Reservoir Optimization
Lessons Learned from the Tarrant Regional Water District, Texas

Upper Colorado River Basin Water Forum: Seeking a Resilient Future

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The Johnstown Flood of 1889 was one of the largest environmental disasters in US history…

But… "It should be noted that no major federal response to flood destruction occurred until the beginning of the 20th century"
[Arnold 1988]

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While the Flood Control Act of 1936 called flood control an "appropriate" federal activity…

- There was no easy way to choose projects.

"…that the Federal Government should improve or participate in the improvement of navigable waters …, for flood control purposes ***if the benefits to whomsoever they may accrue are in excess of the estimated costs****"*

Photo # NH 90687 The Washington Navy Yard during the 1936 Potomac River flood

- Is one objective enough?

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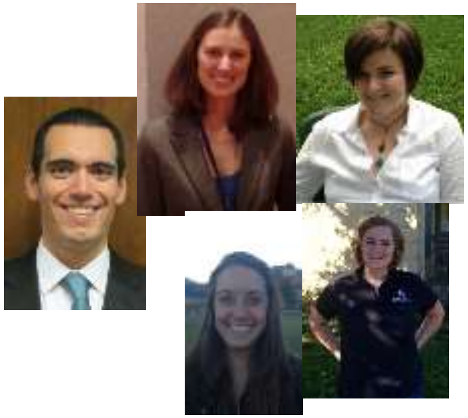
More recent federal guidance

*"[water projects show] varying degrees of effects relative to **environmental, economic, and social goals**. No hierarchical relationship exists among these three goals and a result, **tradeoffs among potential solutions** will need to be assessed…"*

Principles and Requirements for Federal Investments in Water Resources, 2013

My group's research seeks to develop **tradeoffs** for problems with conflicting objectives to increase understanding; creating **innovative solutions** to these problems; and **characterizing uncertainty**.



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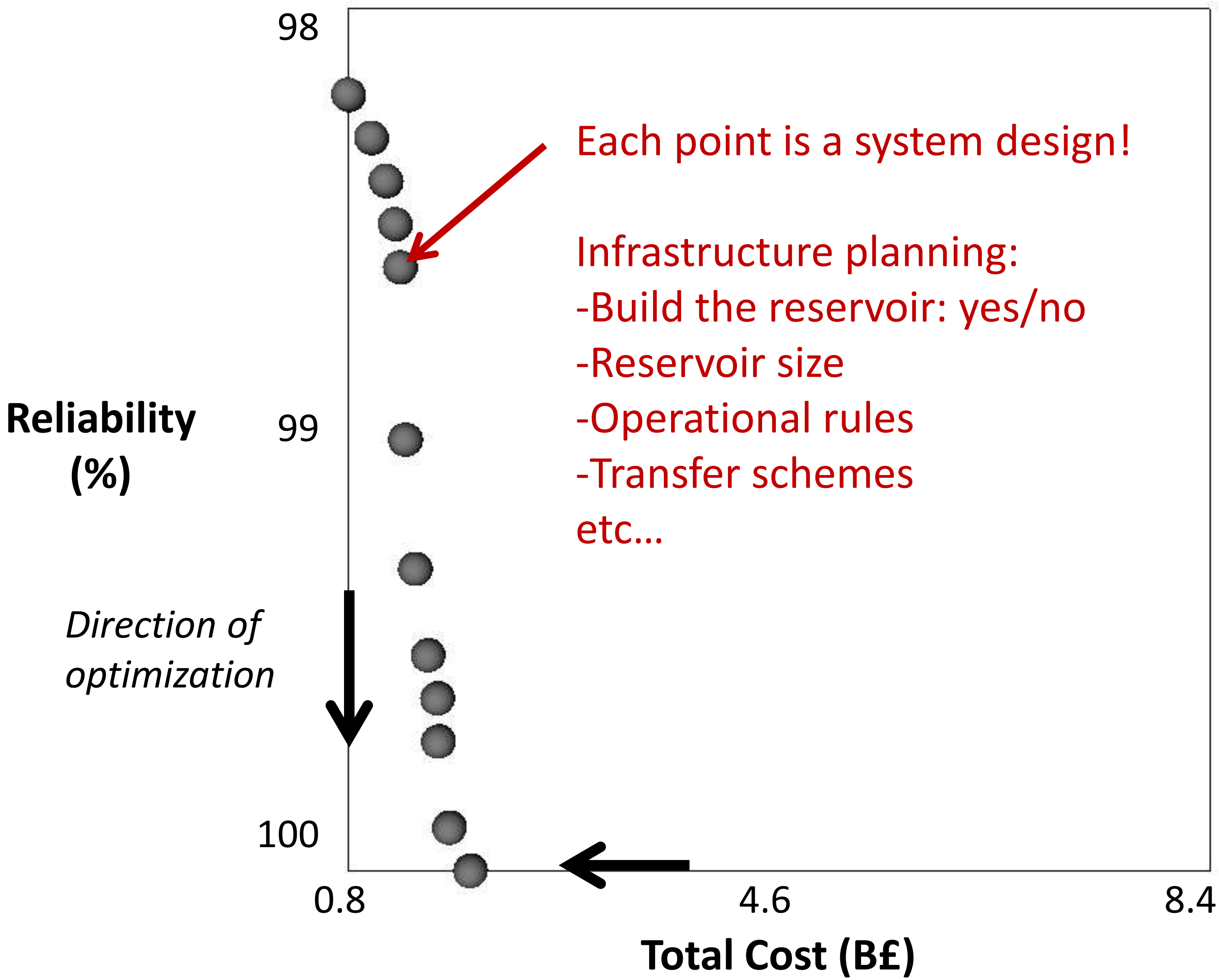
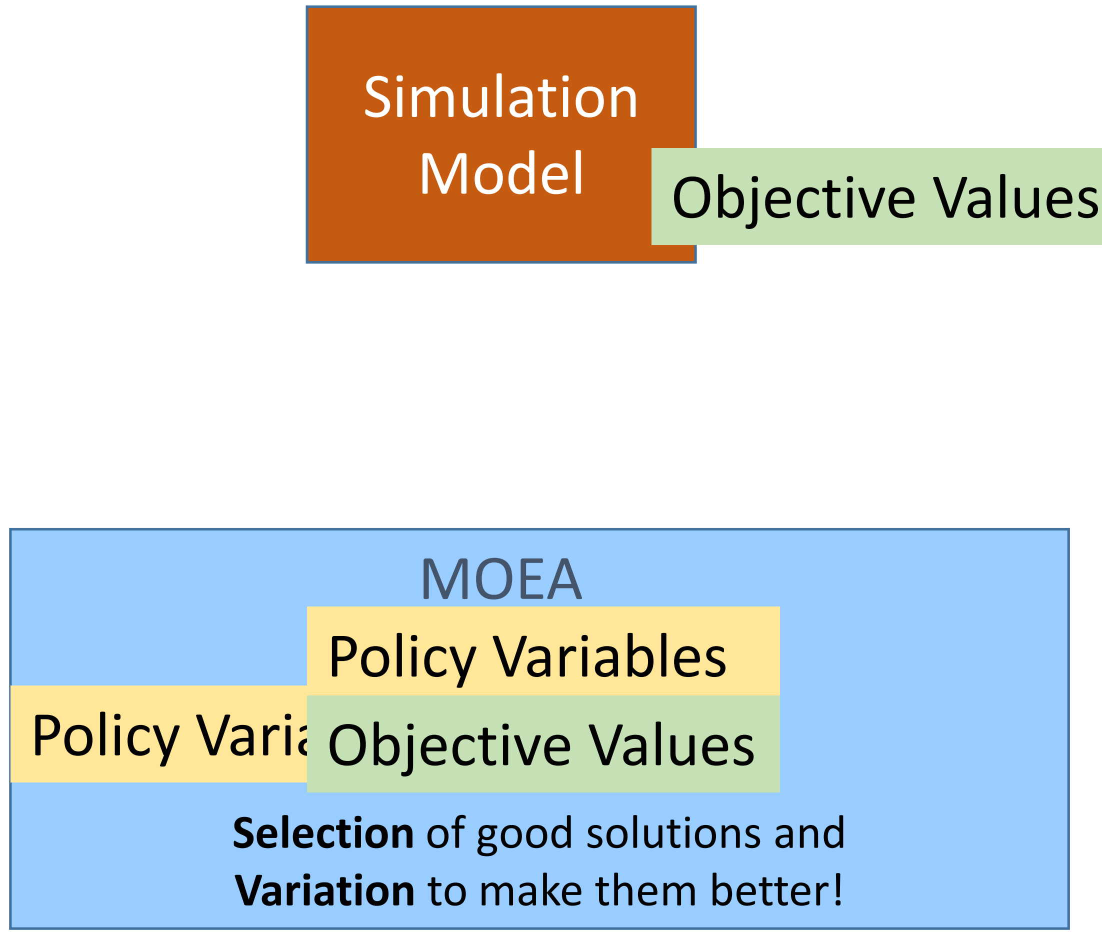
Two objectives: Non-domination



