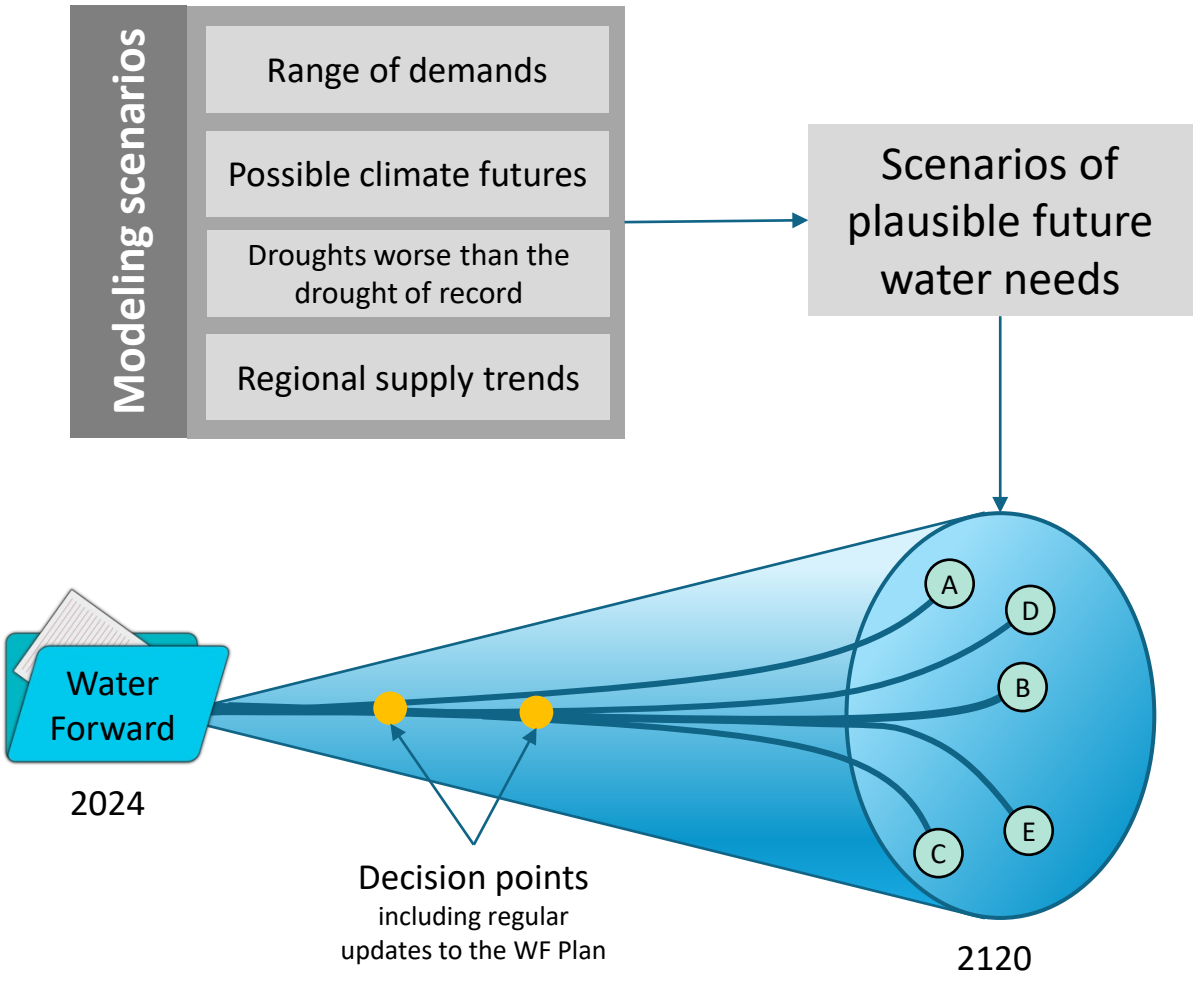
# Water Forward WAVE evaluation

Water Forward Task Force Meeting

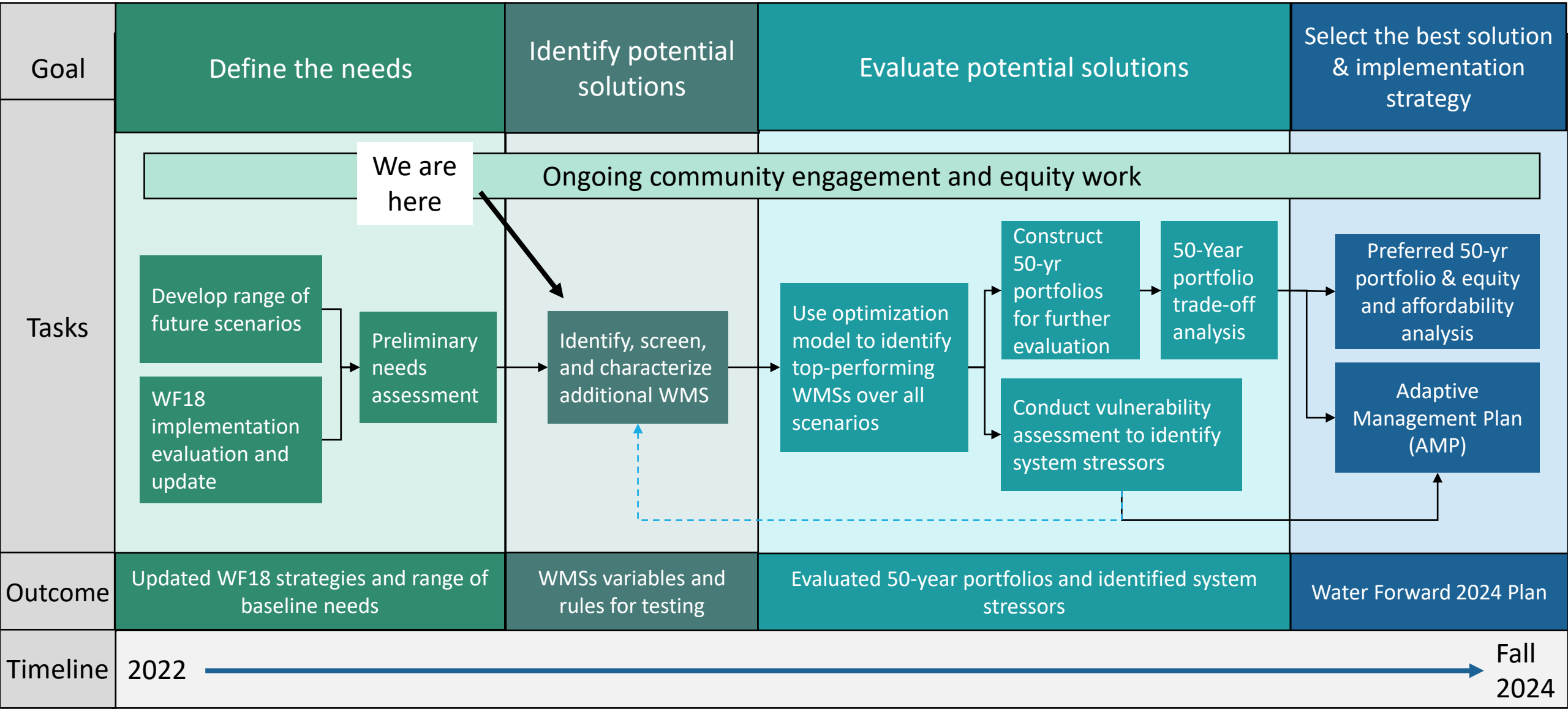
March 5, 2024

# Water Forward: Planning for Uncertainty

- Develop a range of plausible future scenarios
- Find common near-term water management strategies (WMSs) that perform well over many scenarios
- For long-term (WMSs), develop an adaptive management plan with key decision points
- Continue to update the plan, re-evaluate, and adapt



