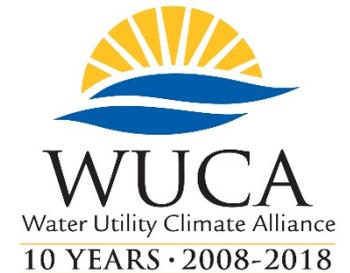


**Building Resilience to a Changing Climate:
A Technical Training in Water Sector
Utility Decision Support**

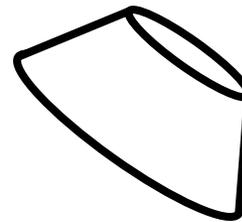


Methods for Decision Making Under Conditions of Deep Uncertainty (DMDU)

Robert Lempert, RAND

You've Received Much Advice So Far

- Past climate is no longer a reliable predictor of future, or even *current*, climate, but no one is sure exactly how climate has and will change
- Climate models are helpful when used appropriately, but far from perfect (But they are probably a lot better than economic models!)
- Don't wait for uncertainties to be resolved -- that won't happen anytime soon.
- Consider multiple objectives (reliability, cost effectiveness, equity, ...)
- Many decisions will prove effective or provide benefits under multiple possible future conditions
- Don't mistake
 - Well-characterized risk
 - For deep uncertainty



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



DMDU Methods and Tools Provide Water Managers Means to Take This Advice

Basic DMDU principles

1. Consider multiple futures, not one single future, in your planning. Choose these futures to stress test your organization's plans
2. Seek robust plans that perform well over many futures, not optimal plans designed for a single, best-estimate future
3. Make your plans flexible and adaptive, which often makes them more robust
4. Use your analytics to explore many futures and options, not tell you what to do

Water managers already conduct risk management.

Decision Making Under Deep Uncertainty (DMDU) will help adapt your risk management to changing climate conditions

There are many ways, small and large, to fold these principles into your organization.



Traditional Risk Management Works Well When Uncertainty is Limited

“Predict then Act”



Predict

Act



These are sometimes called “optimization methods”

“Predict then Act” Can Break Down When Uncertainties are Deep



Under conditions of deep uncertainty:

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

Under Deeply Uncertain Conditions, Often Useful to Run the Analysis “ Backwards”

“Predict then Act”

What will future conditions be?

What is the best near-term decision?

How sensitive is the decision to the conditions?



“Agree on Decisions”

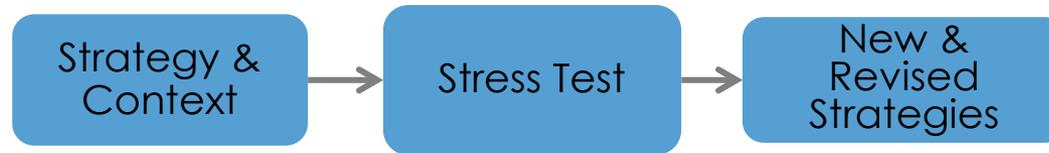
Propose strategy & context

Use analytics to stress test strategy

Identify new & revised strategies that are more robust



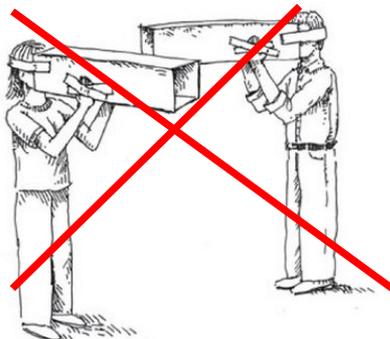
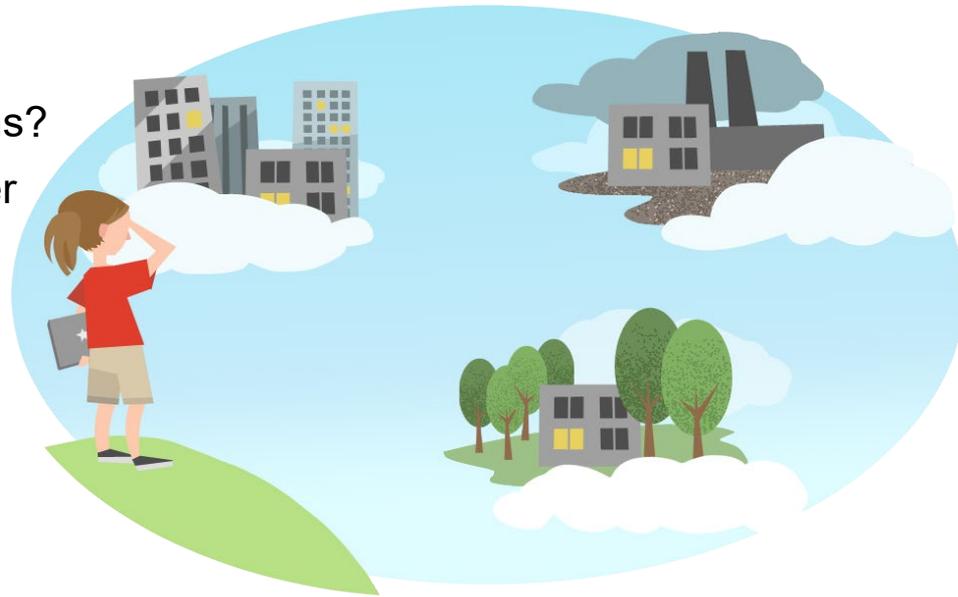
DMDU Helps People Use Computers to Make Better Decisions, Not Better Predictions



”Backwards” analysis can help focus on important questions under deep uncertainty

- Can a robust and flexible strategy perform well over a wide range of futures?
- What uncertainties are most important in determining the success or failure of our plans?
- What actions do we need to take now in order to keep future options open?
- What actions can we postpone?