[Matrosov et al. In-Review]

Multiobjective Evolutionary Algorithms (MOEAs)

- Solves **multiple** objectives or goals at the same time
- “Evolutionary”: an iterative process of **finding better designs**
- You can plug **any simulation model** into the process.



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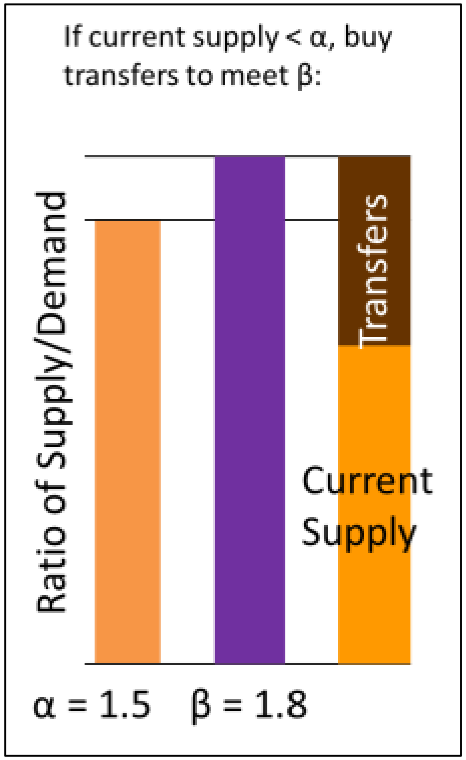
Policy variables: what can change?

New infrastructure

Conservation programs



Thresholds and operating rules

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Objectives and Constraints:
Measuring performance

Cost: fixed, operating…

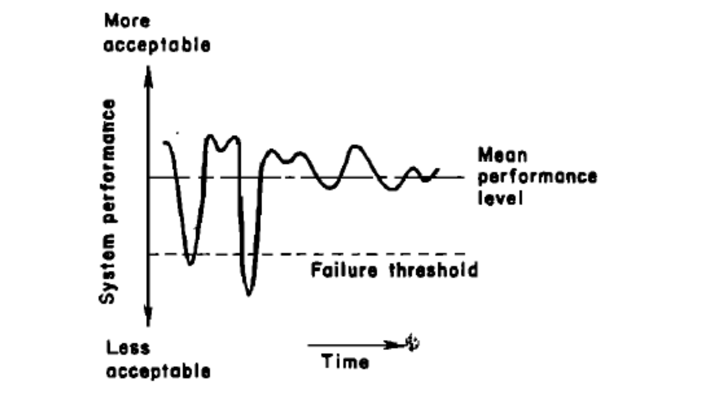


Fig. 1. Variable system performance with infrequent failures.

