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Informing Climate (and Other Contentious) Decisions When the Science is Uncertain:

Or Why You Should Run Your Analysis Backwards

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RAND Corporation

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What Is RAND?

- **RAND is an independent, nonprofit research institution**
- **Its mission is to help improve policy and decisionmaking through research and analysis**
- **RAND's clients include government agencies, private firms, and other nonprofits**

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How to Use Deeply Uncertain Information to Inform Decisions?

Today's decision makers confront many challenges where quantitative information is indispensible to good choices

But the questions commonly asked with quantitative methods and tools can prove counter productive under conditions of deep uncertainty

New methods, exploiting new information technology and recent cognitive science, can improve decisions under such conditions

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Are Quantitative Tools Useful for "Problems of Greatest Human Concern?"

Many commentators have in recent decades argued that such tools are not useful

Messes vs. problems
Wicked vs. tame problems
Swamp vs. high ground
Practical vs. technical
Soft vs. hard systems

Uncertainty over consequences / Uncertainty over objectives	Low	High
High	Judgment	Inspiration
Low	Quantitative policy analysis	Bargaining

Rosenhead and Mingers, Rational Analysis for a Problematic World Revisited, Wiley and Sons (2001)

Such Questions are Part of a Larger, Longer Debate on Role of Science in Democratic Societies

Mill saw representative government as a "cognitive process, fashioned to maximize the production, accumulation, and implementation of politically relevant truths" *Stephen Homes*

Lippman doubted whether the common voter pays enough attention to be trusted with many of the most important questions facing society

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Uncertainty over consequences	Uncertainty over objectives: Low	Uncertainty over objectives: High
High	Judgment	Inspiration
Low	Quantitative policy analysis	Bargaining

A nexus of developments – in decisionmakers' demand, information technology, and decision sciences – has set the stage for significant advances to expand the utility of quantitative analysis in complex policy debates

Outline

- Insights From Decision Support Literature
- Robust decision making
  - Method
  - Examples
- Some closing thoughts

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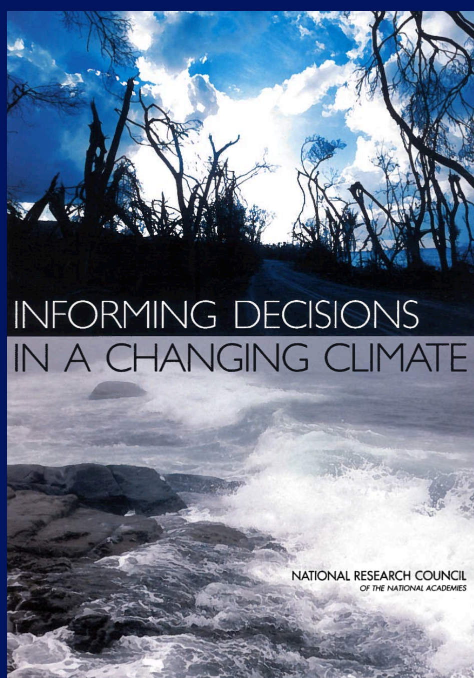
‘Decision Support’ Concept Helps Organize Insights from Cognitive and Organizational Literatures

- **Decision support** represents a set of processes intended to create the conditions and appropriate use of decision-relevant information (p. 34)



- Information is **decision-relevant** if it yields deeper understanding of a choice or, if incorporated into making a choice, yields better results for decision makers and their constituencies (p. 35)

NRC (2009)

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What Constitutes a Good Decision Process?

- Problem Definition
  - Opens problem up to thoughtful consideration
- Clear Objectives
  - Parties to decision achieve clarity about their objectives
- Alternatives Linked to Objectives
  - Identify alternatives that are linked to the problem and objectives
- Assessment of Consequences
  - Anticipate consequences of each alternative on objectives
- Confronting Tradeoffs
  - Parties to decision recognize and consider conflicting objectives and their implications for choices of alternative actions

NRC (2009) p. 22

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Several Elements Contribute to Decision Support

- Products:
  - Includes tangible deliverables such as data, maps, projections, images, tools, models, documents, brochures, web pages, etc.
- Services:
  - Activities, consultations, and other forms of interactions that enable decision makers to make better use of decision-relevant information
- Systems:
  - Individuals, organizations, communications networks, and supporting institutional structures that provide and use decision support services and produces

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NRC (2009) p. 36-37

What Outcomes Should We Expect From Good Decision Support?

Effective decision support improves:

- Usefulness of information:
  - Intended users regard the information as credible, legitimate, actionable, and salient
- Relationships between knowledge producers and users:
  - Producers and users engage in mutual learning and 'coproduction of knowledge' and increase mutual understanding, respect, and trust
- Decisions:
  - Decisions have qualities of a good decision and parties to the decision view it as having been improved by the support received

NRC (2009) p. 37

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What Principles Lead to Good Decision Support?

1. Build from users' needs
   - Identify needs collaboratively in two-way communication between information providers and users
2. Emphasize decision processes over information products
   - Design information systems and products to support decision support processes
3. Employ a multidisciplinary and multi-organization approach
4. Embed decision support in enduring institutions and networks that link users and providers
5. Design decision support for learning

NRC (2009) p. 40-41

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NRC (2009) p. 40-41

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How Should Decision Support Implement Learning?

Recommended process is *deliberation with analysis*:

<u>Deliberate:</u>

- Participants to decision define objections, options, and other parameters

<u>Analysis:</u>

- Participants work with experts to generate and interpret decision-relevant information

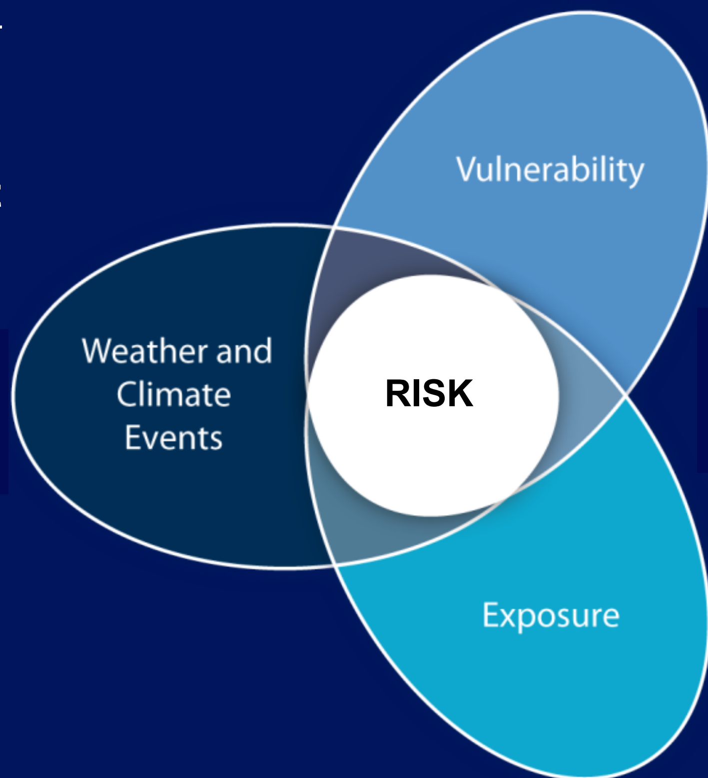
NRC (2009) p. 78

Useful to Consider Climate Change Adaptation as Risk Management

- ***Three factors contribute to risk***
- ***Reducing risk requires addressing all three***

Hazard:

The potential occurrence of a physical event that may cause injury, damage, or loss

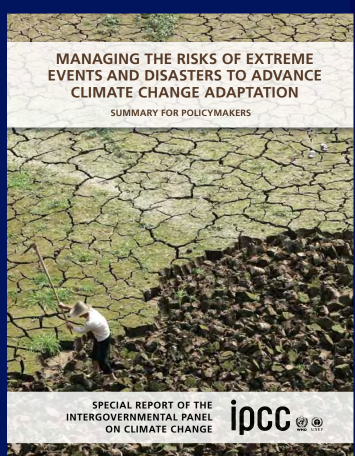


Vulnerability:

The predisposition of a person or group to be adversely affected

Exposure:

The presence of people and the things they care about in places that could be adversely affected



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Lessons From Cognitive and Behavioral Sciences on Effective (Climate) Communications

- Information should be proximate in time and space – this affects *me*.
- Information should be actionable – I can do something with this information
- Different people define risks in different ways
- People need cognitive representations (mental models) of the processes creating and controlling risks, and thus causing uncertainty about them
- Emotion is an essential part of decision making, both contributing and detracting from effective decisions
- Social processes can amplify and attenuate perceptions of risk

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Pidgeon and Fischcoff (2011)

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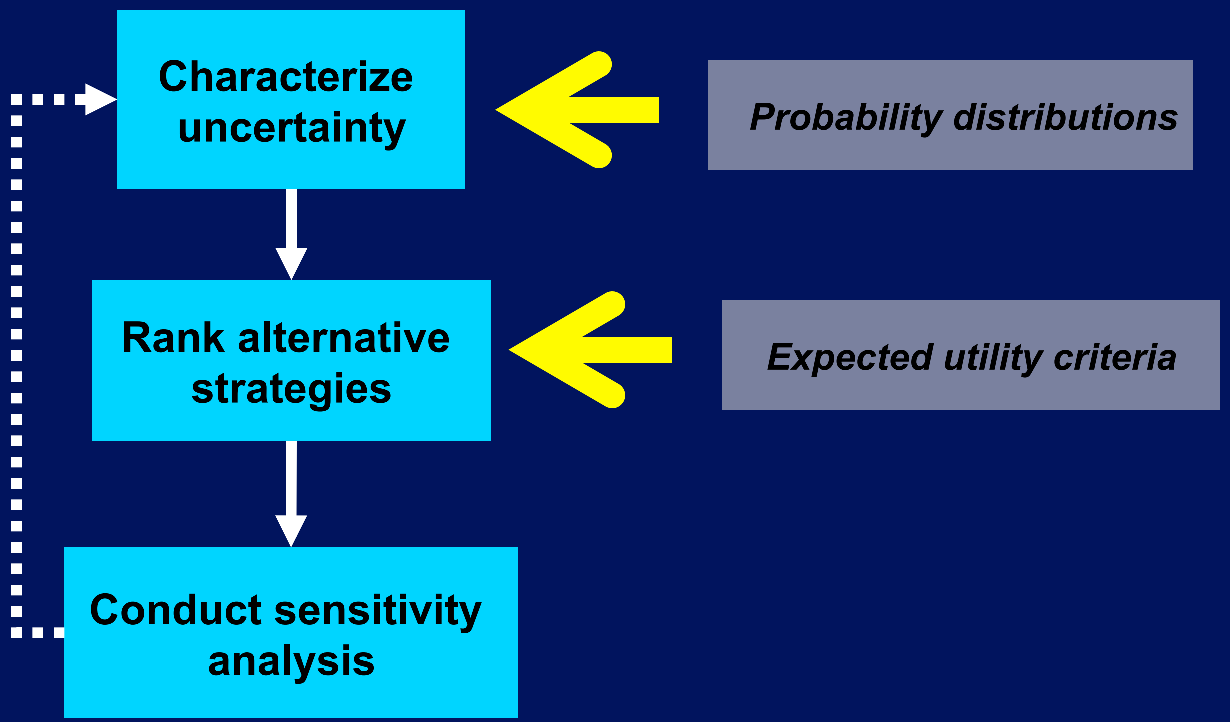
- Some closing thoughts

