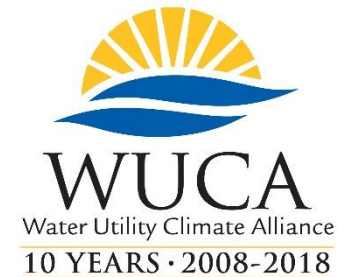
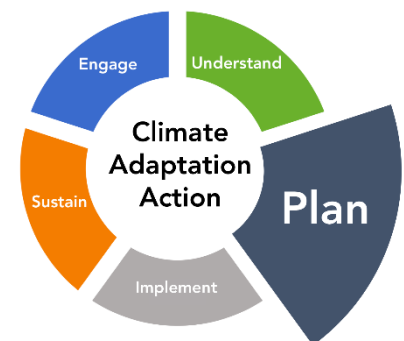


**Building Resilience to a Changing Climate:  
A Technical Training in Water Sector  
Utility Decision Support**



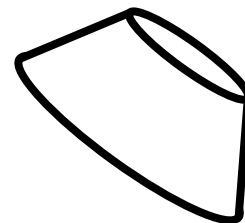
# **Methods for Decision Making Under Conditions of Deep Uncertainty (DMDU)**

Robert Lempert, RAND

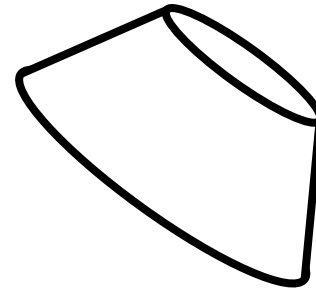


# You've Received Much Advice So Far

- 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

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”

What will future conditions be?

What is the best near-term decision?

How sensitive is the decision to the conditions?

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



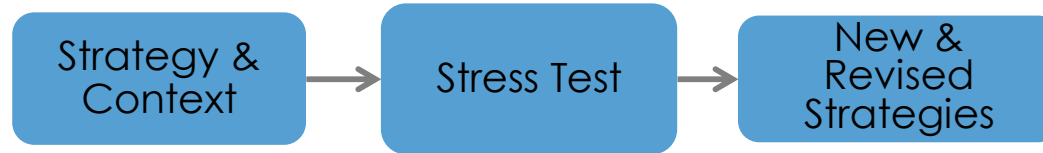
Use analytics to stress test strategy



Identify new & revised strategies that are more robust



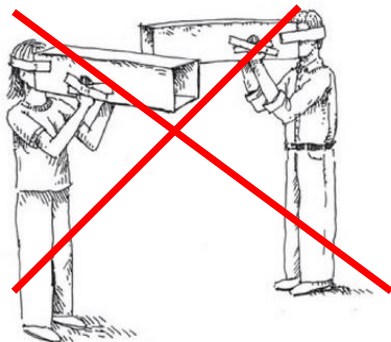
# DMDU Helps People Use Computers to Make Better Decisions, Not Better Predictions



"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

Getting Started

# Outline

Introduction

DMDU Methods

- Scenario planning
- Adaptive pathways
- RDM and variants

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

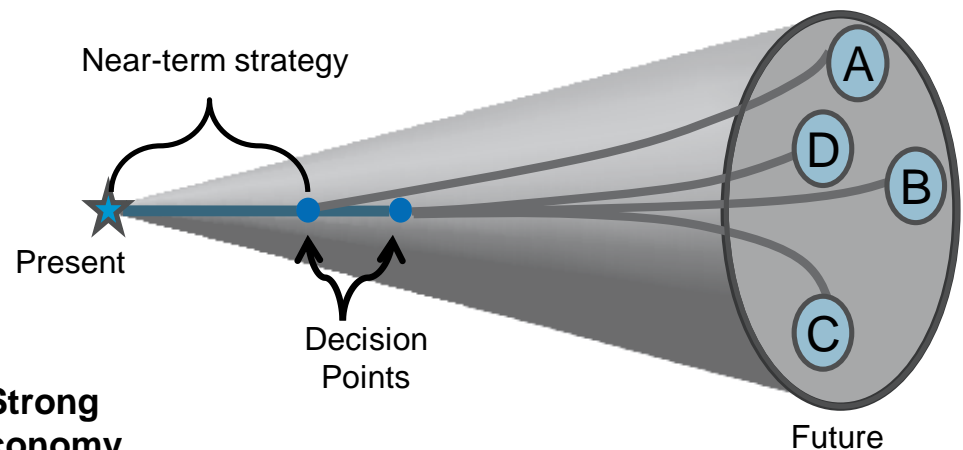
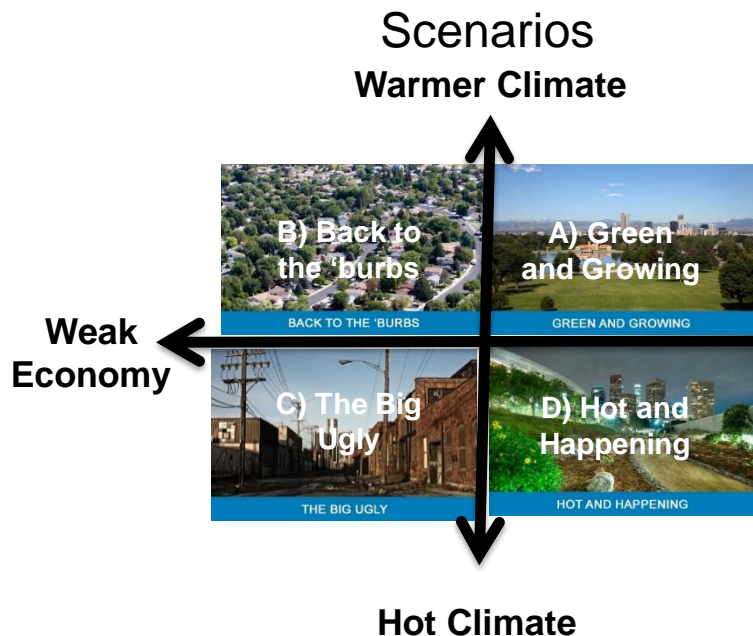