# WF24 Methodology Overview



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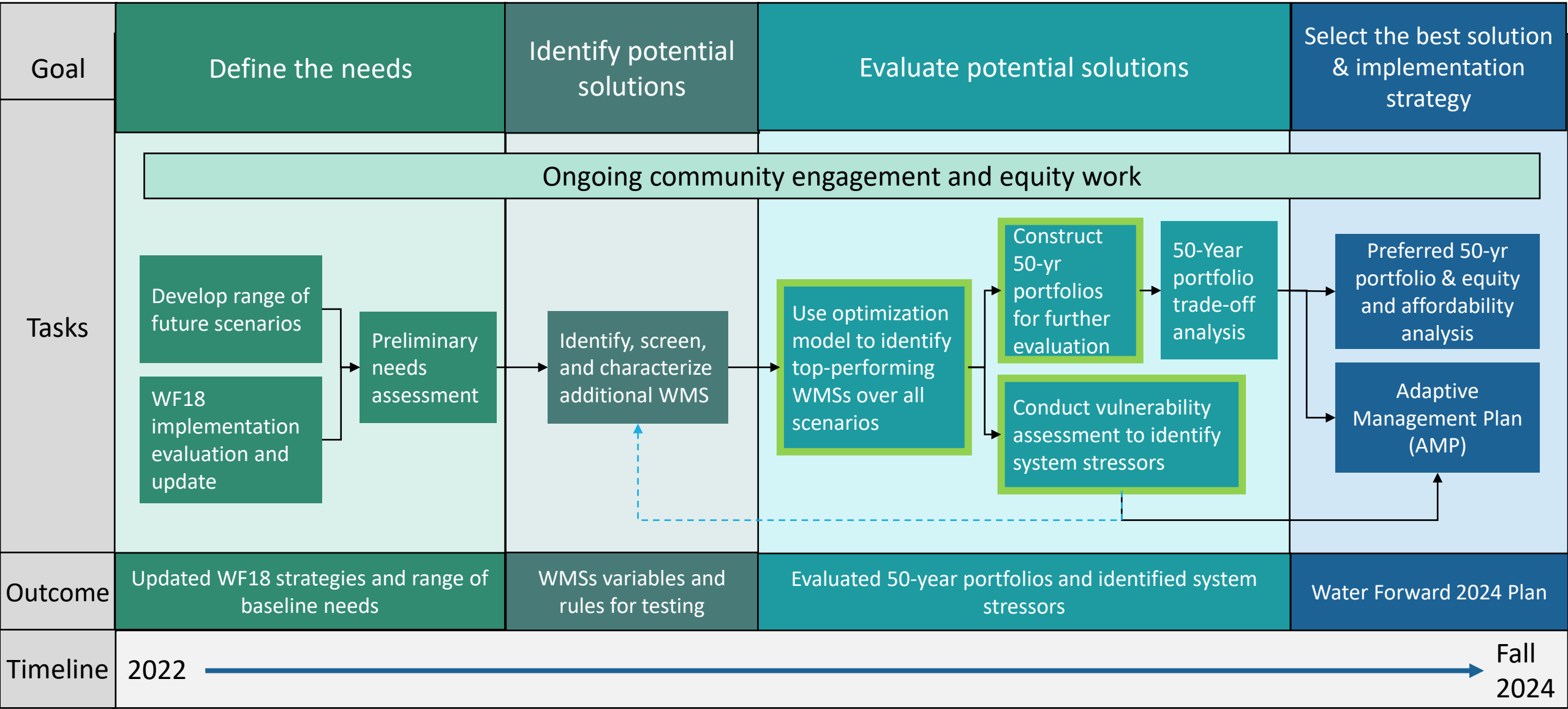


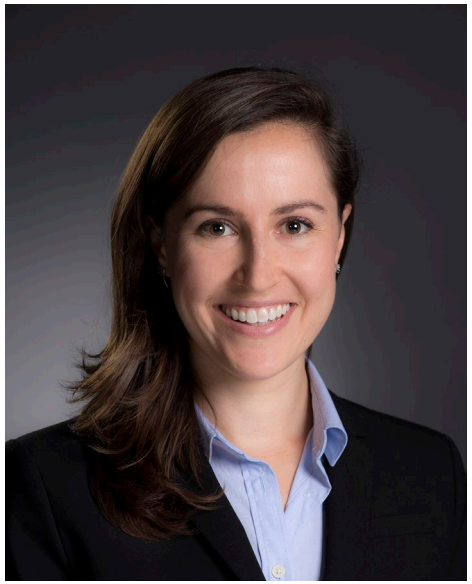
**W**ater management strategy
**A**ssessment and **V**ulnerability
**E**valuation