Traditional Risk Analysis Ranks Responses Based on Probabilistic Characterization of Uncertainties

Predict then Act

- Rank strategies contingent on characterization of uncertainties



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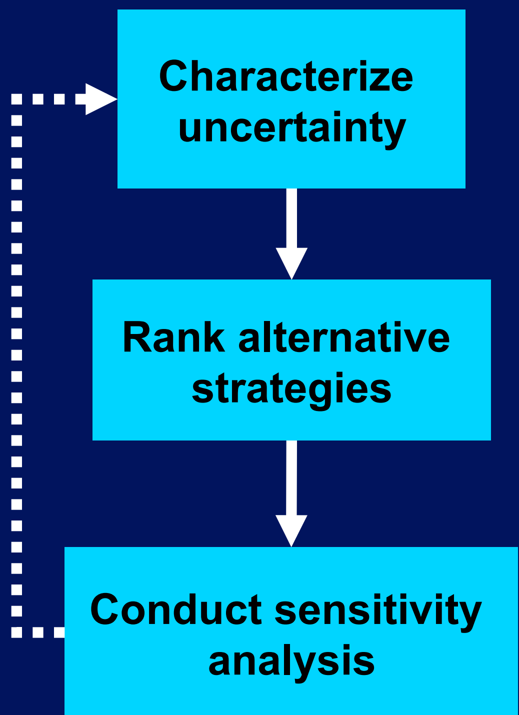
Traditional Risk Analysis Ranks Responses Based on Probabilistic Characterization of Uncertainties

Predict then Act

- **Rank strategies contingent on characterization of uncertainties**



But many situations confront decision makers with deep uncertainty, where

- They do not know, and/or key parties to the decision do not agree on, the system model, prior probabilities, and/or “cost” function

Decisions can go awry if decision makers assume risks are well-characterized when they are not

- Uncertainties are underestimated
- Competing analyses can contribute to gridlock
- Misplaced concreteness can blind decision-makers to surprise

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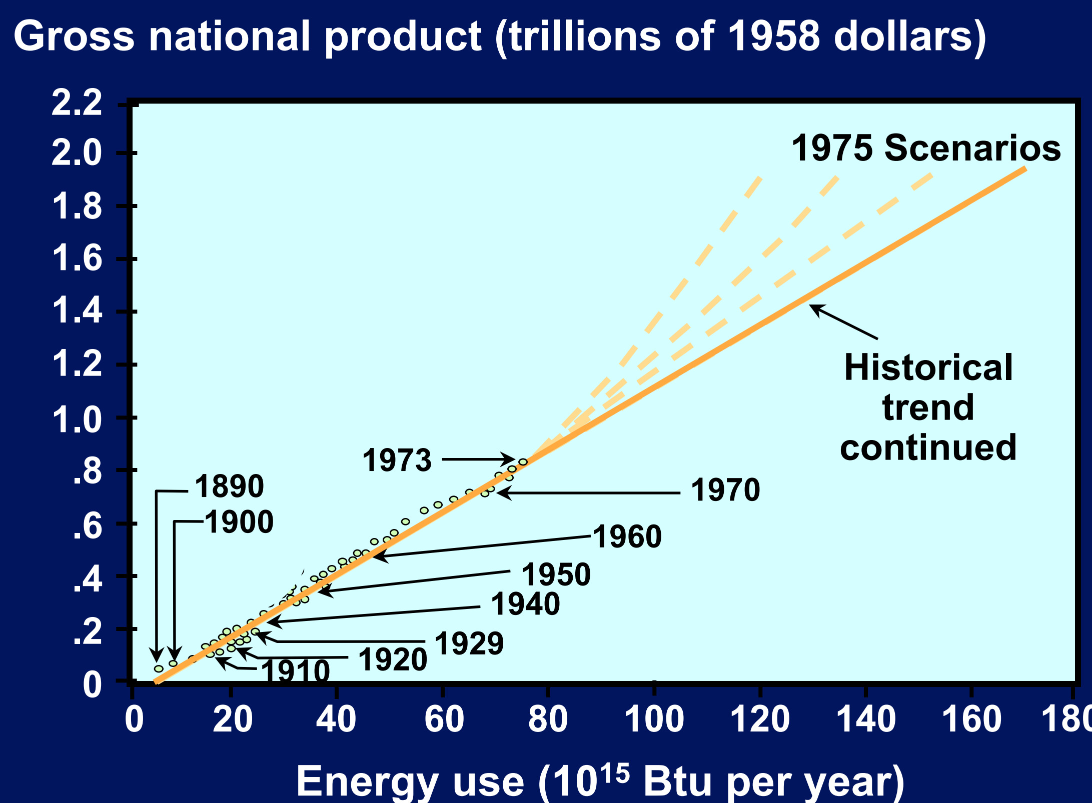
Believing Forecasts of the Unpredictable Can Contribute to Bad Decisions

- In the early 1970s forecasters made projections of U.S energy use based on a century of data



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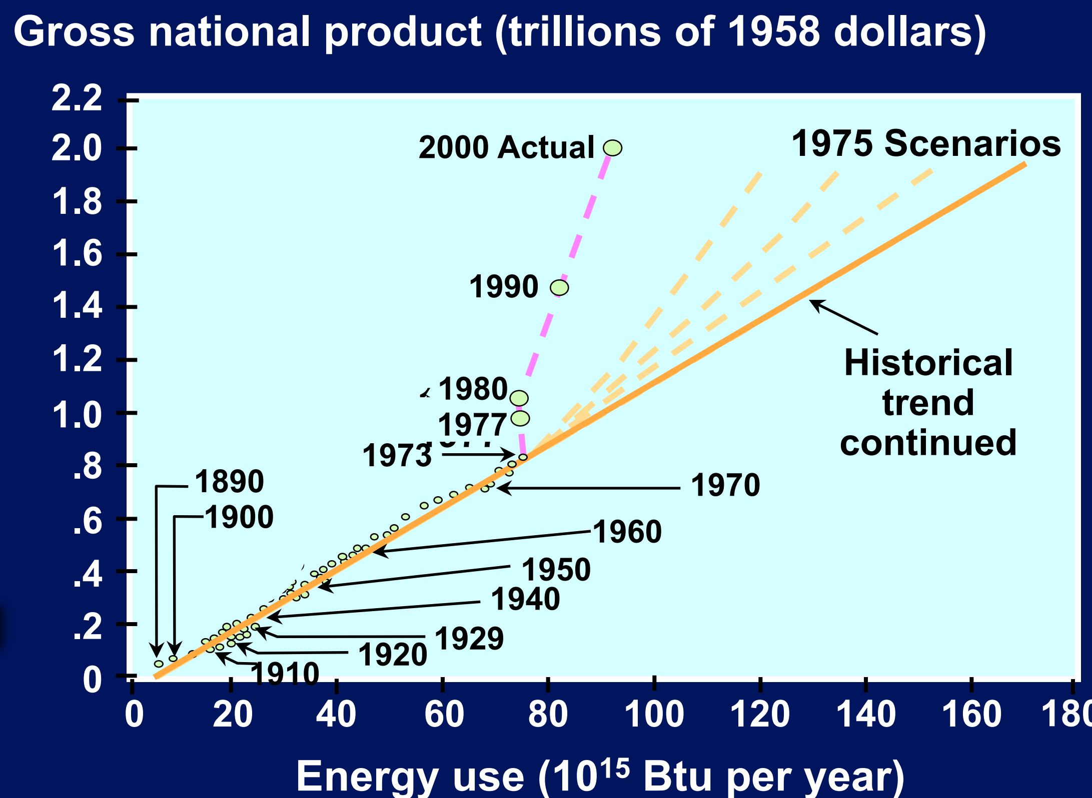
Believing Forecasts of the Unpredictable Can Contribute to Bad Decisions

- **In the early 1970s forecasters made projections of U.S energy use based on a century of data**

… they all were wrong



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Will Technological and Other Change Make Forecasting Even More Difficult Over Next 50 Years?

~1960

2010

~1910

In many respects, transportation and energy systems changed

- **more from 1900 to 1950**
- **than from 1950 to 2000**

What changes will the next fifty years bring?

?