# Scenario Planning Develops Robust Strategies From Scenarios People Create

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

Robust, adaptive strategy



Thanks to Lurna Kaatz

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

# Outline

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DMDU Methods

- Scenario planning
- Adaptive pathways
- RDM and variants

Getting Started

# 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 <sup>1</sup>	High SLR <sup>2</sup>
Current infrastructure	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

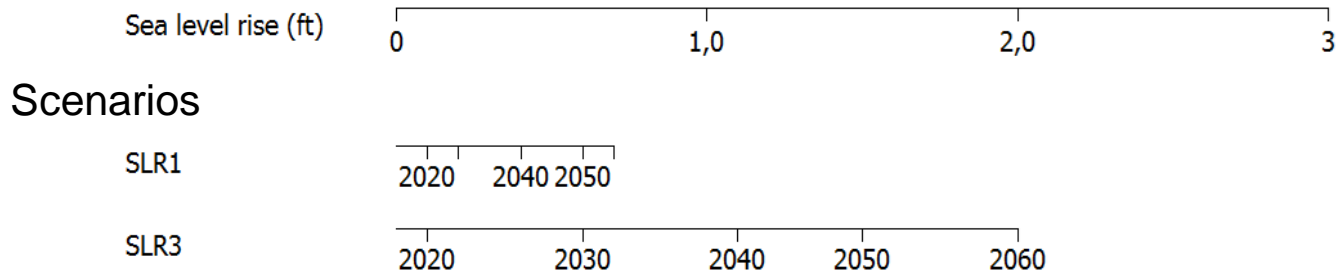
Local pumps

Current infrastructure

M0 no action

Land use

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



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

*Thanks to Kathryn Roscoe and Marjolijn Haasnoot*

Adaptive pathways provides:

- A framework for strategies that adjust over time
- Compelling visualizations of these strategies

Adaptation tipping points focus on how much change your infrastructure and plans can accept