Consider multiple futures



Outline

Introduction

DMDU Methods

Facilitating stakeholder engagement

Getting Started

Outline

Introduction

DMDU Methods

- Scenario planning
- Adaptive pathways
- RDM and variants

Facilitating stakeholder engagement

Getting Started

Humans Are Avid Scenario Builders

The ability to create and share scenarios represents a key difference between humans and other animals

We:

Suddendorf (2013)

Tell stories

Imagine each other's experiences

Contemplate potential explanations

Reflect on moral dilemmas



Scenarios provide benefits, for instance:

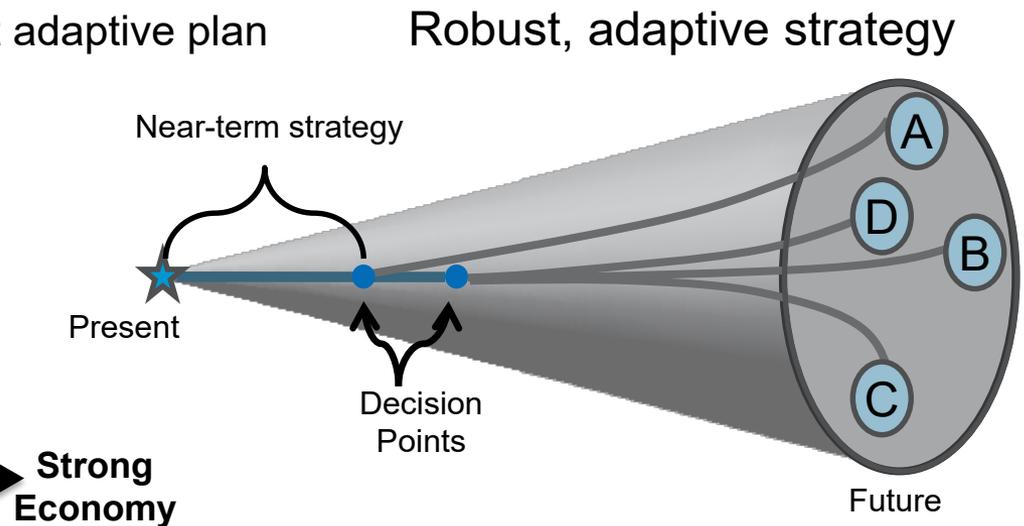
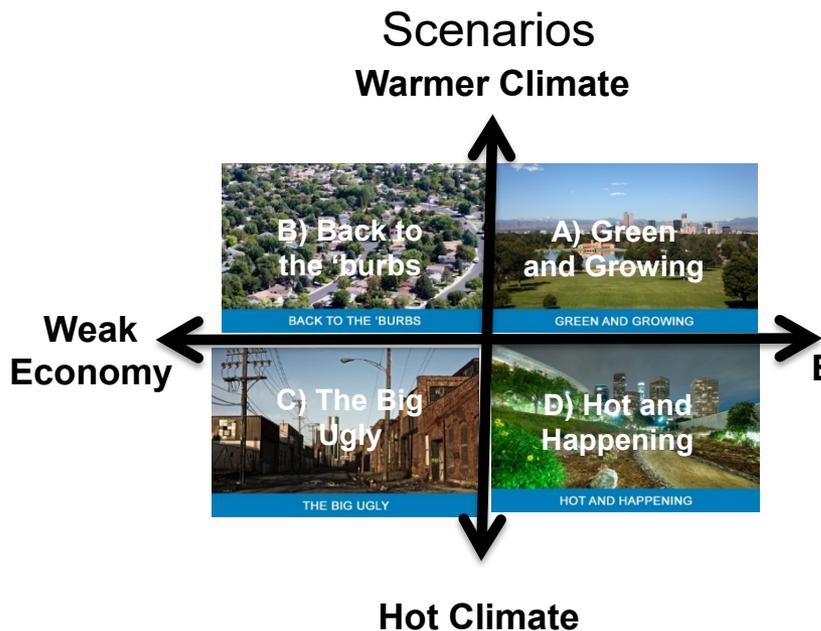
They can
reduce over-
confidence



Scenario Planning Develops Robust Strategies From Scenarios People Create

Steps in scenario planning:

1. Identify decision challenge
2. Chose key driving forces, those most important and uncertain
3. Flesh out scenario narratives
4. Use scenarios to develop a robust adaptive plan



Thanks to Laura Kaatz

Sometime called "story and simulation" approach because people chose the stories and then flesh them out with simulation models

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Adaptive Pathways Provides Framework for Developing Contingency Plans

House by C-7 canal



Coastal gate for C-7 canal



Adaptive pathways:

- Recommended by California’s 2018 Sea Level Rise Guidance
- Recently used to examine urban flooding in Miami

Steps include identifying:

1. SLR thresholds at which damage occurs
2. Year when those thresholds are reached in various scenarios (called “adaptation tipping points”)
3. Signposts indicating which scenario is occurring

Adaptation Tipping Points

Risk Reduction Options	Damage Threshold	Year threshold reached	
		Low SLR ¹	High SLR ²
<i>Current infrastructure</i>	0 ft	2018	2018
Local pumps and gates	0.50 ft	~2050	~2025
Large regional pumps	0.55 ft	~2050	~2025
Raise buildings 6 feet	1.56 ft	> 2065	2050
Raise buildings 8 feet	n/a	> 2065	> 2065

Adaptive pathways helps ask:

- Which options to deploy first?
- What options to deploy next?
- How do we make our choices less vulnerable to uncertainties about the SLR scenario?

Dynamic Adaptive Pathways Identifies and Compares Robust and Flexible Strategies

Pathways

Regional pumps

Local pumps

Current infrastructure

MO no action



Land use measures eventually needed but installing pumps can buy some time.

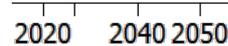
Land use

Sea level rise (ft)

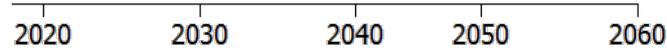


Scenarios

SLR1



SLR3



Map generated with Pathways Generator, ©2015, Deltares, Carthago Consultancy

Thanks to Kathryn Roscoe and Marjolijn Haasnoot

Outline

Introduction

DMDU Methods

- Scenario planning
- Adaptive pathways
- RDM and variants
 - RDM
 - Decision scaling
 - MORDM