2060

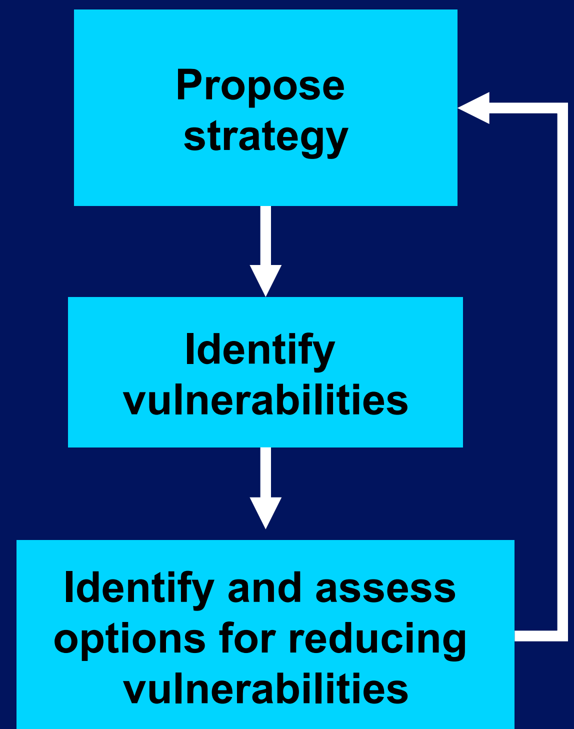
Robust Decision Making (RDM) Characterizes Deep Uncertainties Contingent On Proposed Decision

Robust Decision Making

- Characterize uncertain vulnerabilities contingent on proposed strategy

Key idea – conduct the analysis in reverse order from predict then act:

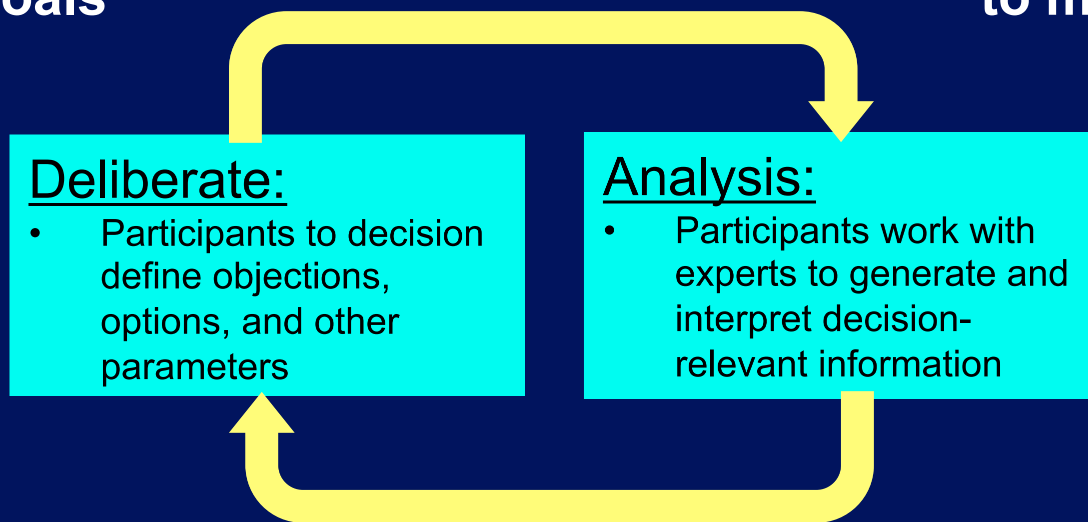
1. Start with a proposed strategy
2. Summarize the future conditions where proposed strategy fails to meet its goals
3. Use these scenarios to identify options that may address vulnerabilities and evaluate tradeoffs among these options



RDM Follows Deliberation with Analysis Process

1. **Start with proposed policy and its goals**

2. **Identify futures where policy fails to meet its goals**



3. **Identify policies that address these vulnerabilities**

4. **Evaluate whether new policies are worth adopting**

RDM Provides an Analytic Underlay to Enhance Scenario Thinking

- **Scenarios provide important cognitive benefits**
  - **Easy means to consider a wide range of futures**
  - **Sense of possibility, as opposed to probability, reduces cognitive barriers to considering novel or inconvenient futures**
- **But traditional scenario approaches**
  - **Have trouble exploring a full range of futures**
  - **Generate scenarios that can appear arbitrary when their implications are controversial**

RDM approach addresses this challenge by analytically deriving scenarios as vulnerabilities of proposed policies

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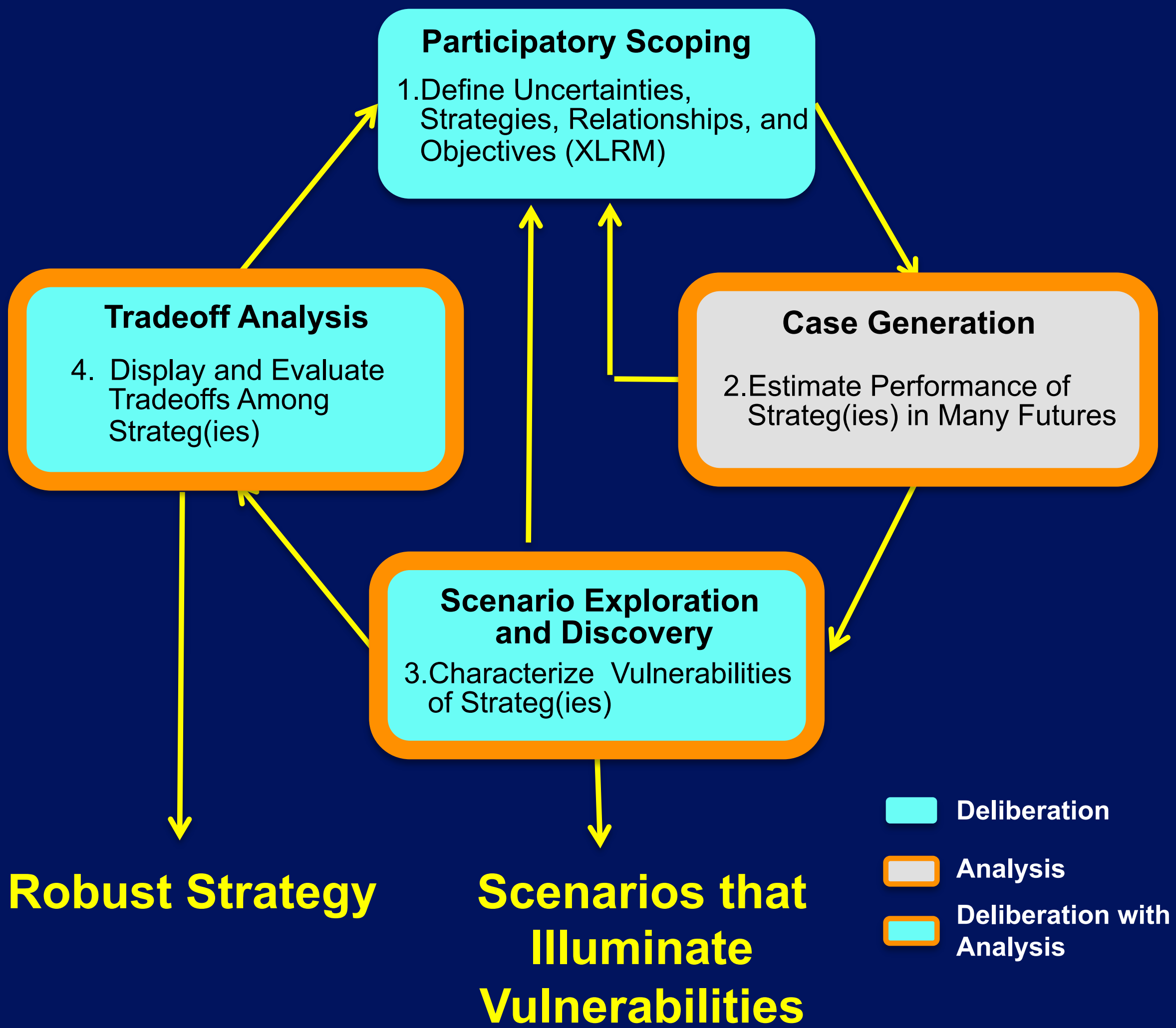
Steps of RDM Process

RDM follows "Deliberation with Analysis" decision support process



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How Should Water Agencies Plan Under Fast-Changing, Uncertain Conditions?

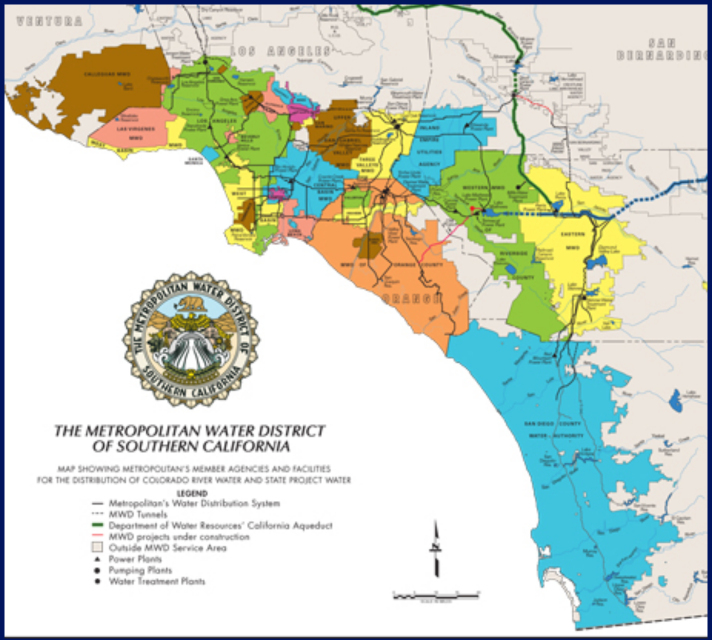
- Water management agencies currently develop long-range plans (20-30 years) to
  - Ensure their ability to provide reliable, cost effective, and environmentally sound supplies
  - Help focus discussion with constituents over priorities and accountability
- Previous best practice used
  - Fixed schedules of investments and policies tested against at most a few scenarios
  - Periodic update with no explicit reference to next update in current plans
- But when predictions are perilous, plans should be flexible and robust

How to make plans more robust and adaptable while preserving public accountability?

Where Does Metropolitan Water District Resource Plan Fail to Meet Its Reliability Goals?

– **The mission of the Metropolitan Water District of Southern California is to:**

  • ***"provide its service area with adequate and reliable supplies of high-quality water to meet present and future needs in an environmentally and economically responsible way"***



– **Metropolitan's 2010 Integrated Resources Plan**

  • **Describes a 25 year investment and policy plan**

  • **Calls explicitly for 10% buffer and adaptive management to address uncertainty**

Metropolitan asked us – what indicators should they monitor to give them warning they need to adjust their plan?

