RAND PARDEE CENTER

# Robust Decision Making: Good Decisions Without Good Predictions

**Robert Lempert**

**Director,**

**RAND Pardee Center for Longer Range Global Policy and the Future Human Condition**

**Sustainable Water Resources**

**UF Water Institute**

**February 11, 2014**

# 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 quantitative methods and tools commonly used to inform decision processes 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

# Climate-Related Decisions Poses Both Analytic and Organizational Challenges

Public planning should be:

- Objective
- Subject to clear rules and procedures
- Accountable to public

Climate-related decisions involve:

- Incomplete information from new, fast-moving, and sometimes irreducibly uncertain science
- Many different interests and values
- Long-time scales
- Near certainty of surprise

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

# *Traditional Water Planning Makes Sense When There Isn't Much Uncertainty*

- **Traditional "predict-then-act" analysis begins by characterizing uncertainty:**

Characterize uncertainty → Rank strategies → Sensitivity analysis

# *Traditional Water Planning Makes Sense When There Isn't Much Uncertainty*

- **Traditional "predict-then-act" analysis begins by characterizing uncertainty:**

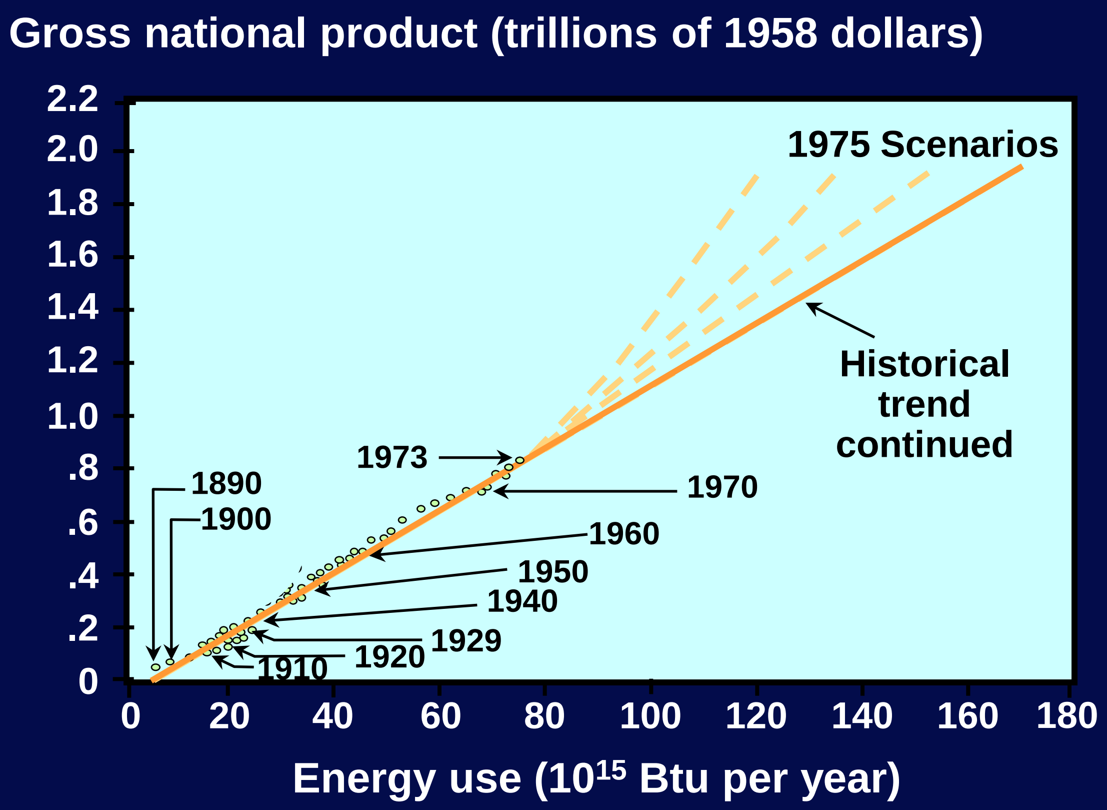
Characterize uncertainty → Rank strategies → Sensitivity analysis

**But when uncertainties are deep:**

- **Uncertainties are underestimated**
- **Competing analyses can contribute to gridlock**
- **Misplaced concreteness can blind decisionmakers to surprise**

# Believing Forecasts of the Unpredictable Can Contribute to Bad Decisions

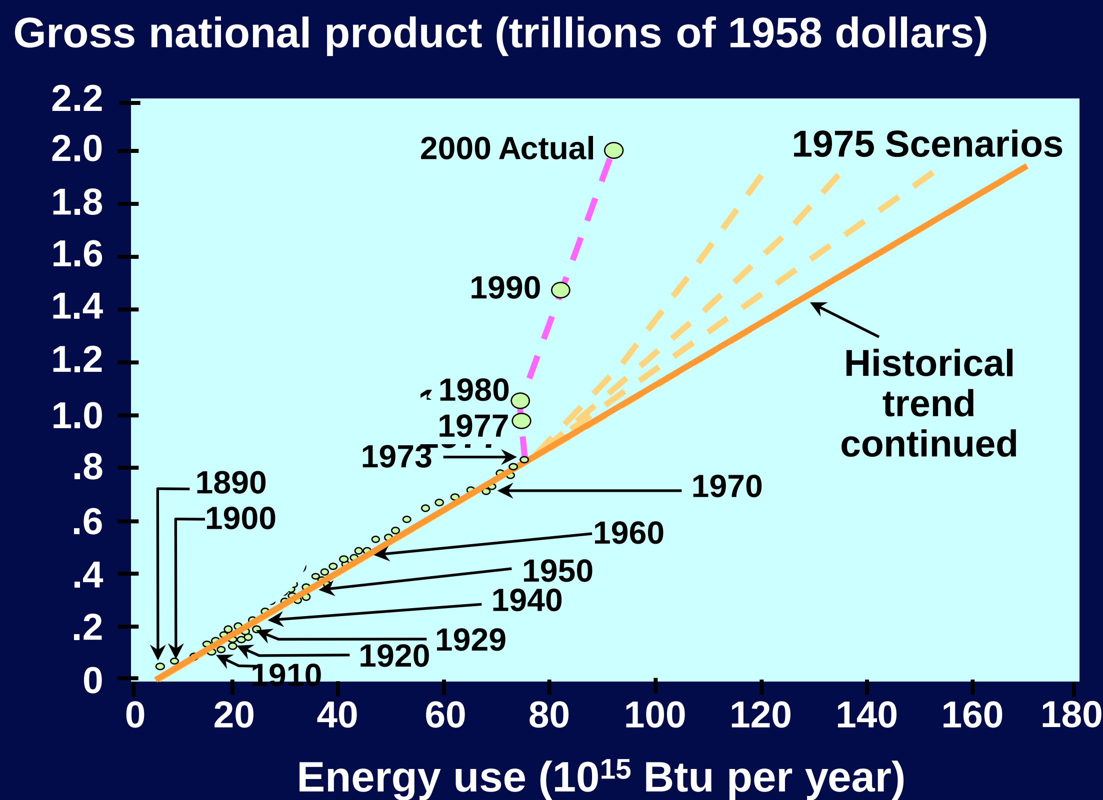
- In the early 1970s forecasters made projections of U.S energy use based on a century of data



# Believing Forecasts of the Unpredictable Can Contribute to Bad Decisions

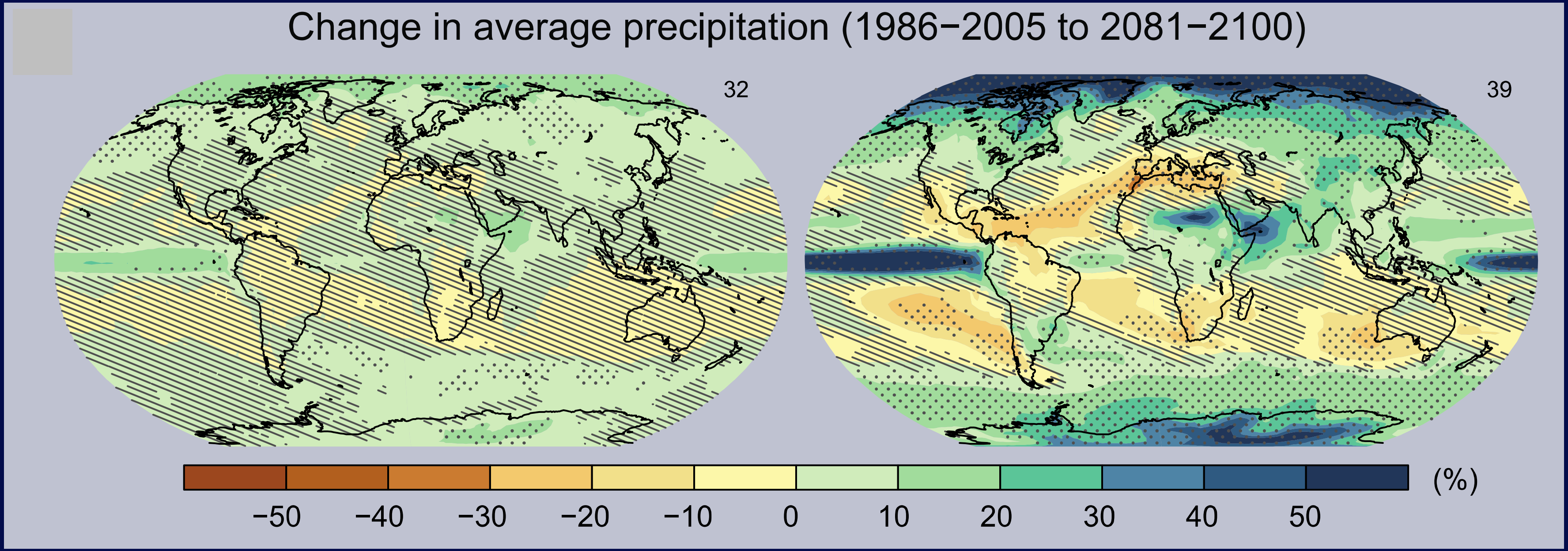
- **In the early 1970s forecasters made projections of U.S energy use based on a century of data**

**… they all were wrong**



# Climate Change Is One Source of Uncertainty Facing Water Managers

IPCC Fifth Assessment report multi-model projections of precipitation changes




Lower emissions scenario (RCP 2.6)

Higher emissions scenario (RCP 8.5)

***Deep uncertainty occurs when the parties to a decision do not know or do not agree on the likelihood of alternative futures or how actions are related to consequences***

RAND

# *Under Conditions of Deep Uncertainty, Often Useful to Run Analysis Backwards*

– **Forwards:**

Characterize uncertainty → Rank strategies → Sensitivity analysis

– **Backwards:**

Candidate strategy → Identify Vulnerabilities → Identify Responses and Tradeoffs

RDM (Robust Decision Making) follows this backwards approach

# Many Resource Management Agencies Use RDM

## Long-term Water Resources Planning

2008

2009

2010

2011

2012

2013

IEUA (NSF)

Denver Water

California Water Plan

EPA Water Quality Case Studies

MWD IRP

Climate Impacts on Sierra Nevada Water Utility (EID)

USBR CO River Basin Study

Water Resource Foundation CO Springs Utilities & NYC

Vulnerability Assessment & Risk Management Tools

World Bank: Climate Resilient African Infrastructure

## Coastal Protection & Restoration

Louisiana Coastal Master Plan

2012 Update

2017 Update

New Orleans Risk Mitigation & Comm. Study (NOAA)

Port of L.A. & sea level rise (NSF)

World Bank: Ho Chi Min City

NY-NJ Climate Resilience Planning

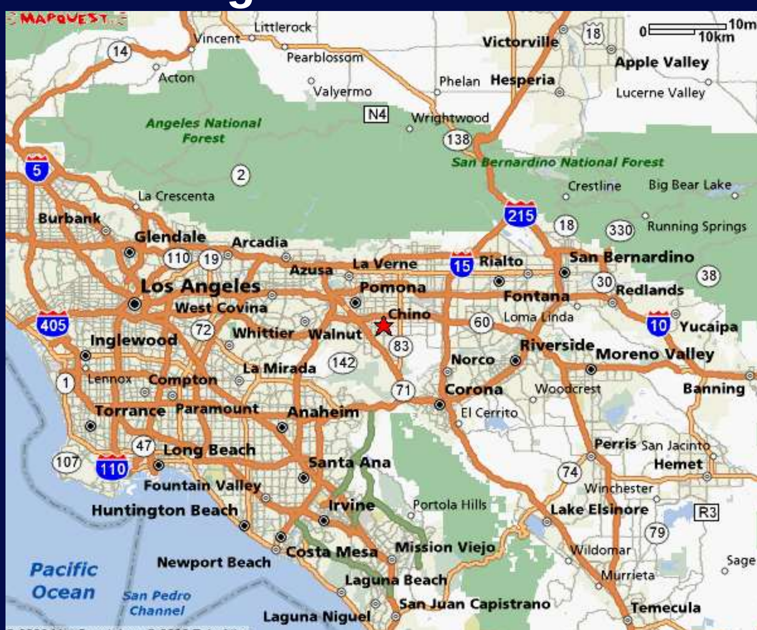
RAND

# *Outline*

- Do the Analysis Backwards
  - Inland Empire Utilities Agency
- Embed analysis in process of stakeholder engagement
  - Colorado River Basin Supply and Demand Study
- How Can You Use RDM?