# Outline

## Introduction

## DMDU Methods

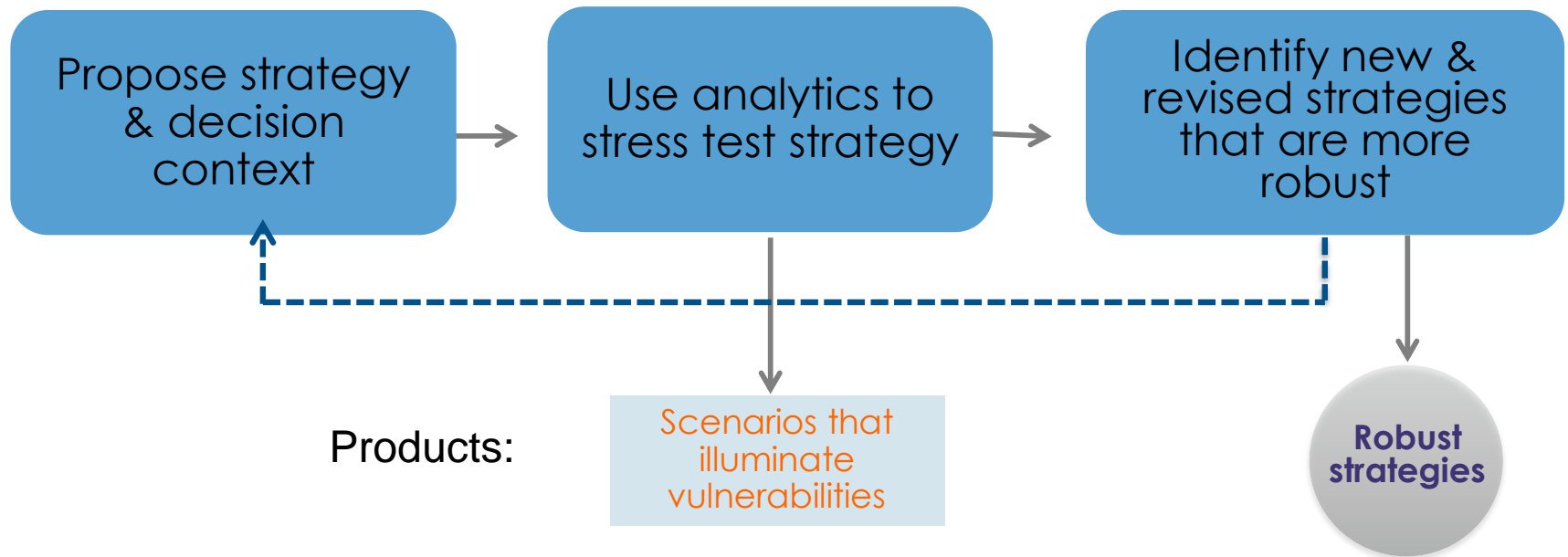
- Scenario planning
- Adaptive pathways
- RDM and variants
  - RDM
  - Decision scaling

## 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:

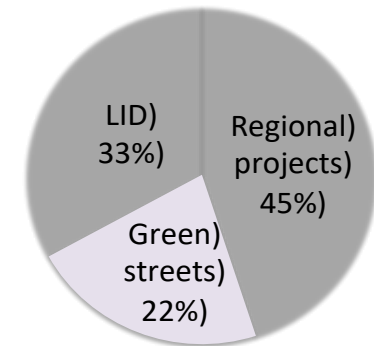
- Stress test strategies over many plausible paths into the future,
- Use the resulting database to identify conditions where strategies fail, and
- Use this information to identify more robust strategies

# 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



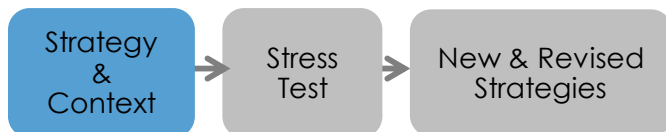
Optimal distribution of BMPs  
(best management practices)  
*assuming we know future climate!*

\* 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**

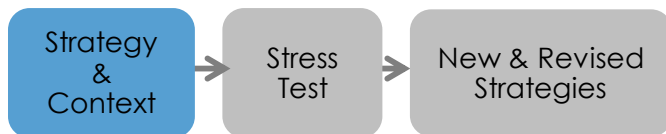
*Will our expensive new water quality investments still  
meet water quality standards in a changing climate?  
If not, what can we do about it?*



# 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)

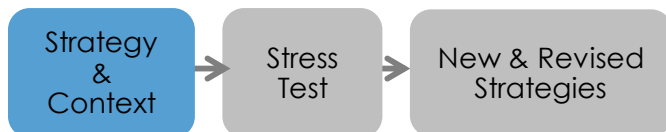


# Summarize Stakeholder Discussions with 'XLRM' Matrix

*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)? <div><div>X, L → M</div><div>R</div></div>	What are we trying to achieve?

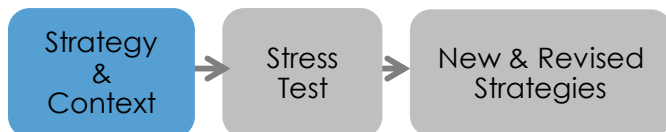
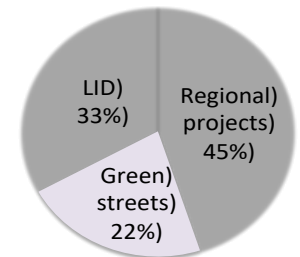
*XLRM is useful independent of RDM*