=

**WAVE**

# WAVE Team Members

Rob Lempert



Michelle Miro

Swaptik Chowdhury

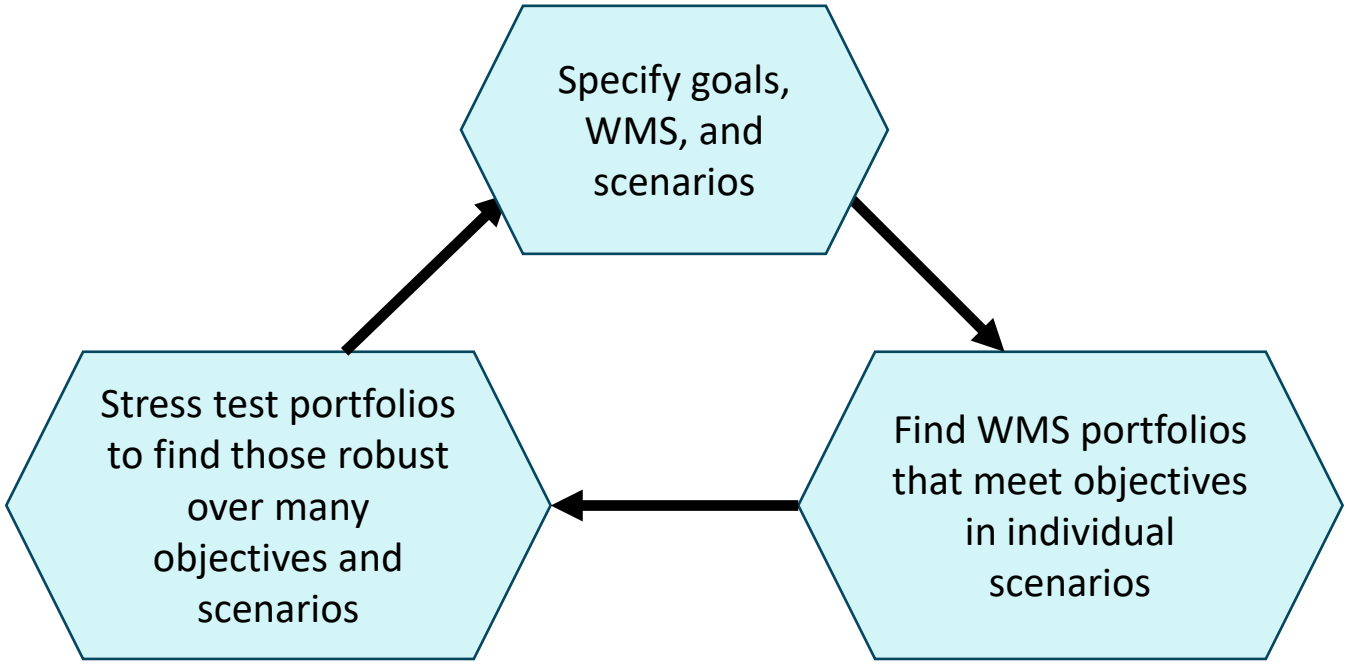
# RAND Will Support the WAVE with Multi-Objective Robust Decision Making (MoRDM)

- We live in a fast-changing, hard-to-predict world
- We can shape the future, even when we can't predict it with confidence
  - But many analyses don't reflect this wisdom
- MoRDM is a multi-objective, multi-scenario analysis that improves decisions under 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*

# MoRDM Identifies Robust Portfolios Through Iterative Optimization and Stress Testing

Process aims to inform better decisions,
not better predictions



# Deep Uncertainty May Seem Daunting, But Considering It Is Empowering

- Inappropriate use of ”predict-then-act” methods risks
  - Over-confidence,
  - Missed opportunities
  - Portfolios brittle against surprise

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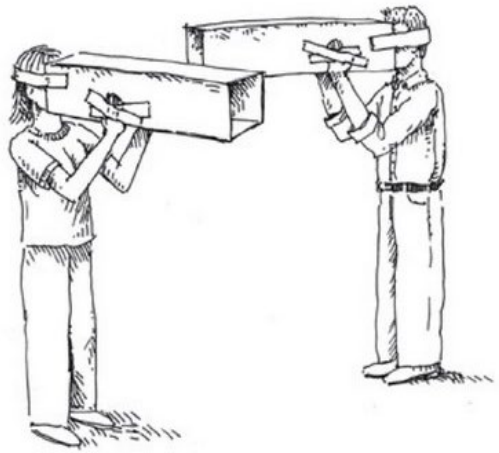

- MoRDM helps identify
  - Low regrets actions
  - Adaptive and flexible plans
  - Steps to keep options open

