Robust Decision Making
For Climate-Related Decisions
Under Conditions of Deep Uncertainty

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Workshop on Nonstationarity, Hydrologic Frequency Analysis, and Water Management

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Relaxing Stationarity Assumptions Poses Both Analytic and Organizational Challenges

• Planning with statistics of future climate based on projections, rather than just replicating recent history, requires
  • Usefully summarizing incomplete information from new, fast-moving, and potentially irreducibly uncertain science
  • Justifying analytic choices to diverse constituencies, many of whom may object to implications of some particular choices

• Solution requires rethinking how we use uncertain climate information in our planning

• Recent CCSP report suggests:
  – There are limits to the applicability and usefulness of classic decision analysis to climate-related problems
  – Seeking robust strategies may prove a preferable approach
Outline

• Robust decision making (RDM) approach to climate-related decision support
• Example water management application
• Evaluating the impacts on decision making
**Optimal Expected Utility**

- Rank strategies contingent on characterization of uncertainties

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1. **Characterize uncertainty**
2. **Rank alternative strategies**
3. **Conduct sensitivity analysis**

**Flowchart**:
- **Probability distributions**
  - Input for Characterize uncertainty
- **Expected utility criteria**
  - Input for Conduct sensitivity analysis
Traditional Decision Analysis Ranks Strategies Based on Probabilistic Characterization of Uncertainties

Optimal Expected Utility
- Rank strategies contingent on characterization of uncertainties

But climate change confronts decision makers with deep uncertainty, where
  - They do not know, and/or key parties to the decision do not agree on, the system model or prior probabilities

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

Optimal Expected Utility
- Rank strategies contingent on characterization of uncertainties

Robust Decision Making
- Characterize uncertain vulnerabilities contingent on proposed strategy

1. Characterize uncertainty
2. Rank alternative strategies
3. Conduct sensitivity analysis

Decision options
1. Identify vulnerabilities
2. Assess alternatives for ameliorating vulnerabilities
Robust Decision Making (RDM) characterizes deep uncertainties contingent on proposed decision.

Key attributes:

- Characterize uncertainty with multiple views of the future, generally
  - Multiple states of the world, or
  - Multiple probability distributions

- Use robustness not optimality criteria to compare strategies

- Conduct iterative vulnerability and response option analysis to identify better decision options

Robust Decision Making

- Characterize uncertain vulnerabilities contingent on proposed strategy

**RDM provides a method for decision support focused on designing better choices, not predicting what will happen**
Robust Decision Making Appears to Facilitate Decisions Under Deep Uncertainty

• Vulnerability and response option analysis framing can help decision makers
  – Reach consensus on key uncertainties and tradeoffs even when they disagree on policy and on expectations about the future
  – Reduce overconfidence and the deleterious impacts of surprise
  – Include imprecise probabilistic information systematically in their consideration of policy options
RDM Most Appropriate When Uncertainty Is Deep and Decision Makers Have a Rich Set of Options

Predict-then-Act Approach

Robust Decision Making

Traditional Scenario Planning

Uncertainty

Complexity

Well-characterized

Low

High

Decision Options

Sparse

Rich

Deep

Well-characterized

Low

High
Outline

• Robust decision making (RDM) approach to climate-related decision support

• Example water management application

• Evaluating the impacts on decision making
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

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Focus of IEUA’s 25 year plan
Used State-of-the-art Regional Probabilistic Climate Projections for Southern California

- Derived from forecasts from 21 GCMs with A1B emissions scenario
- Each forecast weighted by ability to reproduce past climate and level of agreement with other forecasts

(Tebaldi et al.)
Generated Future Weather Sequences by Resampling Historic Local Climate Records

KNN method produces hundreds of local weather sequences

- Daily and monthly variability that matches historic Chino climate
- Temperature and precipitation trends that match climate model forecasts
  (Yates et al.)
Developed New Future Weather Sequences Consistent with Paleo-Record

- Evaluated Palmer Drought Severity Index (PDSI) hind-casts for Southern California
- Developed monthly temperature and precipitation sequences consistent with PDSI record

Temperature and precipitation sequences developed for dry periods indicated above.

Simulation Model Assesses Performance of IEUA Plans in Many Different Scenarios

**Scenario A**
Plan generates **surpluses** in benign future climate

**Scenario B**
Plan suffers **shortages** in adverse future climate

Groves et. al. (2007)
Many Uncertain Factors Could Impact the Performance of Current IEUA Plan

<table>
<thead>
<tr>
<th>Natural Processes</th>
<th>Performance of Management Strategies</th>
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<tbody>
<tr>
<td>• Future temperatures</td>
<td>• Development of aggressive waste-water recycling program</td>
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<td>• Future precipitation</td>
<td>• Implementation of groundwater replenishment</td>
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<td>• Changes in groundwater processes</td>
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<th>Costs of Future Supplies and Management Activities</th>
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<td>• Imported supplies</td>
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<td>• Water use efficiency</td>
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Effective Planning Requires Information About a Full Range of Uncertainties

Conducted elicitations with IEAU stakeholders to estimate likelihood of achieving planning goals

Recycling Goal

Replenishment Goal
"Scenario Maps" Help Decision Makers Visualize a Plans’ Vulnerabilities