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

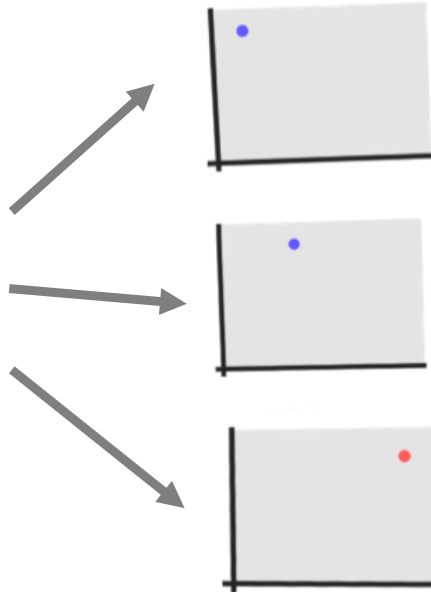


*In this engagement, re-framing added new policy levers*

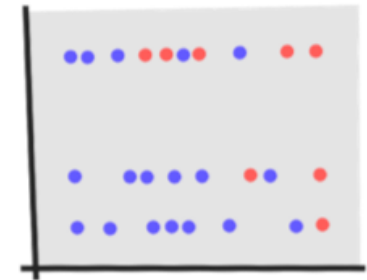
# Generate Cases that Stress Test Strategy in Each of Many Plausible Futures

Run model for each off hundreds to millions of cases  
*Each case tests one strategy in one plausible future*