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Where Southern California Gets its Water

RDM Analyses Often Begin By Summarizing Key Factors to be Considered

Uncertainties (X)	**Policy Levers (L)**
• Future temperature and precipitation • Demographics • Conditions of the Bay Delta • Yields from local resources • Timeliness of IRP project implementation	• 2010 Integrated Resources Plan Update
Relationships (R)	Measures of Merit (M)
• IRPsim • Colorado River Decision Simulator • WEAP Central Valley Model	• Net balance • Storage

These uncertainties and measures emerged from discussions with Metropolitan's stakeholders and staff

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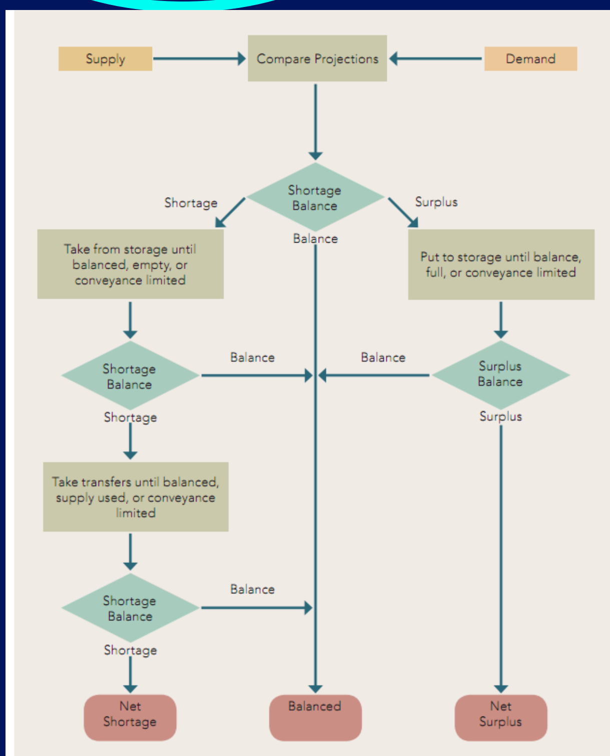
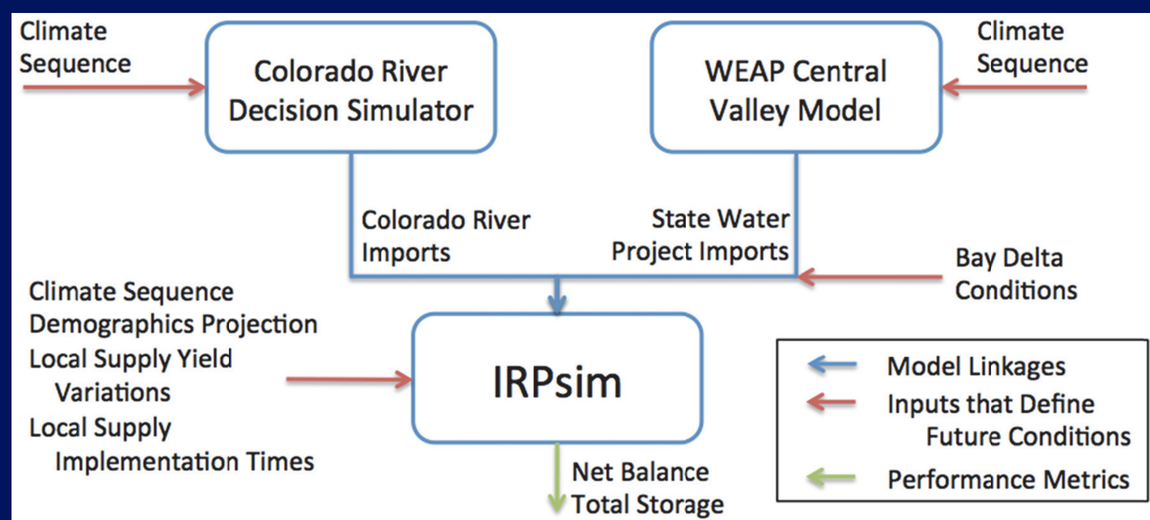
Analysis Based on Metropolitan's Planning Models

Uncertainties (X)	Policy Levers (L)
Relationships (R)	Measures (M)



- IRPsim is mass balance model that
  - Evaluates supplies and demands
  - Uses Metropolitan's resource portfolio to address any imbalances
  - Uses Indexed Sequential Method to estimate impact of climate variability on reliability
- We modified IRPsim to
  - Use climate model projections as well as data on past climate
  - Project variations in CRA and SWP supplies with WEAP models
  - Run large experimental designs in CARs software



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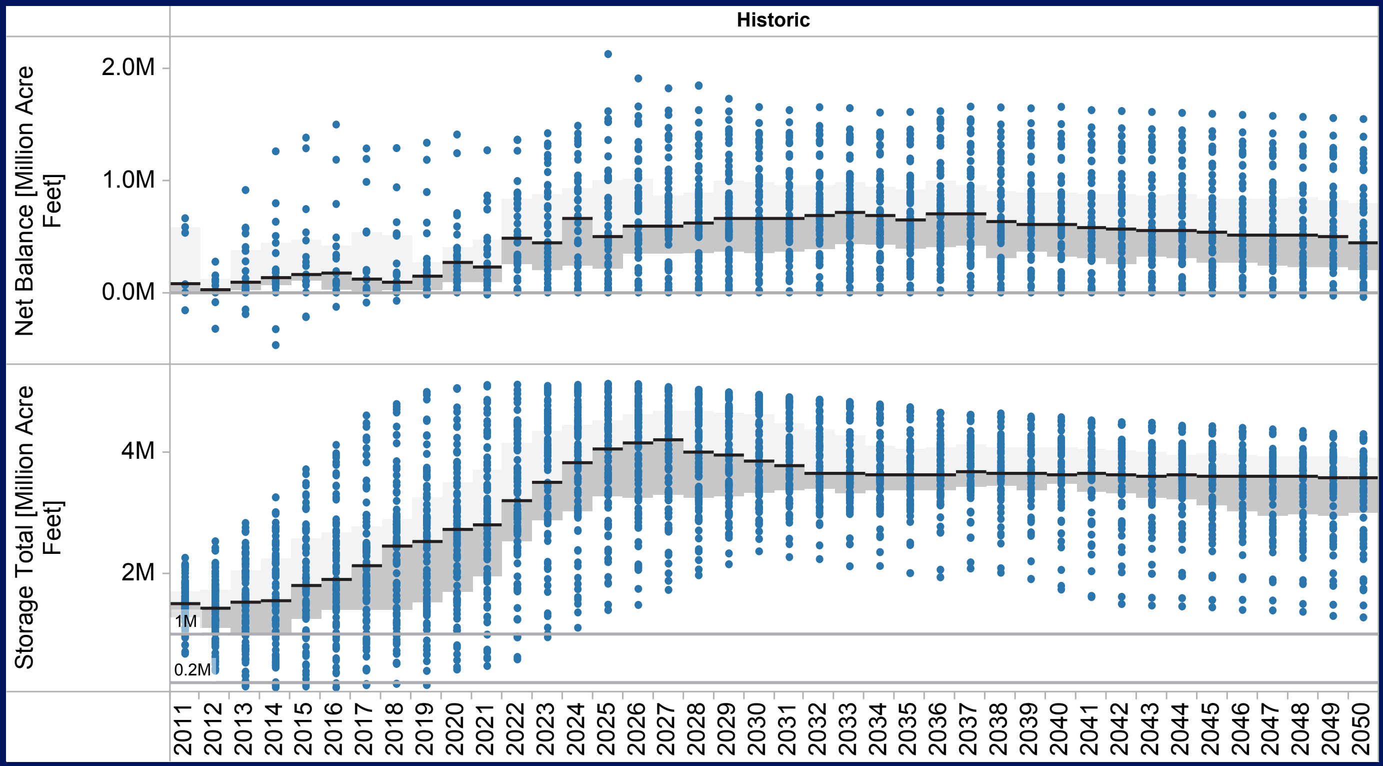
Simulation Produces Detailed Results for Each of Many Cases

Case with baseline growth and historic climate



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Explore Uncertainties Over Large Experimental Design

Climate	6 GCMs x 2 emissions scenarios + historic conditions
Demand	4 cases: 1) Balanced growth, 2) IRP sales model, 3) peri-urban growth, 4) high growth
Delta	3 cases: 1) Full Delta supply, 2) 90% Delta supply, 3) No improvement in Delta supply
Yield	26 cases for project yields • Groundwater yields (80% - 120%) • Recycling yield (80% - 120%) • Conservation savings per expenditure (80%-120%)
Implementation	16 cases for project implementation delays • Desalination delays (0 to 10 years) • Recycling (0 to 10 years) • Conservation (0 to 20 years) • Delta Improvement Delays (0 to 30 years)

Uncertainties (X)	**Policy Levers (L)**
Relationships (R)	Measures (M)