Current IEUA plan forever

PV supply cost ($ billions)

PV shortage cost ($ billions)

Consider options
Identify vulnerabilities
Assess alternative responses

Scenario A
- Benign climate
- $3.3 billion in supply cost
- $0 in shortage cost

Scenario B
- Adverse climate
- $3.4 billion in supply cost
- $1.9 billion in shortage cost

“Scenario Maps” Help Decision Makers Visualize a Plans’ Vulnerabilities

Current IEUA plan forever

Consider options
Identify vulnerabilities
Assess alternative responses

PV supply cost ($ billions)

PV shortage cost ($ billions)

(200 Scenarios)
“Scenario Maps” Help Decision Makers Visualize a Plans’ Vulnerabilities

Current IEUA Plan Forever

Current plan generates high costs in 120 of 200 Scenarios

Consider options

Identify vulnerabilities

Assess alternative responses

PV supply cost ($ billions)

PV shortage cost ($ billions)

$3.75 billion cost threshold

RAND
These three factors explain 70% of vulnerabilities of IEUA’s current plans:

- **Natural Processes**
  - Future temperatures
  - Future precipitation
  - Changes in groundwater processes

- **Performance of Management Strategies**
  - Development of aggressive waste-water recycling program
  - Implementation of groundwater replenishment

- **Costs of Future Supplies and Management Activities**
  - Imported supplies
  - Water use efficiency

**Current IEUA plan fails**

Consider options:

Identify vulnerabilities

Assess alternative responses
IEUA Considered Response Options That Evolve Over Time with New Information

In 2015, 2020, 2025,....

**Act now to augment 2005 Plan?**

- **NO**
  - Monitor, and take additional action if supplies drop too low

- **YES**
  - Implement additional efficiency, recycling, and replenishment
  - In 2015, 2020, 2025,....
  - Monitor, and take additional action if supplies drop too low

**Consider options**

**Identify vulnerabilities**

**Assess alternatives**
Compare Alternative Plans With Different Mixes of “Act Now” vs. “Act Later”

- UWMP with updates
- UWMP + DYY and recycling with updates
- UWMP + replenishment with updates
- UWMP + efficiency
- UWMP + efficiency with updates
- UWMP + all enhancements

Consider options
Identify vulnerabilities
Assess alternatives

Current static UWMP vulnerable in 120 scenarios

Economic Costs Decrease, But Unquantified Opportunity Costs Increase

Number of Scenarios (PV Costs > $3.75 billion)
Compare Alternative Plans With Different Mixes of “Act Now” vs. “Act Later”

- UWMP with updates
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**Economic Costs**

- Decrease, But Unquantified Opportunity Costs Increase

**Number of Scenarios**

(PV Costs > $3.75 billion)

IEUA chose to accelerate their dry-year yield and recycling programs, and adapt as needed down the road
Robust Strategies May Trade Small Costs for Less Vulnerability to Broken Assumptions

Number of Scenarios
(PV Costs > $3.75 billion)
Outline

- Robust decision making (RDM) approach to climate-related decision support
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Conducted Formal Evaluation of Effect of Analysis on Policy-Makers’ Views

• Four IEUA workshops presented modeling results to participants including:
  – Agency professional managers and technical staff
  – Local elected officials
  – Community stakeholders

• Compared RDM, probabilistic, and traditional scenario approaches

• “Real-time” surveys measured participants’
  – Understanding of concepts
  – Willingness to adjust policy choices based on information presented
  – Views on RDM and alternative approaches
Evaluation Suggests Analyses Changed Views

Participants reported:

– Tradeoffs between the simplicity and usefulness of alternative approaches
– Preferences for scatter plots over histogram scenario maps

After the workshops:

– 35% said consequences of bad climate change now appeared “more serious” than before
– 40% thought the likelihood of of bad climate change outcomes for the IEUA was “greater” than before
– 75% though the ability of IEUA planner to plan for and manage effects was “greater” than before

Overall, RDM analysis increased:

– Perceived likelihood of serious climate impacts
– Confidence that IEUA could take effective actions to reduce its vulnerability to climate change
– Support for near-term efficiency enhancements to current IEUA plan
Currently Applying This RDM Approach With Many Resource Management Agencies

Long-term Water Resources Planning

2004
- 2005 California Water Plan (NSF)

2005
- IEUA Climate Adaptation Studies (NSF)

2006
- 2009 California Water Plan
- MWD 2009 Integrated Resource Plan
- Colorado River Study (NSF)

2007
- Denver Water Pilot Project

2008
- Sierra Nevada Climate Adaptation Study (PIER)

2009
- Port of LA & sea level rise (NSF)

2010
- LA OCPR Annual Plan 2010

2011
- RAND
- New Orleans Risk Mitigation Study (NOAA)

Coastal Protection and Restoration

- US ACE Risk Informed Decision Framework
- Gulf Coast Fisheries Study
Key Features of Robust Decision Making Approach

- Characterize uncertainty with multiple views of the future
- Use robustness not optimality criteria to compare strategies
- Conduct iterative vulnerability and response option analysis to identify better decision options

*RDM 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?”
More Information


www.rand.org/ise/projects/improvingdecisions/
Thank you!