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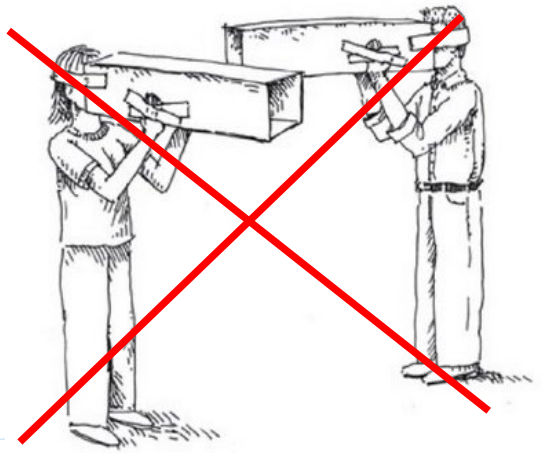


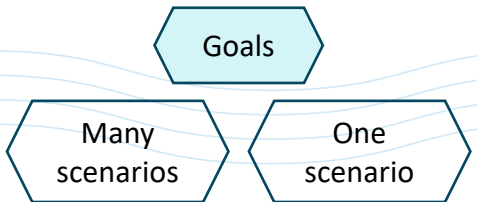
*Plan over multiple futures*

*Find robust strategies*

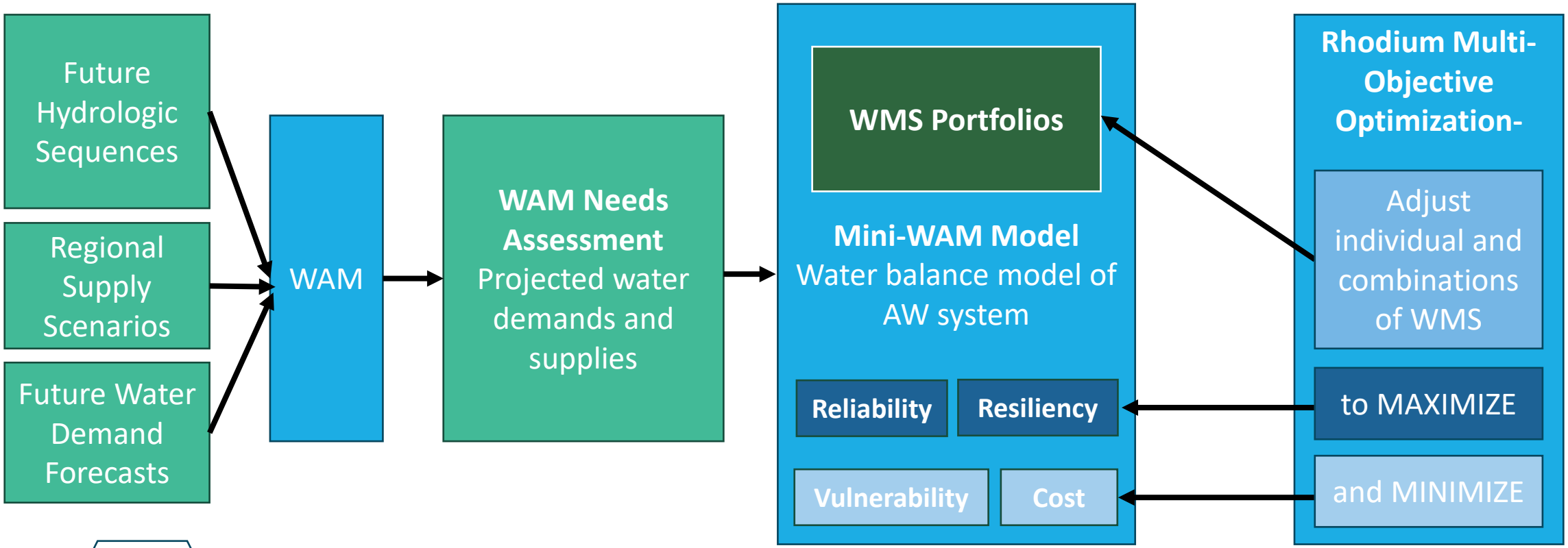
- MoRDM helps identify
  - Low regrets actions
  - Adaptive and flexible plans
  - Steps to keep options open

# Using MoRDM, we will build robust portfolios of water management strategies

- Inputs:
  - Characterized WMS
  - Preliminary needs WAM outputs
- Tools
  - Mini-WAM model
  - Rhodium multi-objective optimization library
- Outputs
  - Optimized portfolios of WMSs
  - Metrics describing reliability, resiliency, vulnerability and cost of portfolios