# *Helped Inland Empire Utilities Agency (IEUA) Include Climate Change in Their Long-Range Plans*

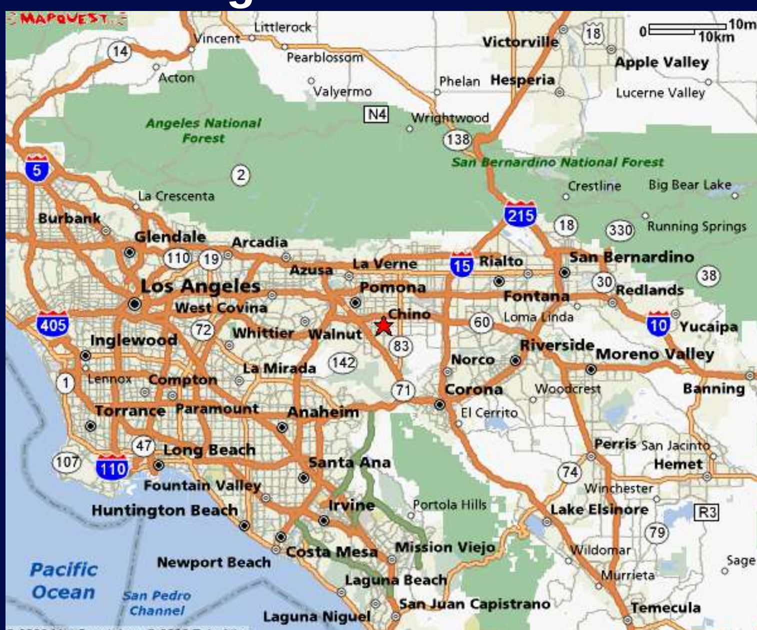
- **IEUA currently serves 800,000 people**
  - **May add 300,000 by 2025**
- **Water presents a significant challenge**




- **Current water sources include:**
  - **Groundwater 56%**
  - **Imports 32%**
  - **Recycled 1%**
  - **Surface 8%**
  - **Desalter 2%**

# *Helped Inland Empire Utilities Agency (IEUA) Include Climate Change in Their Long-Range Plans*

- **IEUA currently serves 800,000 people**
  - **May add 300,000 by 2025**
- **Water presents a significant challenge**

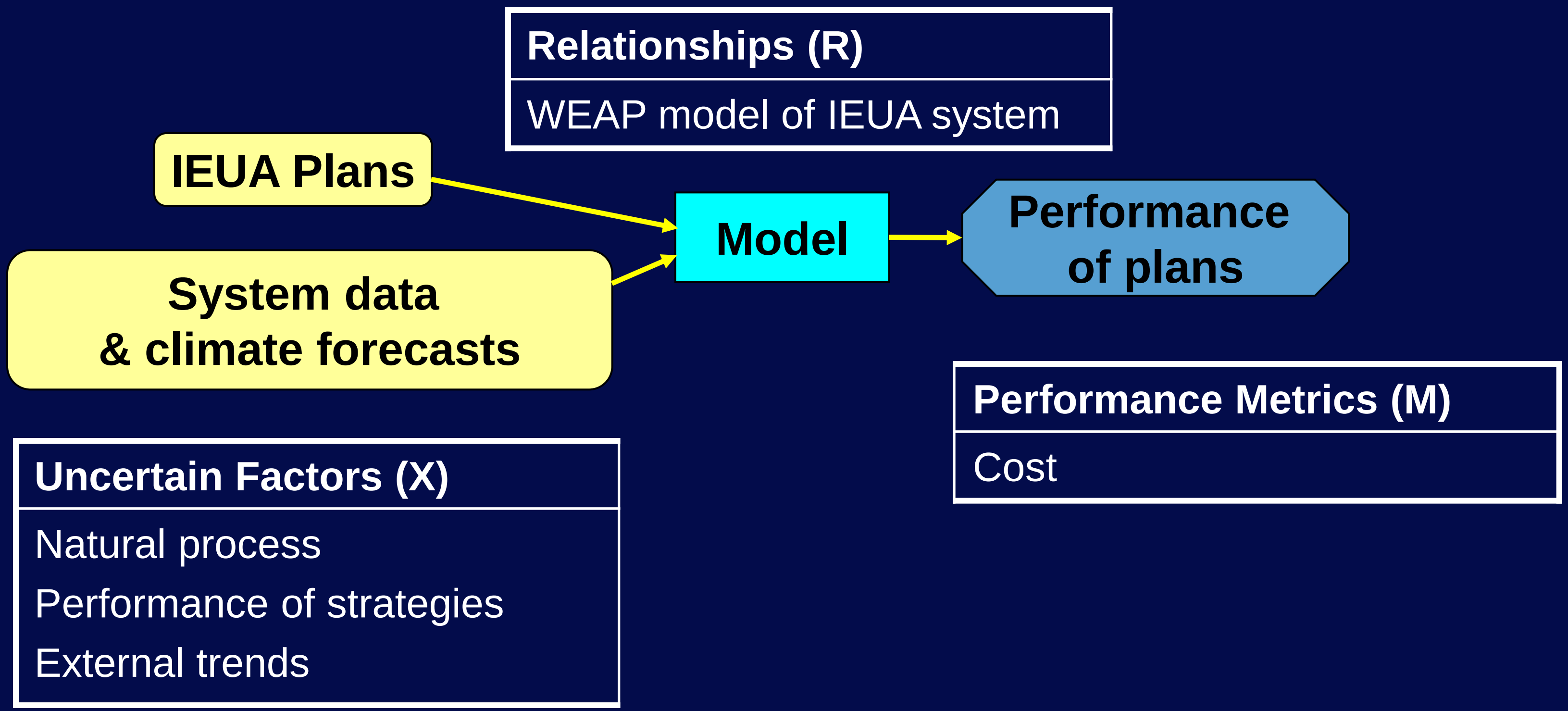



- **Current water sources include:**
  - **Groundwater 56%** ✓
  - **Imports 32%**
  - **Recycled 1%** ✓✓
  - **Surface 8%**
  - **Desalter 2%**

***Focus of IEUA's 25 year plan***

# Simulation Model Assesses Performance of IEUA Plans in Alternative Futures

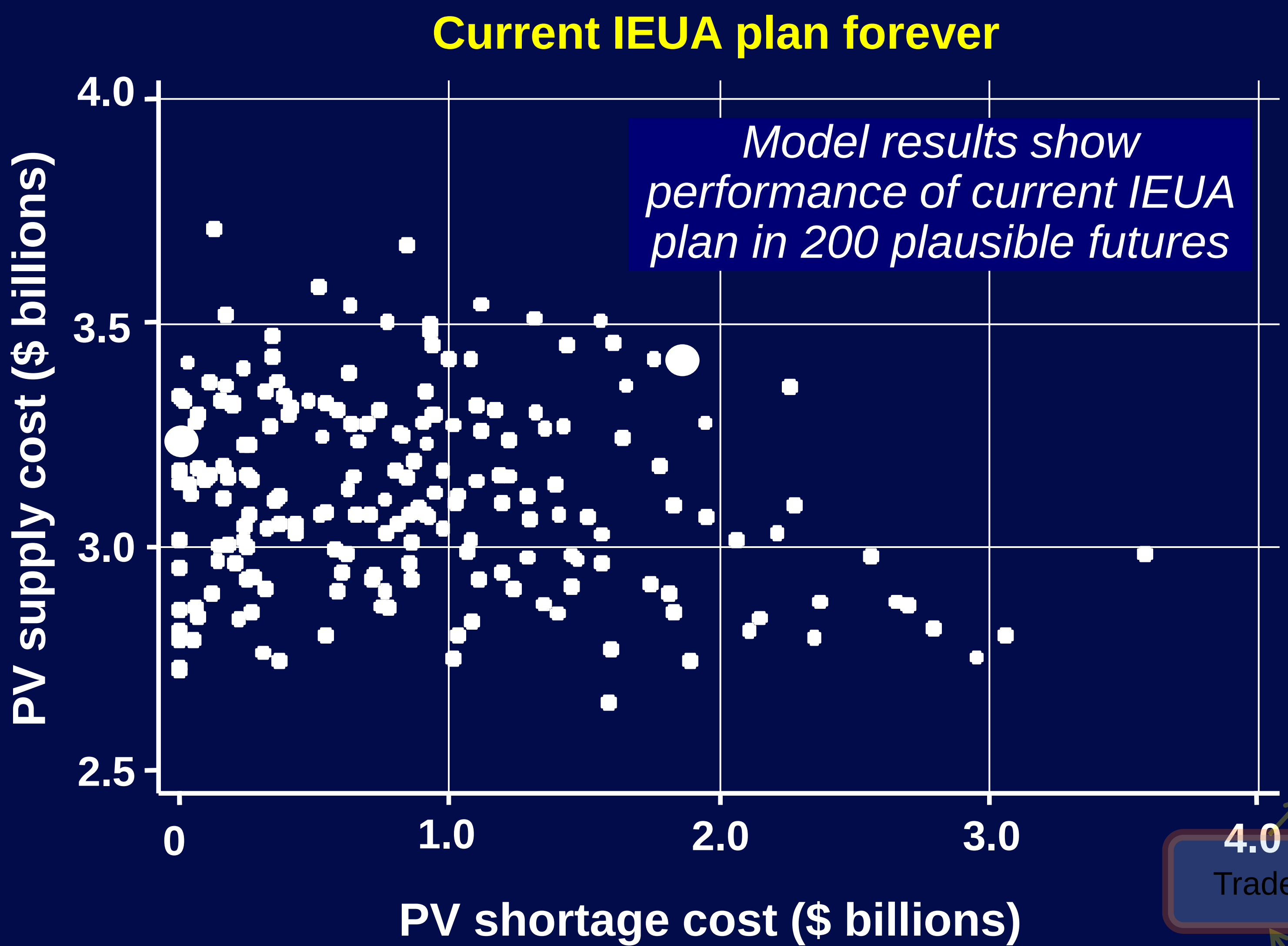
Use simulation model to assess performance of IEUA plan in each of hundreds of futures