Performance: Reliability, Resilience, Vulnerability [Hashimoto et al. 1982]

Equity: Consideration of multiple perspectives, meeting different purposes for a design

Example:

Optimizing Pumping and Releases in a Multi-Reservoir Supply Network

Rebecca Smith, Joseph Kasprzyk, Edie Zagona

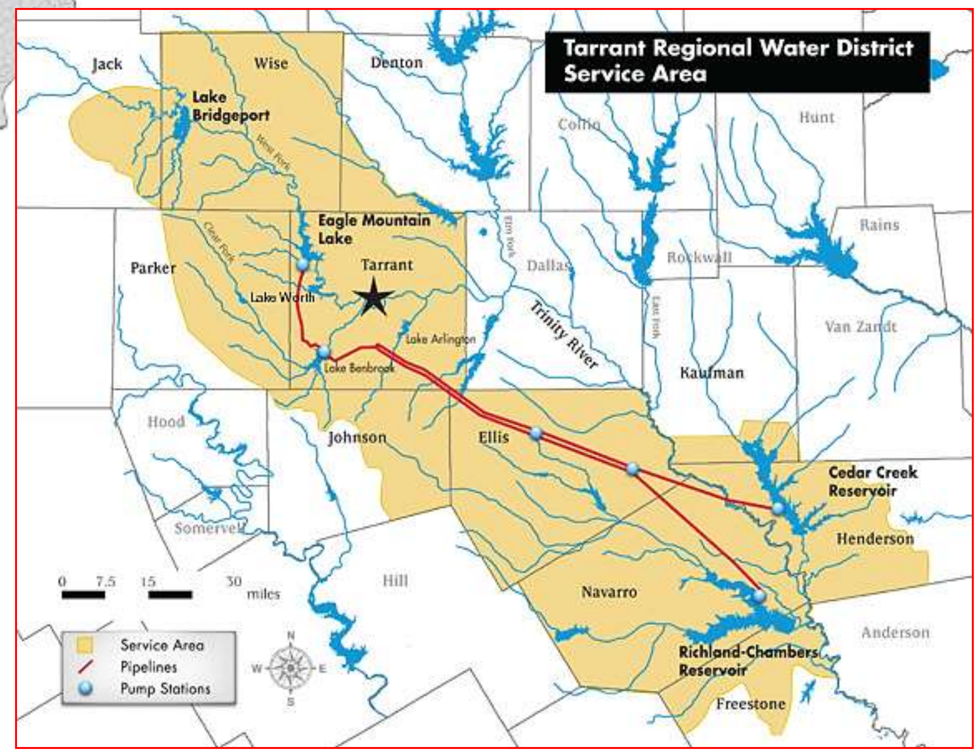
Smith MS Thesis (2014)
In Prep, Journal of Water Resources Planning and Management

CADSWES trwd Tarrant Regional Water District Hydros Consulting

Photo: http://www.awilliamsmediaarchive.com/drought-lake-bridgeport-#/id/i6675161

Tarrant Regional Water District (TRWD)

- Provides raw water to 30 water treatment plants
  - —More than 1.8 million customers served
  - —Includes Ft. Worth and Arlington
- Challenges
  - —2011-2014: most severe Texas drought on record
  - —Projected regional population increase of 37% by 2030



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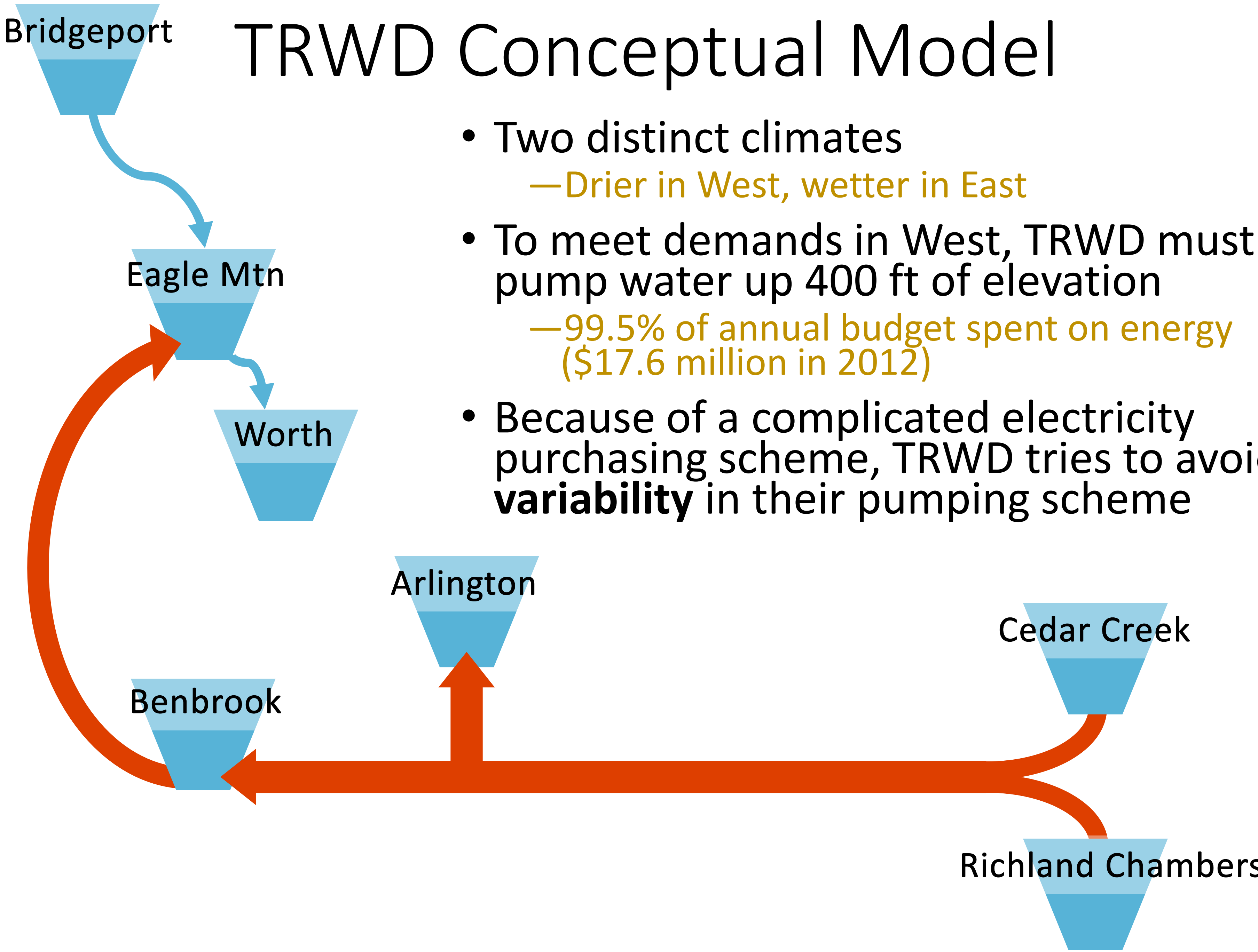
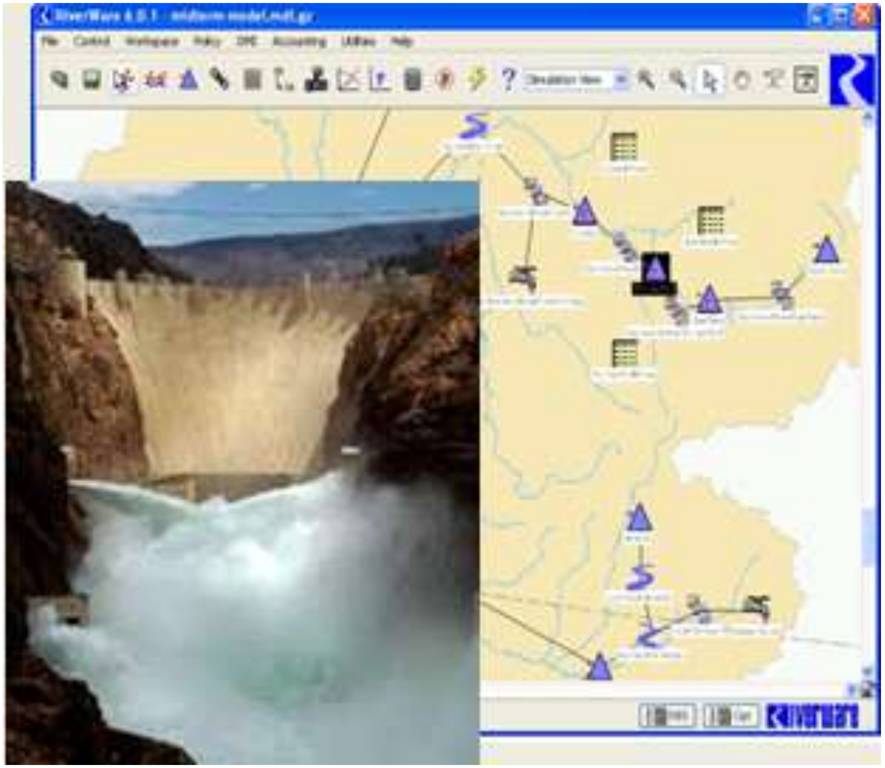
TRWD Conceptual Model