# Portfolios of WMS balance water management goals



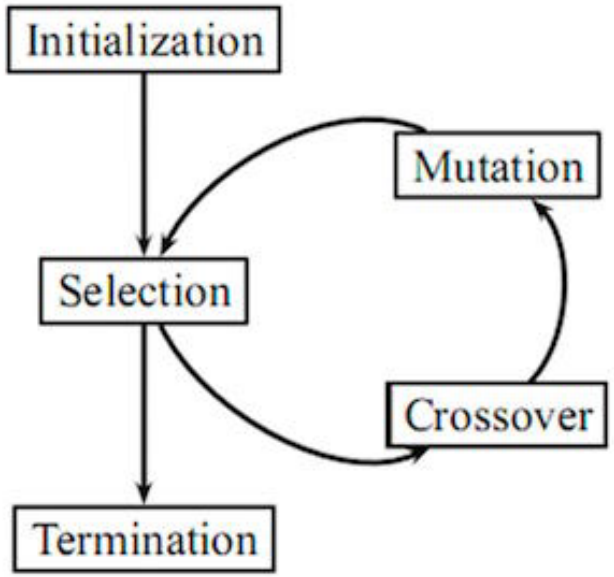

Goals

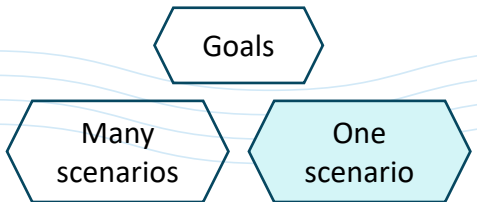
Many scenarios

One scenario

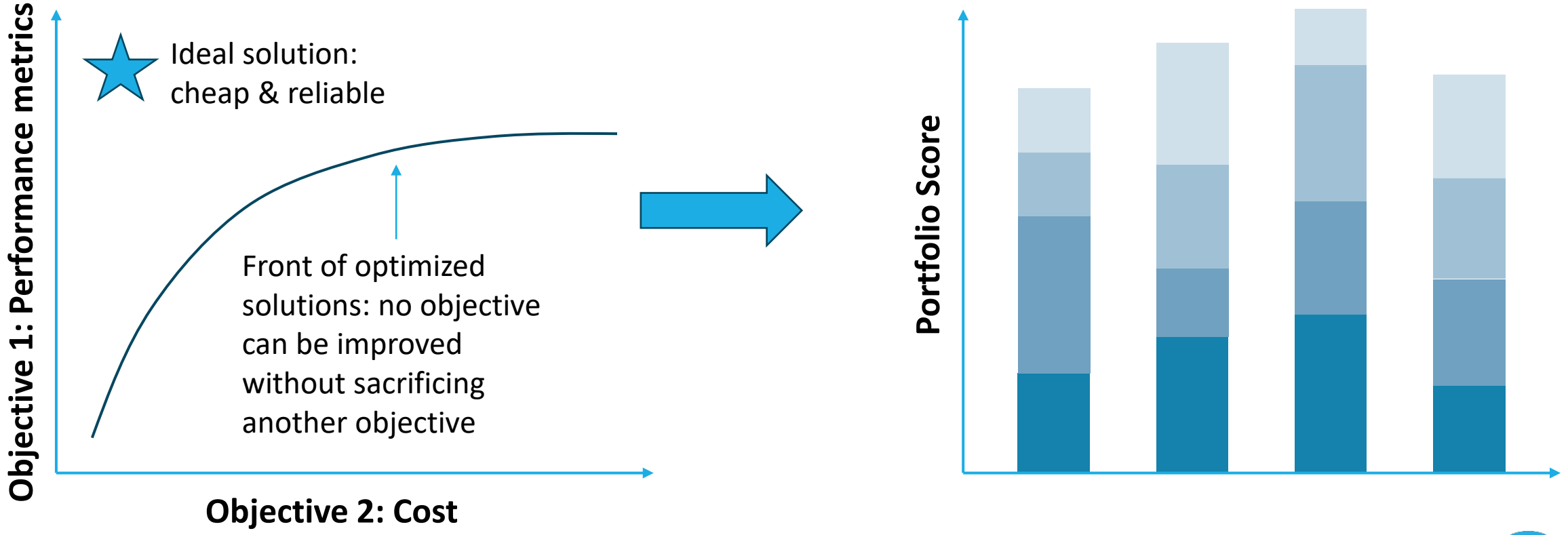
# We carry out a multi-objective optimization to build WMS portfolios