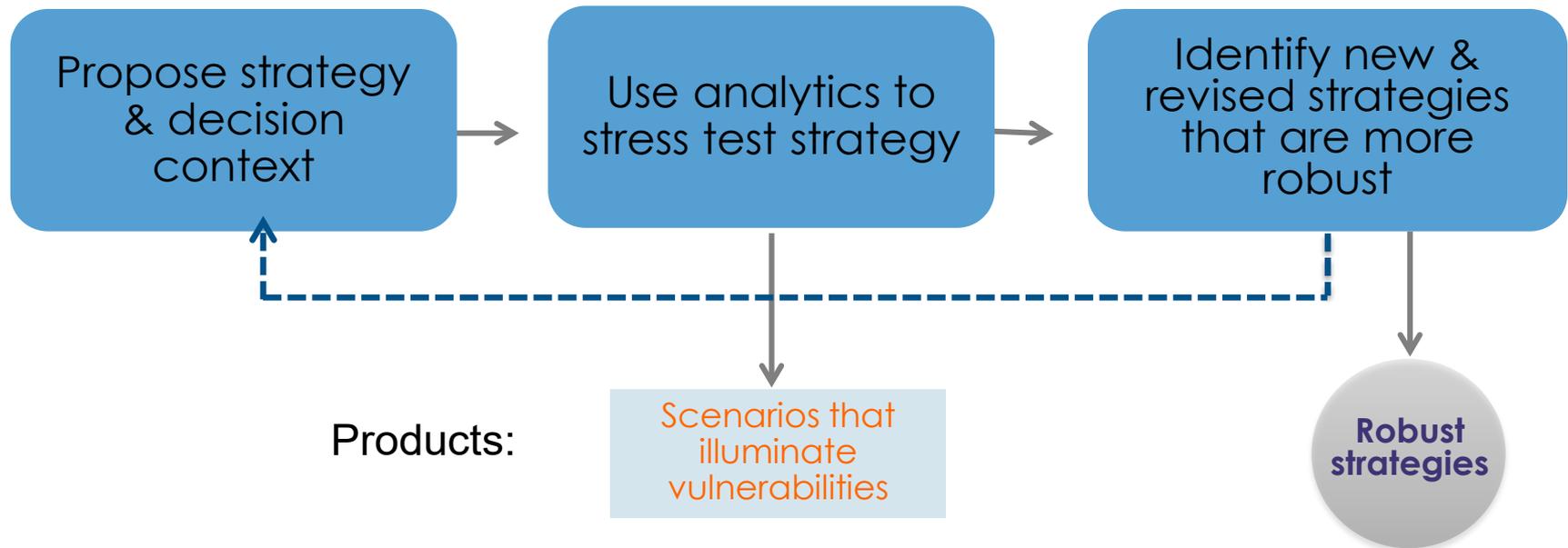
Facilitating stakeholder engagement

Getting Started

Robust Decision Making (RDM) is a Quantitative DMDU Method

RDM is an iterative analytic process, often used in engagements with stakeholders, designed to support decision making under deep uncertainty

Process:



Products:

Key idea:

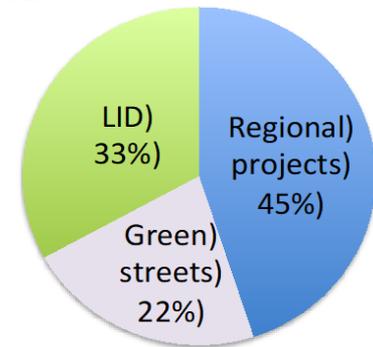
- Stress test strategies over many plausible paths into the future,
- Use the resulting database to identify conditions where strategies fail, and
- Use this information to identify more robust strategies

Can Los Angeles Meet its Water Quality Goals in the Face of Climate Change?

New water quality implementation plans for the Los Angeles River* aim to meet federal standards by 2035



The Plan



Distribution of BMPs (best management practices)

* Our study focuses on Tujunga sub-watershed: 225 square miles (165 sq. miles Los Angeles National Forest + 60 sq. miles urbanized San Fernando Valley floor)

RDM Begins with Decision Framing

Decision makers and stakeholders deliberate over key factors in analysis

*Will our expensive new water quality investments still meet water quality standards in a changing climate?
If not, what can we do about it?*



Summarize Stakeholder Discussions with 'XLRM' Matrix

*Will our expensive new water quality investments still meet water quality standards in a changing climate?
If not, what can we do about it?*

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



Summarize Stakeholder Discussions with 'XLRM' Matrix

*Will our expensive new water quality investments still meet water quality standards in a changing climate?
If not, what can we do about it?*

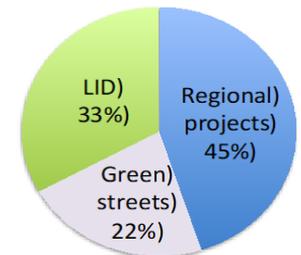
Uncertainty Factors (X)	Policy Levers (L)
What uncertain factors outside our control affect our ability to pursue our goals?	What actions might we take to pursue our goals?
Relationships (R)	Performance Metrics (M)
How might levers (L) and uncertainties (X) affect goals (M)? 	What are we trying to achieve?



Summarize Stakeholder Discussions with 'XLRM' Matrix

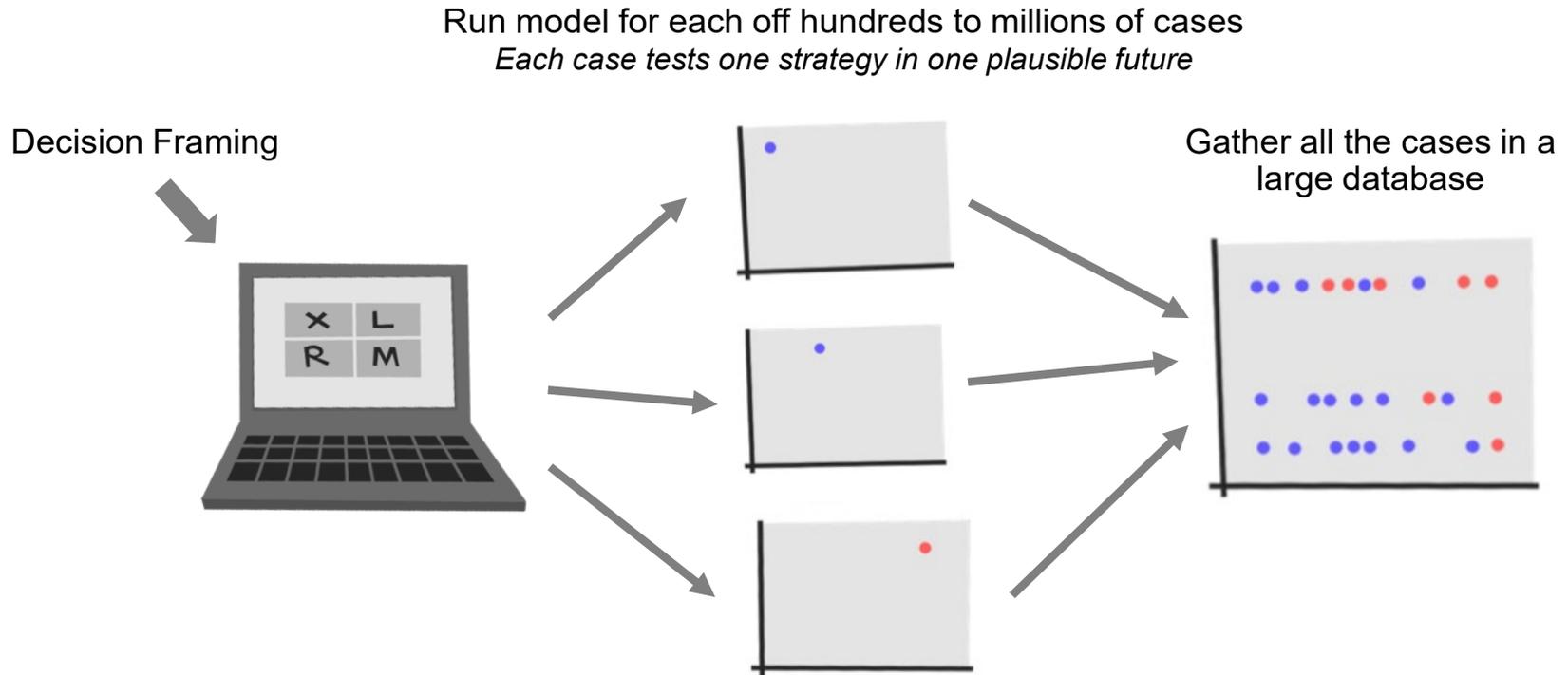
*Will our expensive new water quality investments still meet water quality standards in a changing climate?
If not, what can we do about it?*