- Two distinct climates
  - Drier in West, wetter in East
- To meet demands in West, TRWD must pump water up 400 ft of elevation
  - 99.5% of annual budget spent on energy ($17.6 million in 2012)
- Because of a complicated electricity purchasing scheme, TRWD tries to avoid **variability** in their pumping scheme



General purpose software such as RiverWare is often used to model multi-reservoir systems operationally.

- Nodes (water storage) and links (conveyance)
- Includes operational rules, accounting of water rights
- Multiple run manager for multiple sets of input data



For more info:
http://cadswes.colorado.edu/

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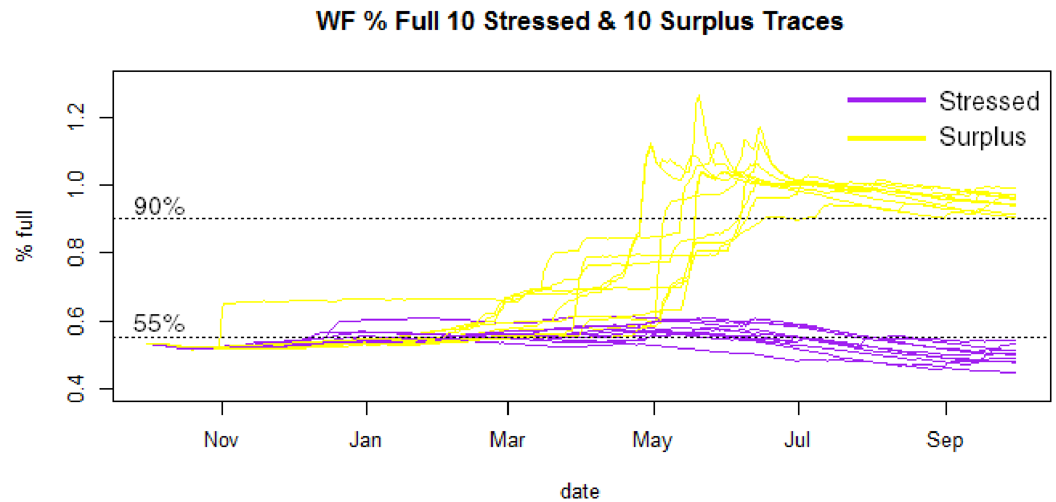
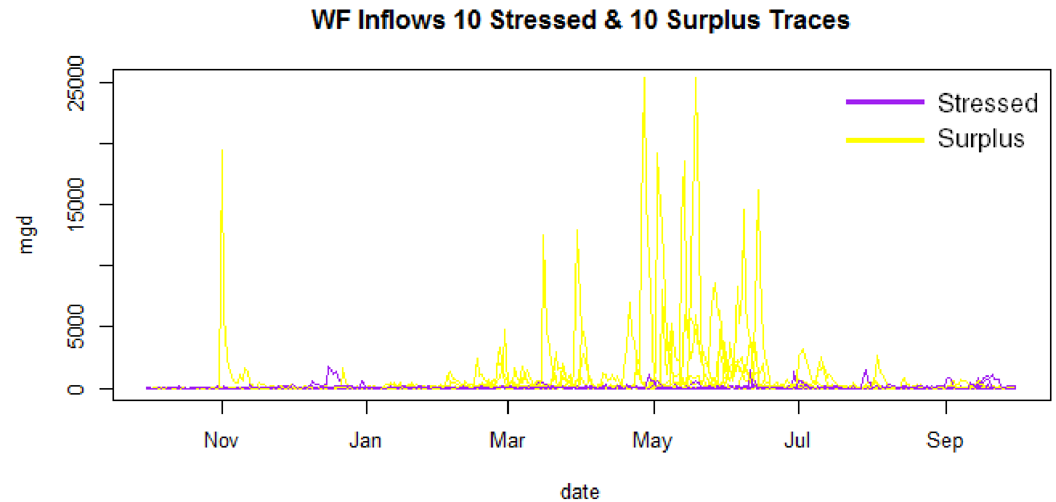
We consider hydrologic variability by using ‘stressed’ and ‘surplus’ scenarios.