- Multi-objective optimization finds an “optimal solution” satisfying multiple objectives simultaneously
  - “Optimal solution” is a set of points describing tradeoffs between different objectives
- We use multi-objective evolutionary algorithms
  - Evolutionary algorithms use more than one solution in each iteration (population-based approach) to find multiple optimal solutions



# The optimization process will generate an “optimal” set of solutions which will be evaluated as portfolios



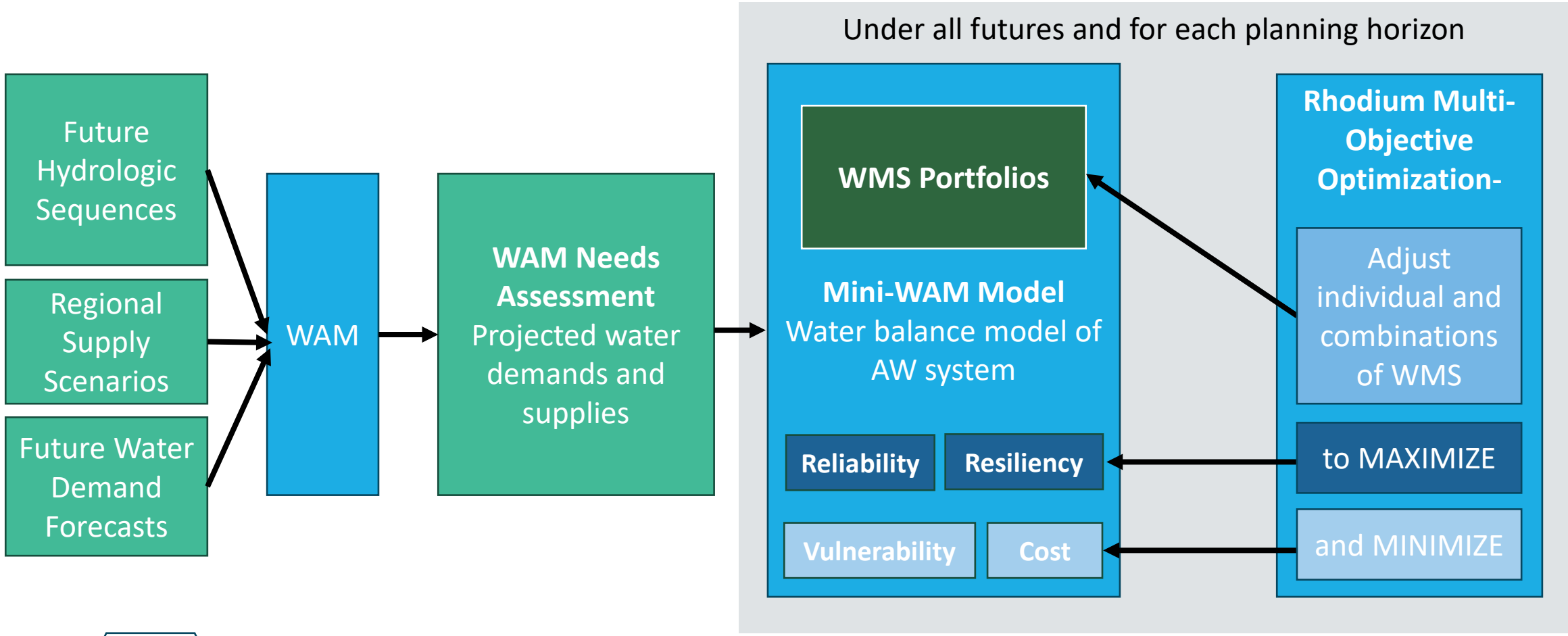
# 50-year portfolios will be evaluated using a multi-criteria decision analysis (MCDA) incorporating additional criteria

| Objectives | Performance Measures |
|---|---|
| Avoid severe water shortages during drought and a variety of climate change scenarios | • WAM/WAVE modeling results |
| Focus on water conservation and water use efficiency<br>Include diverse water management strategies that make use of all water sources. | • Potable GPCD<br>• Portfolio diversity score |
| Minimize impacts and maximize benefits of plan outcomes for marginalized communities | • Cost (lifecycle, capital, O&M)<br>• Equity & Affordability Tool |
| Develop strategies that continue to protect the natural environment, including source and downstream water quality | • Net return flows<br>• Operational energy use<br>• Water quality impacts |
| Develop strategies that are technically, socially, and economically feasible and can be implemented and operated with a manageable level of risk | • Implementation and operational risk score<br>• System resiliency benefits |
| Develop strategies that make use of locally available and AW-controlled water resources | • Volume of local and AW-controlled water resources |