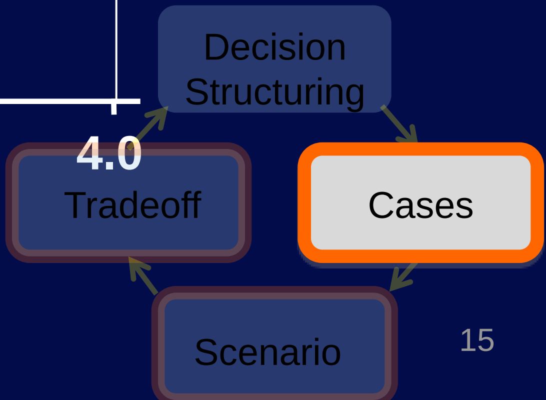



RAND

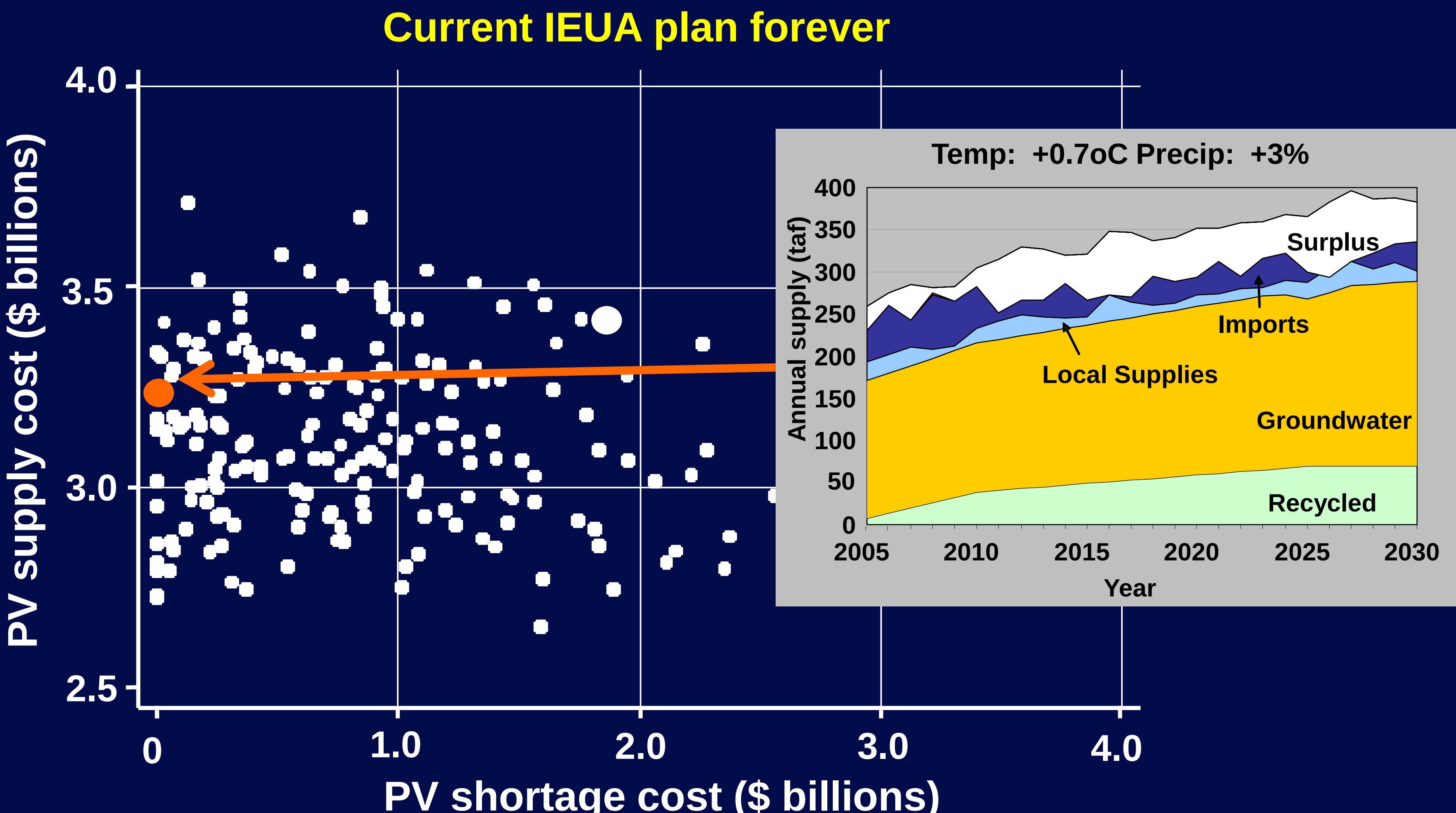
Groves et. al. (2007)