- Stochastic generation of hydrologic traces
- Split up scenarios by West Fork %Full





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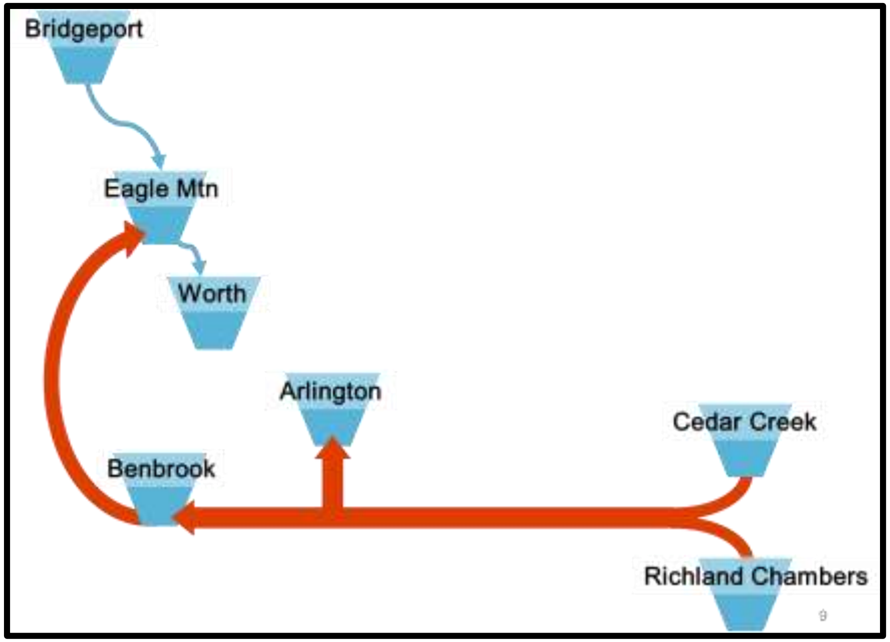
Decision Variables

- Balancing variables
  - —Storage zones that balance Eagle Mountain and Bridgeport
  - —Desired elevations for Worth
- Supplementation variables
  - —Eagle Mountain Trigger Rates
  - —Pump Rates



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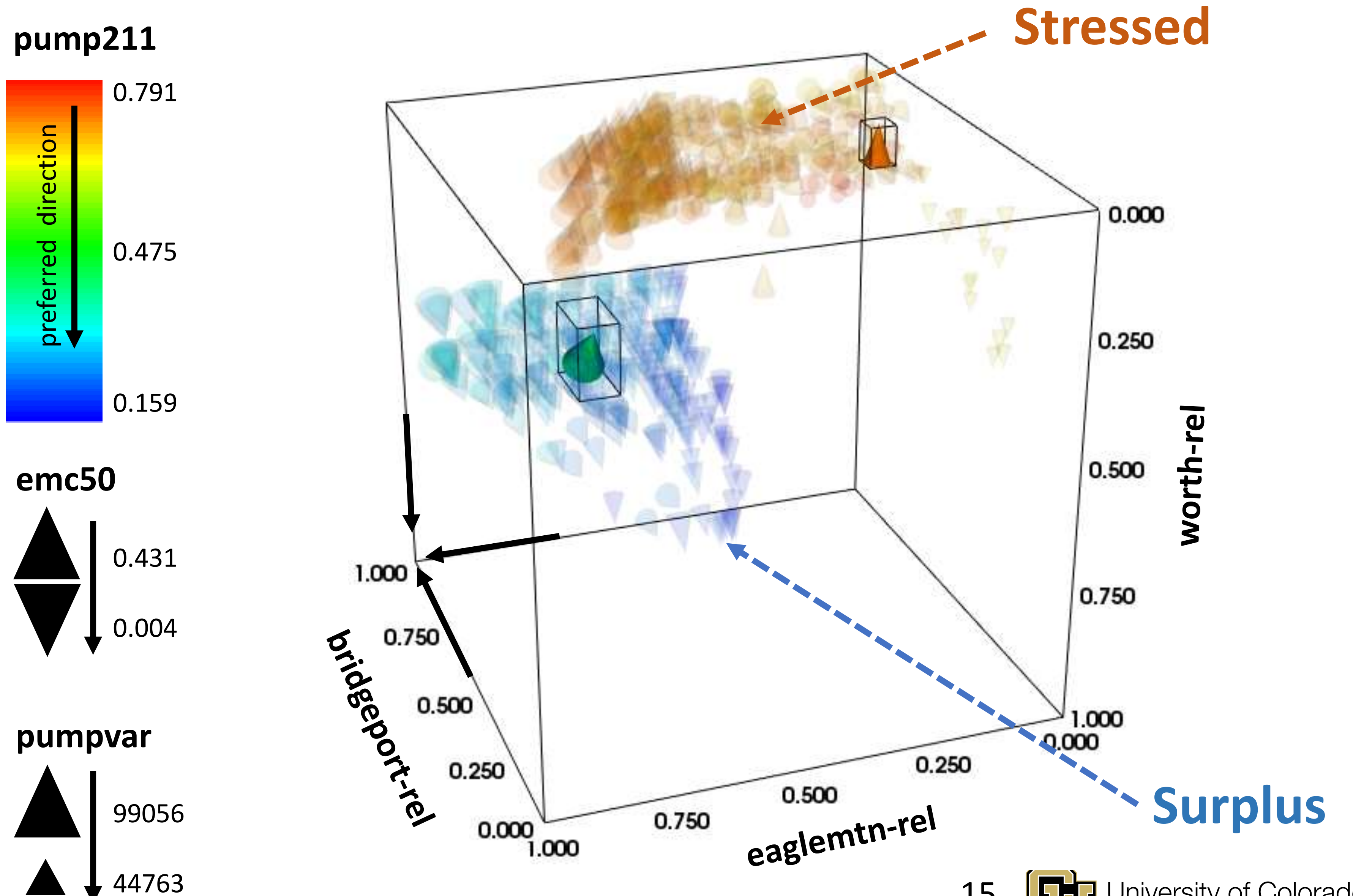
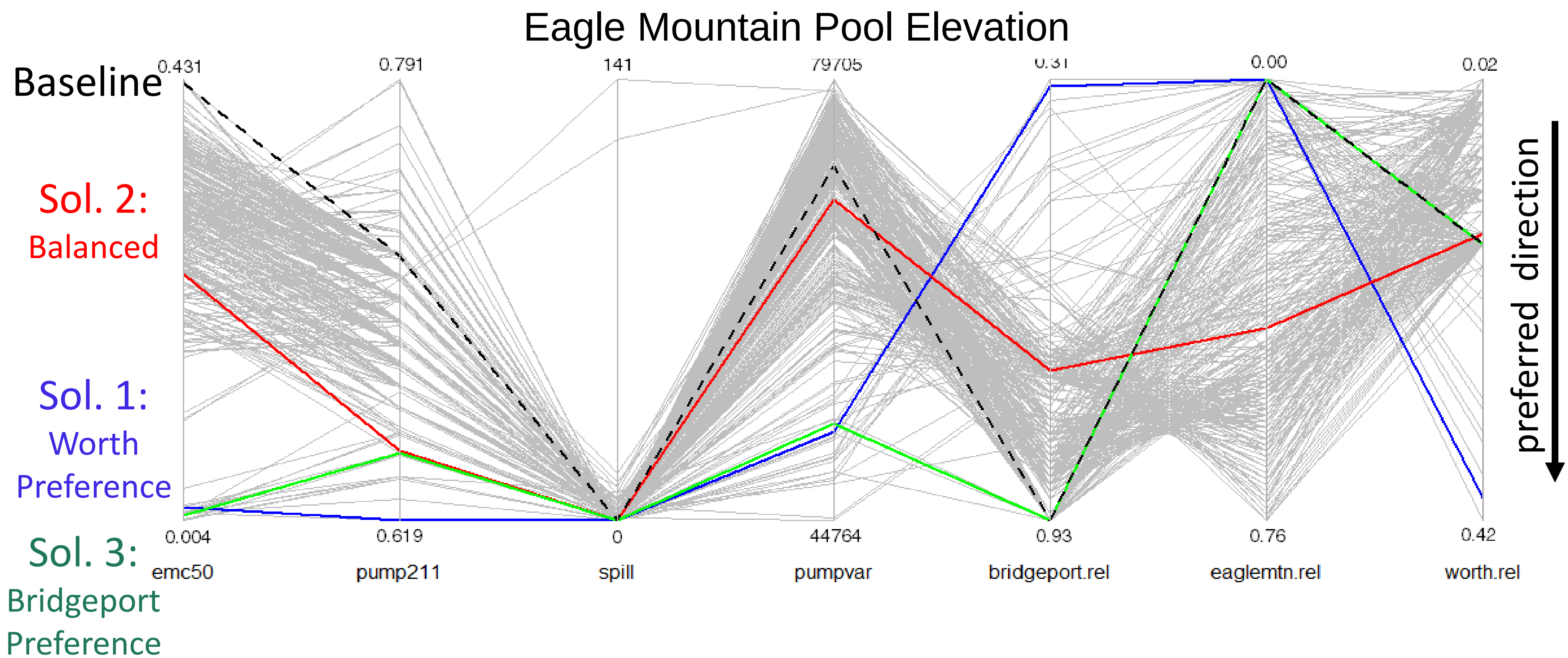
Stressed & Surplus: Comparing results to baseline (boxed)