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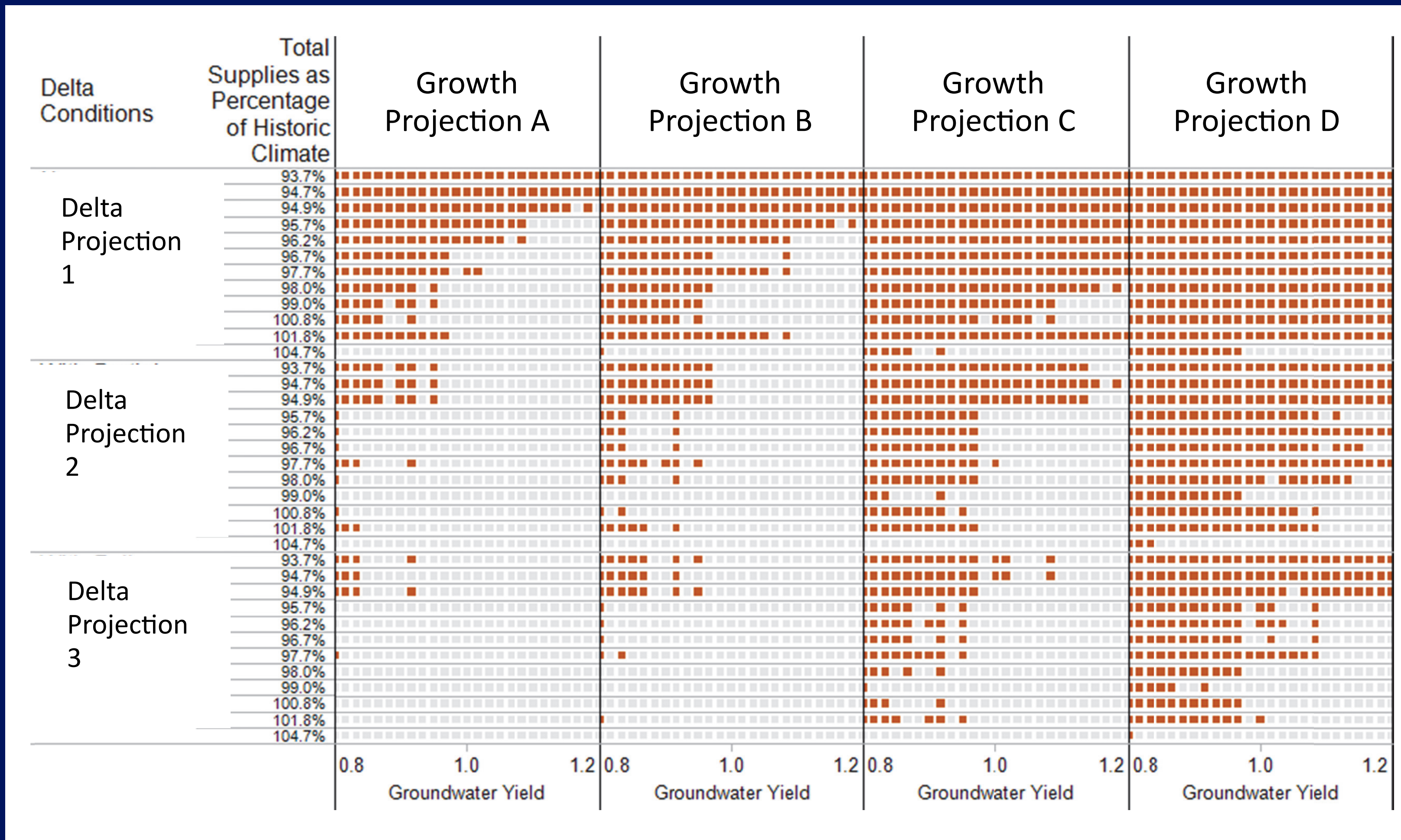
Consider performance of Metropolitan's IRP in 10,368 cases

Visualizations Show Key Drivers of Futures Where IRP May Fail to Meet Goals



-All delays at zero
-Explore over yields
-Each cell contains one case

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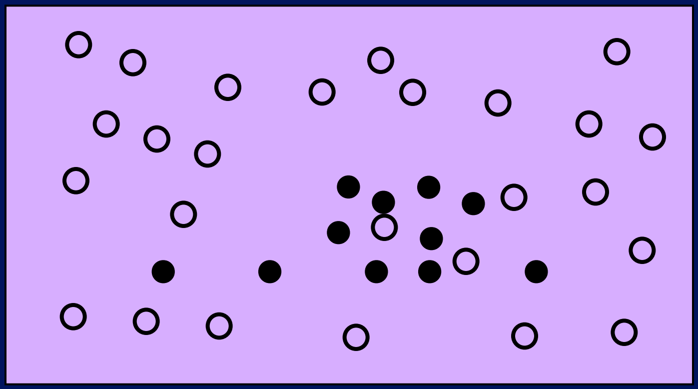
Scenario Discovery Provides an Approach for Computer-Assisted Scenario Development

1. *Indicate policy-relevant cases in database of simulation results*



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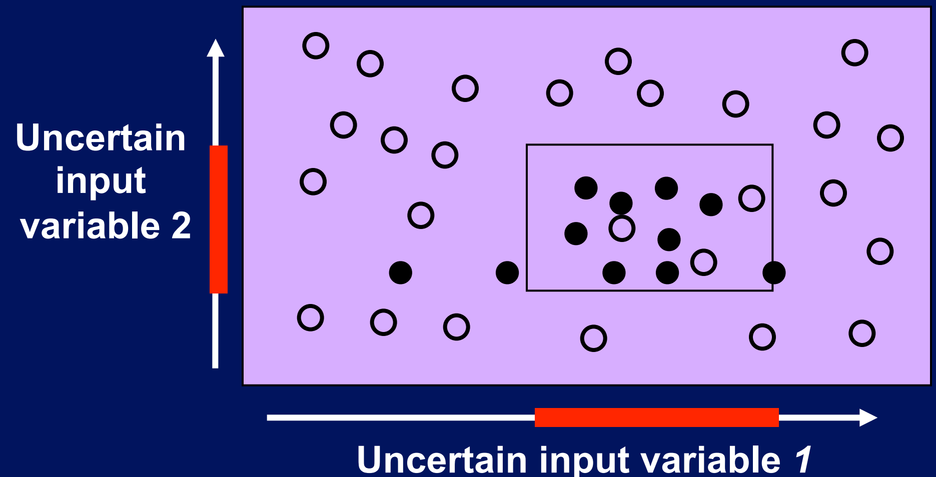
Bryant and Lempert (2010)

Scenario Discovery Provides an Approach for Computer-Assisted Scenario Development

1. *Indicate policy-relevant cases in database of simulation results*
2. *Statistical analysis finds low-dimensional clusters with high density of these cases*



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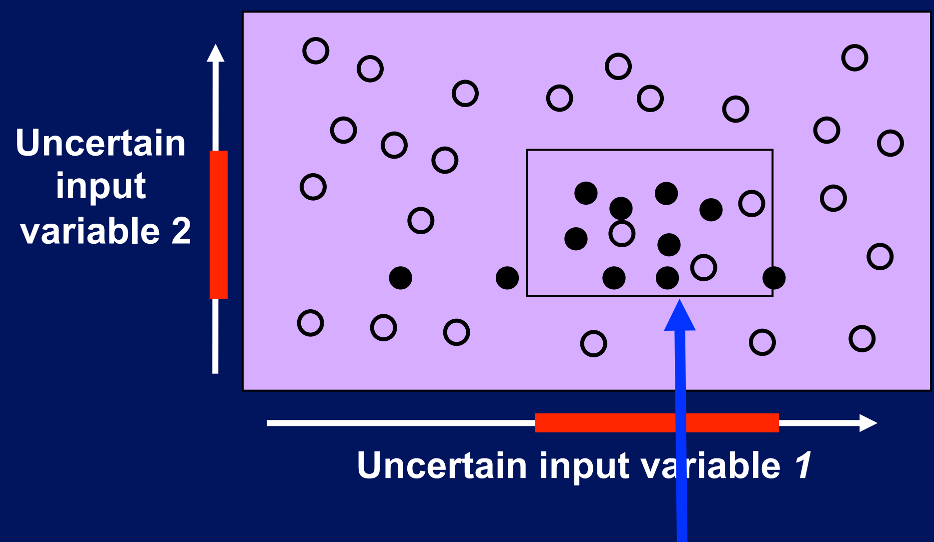

3. *Clusters represent scenarios and driving forces of interest to decision makers*

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Bryant and Lempert (2010)

Scenario Discovery Provides an Approach for Computer-Assisted Scenario Development

Approach provides measures of merit for scenario quality

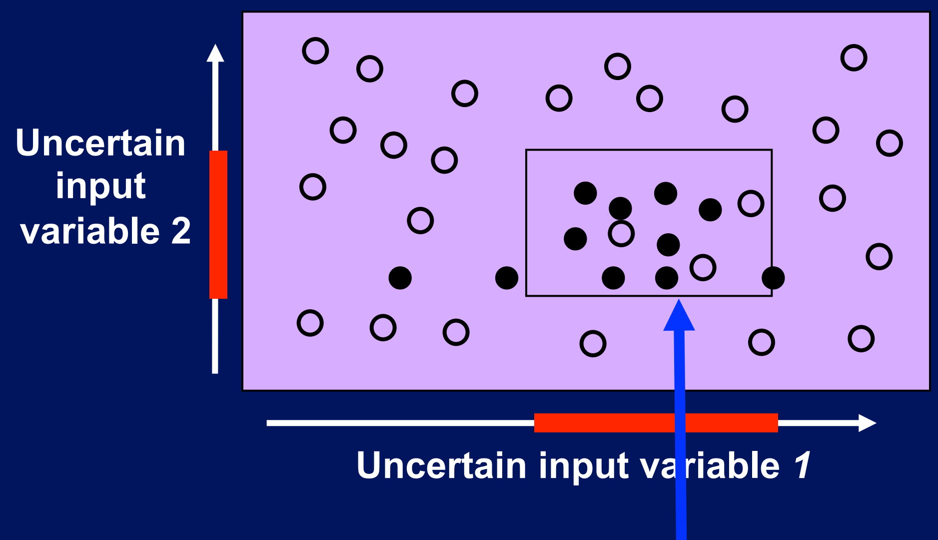
Density:
- How many cases inside the scenario are *policy-relevant?* (e.g. 75%)

Coverage:
- How many of all the *policy-relevant* cases do the scenarios include? (e.g. 82%)

Interpretability:
- Is the number of scenarios and driving forces sufficiently small to understand? (e.g. 1 scenario with two driving forces)