# "Scenario Maps" Help Decision Makers Visualize a Plans' Performance Over Many Futures



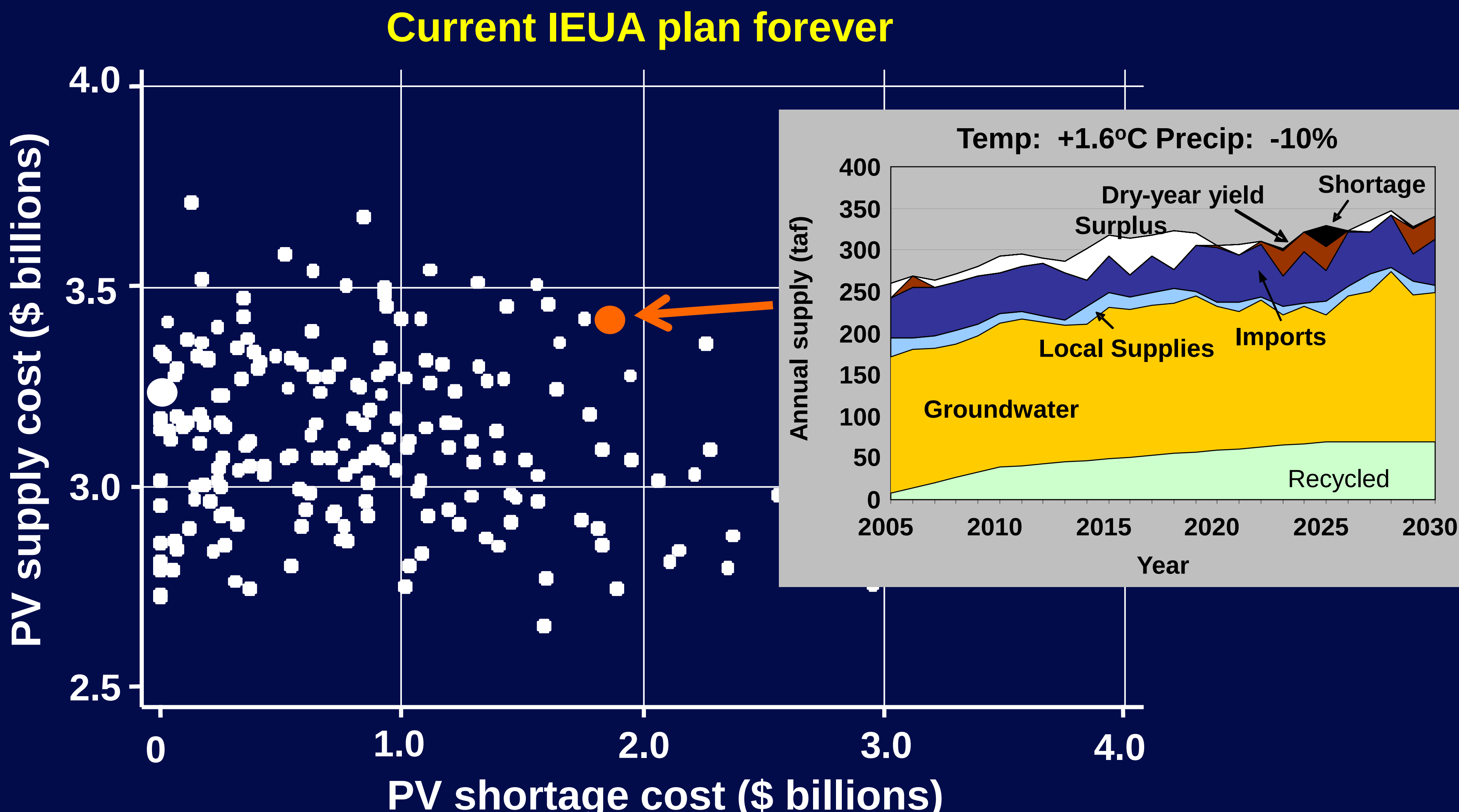



# Note That Plan Generates Surpluses in a Future With Benign Future Climate

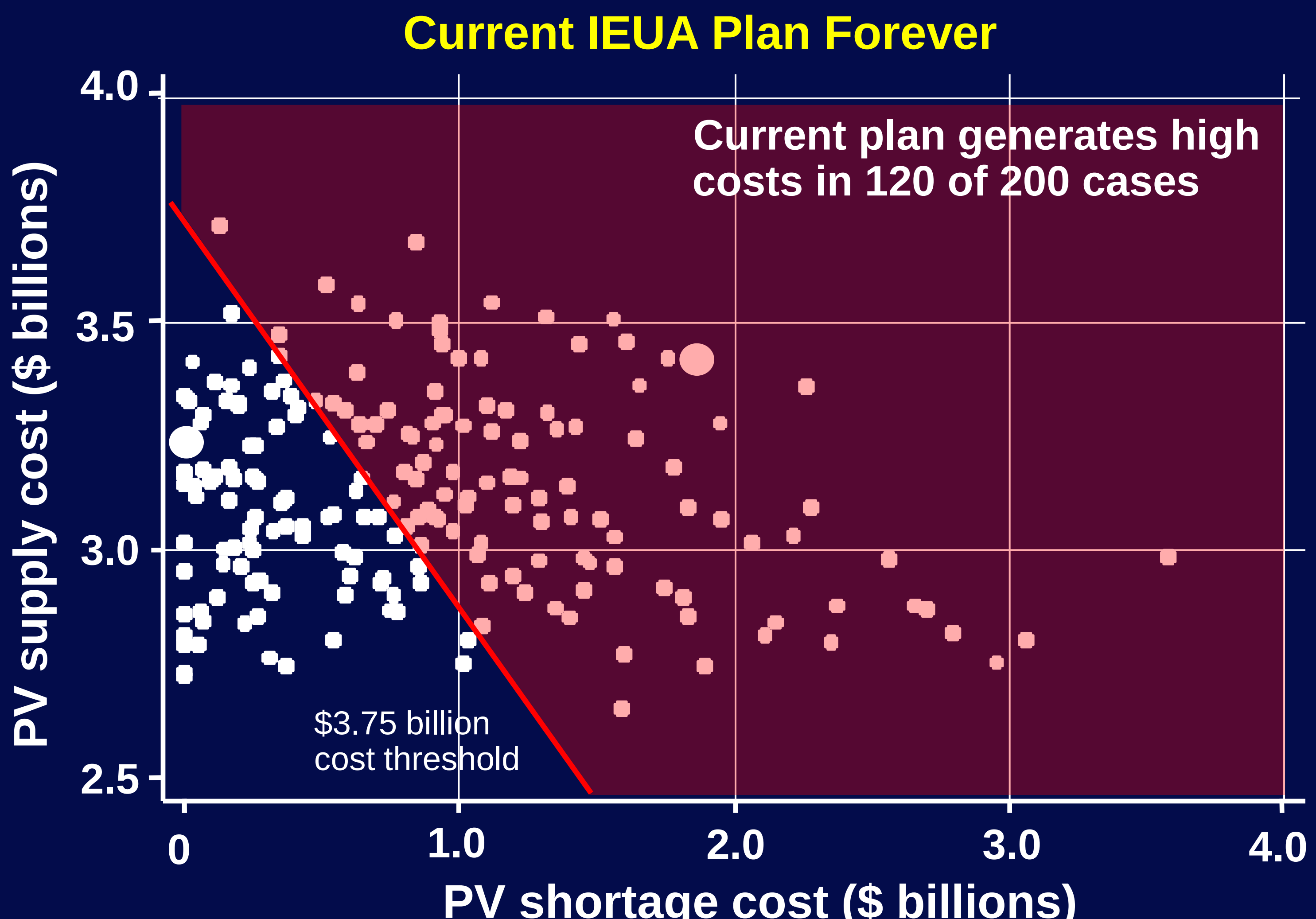



RAND

# But Plan Suffers Shortages in a Future With Adverse Future Climate



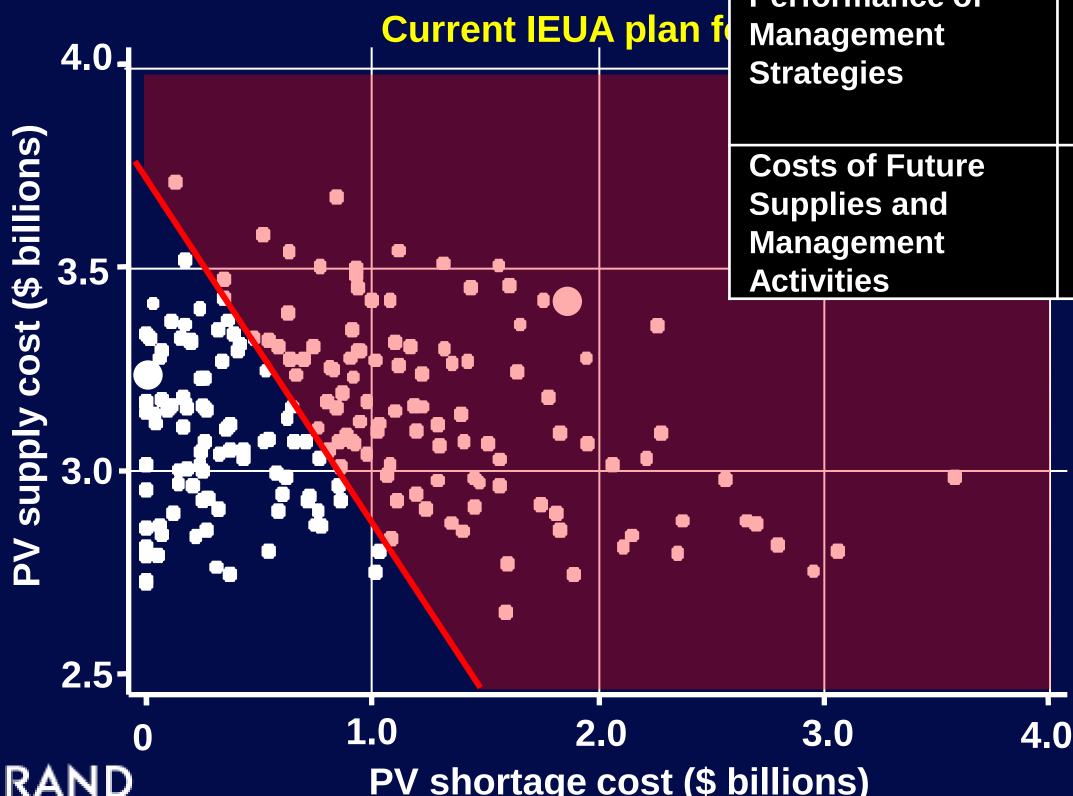
# Analyzing Patterns Across Many Futures Provides Decision-Relevant Information

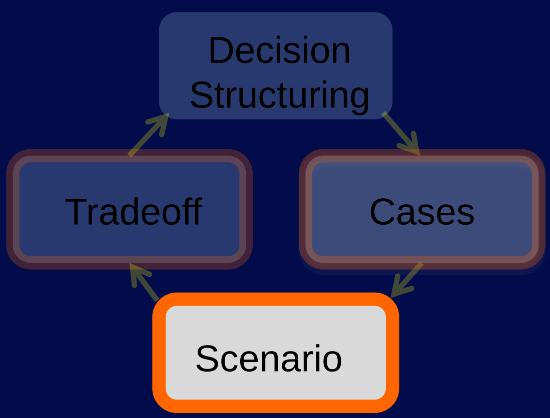


# Statistical "Scenario Discovery" Analysis Identifies Scenario Where Existing Plan Fails

**These three factors explain 70% of vulnerabilities of IEUA's current plans**

| | |
|---|---|
| **Natural Processes** | • Future temperatures<br>• **Future precipitation**<br>• **Changes in groundwater processes** |
| **Performance of Management Strategies** | • **Development of aggressive waste-water recycling program**<br>• Implementation of groundwater replenishment |
| **Costs of Future Supplies and Management Activities** | • Imported supplies<br>• Water use efficiency |



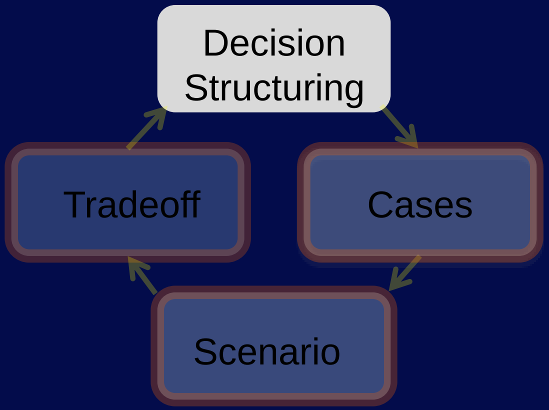



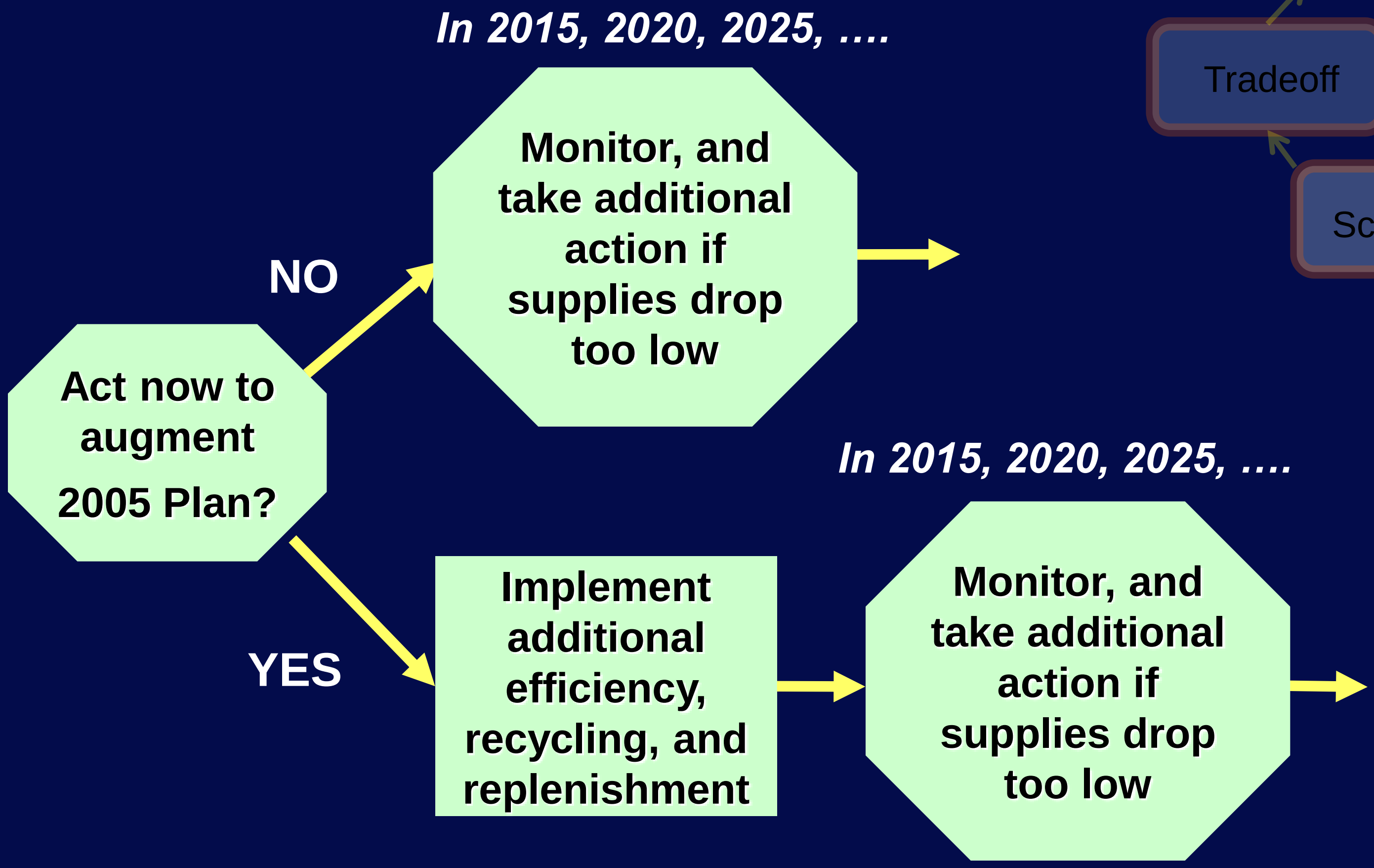

RAND



RAND DB-550-NSF

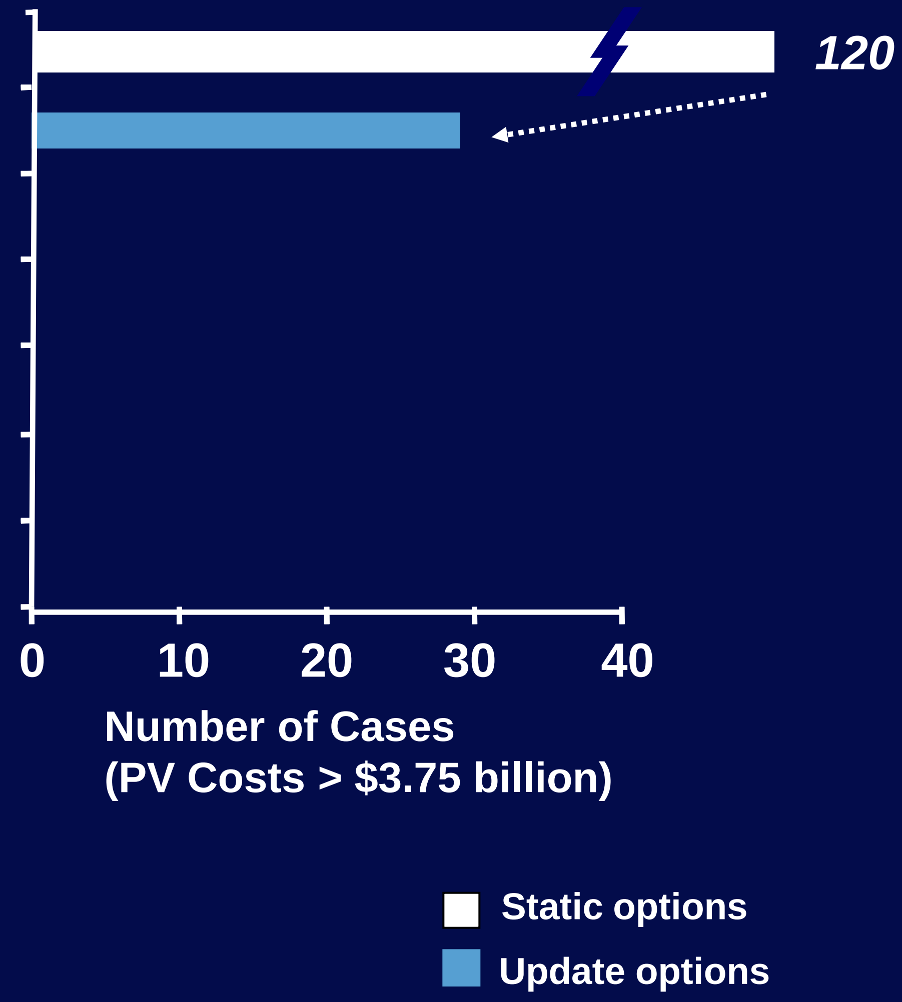
# What Should IEUA Do Now, and What Can They Wait to Do Later?