Uncertain Factors (X)	Policy Levers (L)
<ul style="list-style-type: none"> • Future climate • Future land use 	<ul style="list-style-type: none"> • Proposed water quality plan <ul style="list-style-type: none"> – Regional projects – Green streets – Low impact development
Relationships (models)	Performance metrics (M)
<ul style="list-style-type: none"> • Simulation models used for regulatory assurance analysis (SUSTAIN & LSPC) 	<ul style="list-style-type: none"> • Ability to meet zinc TMDL targets • Cost of additional BMPs • Co-benefits



In this engagement, re-framing added new policy levers

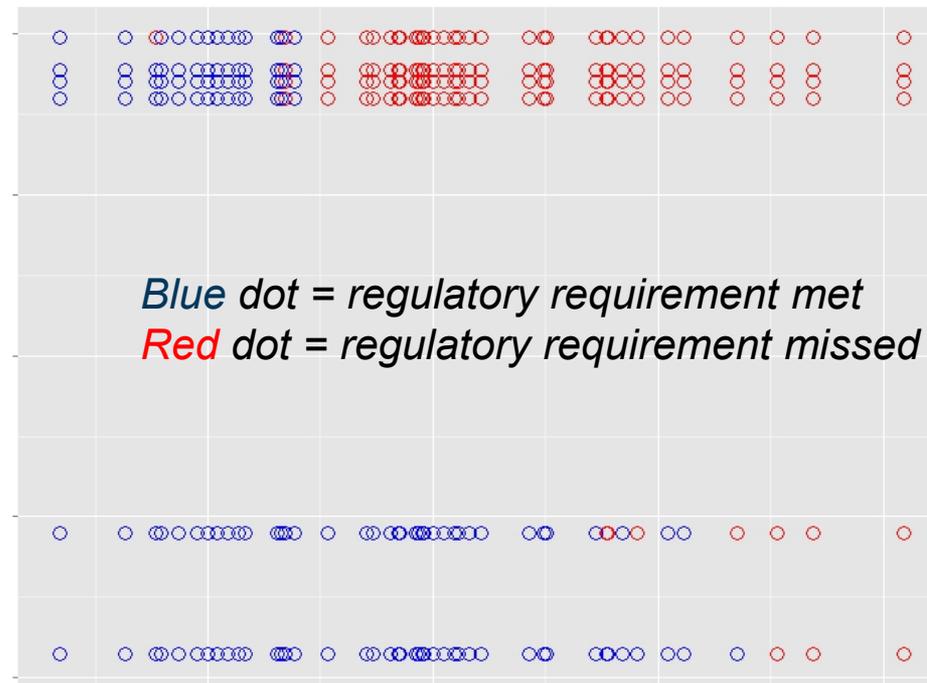
Generate Cases that Stress Test Strategy in Each of Many Plausible Futures



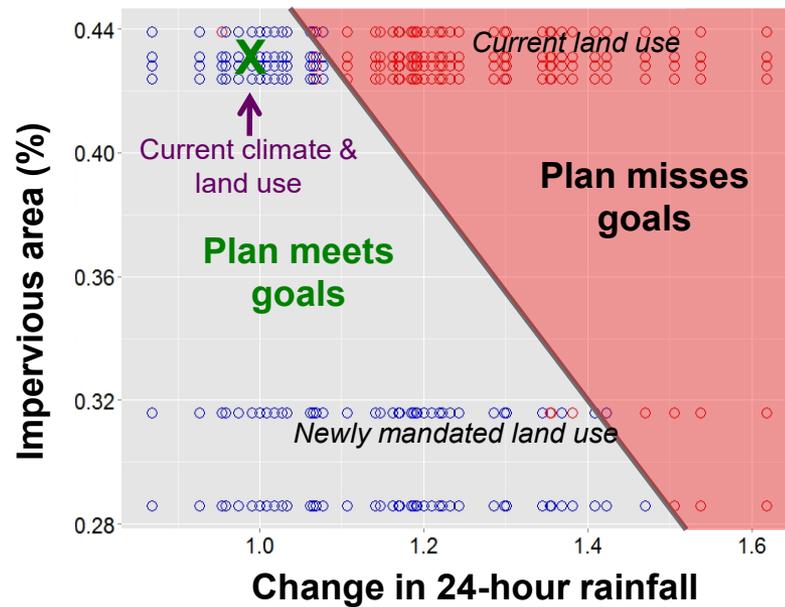


Generate Cases that Stress Test Strategy in Each of Many Plausible Futures

- Stress test Tujunga water quality implementation plan over 47 climate times 6 land use = 282 futures
- Each record in the database (a case) represents the performance of the plan in one future



Summarize All These Model Runs In a Map Showing the Stress Test Results



Computer algorithms and visualization help separate all the model runs into two sets of futures:

- In one set LA's water quality plan generally meets its regulatory goal
- In the second set LA's water quality plan generally fails to meet its regulatory goal