1. Indicate policy-relevant cases in database of simulation results

2. Statistical analysis finds low-dimensional clusters with high density of these cases



3. Clusters represent scenarios and driving forces of interest to decision makers

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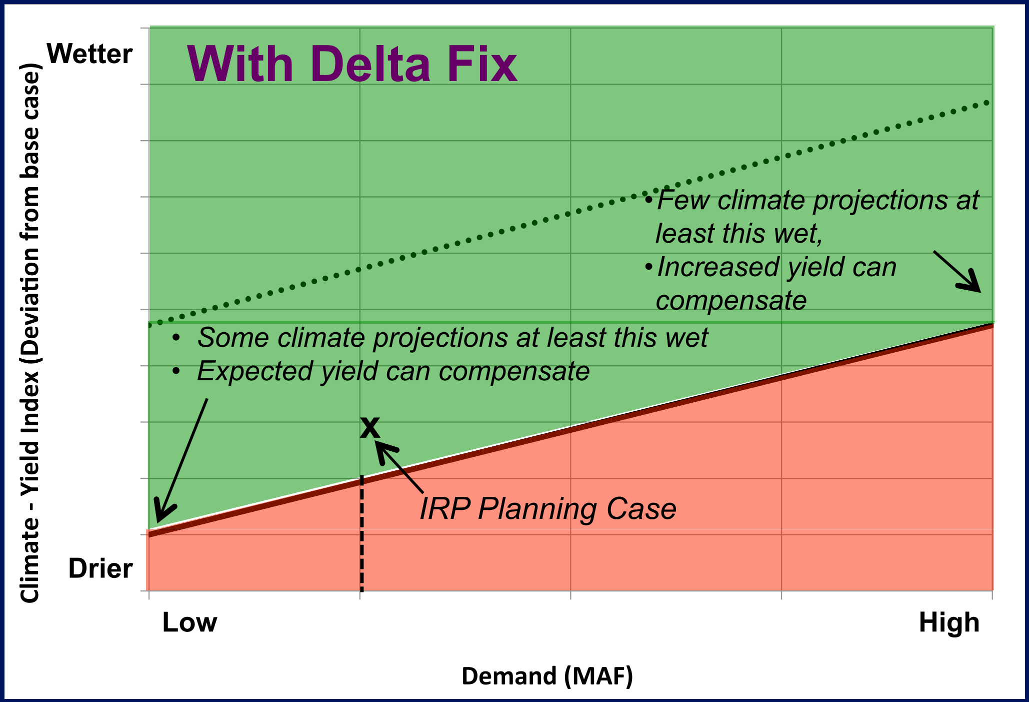
Bryant and Lempert (2010)

Summary Plots Suggests Scenarios Where Metropolitan's IRP Fails to Meet Its Reliability Goals



- The results suggest
  - The IRP can meet its goals even if one big thing goes wrong, as along as everything else goes right
  - Key indicators Metropolitan should track to determine whether it should adjust its IRP

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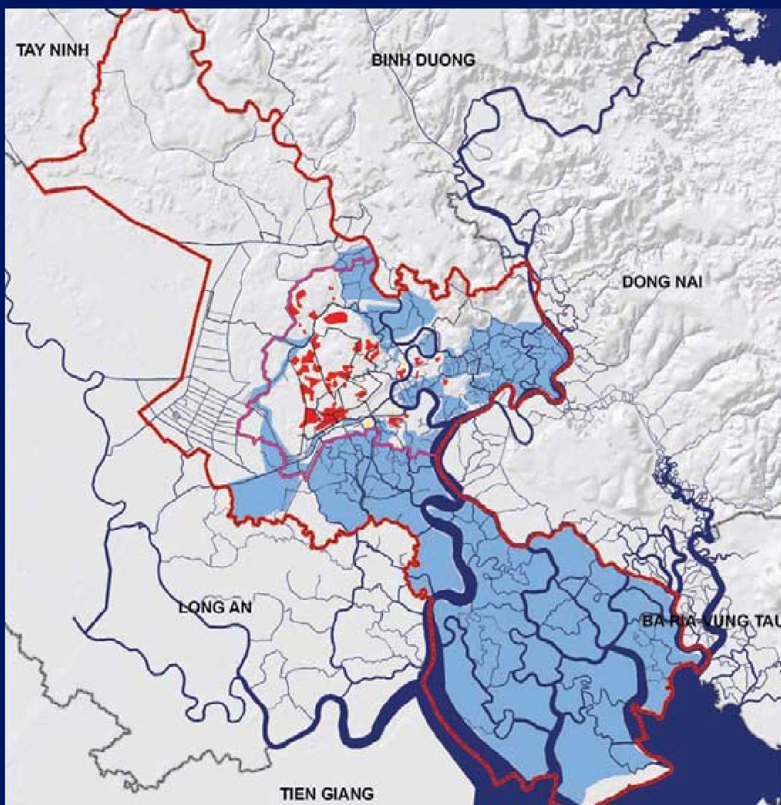
Ho Chi Minh City Developing an Integrated Flood Risk Management Strategy

HCMC Areas Currently Subject To Flooding



HCMC

- **Already experiences extensive routine flooding**
- **Ranks on "top ten" lists of places most likely to be affected by climate change**
- **Engaged in a multi-billion dollar infrastructure construction campaign**

Failure of previous strategies has sensitized HCMC to need for a new strategy that is robust over a wide range of future conditions

Source: Asian Development Bank. Ho Chi Minh City Adaptation To Climate Change. Mandaluyong City, Philippines: Asian Development Bank, 2010.

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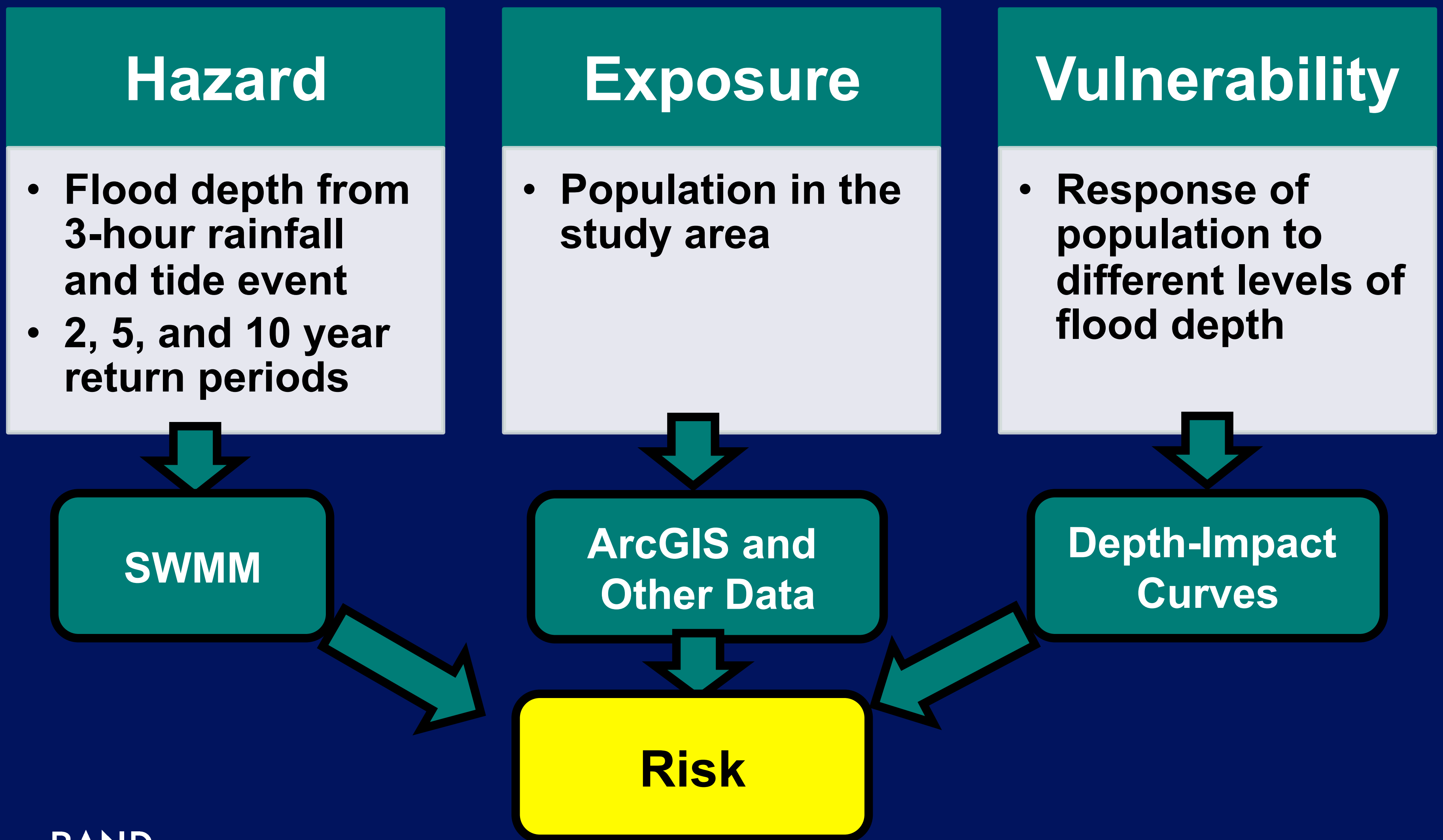
Coupled Models Project Risk