Decision Framing



Gather all the cases in a large database



Strategy & Context

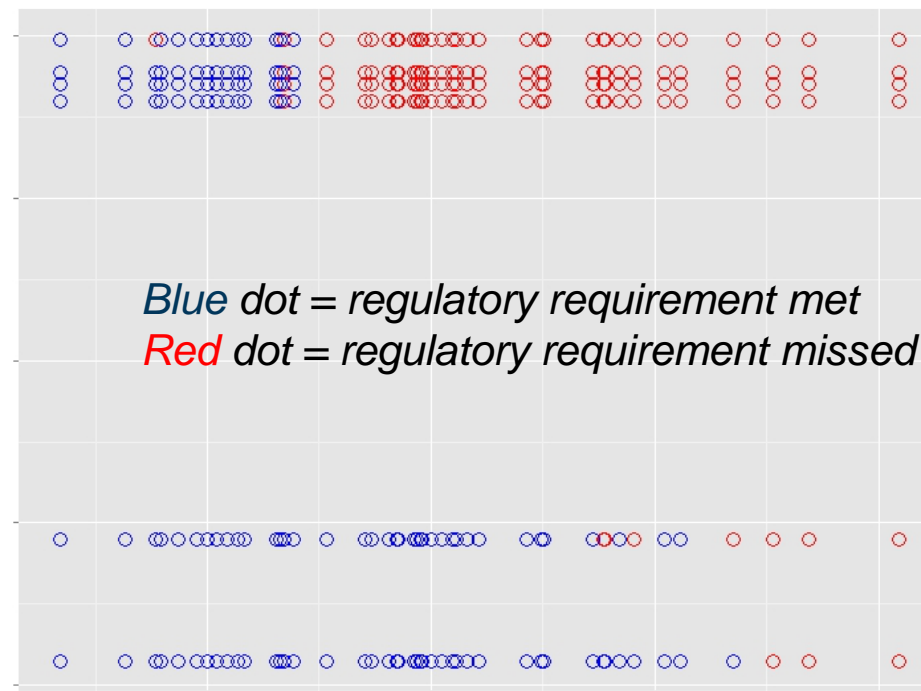
Stress Test

New & Revised Strategies

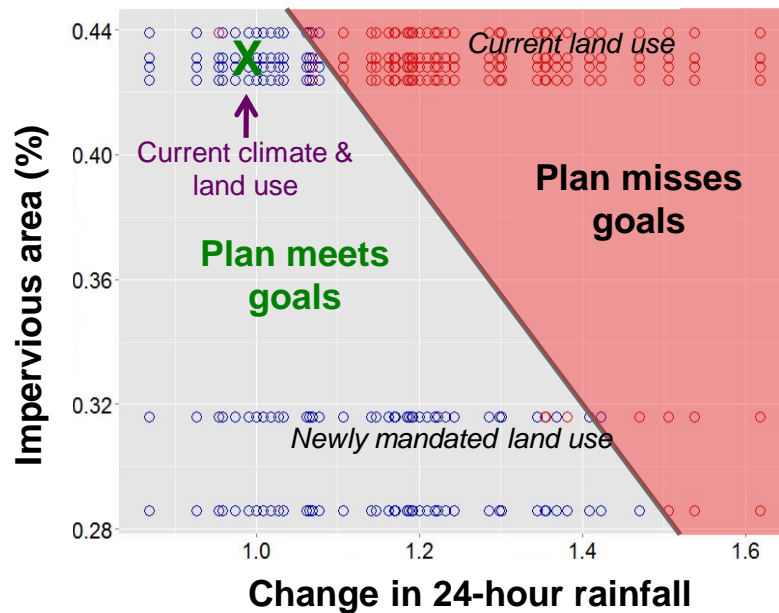


# Generate Cases that Stress Test Strategy in Each of Many Plausible Futures

- 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

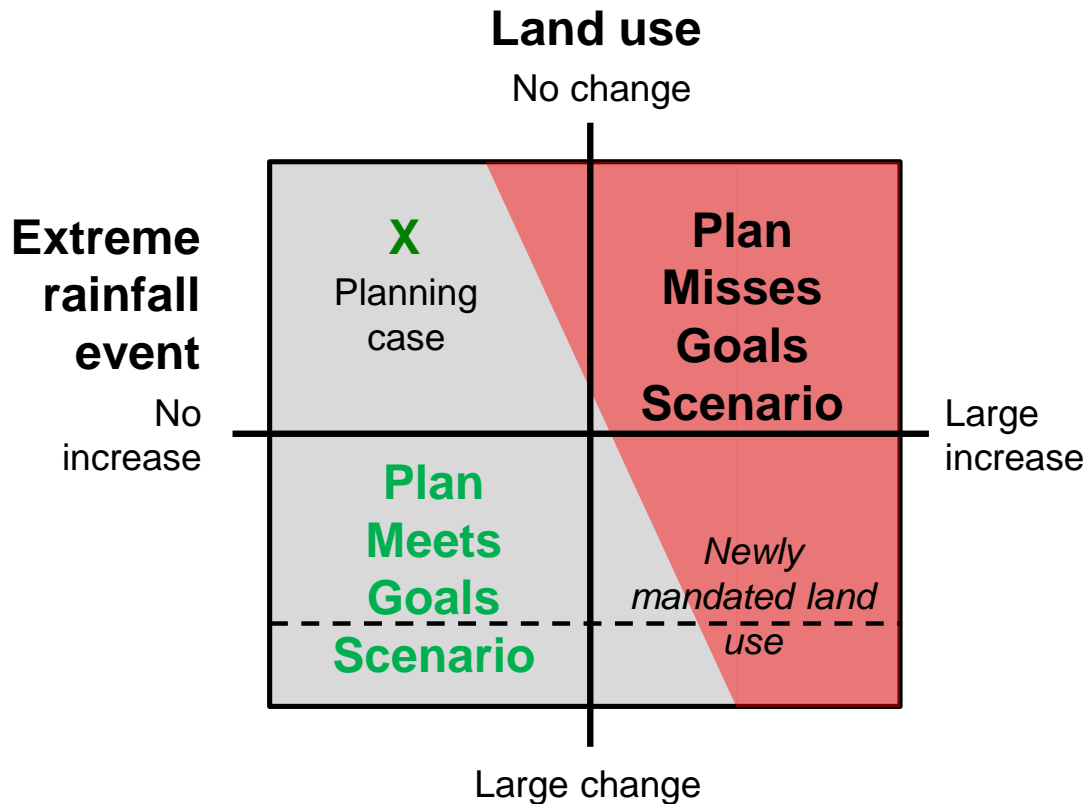
The algorithms and visualizations also identify the combination of uncertainties *most important* in distinguishing these two sets of futures

*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



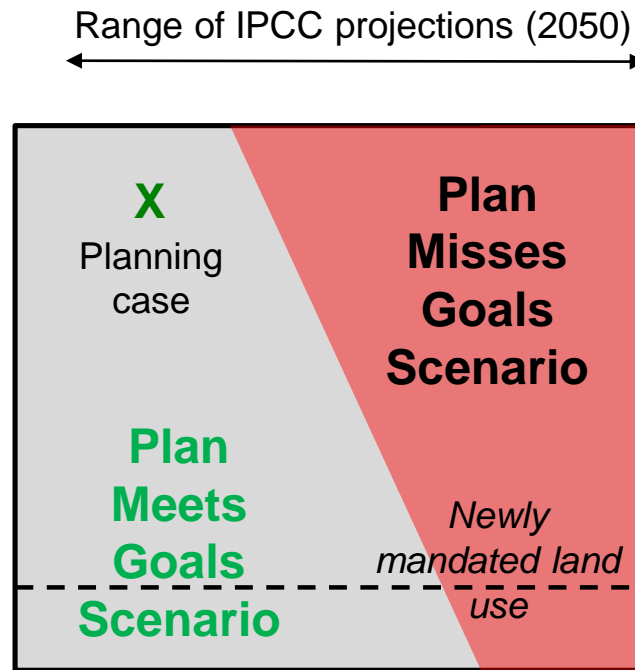
- Scenarios emerge from the analysis. They aren't inputs to it
- Scenarios show high-confidence information. People who disagree about the likely future can agree on the conditions in which LA's plan would meet or miss its regulatory goals