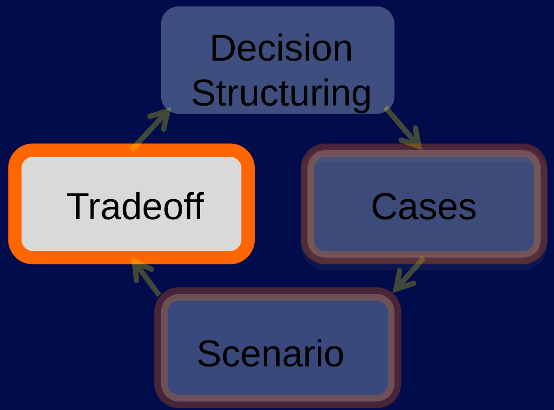


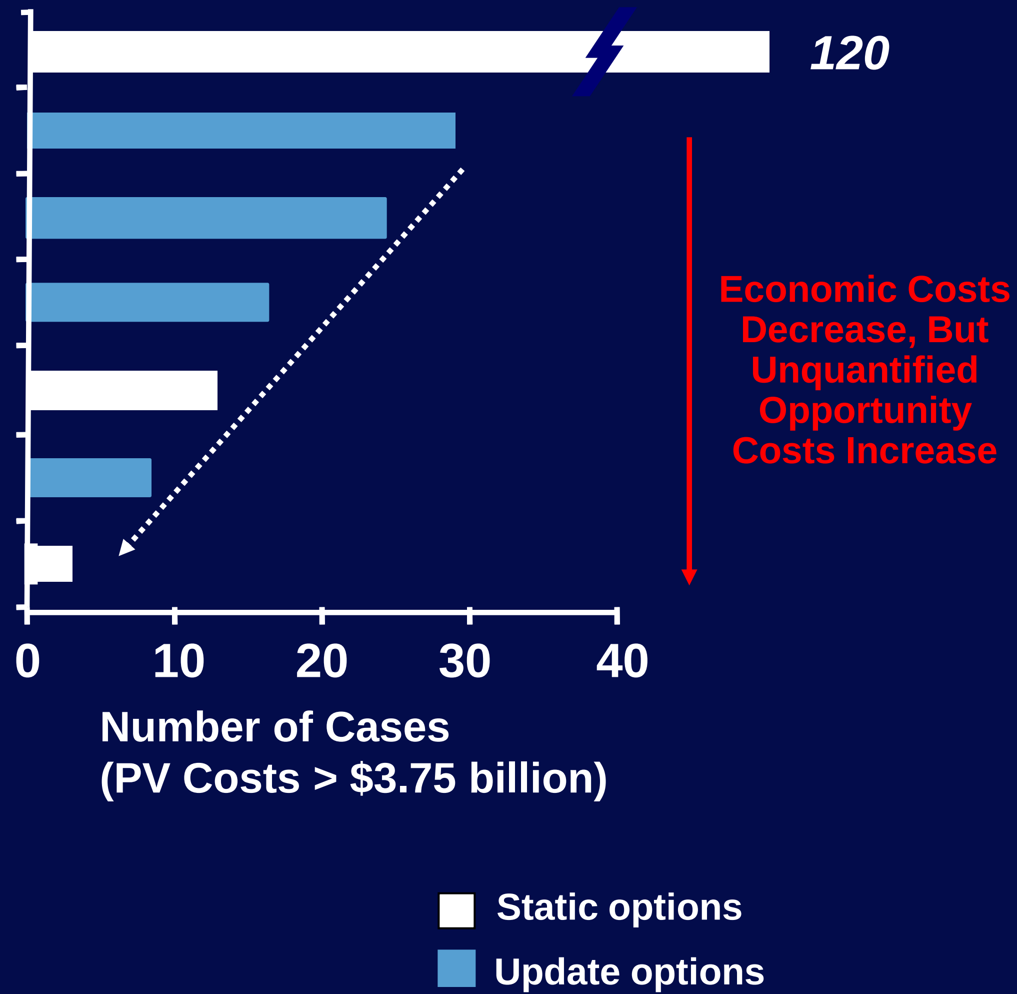

RAND

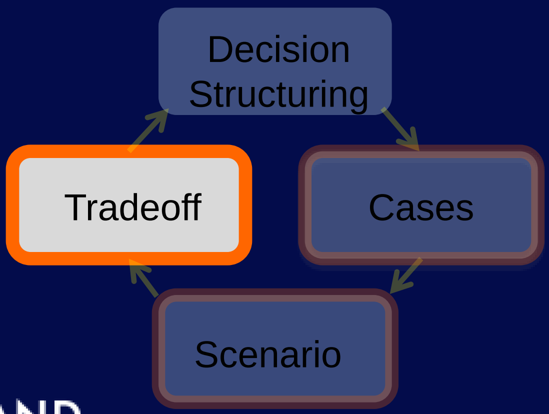
# Just Allowing the Current UWMP to Update Reduces Vulnerable Cases Substantially



# Compare Alternative Plans With Different Mixes of "Act Now" vs. "Act Later"



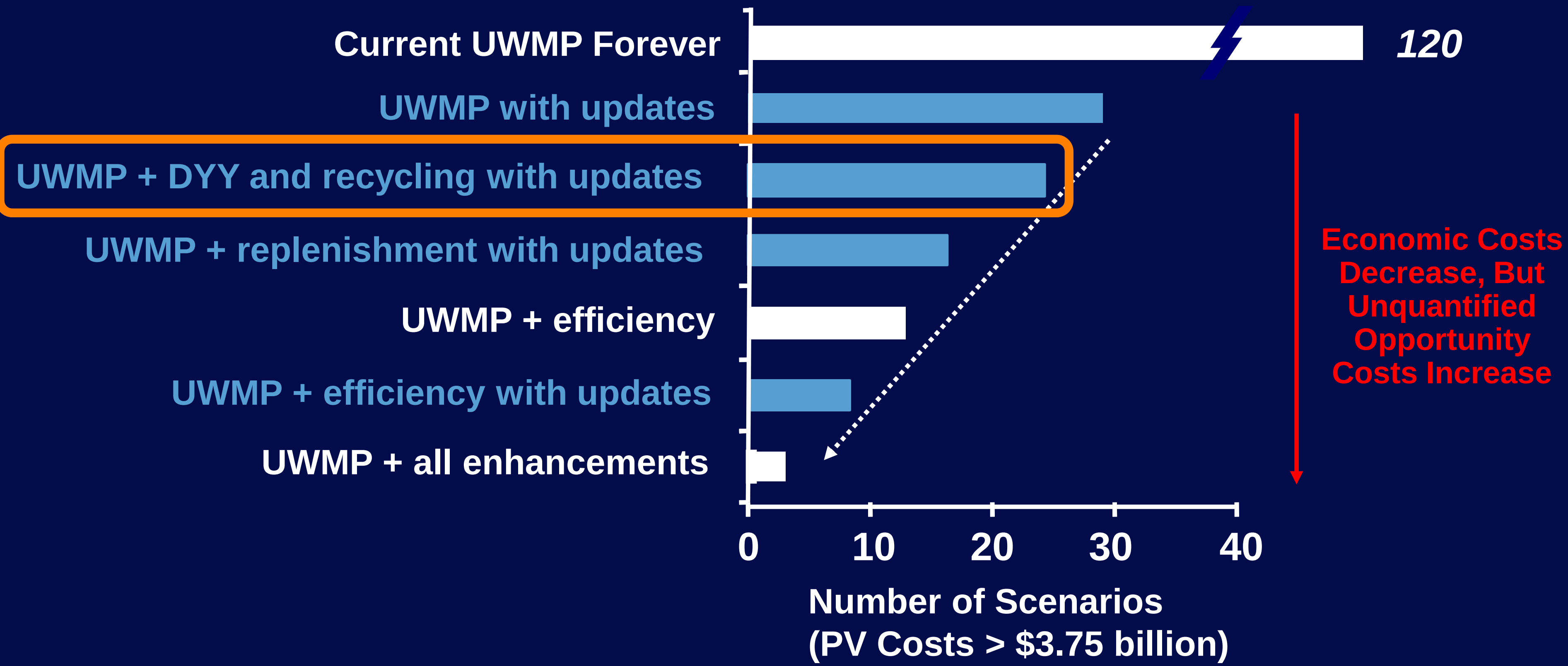




RAND



RAND DB-550-NSF

# Compare Alternative Plans With Different Mixes of "Act Now" vs. "Act Later"




***IEUA chose to accelerate their dry-year yield and recycling programs, and adapt as needed down the road***

# Outline

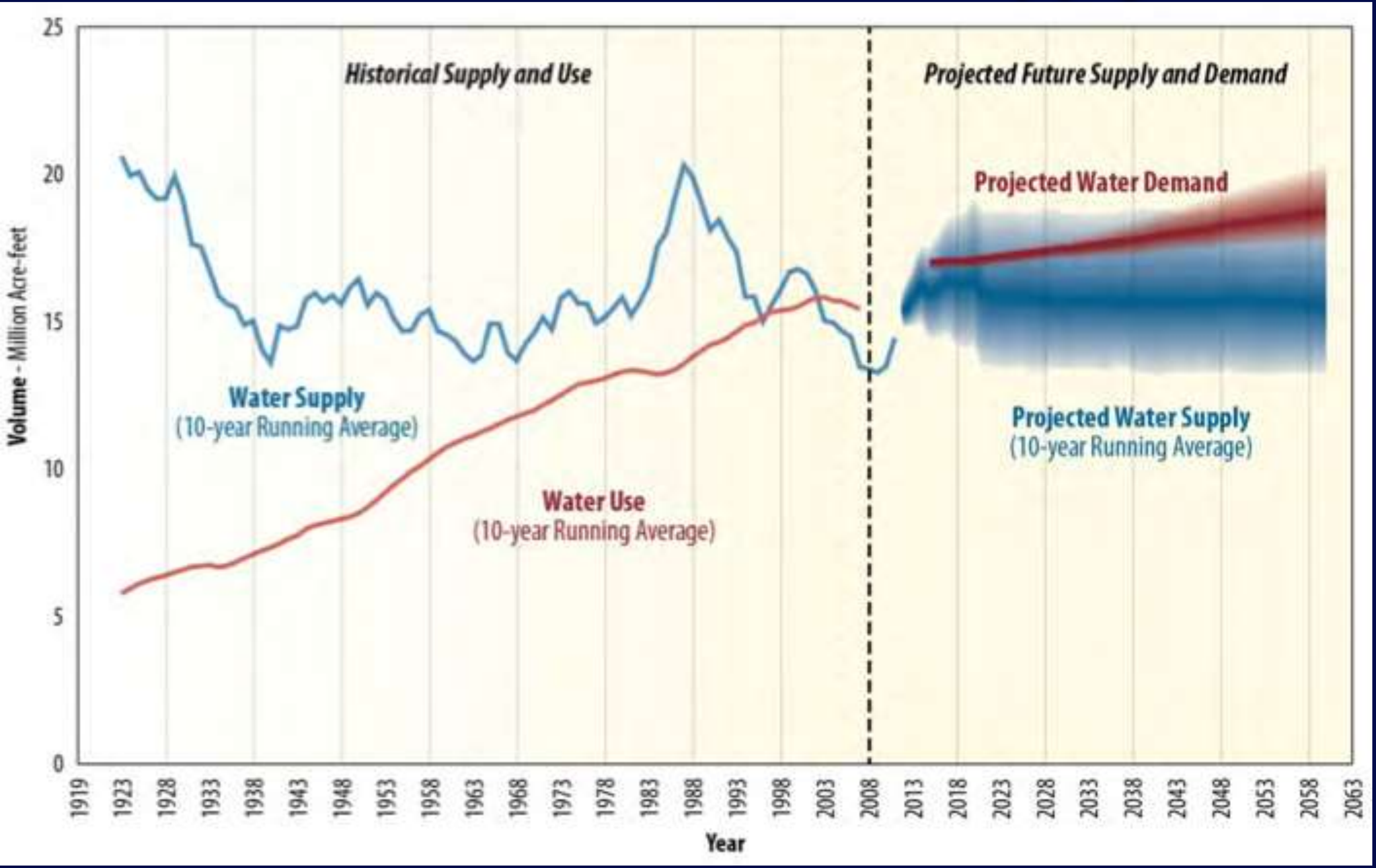
- Do the Analysis Backwards
  - Inland Empire Utilities Agency
- Embed analysis in process of stakeholder engagement
  - Colorado River Basin Supply and Demand Study
- How Can You Use RDM?