# We leverage Rhodium to carry out WMS portfolio optimization


- Open-source Python library developed by researchers
- Contains framework for evolutionary computing in Python supporting different MOEAs
  - EAs such as NSGA-II, NSGA-III, MOEA/D, IBEA, Epsilon-MOEA, SPEA2, GDE3, OMOPSO, SMPSO, and Epsilon-NSGA-II
- Has built-in capabilities for high-dimensional, interactive scientific visualization
- Parallelization capabilities with in-built wrapper function for linking to other models

# WMS portfolios are assessed under each future combination of climate, supply and demand




Goals

Many scenarios

One scenario

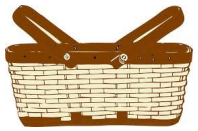
# Use Regret to Compare Portfolios Across Multiple Scenarios

- A portfolio's regret in any future is the difference between its outcome in that future and the outcome of the best portfolio in that future

# Let’s See How This Works

**Strategies**

Stay home



Go for picnic

# Let’s See How This Works

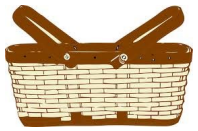
**Futures**

Sun

Rain

**Strategies**

Stay home



Go for picnic

# Let's See How This Works

**Futures**

Sun Rain

**Strategies**

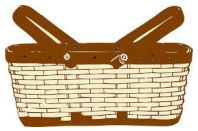
Stay home

Bad ($u_{11}$)

Good ($u_{12}$)

$u_{12} > u_{11}$

*Outcomes*



Go for picnic

Good ($u_{21}$)

Bad ($u_{22}$)

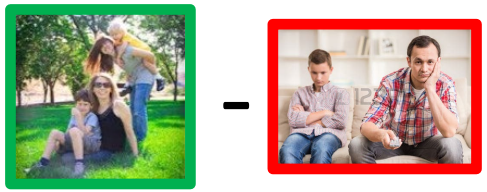
$u_{21} > u_{22}$

# Let's See How This Works

**Futures**

**Strategies**

Stay home



Regret = $u_{21} - u_{11} > 0$

Regret = 0

# Let's See How This Works

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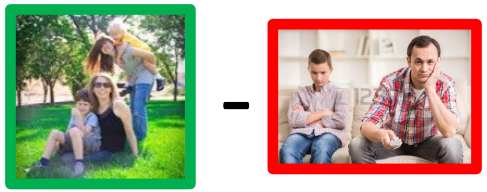

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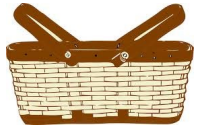

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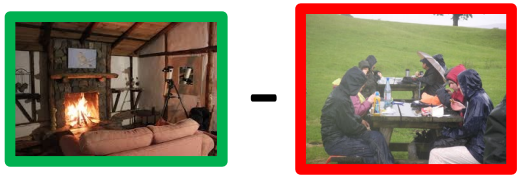
$$\text{Regret} = 0$$



$$\text{Regret} = u_{12} - u_{22} > 0$$

# Use Regret to Compare Portfolios Across Multiple Scenarios

- A portfolio's regret in any future is the difference between its outcome in that future and the outcome of the best portfolio in that future
- Use Multi-objective optimization to find WMS portfolios will small reliability, resiliency, vulnerability, and cost regret over a wide range of scenarios

# Next steps

- Analytical steps:
  - Complete characterization of WMSs
  - Input all WMSs into optimization model
  - Form portfolios and analyze trade-offs and vulnerabilities
- Presenting preliminary WAVE results at May WFTF
- Presenting final WAVE results at July WFTF
  - Use WAVE results to build 50-year portfolios
- Use WAVE results to perform vulnerability evaluation and develop adaptive management plan

# Questions?