*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*



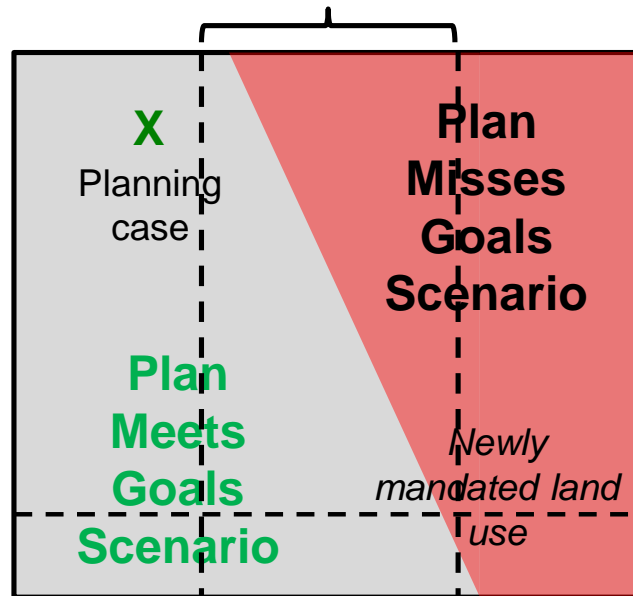
*These IPCC projections don't include any downscaling*



# 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)*

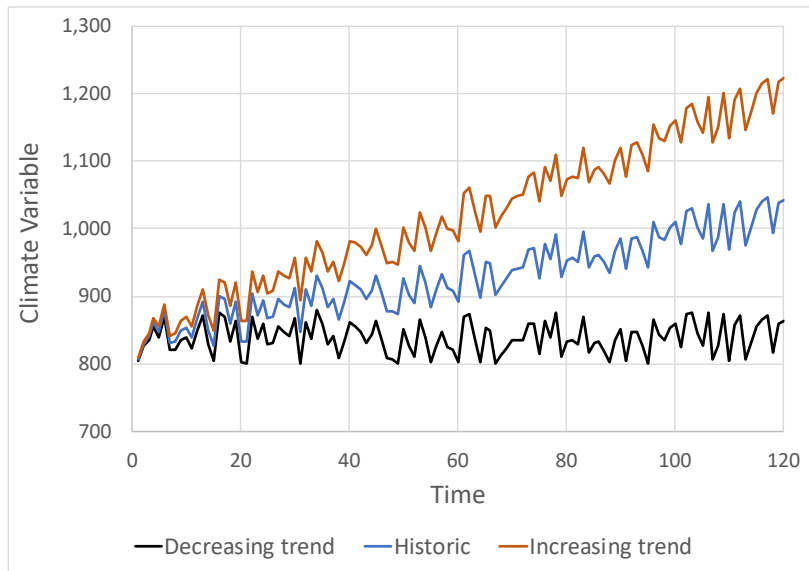
*These projections involve very high resolution (2 km) downscaling*



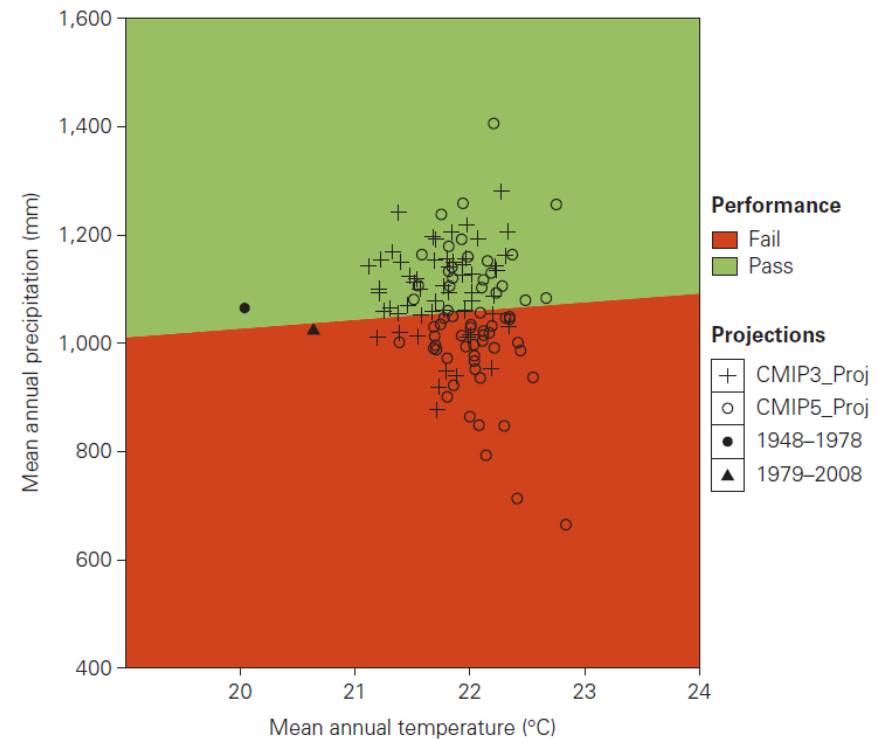
# Decision Scaling, Another DMDU Method, Focuses on Climate Stress Tests

