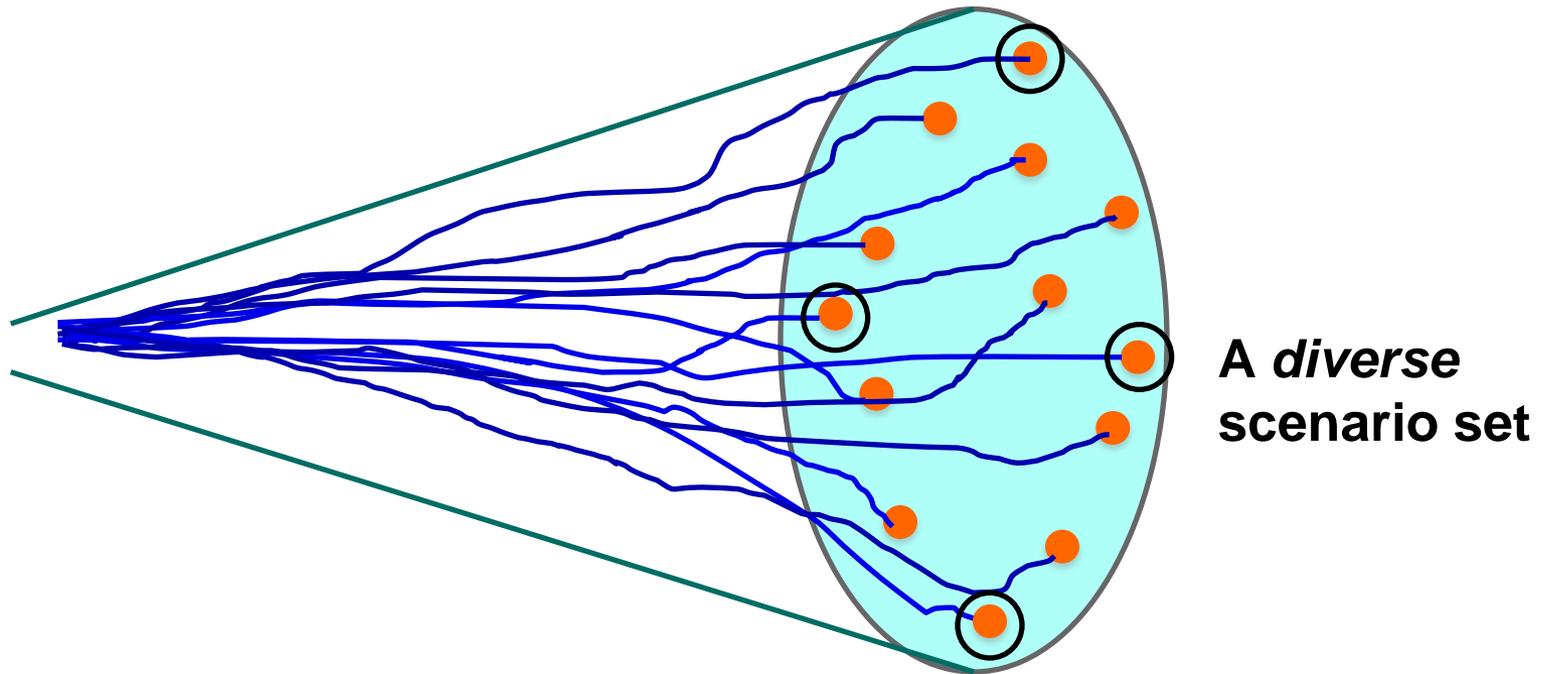
Use Scenario Diversity Analysis to Find Small Number of Representative Climate Futures to Examine