# RDM Approach Also Used to Help Develop New Plans for Managing Colorado River

2012 Bureau of Reclamation study, in collaboration with seven states and other users:

- **Generated consensus on potential risks to system**
- **Suggested adaptive contingency plan, with**
    - **High priority near-term actions &**
    - **Future actions contingent on how the future unfolds**

# Basin Expected to Face Imbalances Between Demand and Supply




Groves. Fischbach, Bloom, Knopman and Keefe. Adapting to a Changing Colorado River: Making Future Water Deliveries More Reliable Through Robust Management Strategies. RAND Corporation, 2013.

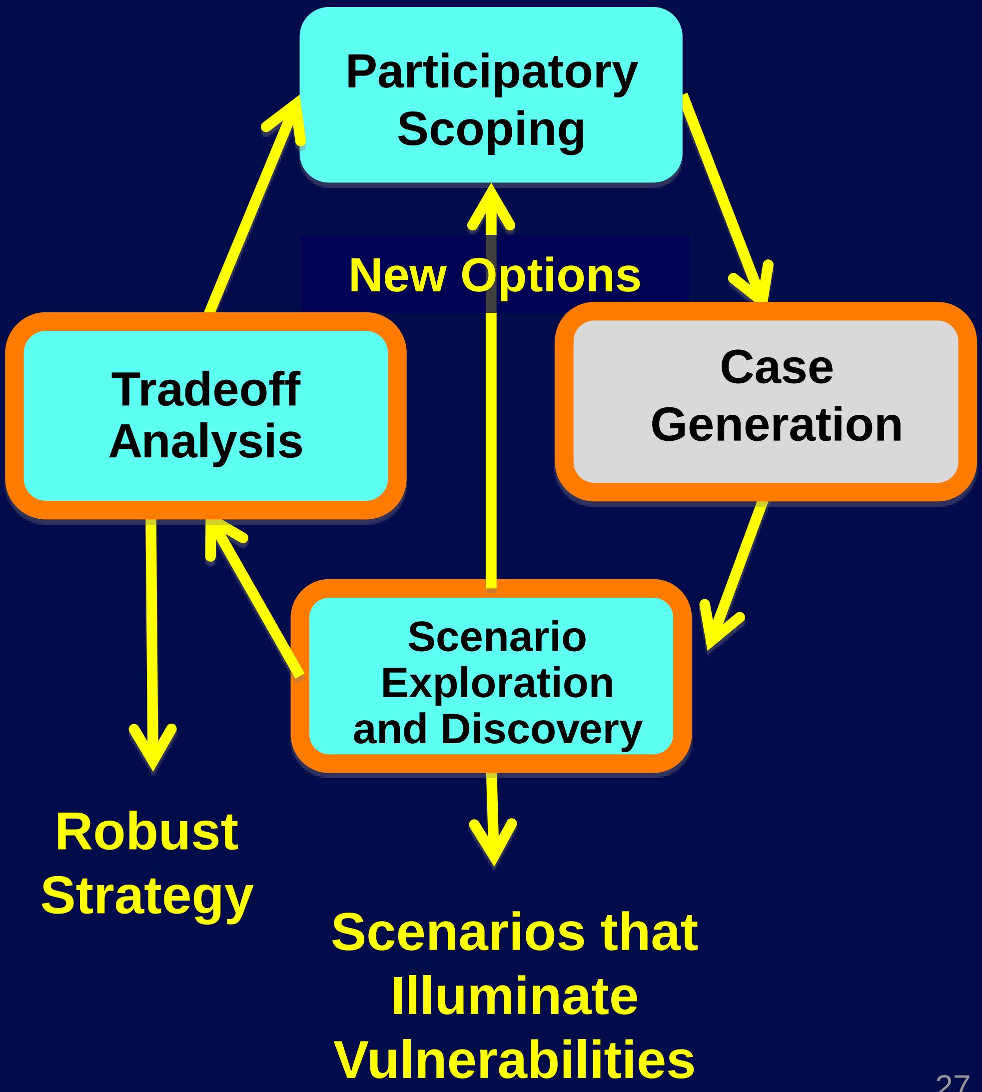
RAND

# RDM Embeds Analytics in a "Deliberation with Analysis" Decision Support Process

Decision support recognizes that decision processes at least as important as decision products

Key elements of RDM process include:

1. Scenarios that illuminate vulnerabilities of plans
2. New or modified plans that address these vulnerabilities
3. Tradeoff curves that help decision makers choose robust strategies




Deliberation
Analysis
Deliberation with Analysis

# *Decision Structuring: Work with Decision Stakeholders to Define Objectives/Parameters*

**1. Decision Structuring**

**Deliberation with Stakeholders**

- **Metrics** that reflect decision makers' goals
- **Management strategies (levers) considered to pursue goals**
- **Uncertain factors** that may affect ability to reach goals
- **Relationships** among metrics, levers, and uncertainties

**Information needed to organize simulation modeling**

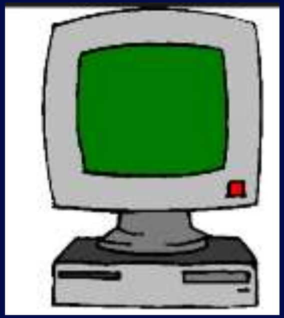
***Also called "XLRM"***

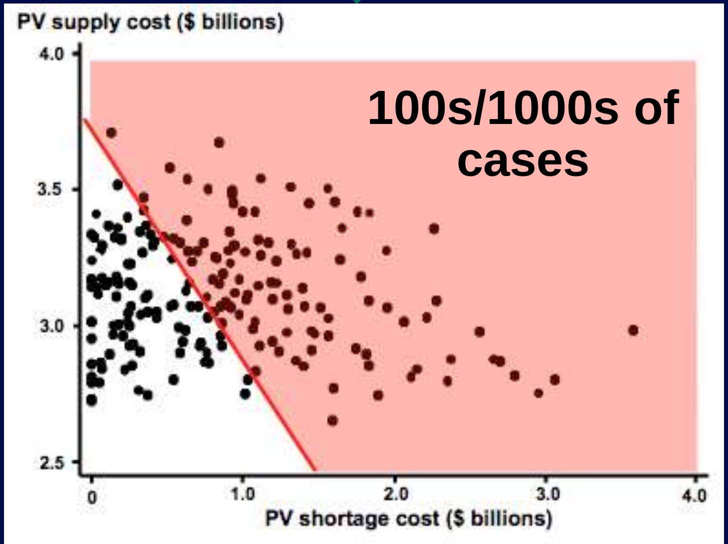
# Case Generation: Evaluate Strategy in Each of Many Plausible Futures

**2. Case Generation**

**Simulating Futures**

- Strategy
- Plausible assumptions
- Potential outcomes



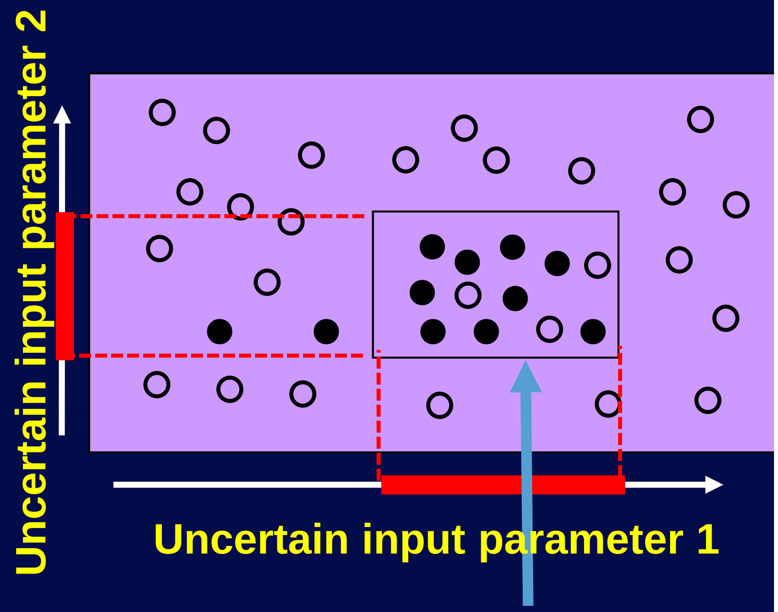



**Large database of simulations model results**
(each element shows performance of a strategy in one future)

# Scenario Discovery: Mine the Database of Cases to Identify Policy-Relevant Scenarios

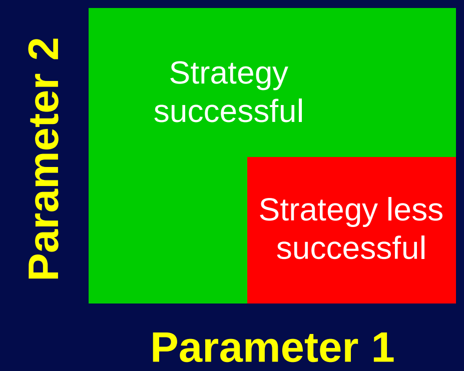
**3. Scenario Discovery**

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 decisionmakers

**Scenarios that illuminate vulnerabilities of proposed strategy**

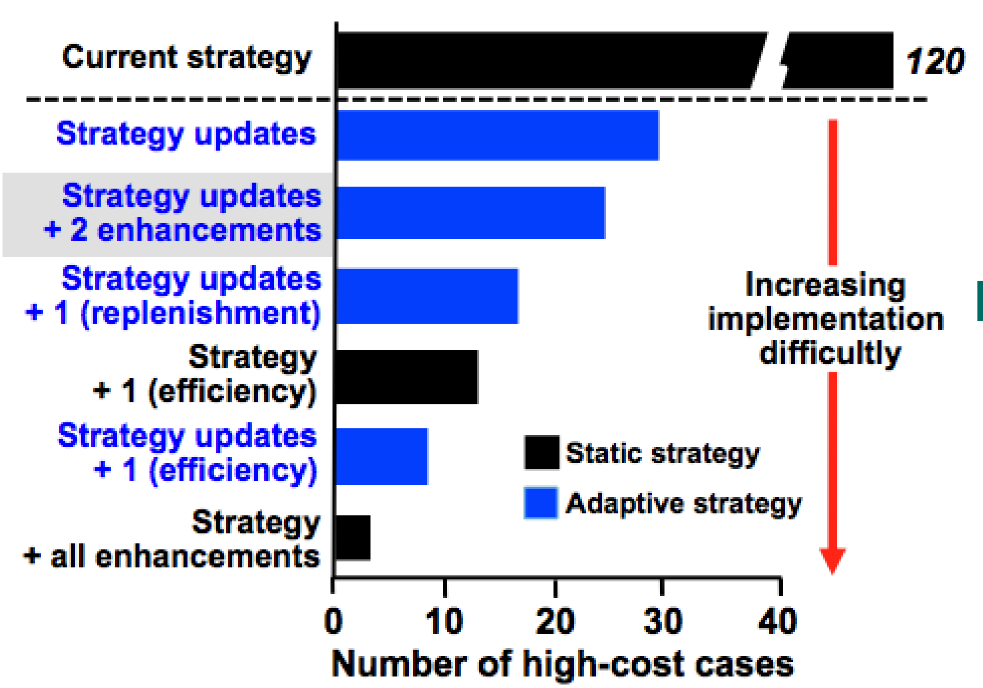



RAND

# *Tradeoff Analysis: Help Decision-makers to Compare Tradeoff Among Strategies*

**4. Tradeoff Analysis**

**Visualization helps decision-makers compare strategies**



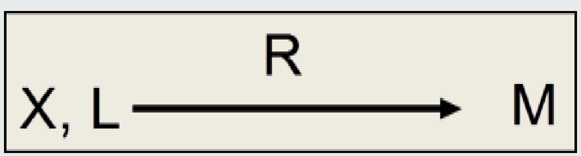

**Robust strategy or information to enable decision-makers to make more robust strategy**

# "XLRM" Framework Helps Put Simulation in Decision Support Context

| Uncertainty Factors (X) | Policy Levers (L) |
|---|---|
| | |
| **Relationships (R)** | **Performance Metrics (M)** |
| | |