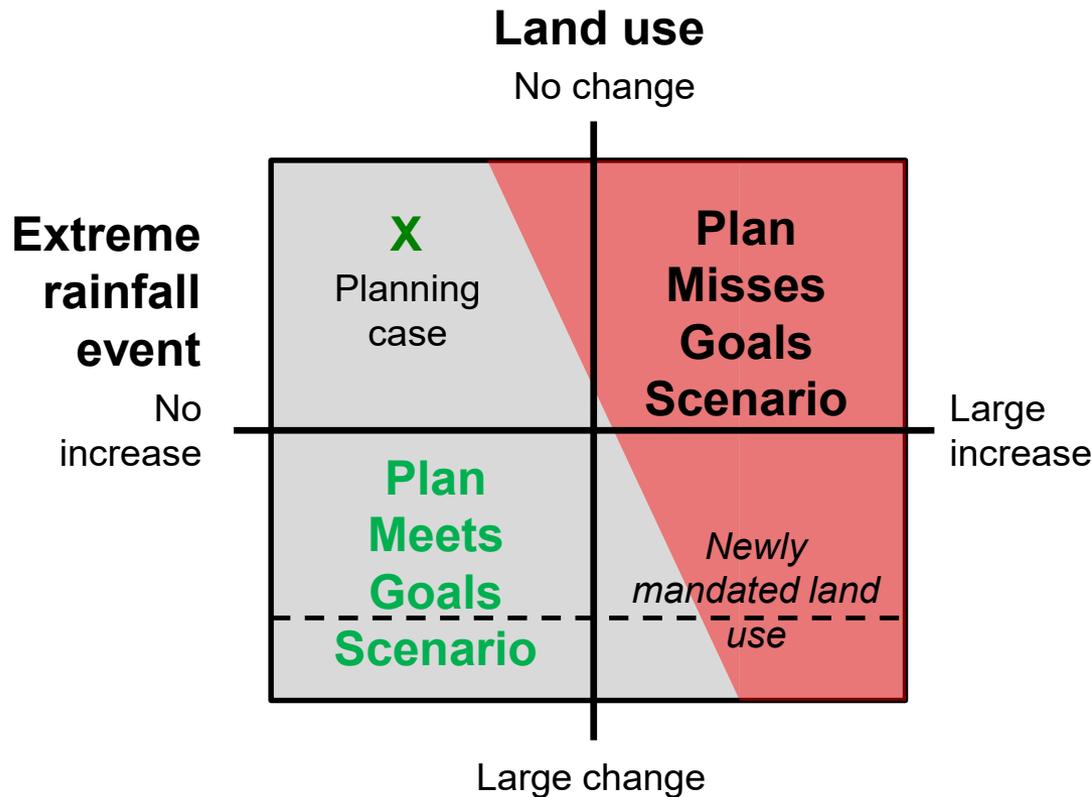
The algorithms and visualizations also identify the combination of uncertainties *most important* in distinguishing these two sets of futures

We can use this scenario map to orient ourselves



Use the Database of Cases to Identify Policy-Relevant Scenarios

Results of this stress test can be interpreted as two scenarios



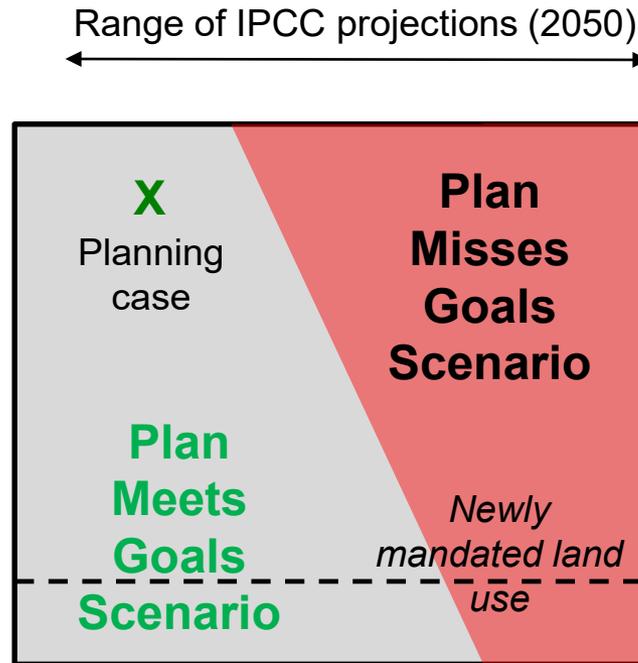
- Scenarios emerge from the analysis. They aren't inputs to it
- Scenarios show high-confidence information. People who disagree about the likely future can agree on the conditions in which LA's plan would meet or miss its regulatory goals

Note that scenario driving forces depend both on climate and socio-economic uncertainties



Use Available Scientific Information to Consider Whether The Vulnerable Scenario is Significant

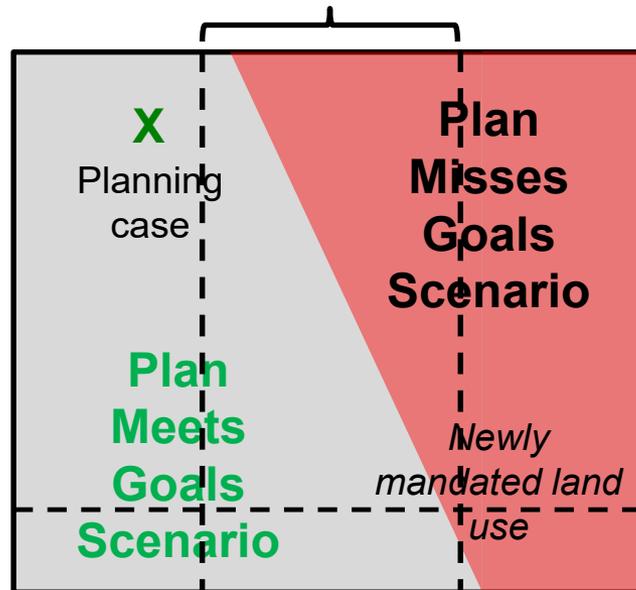
Compare Available Science to The “Plan Misses Goals” Scenario



Use Available Scientific Information to Consider Whether The Vulnerable Scenario Is Significant

Compare Available Science to The “Plan Misses Goals” Scenario

Evidence from best study of local climate in 2050 (Berg et al 2015)*



Bottom line:

- We looked at two ways to estimate the probability of extreme precipitation events
- Both indicate Los Angeles' water quality implementation plan may not meet regulatory standards if the climate changes (or has changed)