An unbalanced scenario set

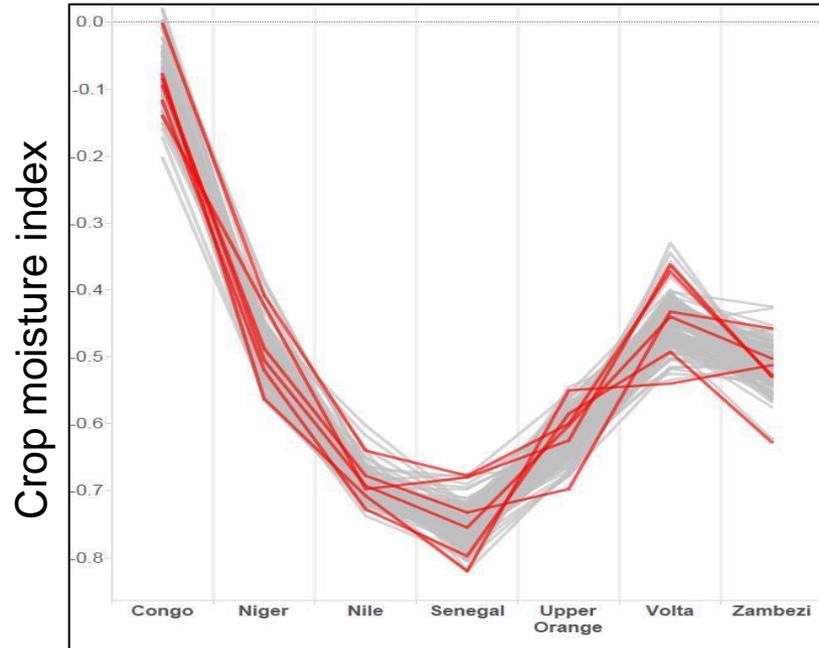
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Use Scenario Diversity Analysis to Find Small Number of Representative Climate Futures to Examine



How can one best select a small number of representative scenarios?

Scenario Diversity Analysis Identifies Small Number of Representative Climate Futures to Examine

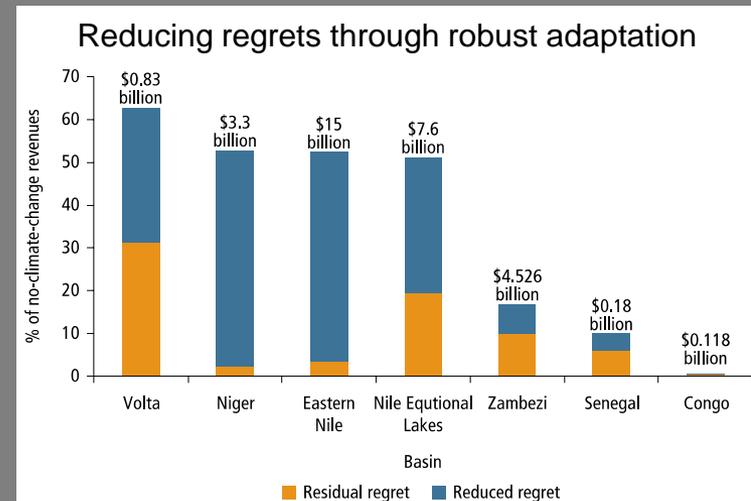


Use these projections to identify robust adaptations

Optimization (brute force) identifies six projections that best meet the following criteria:

- Extreme precipitation for each basin
- Extreme precipitation for several basins
- Projection near ensemble mean
- Significant number of CMIP5 projections

Calculate perfect foresight and robust adaptations for six, maximally diverse, representative climate projections



When Does Resolution Matter?