# “XLRM” Framework Helps Put Simulation in Decision Support Context

| Uncertainty Factors (X) | Policy Levers (L) |
|---|---|
| What uncertain factors outside decision makers’ control affect their ability to pursue their goals? | What actions might they take to pursue their goals? |
| **Relationships (R)** | **Performance Metrics (M)** |
| How might policy levers (L) and uncertainties (X) be related to decision makers’ goals (M)? | What are decision makers trying to achieve? |



# "XLRM" Framework for the Colorado River Basin Study

| Uncertain Factors (X) | Options and Strategies (L) |
| --- | --- |
| Demand Conditions (6)<br>Supply Conditions (4)<br>• Observed Resampled (103 traces)<br>• Paleo Resampled (1,244 traces)<br>• Paleo Conditioned (500 traces)<br>• Downscaled GCM Projected (112 traces)<br>System Operations Conditions (2) | Options for demand reduction and supply augmentation (40)<br><br>Portfolios of many options designed to adjust over time in response to new information (4)<br>• Near-term actions<br>• Signposts<br>• Contingent actions |
| **Relationships or Models (R)** | **Performance Metrics (M)** |
| Colorado River Simulation System (CRSS) | • Water delivery (5)<br>• Electric power (3), Recreation (11), Ecological (5), Water quality (1), and Flood control (1) |

# Analysis with Colorado System Simulations Reveal Key Vulnerabilities

**Baseline strategy**

+

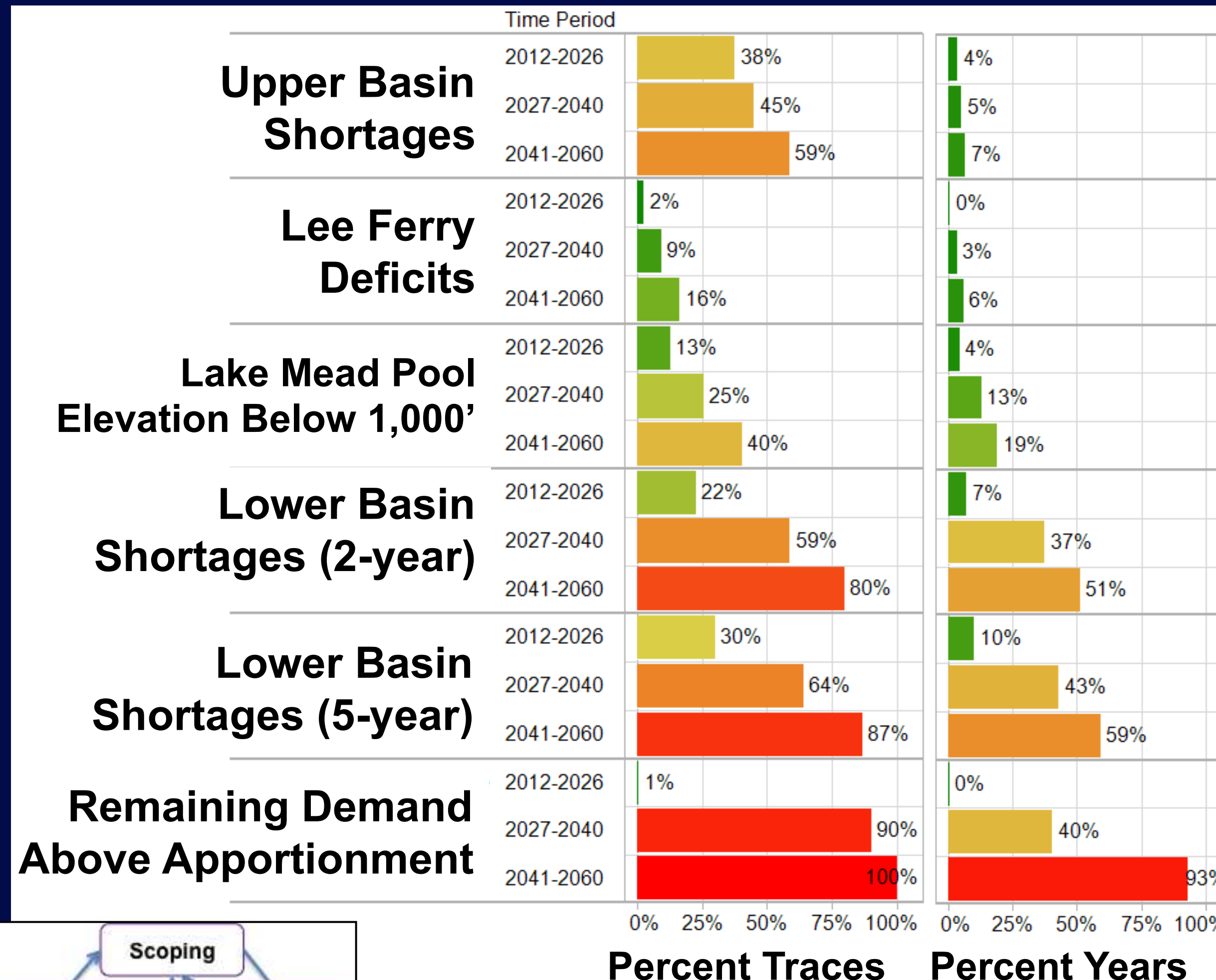
**24,000 Futures, with:**

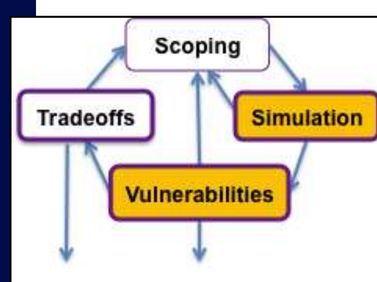
Climate projections
- Recent historic
- Paleo records
- Model projections
- Paleo-adjusted model projections