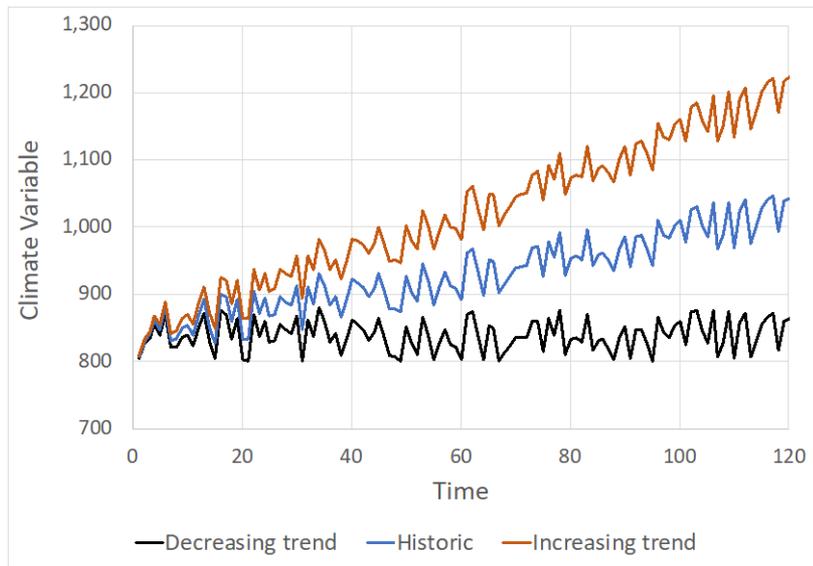
*This is the very high resolution (2 km) dynamic downscaling that Alex Hall showed to you



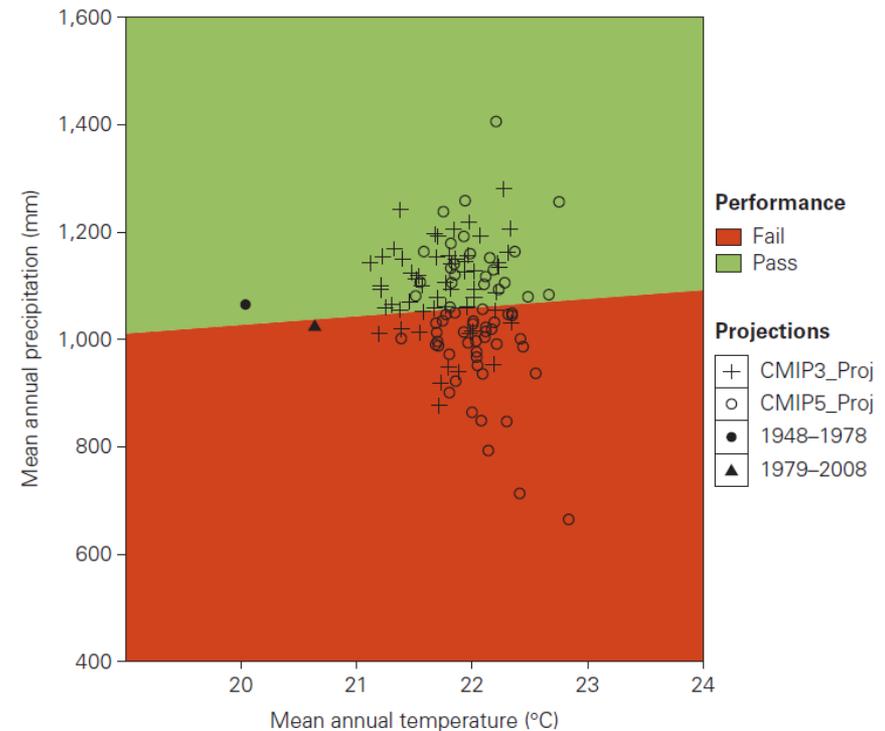
Decision Scaling, Another DMDU Method, Focuses on Climate Stress Tests

Decision scaling provides a simple way to perform a climate stress test

- Start with historical climate record
- Perturb key climate variables
- Use perturbed climate variables in hydrology models



Example results



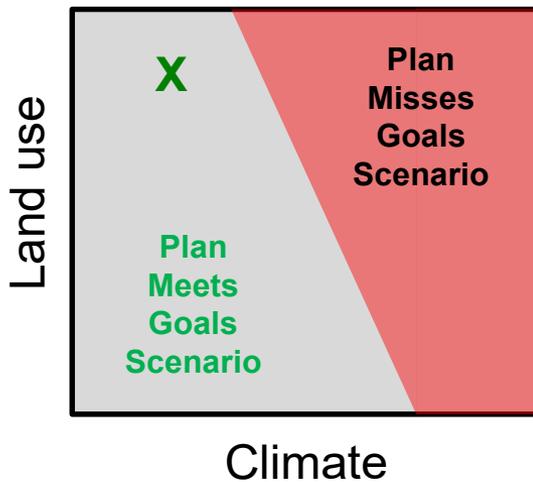
Ray and Brown (2015)



In Water Quality Example, Use Stress Test to Identify New Options for Reducing Vulnerabilities

Study considered an adaptive plan consisting of near-term actions, signposts to monitor, and contingent actions if signposts are observed

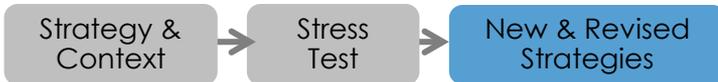
Vulnerability analysis informs signposts



Study identified such and adaptive plan to reduce this vulnerability



* Used optimization to identify augmented plan

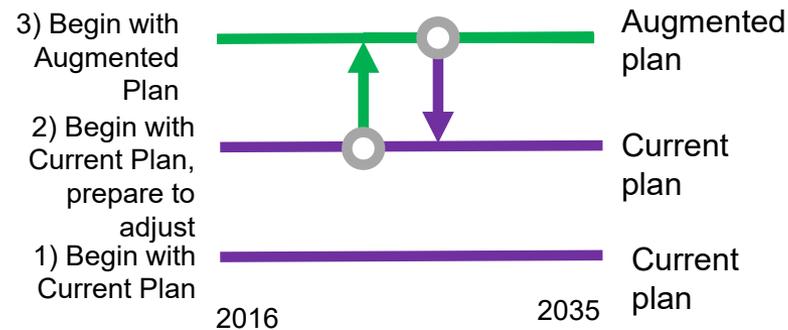


Help Decisionmakers to Compare Tradeoffs Among Alternative Strategies

Present Multi-Objective Trade Off Analysis

Compare three alternative strategies:

1. Begin with current plan, but do not prepare to adjust
2. Begin with current plan, but prepare to adjust
3. Begin with augmented plan, but prepare to adjust



Note: RDM is designed to illuminate tradeoffs for people to evaluate, rather than dictate optimal solutions