Stressed: Detailed Comparison



Each solution is a straight line, and when solutions' lines cross this indicates a conflict between objectives!

TRWD Study Implications

- TRWD can implement individual solutions into their planning model
- Tradeoff analysis facilitated new **learning** about system dynamics
  - Example: TRWD was favoring Bridgeport storage during drought
- It is helpful to add the utility's input into this process
  - Some management alternatives may be impossible to implement
- Integration of MOEA and complex model was successful and can lead to further integrated studies
  - Adding energy planning, rainfall-runoff modeling…

Acknowledgements: Rebecca Smith (CU), John Carron, Nick Mander (Hydros Consulting); Laura Blaylock (TRWD); Edie Zagona, Bill Oakley, Neil Wilson, Jim Pasquotto, Gwen Miller (CADSWES)

Balancing Severe Decision Conflicts under Climate Extremes in Water Resource Management

Funded by the NOAA Sectoral Applications Research Program (SARP)

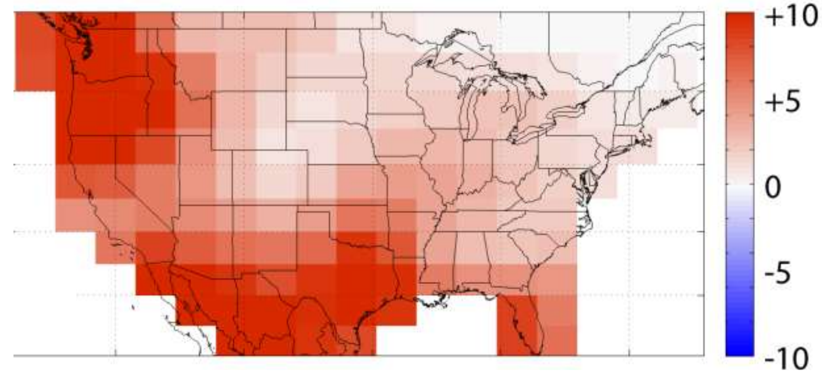
PI: Lisa Dilling

Team: Joseph Kasprzyk, Imtiaz Rangwala, Eric Gordon, Kristen Averyt (CU), Laurna Kaatz (Denver Water), Leon Basdekas (Colorado Springs Utilities)

Graduate Assistant: Rebecca Smith

Motivation

- Increasing calls for decision support for climate;
- Managers are interested in new tools like MOEAs, but they have not been extensively tested



GCM ensemble estimate of change in maximum consecutive dry days per year, between 2080-2099 and 1950-2000, from [Kollat et al. 2012]

Is Multiobjective Optimization Ready for Water Resources Practitioners? Utility's Drought Policy Investigation

Leon Basdekas, Ph.D., P.E., M.ASCE

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DOI: 10.1061/(ASCE)WR.1943-5452.0000415

To illustrate the ability of a midsized water utility to use a

leading to dramatic increases in Colorado River Basin snow pack. While some residents questioned the need for watering restrictions in light of the storms, total seasonal snowpack remained below normal, resulting in the need for continued restrictions. This example of short-term uncertainty exemplifies the need for robust and flexible operational policies, along with analytical methods capable of supporting the necessary complexity. While more traditional Monte Carlo–type analyses may still play a role in risk assessments

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Project Plan

- **Initial Workshop** with water managers
- **Testbed:** Develop a representative system to test
- **Final Workshop** to receive feedback

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We have partnered with an array of water utilities in the Front Range.

http://www.coloradoan.com/story/news/local/2014/07/17/northern-water-opts-gradual-rate-increase/12813261/

BOULDER WATER UTILITIES DIVISION

https://bouldercolorado.gov/water

AURORA COLORADO
your city, your community, your home

https://www.auroragov.org/LivingHere/Water/

Colorado Springs Utilities
It's how we're all connected

https://www.csu.org/

DENVER WATER

http://www.denverwater.org/

City of Fort Collins

http://www.fcgov.com/utilities/

Goal: Better enable MOEAs to be able to affect real management decision. Surveys and the testbed will hopefully provide 'best practices' for implementation.