Several demand projections

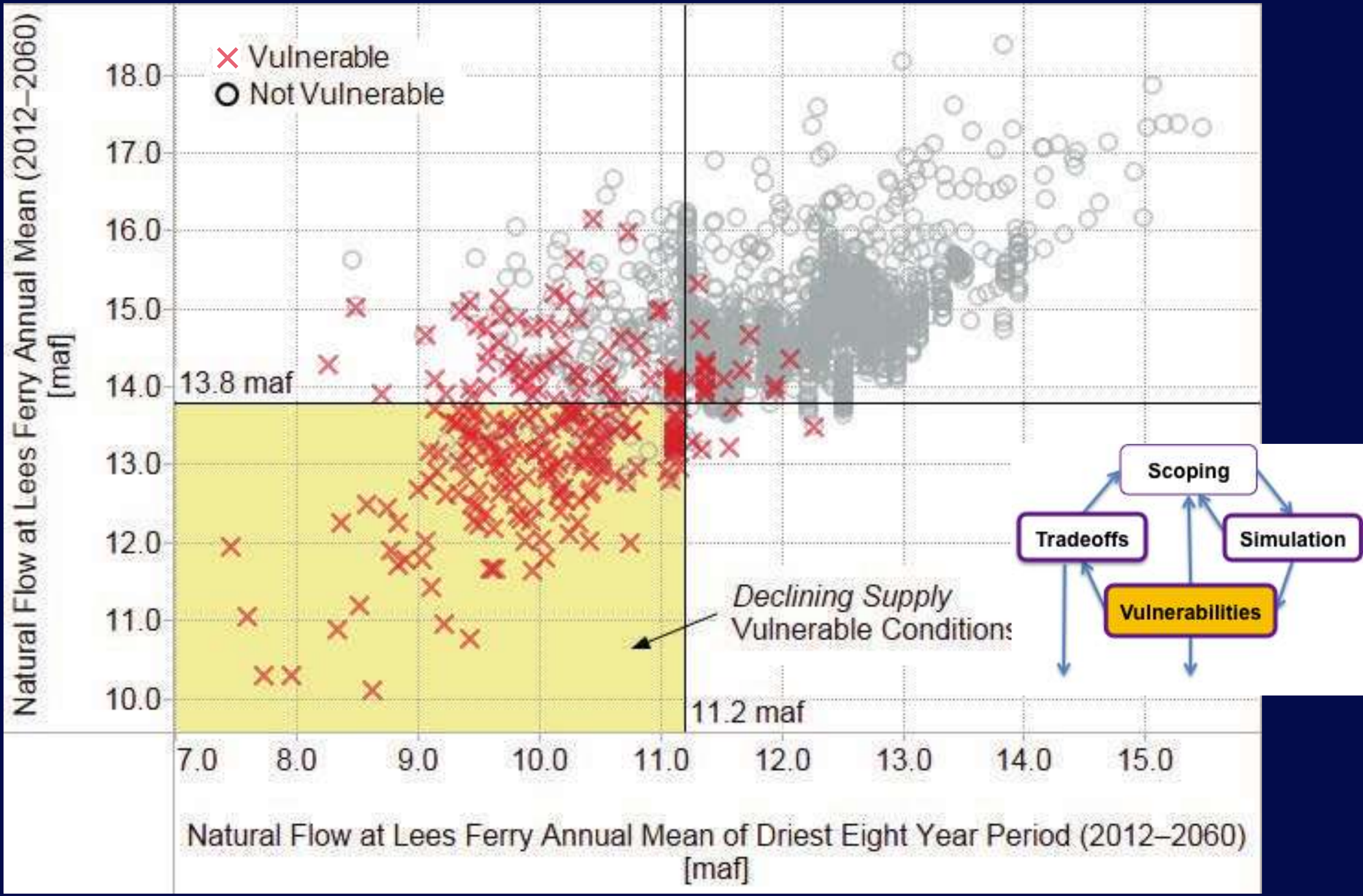
+

**Reclamation's Colorado River Simulation System**

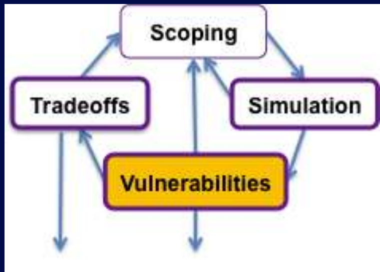


# Scenarios Illuminate Vulnerabilities of Plan

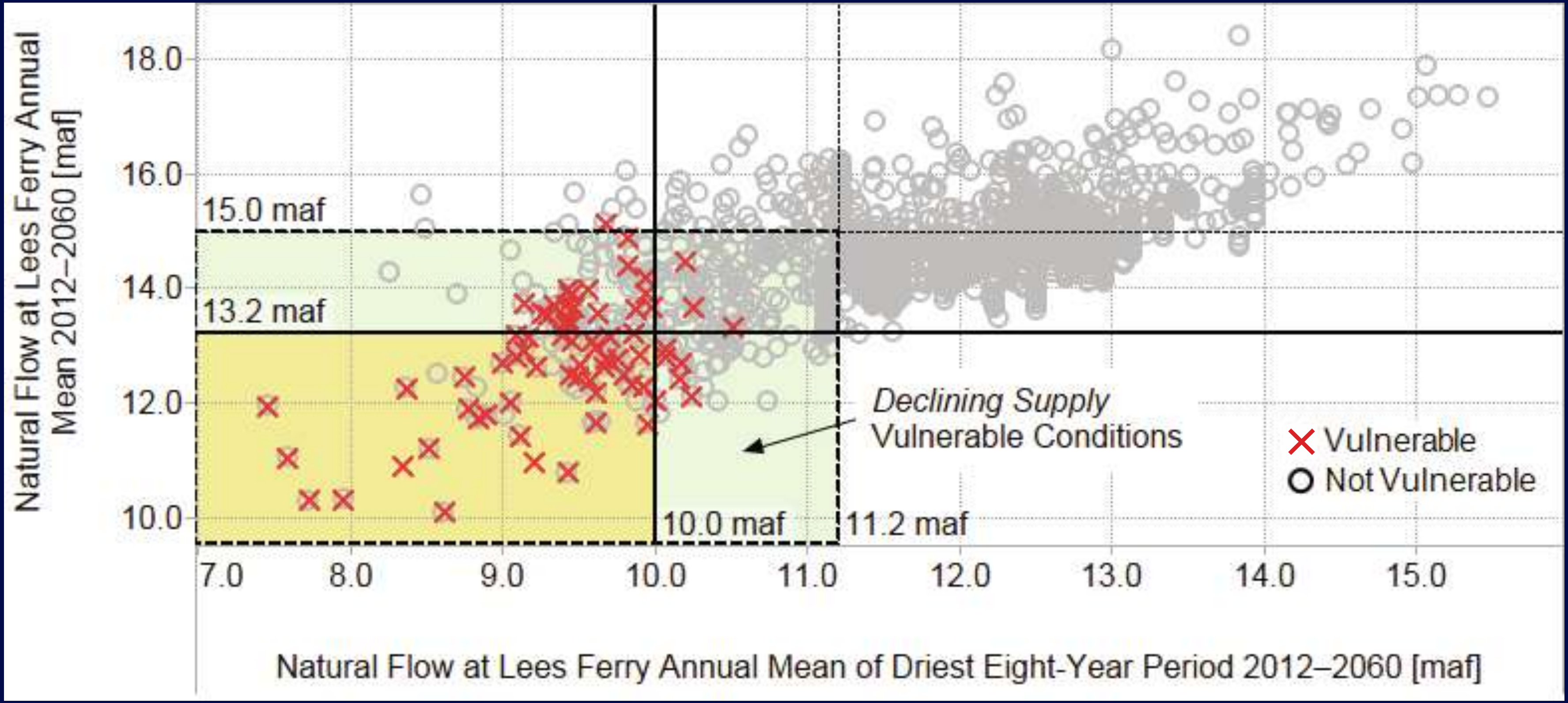


# Response Options Reduce Key Vulnerabilities




| | Time Period | Baseline | Portfolio A | Portfolio B | Portfolio C | Portfolio D |
|---|---|---|---|---|---|---|
| **Upper Basin Shortages** | 2012-2026 | 4% | 3% | 3% | 3% | 3% |
| | 2027-2040 | 5% | 3% | 3% | 3% | 3% |
| | 2041-2060 | 7% | 2% | 2% | 3% | 3% |
| **Lee Ferry Deficits** | 2012-2026 | 0% | 0% | 0% | 0% | 0% |
| | 2027-2040 | 3% | 1% | 2% | 1% | 2% |
| | 2041-2060 | 6% | 1% | 2% | 1% | 3% |
| **Lake Mead Pool Elevation Below 1,000'** | 2012-2026 | 4% | 4% | 4% | 4% | 4% |
| | 2027-2040 | 13% | 7% | 7% | 8% | 8% |
| | 2041-2060 | 19% | 3% | 3% | 5% | 6% |
| **Lower Basin Shortages (2-year)** | 2012-2026 | 7% | 5% | 5% | 5% | 5% |
| | 2027-2040 | 37% | 22% | 19% | 23% | 23% |
| | 2041-2060 | 51% | 10% | 10% | 13% | 14% |
| **Lower Basin Shortages (5-year)** | 2012-2026 | 10% | 9% | 9% | 9% | 9% |
| | 2027-2040 | 43% | 35% | 30% | 36% | 36% |
| | 2041-2060 | 59% | 23% | 23% | 26% | 28% |
| **Remaining Demand Above Apportionment** | 2012-2026 | 0% | 0% | 0% | 0% | 0% |
| | 2027-2040 | 40% | 2% | 1% | 1% | 2% |
| | 2041-2060 | 93% | 5% | 5% | 7% | 5% |
| | | 0% 50% 100% Percent Years Vulnerable | 0% 50% 100% Percent Years Vulnerable | 0% 50% 100% Percent Years Vulnerable | 0% 50% 100% Percent Years Vulnerable | 0% 50% 100% Percent Years Vulnerable |

# Scenario Maps Show How Response Options Reduce Vulnerabilities



# Analysis Supports Consideration of Near- and Longer-Term Actions

| Option Category | Option Group | Conditions: All Traces | Conditions: Low Historical Supply | Conditions: Declining Supply |
|---|---|---|---|---|
| Ag. Conservation | Ag Conservation with Transfers | 100% | 100% | 100% |
| Desalination | Desal-Groundwater | 99% | 100% | 100% |
| | Desal-Salton Sea | 81% | 92% | 100% |
| | Desal-Yuma | 100% | 100% | 100% |
| Energy WUE | Energy Water Use Efficiency | 20% | 35% | 93% |
| M & I Conservation | M&I Conservation | 93% | 93% | 98% |
| Reuse | Reuse-Industrial | 42% | 65% | 99% |
| | Reuse-Municipal | 53% | 72% | 96% |
| Watershed Management | Watershed-Weather Mod | 59% | 67% | 99% |

Minimum Delay (years): 0, 5, 10, 15, 21

Contingent Actions

Initial Actions

Initial Actions (dependent on beliefs)

# Outline

- Do the Analysis Backwards
  - Inland Empire Utilities Agency
- Embed analysis in process of stakeholder engagement
  - Colorado River Basin Supply and Demand Study
- How Can You Use RDM?

# RDM Uses Exploratory, Rather Than Consolidative, Models

- Consolidative models:
  - Bring together all relevant knowledge into a single package which, once validated, can be used as a surrogate for the real world
  - Aim to provide predictions
- Exploratory models:
  - Map assumptions onto consequences, without privileging any one set of assumptions
  - Cannot be validated
  - Aim to provide large databases of simulation results that can be used to inform policy choices



Bankes (1993); Weaver et. al. (2013)

# Software Tools Help Implement RDM

Exploratory modeling tools facilitate running computer simulation models many times to create a database that links a wide range of assumptions to their consequences

Scenario Discovery methods uses cluster analysis on these databases of model results to simply characterize the future conditions where a the proposed strategy does not meet its goals

Visualization packages help display results for decision makers

For examples, see:

http://www.rand.org/methods/rdmlab.html

# RDM Considers
# Sets of Alterative Probability Distributions

Expected value of strategy *s* for distribution ρ(x) is given by

$$EV = \int \rho\left(\vec{x}\right) V\left(s, \vec{x}\right) d\vec{x}$$

HARD

1. Choosing what strategies to consider
2. Choosing what futures to consider
3. Calculating the performance $V\left(s, \vec{x}\right)$ of strategy *s* in some future *x*
4. Knowing – and convincing other people that you know – the true probability distribution

EASY

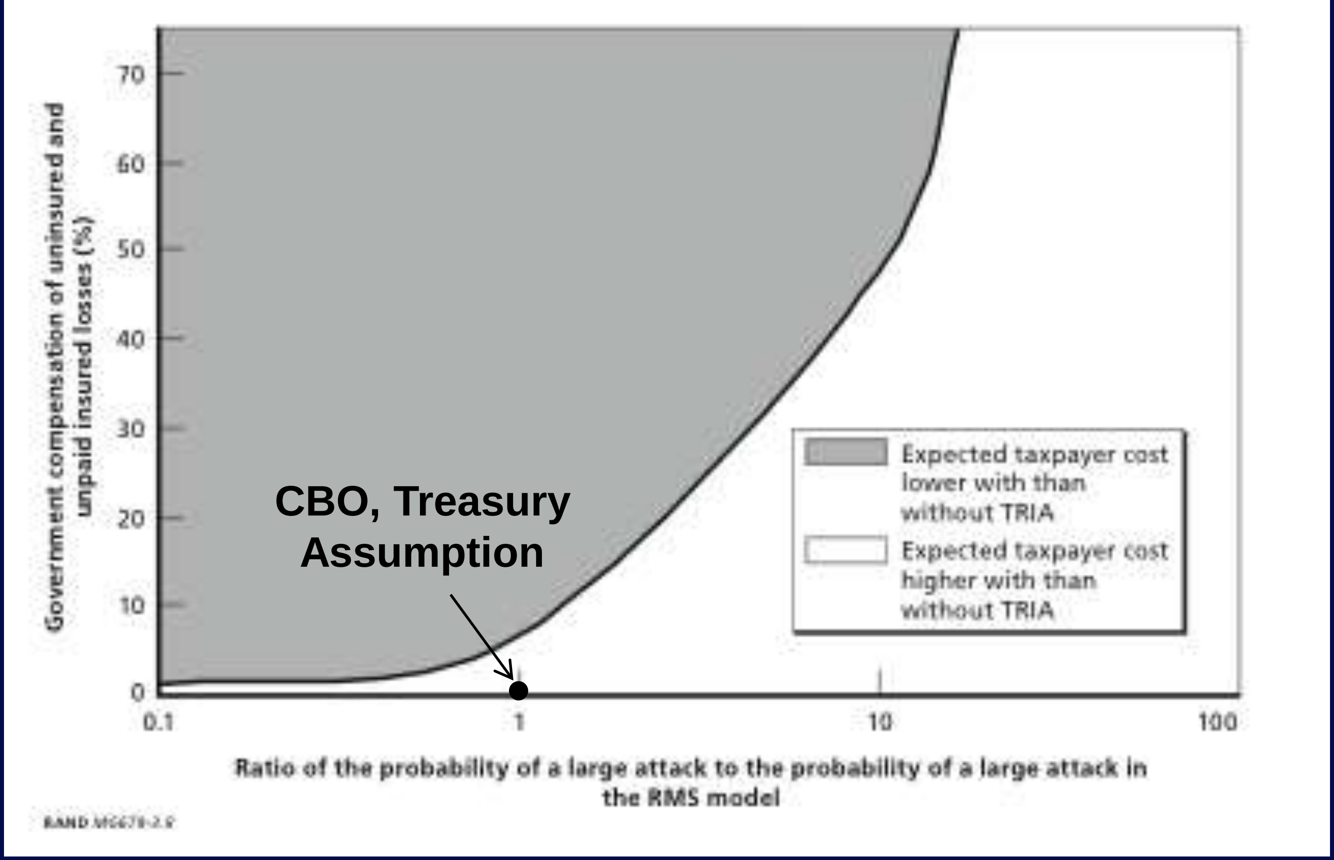
- Calculating the integral for any $\rho\left(\vec{x}\right)$ once you have 1-3 above

**Thus RDM considers many probability distributions over the set of futures x -- *NOT a uniform distribution***

# Some Strategies Are Robust Over a Wide Range of Probability Estimates

**This chart:**

- **Shows expected cost to taxpayers from re-authorizing U.S. Terrorism Risk Insurance Act**
- **Quoted on floor of US Senate by a proponent**
- **Called "insidious" by opponents**
- **Usefully informed Congressional debate**




RAND



RAND, MG-679-CTRMP

# *How Can You Use RDM?*

- **RDM can help inform flexible and robust plans that manage climate and other uncertainties**
- **Rests on straightforward concept**

***Stress test plans against wide range of futures***

- **To implement RDM's "backwards" analysis:**
  1. **Identify 'XLRM' factors**
  2. **Run your planning models for many different futures**
  3. **Use statistics and visualization on database of runs to identify vulnerable scenarios and robust responses**

http://www.rand.org/methods/rdmlab.html

http://www.rand.org/international/pardee/

# Thank you!