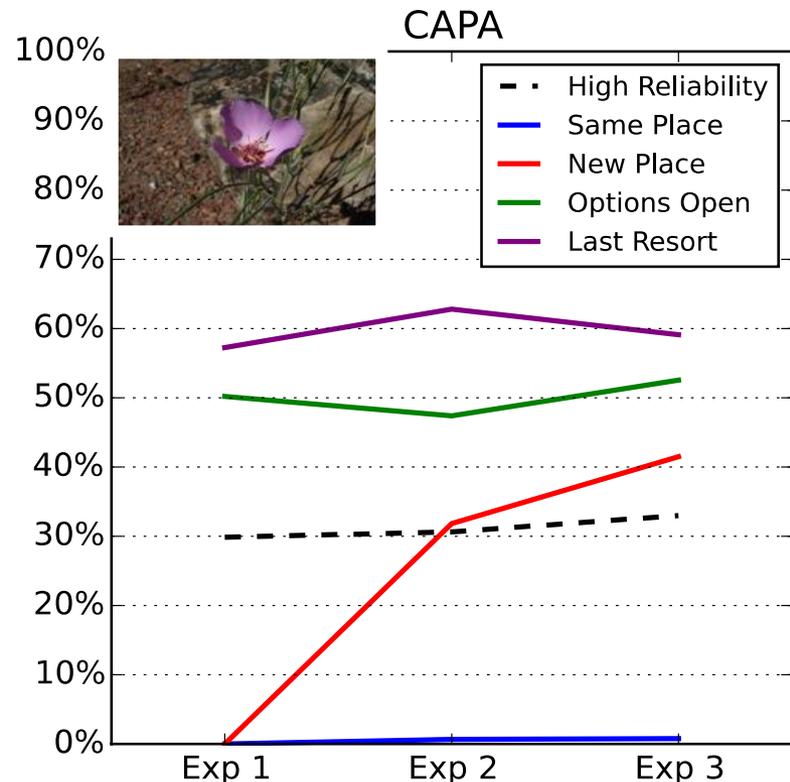
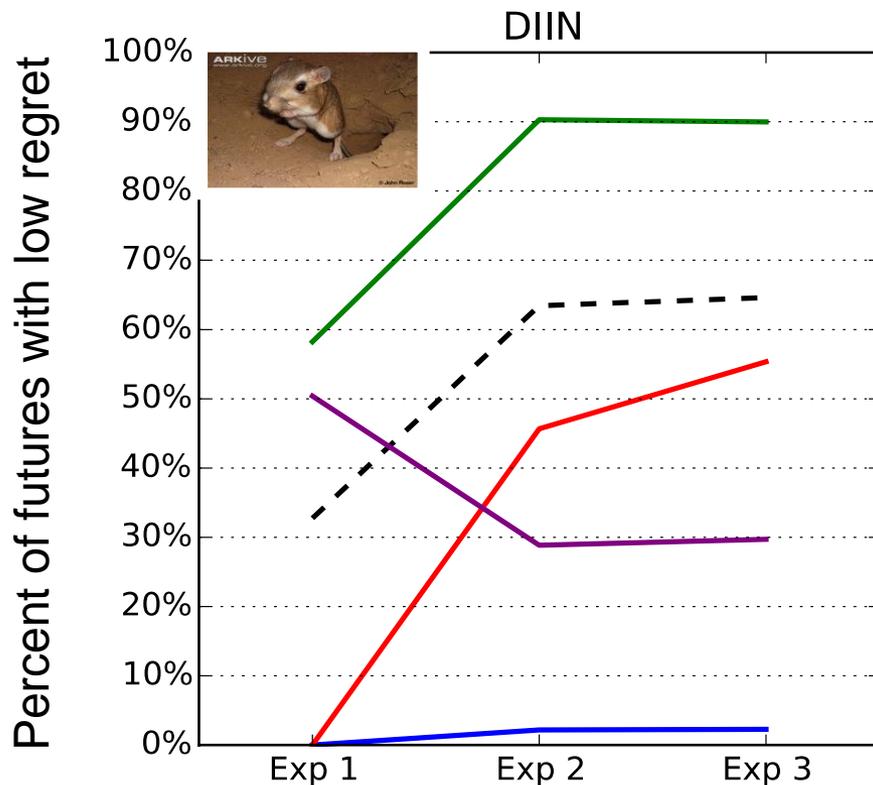
Comparing the results of decision support exercises using different ensembles of climate projections