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)

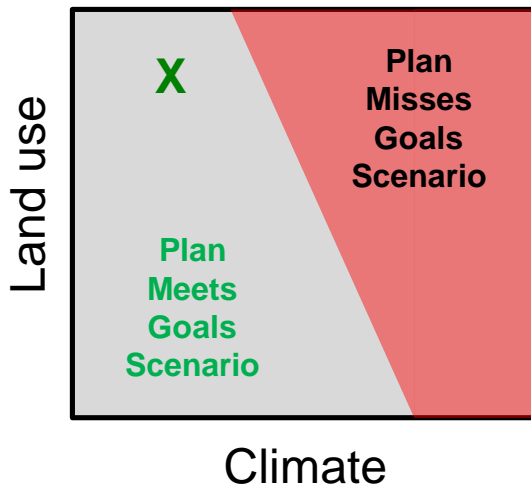


Decision scaling provides a climate vulnerability analysis, without relying on extensive climate modeling

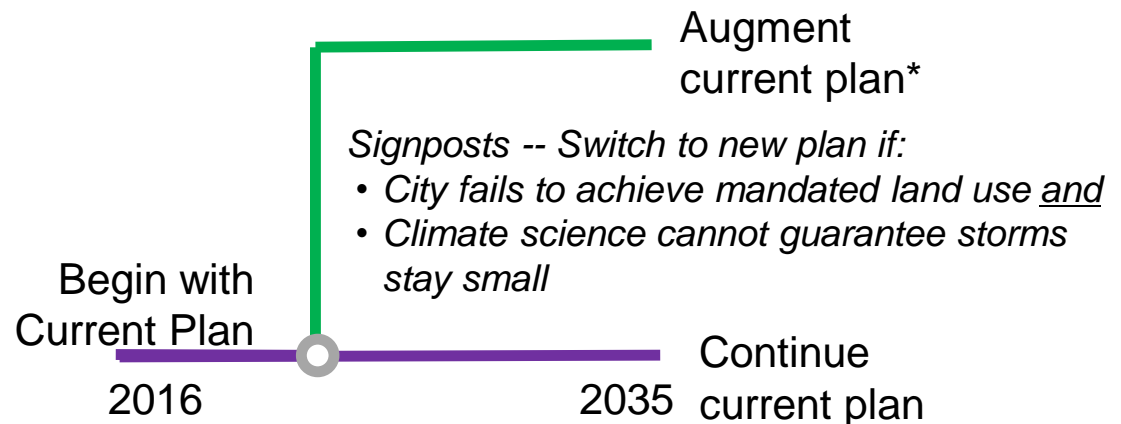
# In LA Water Quality Example, Use Stress Test to Identify New Options for Reducing Vulnerabilities