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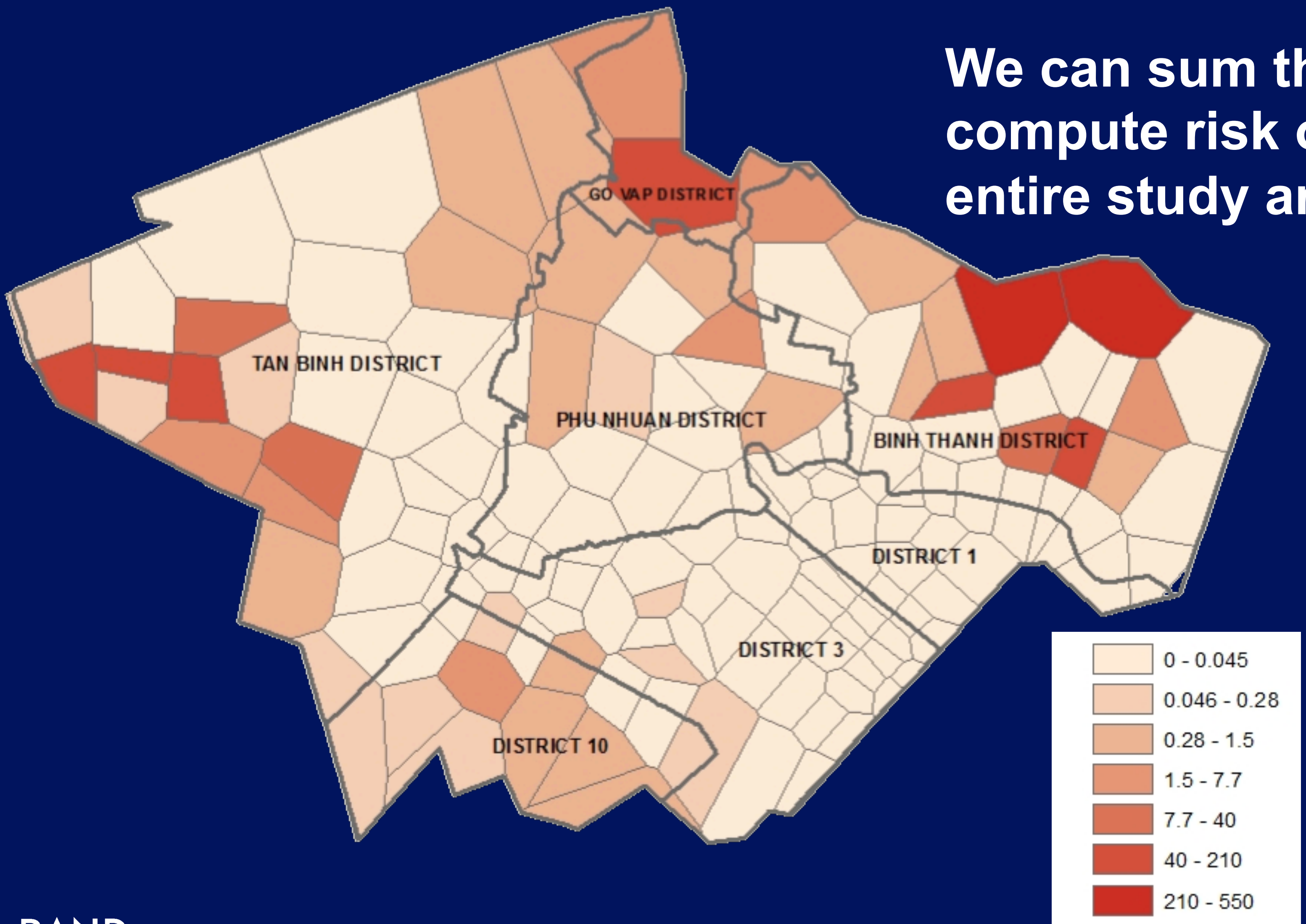
Model Generates Map of Risk In Different Subcatchments

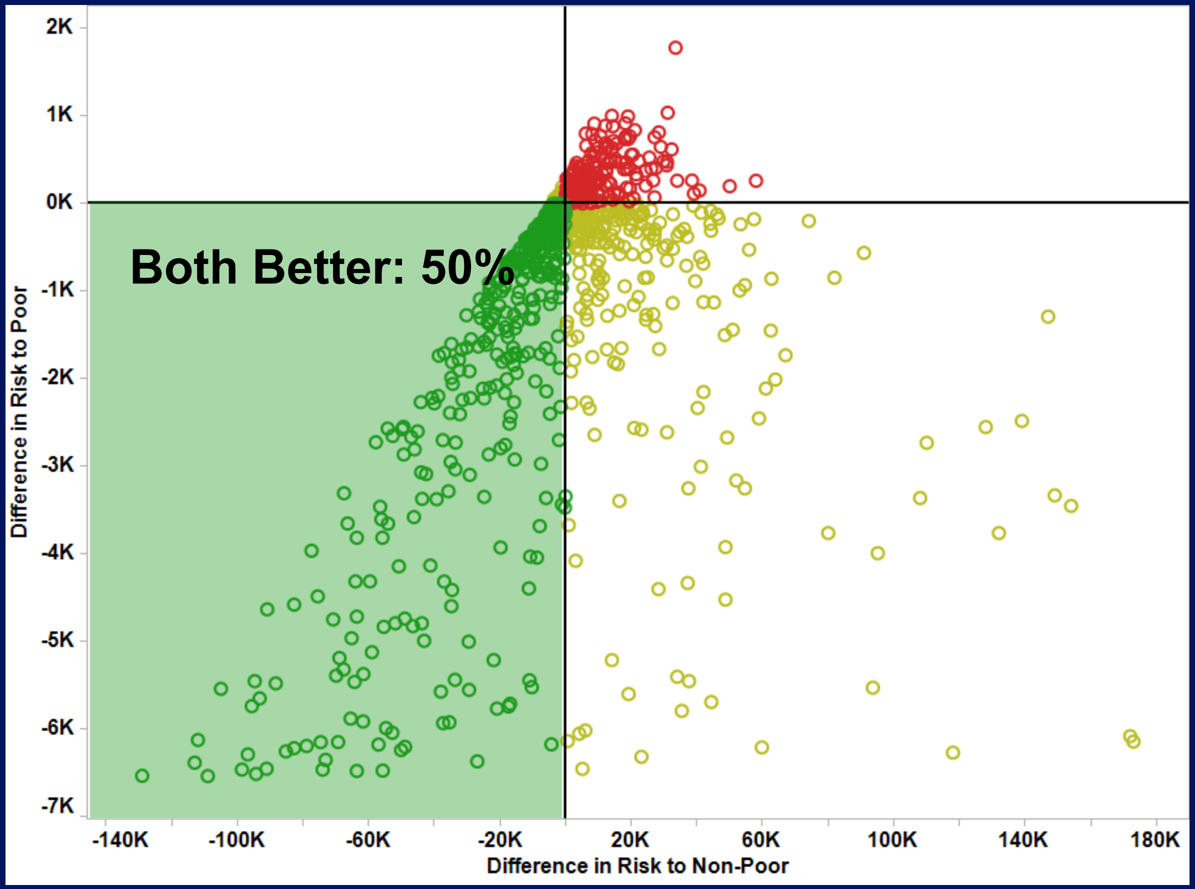


We can sum these to compute risk over the entire study area

Run Model Over 1000 Cases For Each of Several Flood Risk Management Strategies

Uncertainties include future:

- Rainfall intensity
- SLR
- Population
- Poverty rate
- Depth-impact curve used



Compare policies to infrastructure only case

Consider risk to poor and non-poor

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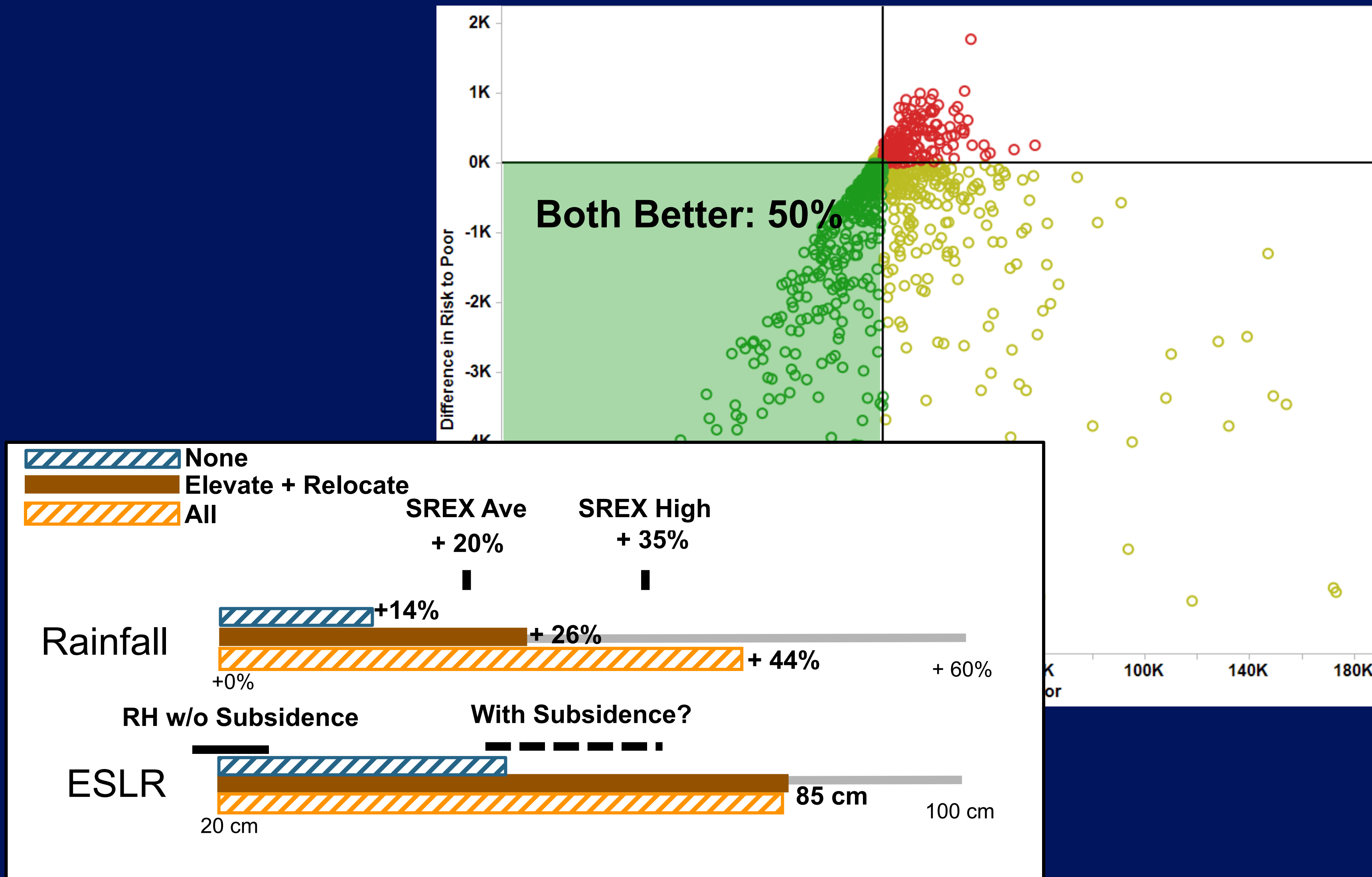
'Non-Structural" Policies Can Significantly Change HCMC's Flood Risk



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Coverage/Density = 63/90

What Is the Best Emissions Reduction Strategy in the Face of Potential Abrupt Climate Change?