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Acknowledgements

Thanks! Questions?

- TRWD Reservoir Planning
  - Rebecca Smith (CU), John Carron, Nick Mander (Hydros Consulting); Laura Blaylock (TRWD); Edie Zagona, Bill Oakley, Neil Wilson, Jim Pasquotto, Gwen Miller (CADSWES)
- NOAA SARP project
  - Rebecca Smith, Lisa Dilling, Imtiaz Rangwala, Eric Gordon, Kirsten Averyt (CU); Laurna Kaatz (Denver Water), Leon Basdekas (Colorado Springs Utilities)
- Other Collaborators
  - Patrick Reed, Jon Herman (Cornell) Greg Characklis (University of North Carolina); Joshua Kollat (DecisionVis, LLC); David Hadka (Penn State)

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Extra Slides

Too Many Proposals Pass the Benefit Cost Test

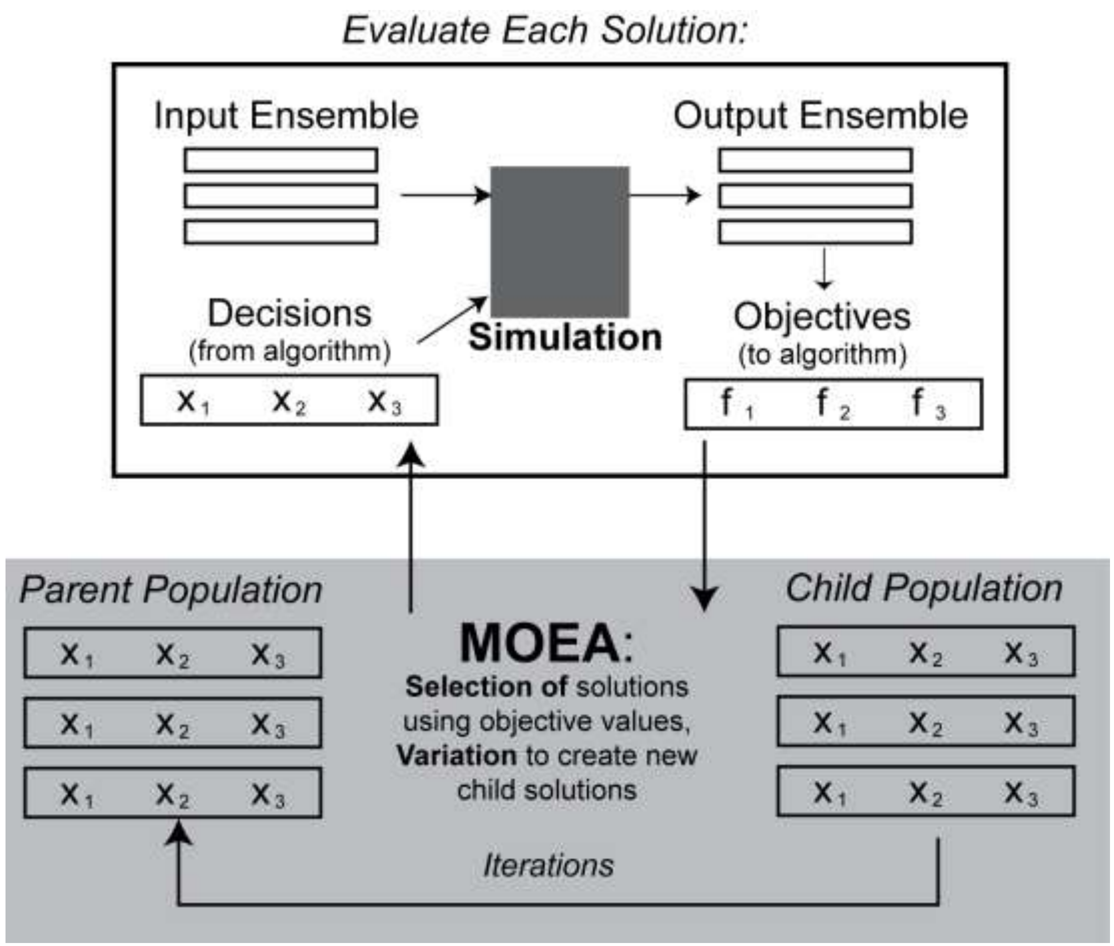
By John P. Hoehn and Alan Randall*

- Each federal agency evaluates policies independently (with their own agenda)
- As the number of policy proposals becomes large, the net benefits become overstated
- Many possible alternatives, but limited productive capacity of the economy