Strategy & Context

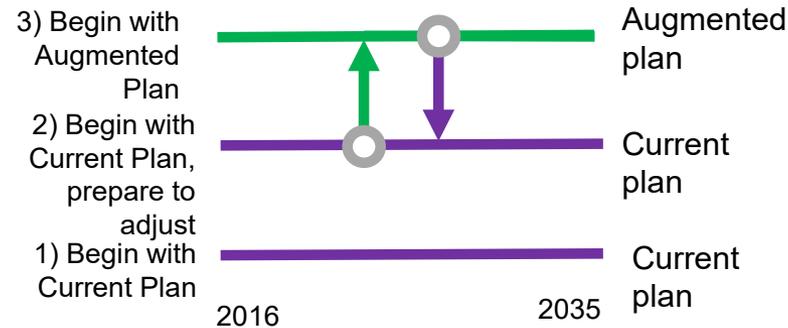
Stress Test

New & Revised Strategies

Help Decisionmakers to Compare Tradeoffs Among Alternative Strategies

These strategies aim to meet two objectives:
1) ensuring water quality and 2) low cost

Plan Meets Goals Scenario	
Water quality	Cost
Yes	Highest
Yes	Slightly higher
Yes	Lowest



Strategy & Context

Stress Test

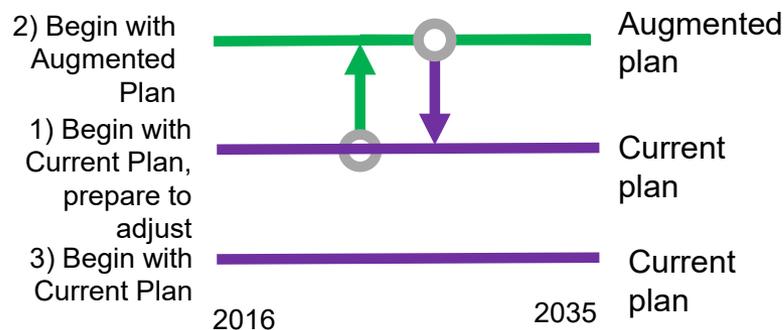
New & Revised Strategies

Help Decisionmakers to Compare Tradeoffs Among Alternative Strategies

The strategies perform very differently across the two scenarios

Plan Meets Goals Scenario		Plan Misses Goals Scenario	
Water quality	Cost	Water quality	Cost
Yes	Highest	Yes	Lowest
Yes	Slightly higher	Yes	Slightly higher
Yes	Lowest	No	Highest

The adaptive “Begin with current plan, but prepare to adjust” plan represents a “low regret” strategy



In general, a robust strategy is one that:

- Performs well over a wide range of plausible futures,
- Keeps options open, or
- Trades some optimal performance for less sensitivity to broken assumptions

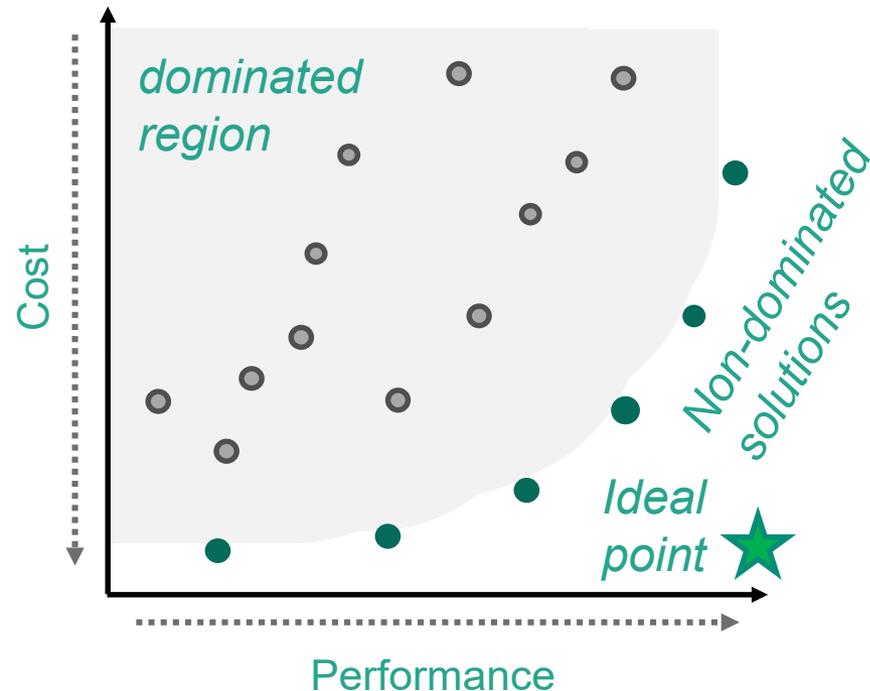
Strategy & Context

Stress Test

New & Revised Strategies

Multi-Objective Decision Analysis is a Wonky Term for Seeking to Recognize the Diversity of Human Interests

Multi-objective tradeoff curve

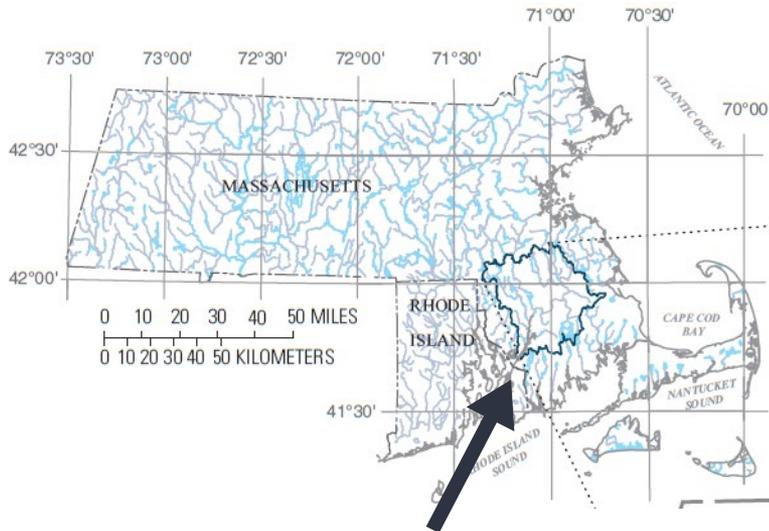


- Optimizing using a single measure of performance (e.g. BCA) assumes that everyone has the same values
- But a diversity of priorities, goals, and values is a fundamental attribute of our world
 - Some see this as a feature, not a bug
- Multi-objective decision analysis can usefully reflect this diversity
 - This is particularly true when supporting participatory processes