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



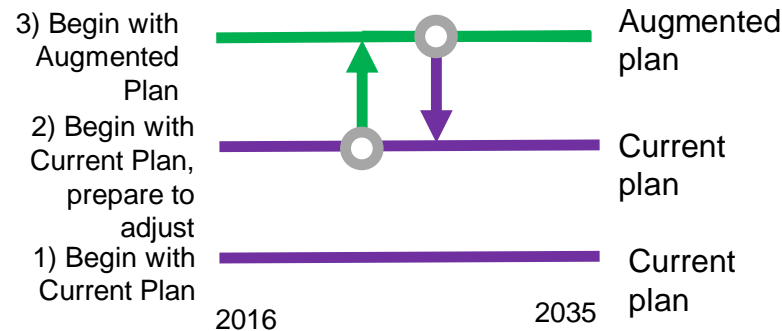


# Help Decisionmakers to Compare Tradeoffs Among Alternative Strategies

## 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

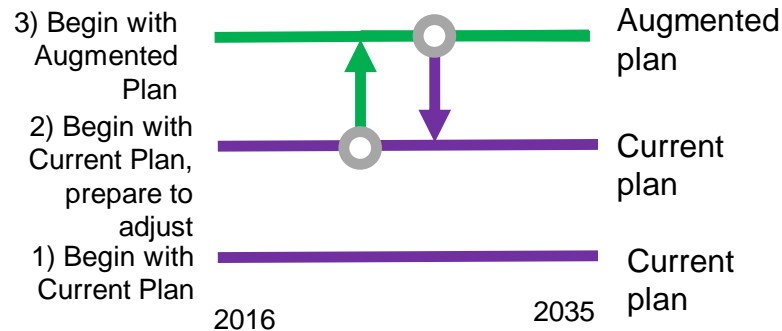


*Note: RDM is designed to illuminate tradeoffs for people to evaluate, rather than dictate optimal solutions*

# 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

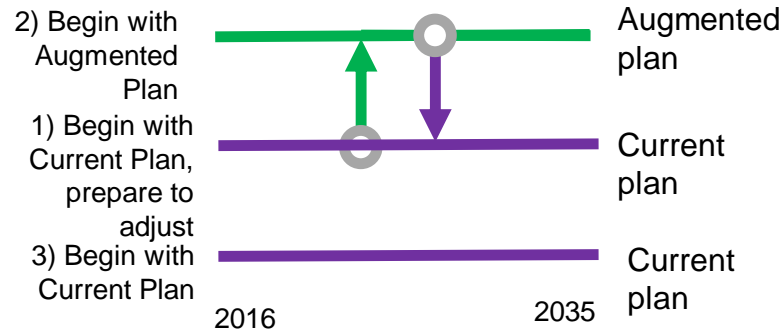
New & Revised Strategies

# 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

# 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

# Outline

Introduction

DMDU Methods

Getting Started

# 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 scientific climate advisory panel

You can adopt DMDU incrementally,  
augmenting each planning cycle

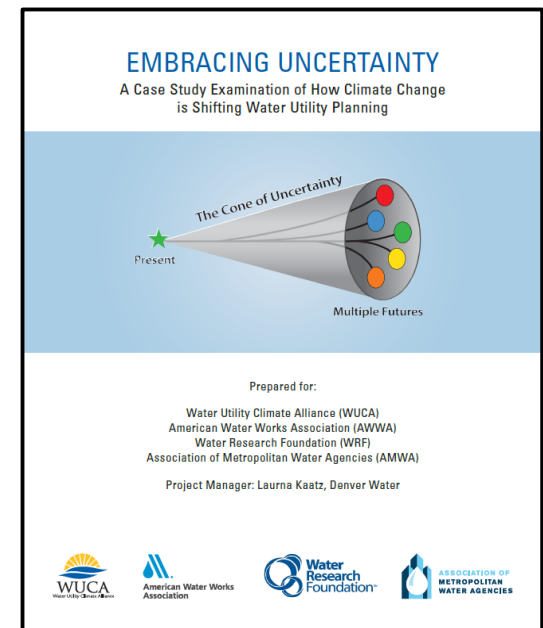
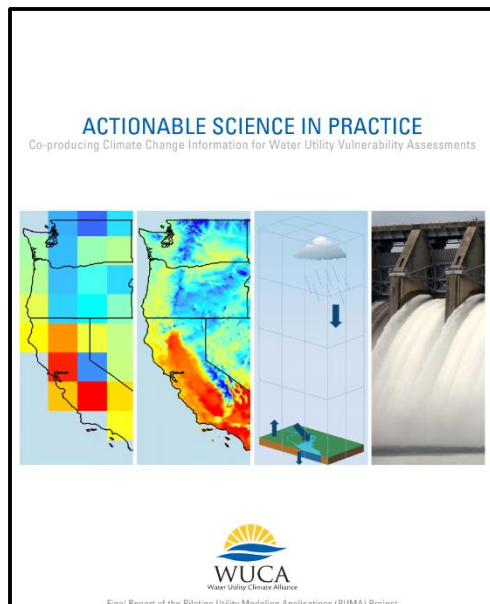
# One Potential Sequence for “Mainstreaming” DMDU into Your Organization

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

***These WUCA documents can help***

***Actionable Science in Practice***

***Embracing Uncertainty***



# 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

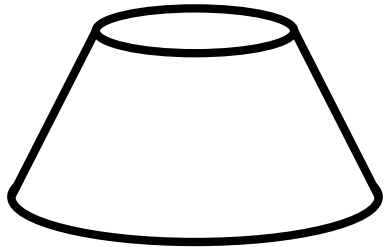




# DMDU Methods and Tools Can Help Water Managers Address Today's Uncertain Conditions

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



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[lempert@rand.org](mailto:lempert@rand.org)

**QUESTIONS???**