- Each with differing mixes of dynamic and statistical downscaling to reach 1 km

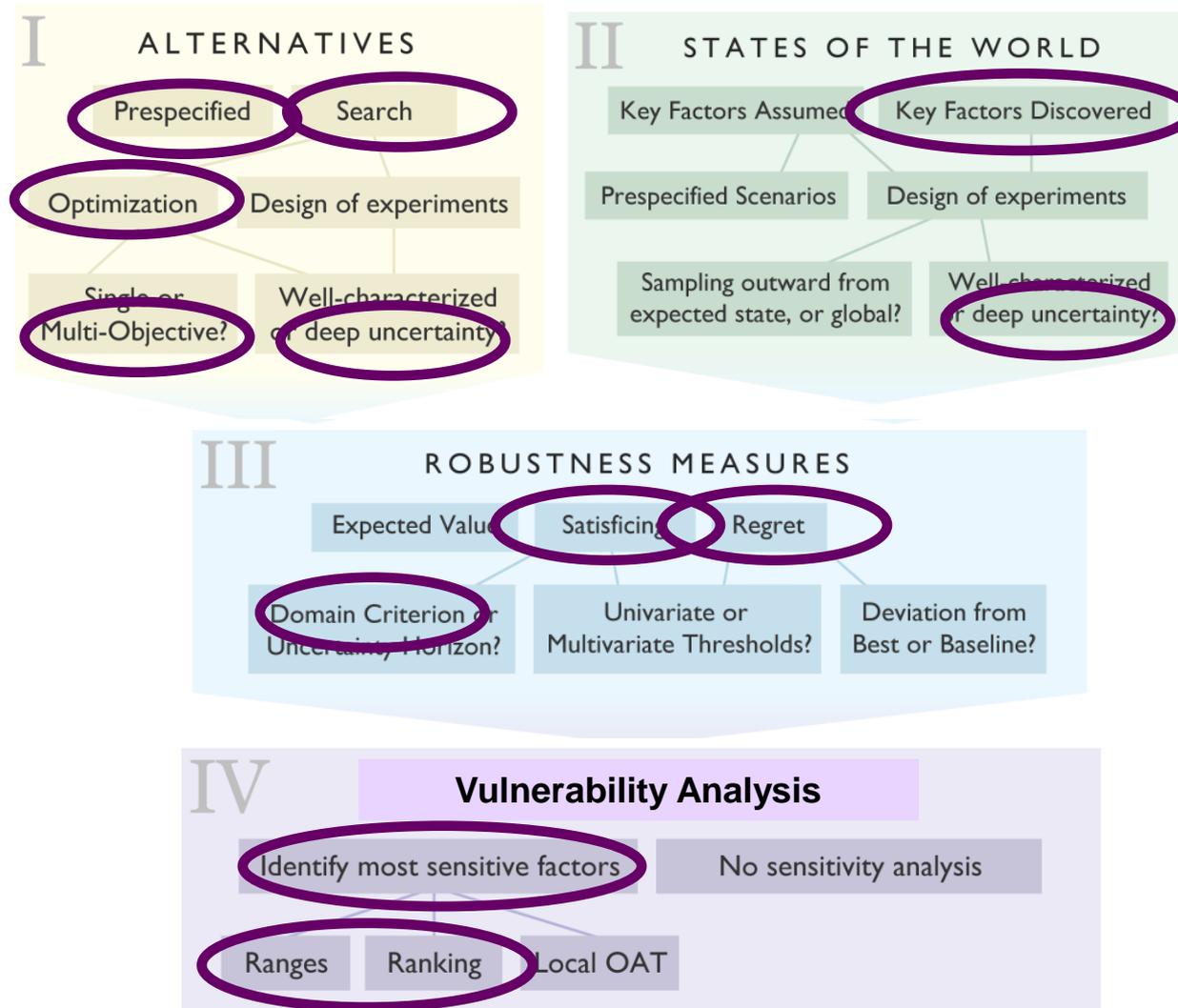
High resolution	Medium Resolution	“Good news”/Low Resolution
Expt 1, 2, & 3	Experiment 2 & 3	Experiment 3
CCSM-WRFH	ECP2-GFDL, MM5I-CCSM, CNRM-CCSM, WRFG-CCSM, RCM3-GFDL, HRM3-HadCM3, HRM3-GFDL, CRCM-CGCM3, RCM3-CGCM3, WRFG-CGCM3, MM5I-HadGCM3	GISS-E2-R, FIO-ESM, CNRM-CM5, EC-EARTH (RCP 4.5) MRI-CGCM3 (RCP 8.5)
10 km/1 km	50 km/1 km	200 km /1 km
CMIP3-A2	CMIP3-A2	CMIP5-RCP 4.5, 8.5

For Biodiversity Exercise in California, Resolution Doesn't Matter

- Most variability in (48) bioclimatic models, not climate projections
- Ranking of strategies changes with multiple climate projections, but means of getting to 1 km doesn't matter



Many Types of Robustness Analysis Exist



Observations

- Decision support often uses local, trusted models for reasons for salience, legitimacy, and credibility.
 - Flexible means to link these models with other models at regional and global scale could prove useful
- Most important models couplings often emerges out of iterative stress testing, which asks what factors, not include in current modeling system
 - Will break proposed strategies?
 - Might allow consideration of policy actions that would contribute to more robust strategies?
- Simple/reduced form models (e.g. emulators, elicitation-derived) often useful for system components for which more detailed representations are not readily available
- Emerging toolkits for decision support for wicked problems now exist:
 - Improving, evaluating, and linking them among our communities may represent an important research priority

Thank you!

<http://www.rand.org/pardee.html>

www.rand.org/water



<http://www.deepuncertainty.org>