Multi-Objective RDM (MORDM) Focuses on Developing New Options

MORDM uses evolutionary robust optimization algorithms to help decision makers identify strategies that perform well over many objectives and futures

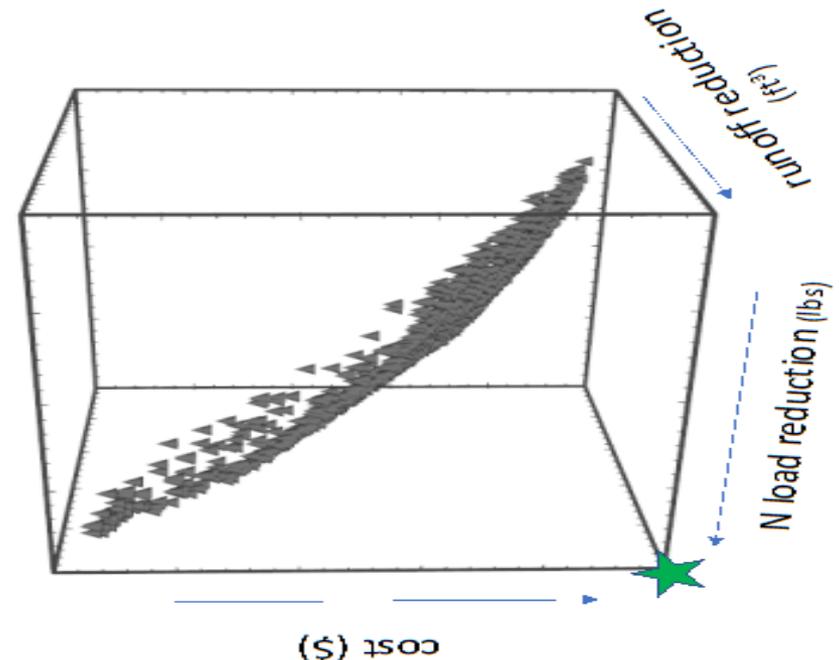
EPA using MORDM to incorporate green infrastructure into watershed management



- Taunton River Watershed TMDL requires 20% nitrogen reduction
- EPA using WMOST model to evaluate alternative portfolios of green infrastructure

Multi-objective tradeoff curve for alternative combinations of:

- Bioretention basins
- Permeable pavement
- Infiltration trenches



Comparing Methods

- **Scenario planning** develops robust strategies from scenarios that people create
- **Adaptive pathways** provides a framework for developing strategies that adjust over time
 - Works especially well when the "tipping points" are simple
- **RDM** proves useful for more complicated vulnerabilities,
 - Scenarios emerge from analysis and often depend on combinations of climate and socio-economic factors
 - Need to start with a proposed strategy
- **Decision scaling** focuses on vulnerability analysis, in particular vulnerabilities associated with climate change
 - Reduces reliance on climate models
- **MORDM** is RDM for complicated multi-objective adaptive strategies

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Facilitating Stakeholder engagement

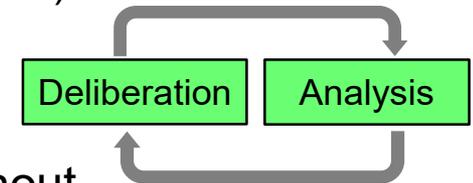
Getting Started

DMDU Analytics are Designed to Support Deliberative Processes of Stakeholder Engagement

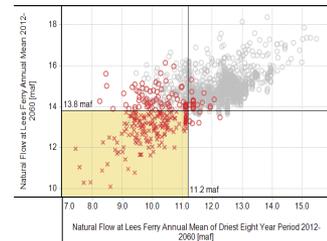
- Stakeholder engagement often important and sometimes required
- RDM and other DMDU approaches designed to support a decision support process call “deliberation with analysis”
 - Stakeholder deliberate over problem framing (e.g. with XLRM)
 - Analysts produce decision relevant information products



- Key idea is that people can agree on actions without agreeing on reasons for those actions



- RDM produces high confidence information products that support such consensus-building. People can agree on a:
 - Scenario that illuminates vulnerabilities without agreeing on the likelihood of that scenario
 - Robust strategy without agreeing which future will come to pass
- RDM-supported deliberation with analysis was used by Reclamation in the Colorado Basin Supply and Demand study



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DMDU Is Part of “Mainstreaming” Climate Adaptation into Your Organization

Most important step is to get started

- Conduct a climate vulnerability analysis
- Use scenario planning
- Recruit a climate advisory panel

DMDU Is Part of “Mainstreaming” Climate Adaptation into Your Organization

- Adopt DMDU incrementally, augmenting each planning cycle
- One potential sequence
 1. Embrace concepts of multiple futures, robust and flexible strategies
 2. Employ qualitative methods and/or separate, piecework analyses
 3. Then begin running your system models over multiple futures to i) stress test plans and ii) identify and evaluate robust and flexible plans

Incremental Improvement Aided Because Most DMDU Methods are Similar

WUCA's case study new planning approaches embrace DMDU concepts

Qualitative or “piecework” analyses:

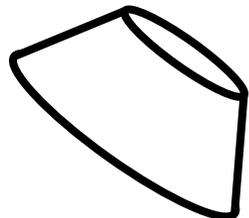
- Scenario planning
- Climate vulnerability assessments
- Plan for plausible ranges of extremes

Fully quantitative analyses:

- Decision scaling
- RDM
- Dynamic adaptive pathways
- Multi-objective RDM

Can start with any of these and move to the others

Different types of risk



DMDU methods:

- Consider multiple futures
- Seek robust and flexible plans

Resources Becoming More Available to Help Implement DMDU Methods

There now exists:

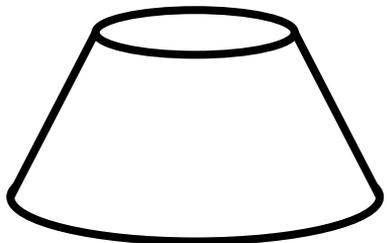
- Open source software for implementing most DMDU methods
- Increasing numbers of case studies
- Many groups able to help



DMDU Methods and Tools Can Help Water Managers Address Today's Uncertain Conditions

Our current and future climate is not the same as past climate, and no one is sure exactly how it has and will change

1. Consider multiple futures, not one single future, in your planning. Choose these futures to stress test your organization's plans
2. Seek robust plans that perform well over many futures, not optimal plans designed for a single, best-estimate future
3. Make your plans flexible and adaptive, which often makes them more robust
4. Use your analytics to explore many futures and options, not tell you what to do



www.deepuncertainty.org

www.rand.org/water

lempert@rand.org

QUESTIONS???