Elements of RDM analysis

Uncertainties	Strategies
• Climate sensitivity • Carbon intensity growth rate • Damages due to MOC collapse • MOC vulnerability (binary parameter)	Four alternative emission reduction paths with learning, labeled: • Business as Usual • Expected Utility • Safety First • Limited Degree of Confidence
Model/Relationships	**Measures of Merit**
• Nordhaus DICE model with simple representation of MOC collapse	• Present value consumption

Source: Hall, Lempert, Keller, Hackbarth, Mijere, McInerney, Robust climate policies under uncertainty: A comparison of Robust Decision-Making and Info-Gap methods RISK ANALYSIS 2012

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Create Database of Simulation Results

General procedure:

- **Specify plausible range for each uncertain parameter**
- **Create experimental design to effectively sample space defined by uncertain parameters**
- **Run simulation for each alternative policy for each case in experimental design to create database of simulation results**
- **Gather any probabilistic estimates over cases for subsequent use in analysis**

In this example:

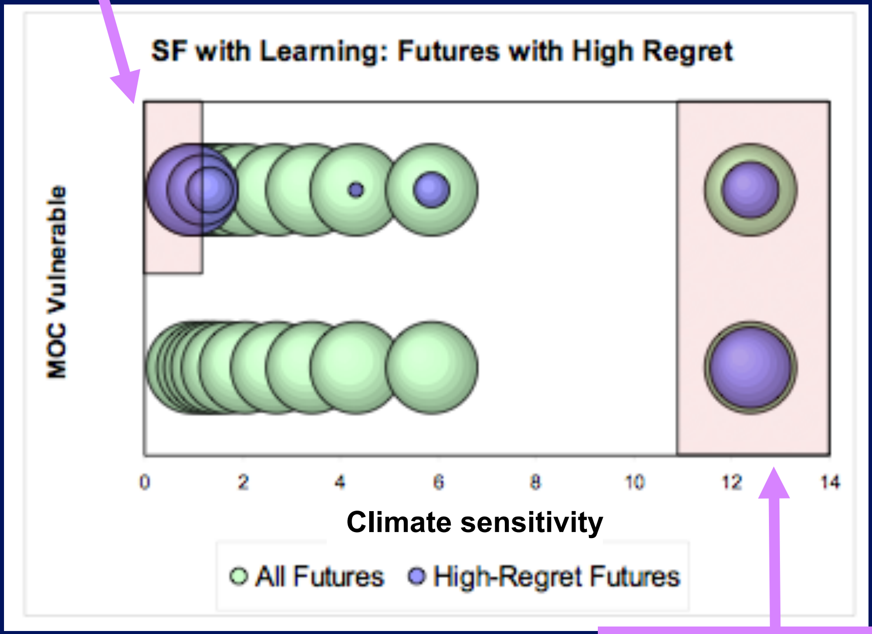
- **Estimated distributions for first three uncertain parameters**
- **Experimental design is full factorial over 11 equally likely intervals and two cases of MOC shutdown, with 11^3 x 2 = 2662 cases**

Uncertainties	Strategies
Relationships	Measures

Uncertain parameter	Range	
Climate sensitivity	[0.5 - 15]	°C
Carbon intensity growth rate	[-0.2 - -0.02]	per decade
Damages from MOC collapse	[-0.055, 0.30]	% GWP
Is MOC shutdown possible?	[Yes, No]	

Scenario Discovery Identifies Vulnerabilities of Safety First Strategy

Density = 82%
Coverage = 49%



Density = 62%
Coverage = 37%

Choose candidate strategy → **Identify vulnerabilities** → Identify & assess options

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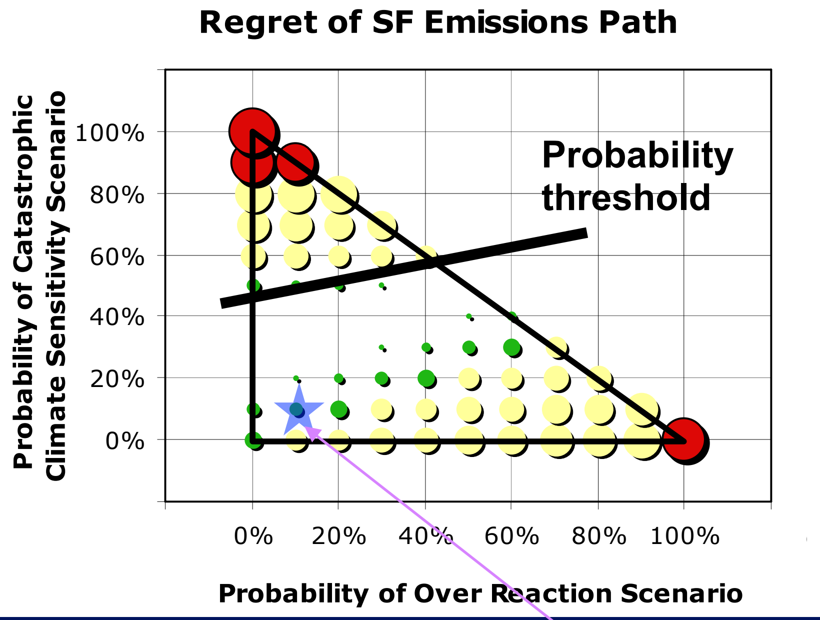
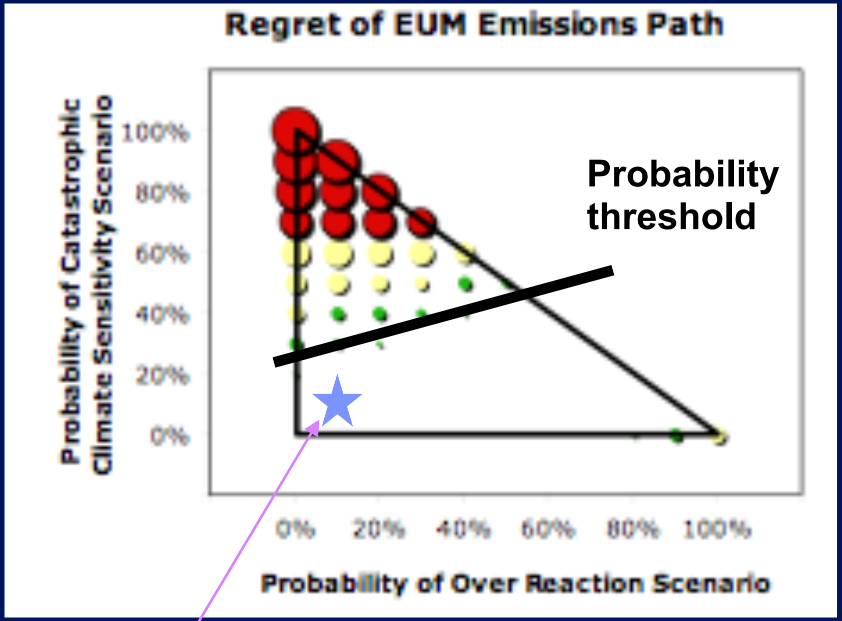
Can Now Assess Tradeoffs Among Alternative Strategies

Analysis provides context for judgments about imprecise likelihoods and confidence in those judgments

- For *Safety First*, a key judgment is likelihood of very high climate sensitivity





Best estimate likelihood

Choose candidate strategy → Identify vulnerabilities → **Identify & assess options**

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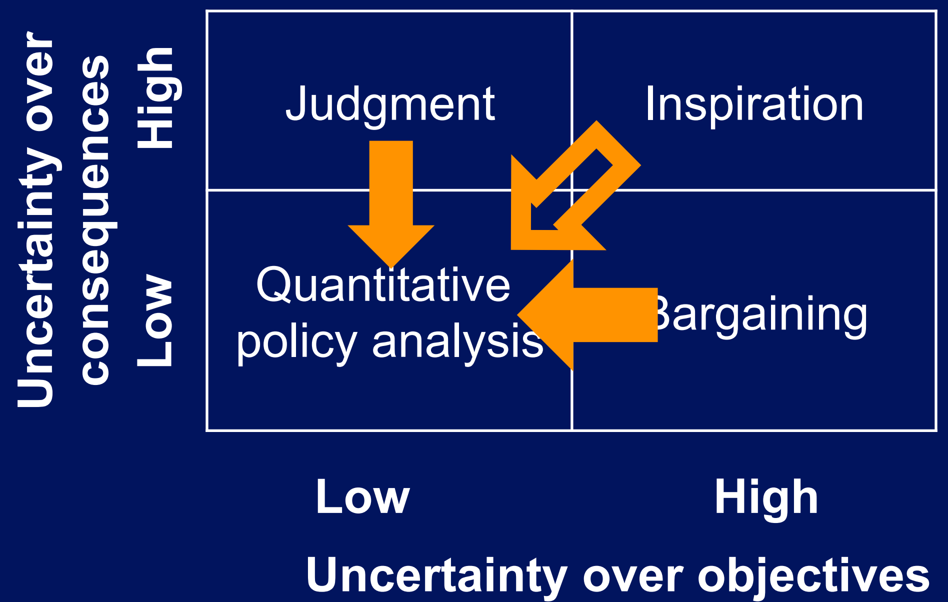
Address the Cascade of Uncertainty By Conducting the Analysis Backwards

1. Begin with a policy under consideration
2. Create a database of many runs that samples the performance of the policy across many future conditions
3. Partition the ensemble into cases where the policy performs well or poorly
4. Identify the key drivers that in combination are highly predictive of policy success or failure
5. Use this information – along with available projections -- to help decision makers choose among policies, or identify new ones

RDM May Help Reframe Decision, Making Quantitative Information More Actionable and Salient

Identifying robust solutions may move from "judgment" to "intellective" task



Identifying robust solutions may move from "majority rules" to "truth wins"

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Summary

- Predictions are often seductive and flawed
  - But decision makers require some means to scan through a multiplicity of plausible futures to identify those that should command their attention
- RDM uses sophisticated analytic tools within a specific process of stakeholder engagement, but key idea is even more broadly applicable:
  - *Use analysis to identify vulnerabilities of specific plans and compare robust responses*

Encourage policy makers to change the question from

"What will the future bring?"

to

"What steps can we take today to most assuredly shape the future to our liking?"

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