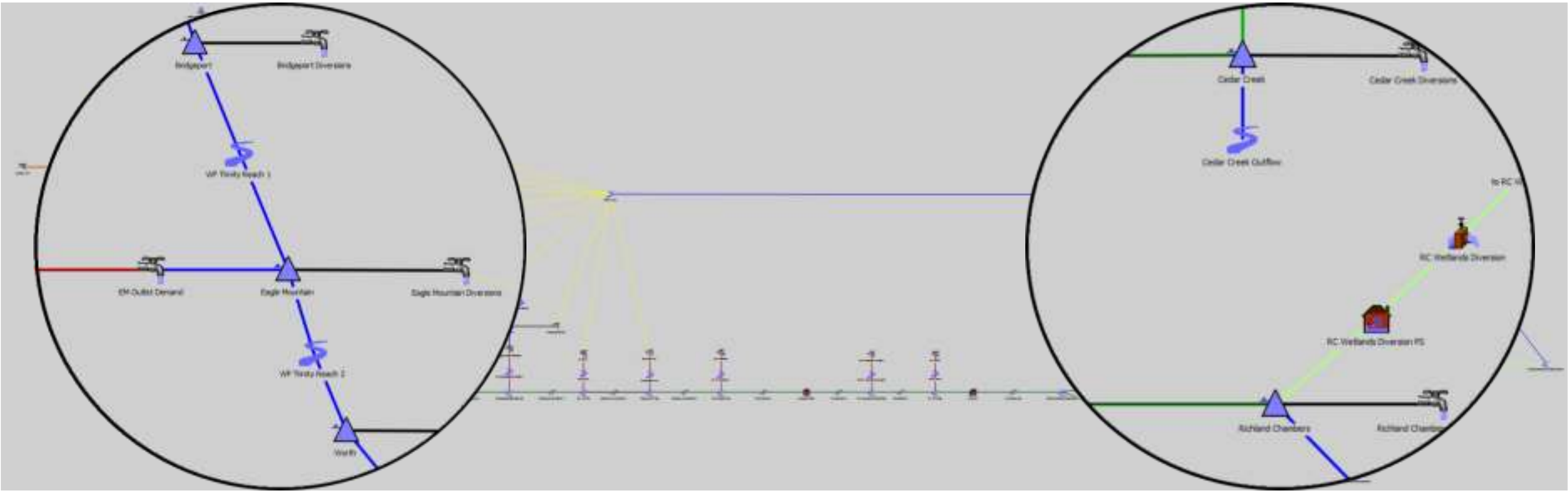
 [Hoehn and Randall 1989]

Multiobjective Evolutionary Algorithms (MOEAs)

- Global search
- Effective on difficult problems, e.g.:
  - —Many-Objective (>4 objectives)
  - —Non-linear
  - —Stochastic
- Can embed complex system representations



TRWD uses a specific model schematic within RiverWare for their planning.



The figure shows a more detailed version of the TRWD schematic, including multiple demands and hydrologic inputs

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Computational Setup

- Detailed representation of the system embedded directly into the Borg MOEA
  - —Similar to TRWD's use, consider 1 year simulation at daily time step
- **Challenge:** Approx. 2 min per evaluation of stochastic ensemble
  - —Limit the search duration, with visualizations of search progress
  - —~3000 function evaluations (4 days per run, on 12-core machine)
- Two hydrologic scenarios chosen based on baseline response:
  - —Stressed
  - —Surplus

mwomercs.com

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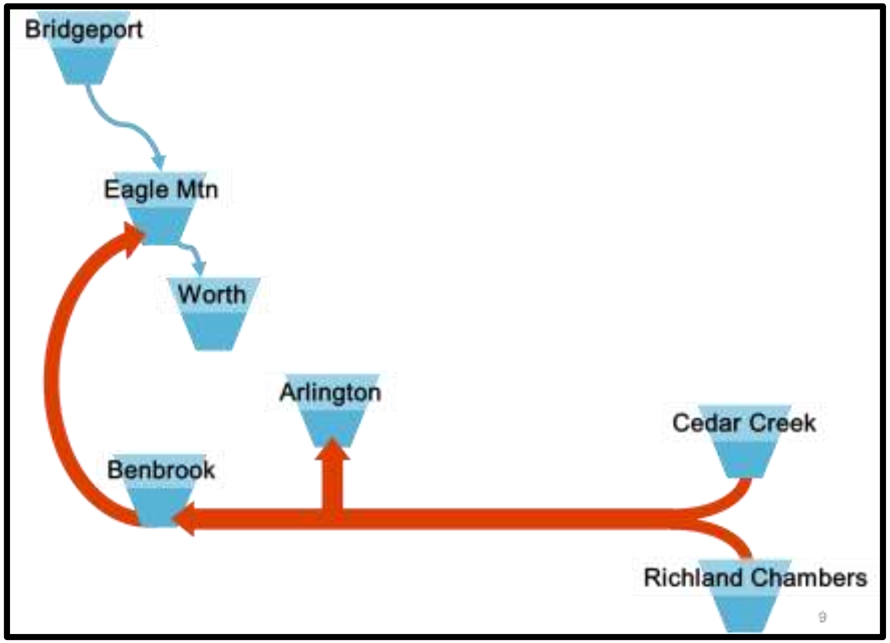
Problem Formulation: Initial Objectives

- Our discussions indicated that TRWD looked at the system as a whole
  - Objectives are discovered as part of the planning process itself! [Hitch, 1960; Liebman, 1976]
- Started with four objectives
  - Minimize occurrence of large supplementation (*emc50*)
  - Minimize occurrence of high pumping rates (*pump211*)
  - Minimize variation in pumping rates (*pumpvar*)
  - Minimize wasted pumping (*spill*)



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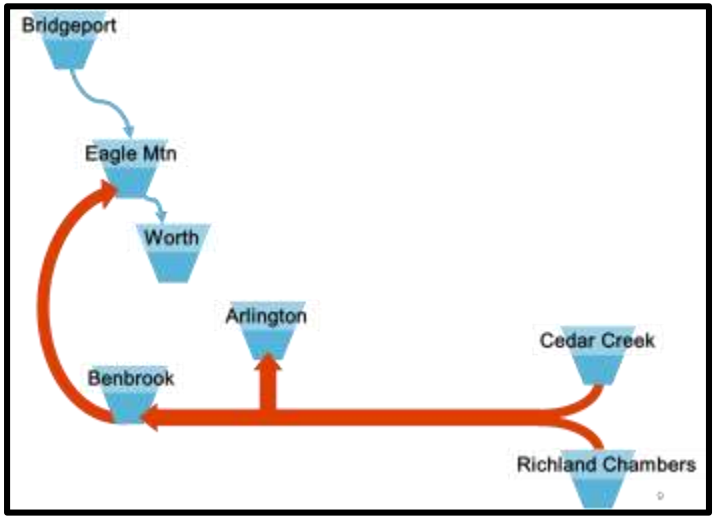
Problem Formulation: Revised Objectives

- Systemwide objectives
  - —Minimize occurrence of large supplementation (*emc50*)
  - —Minimize occurrence of high pumping rates (*pump211*)
  - —Minimize variation in pumping rates (*pumpvar*)
  - —Minimize wasted pumping (*spill*)
- Reliability objectives help keep reservoirs balanced
  - —Bridgeport (*bridgeport-rel*, 811.0 ft, for release purposes)
  - —Eagle Mountain (*eaglemtn-rel*, 644.1 ft, for recreation)
  - —Worth (*worth-rel*, 590.0 ft, for regulatory considerations)



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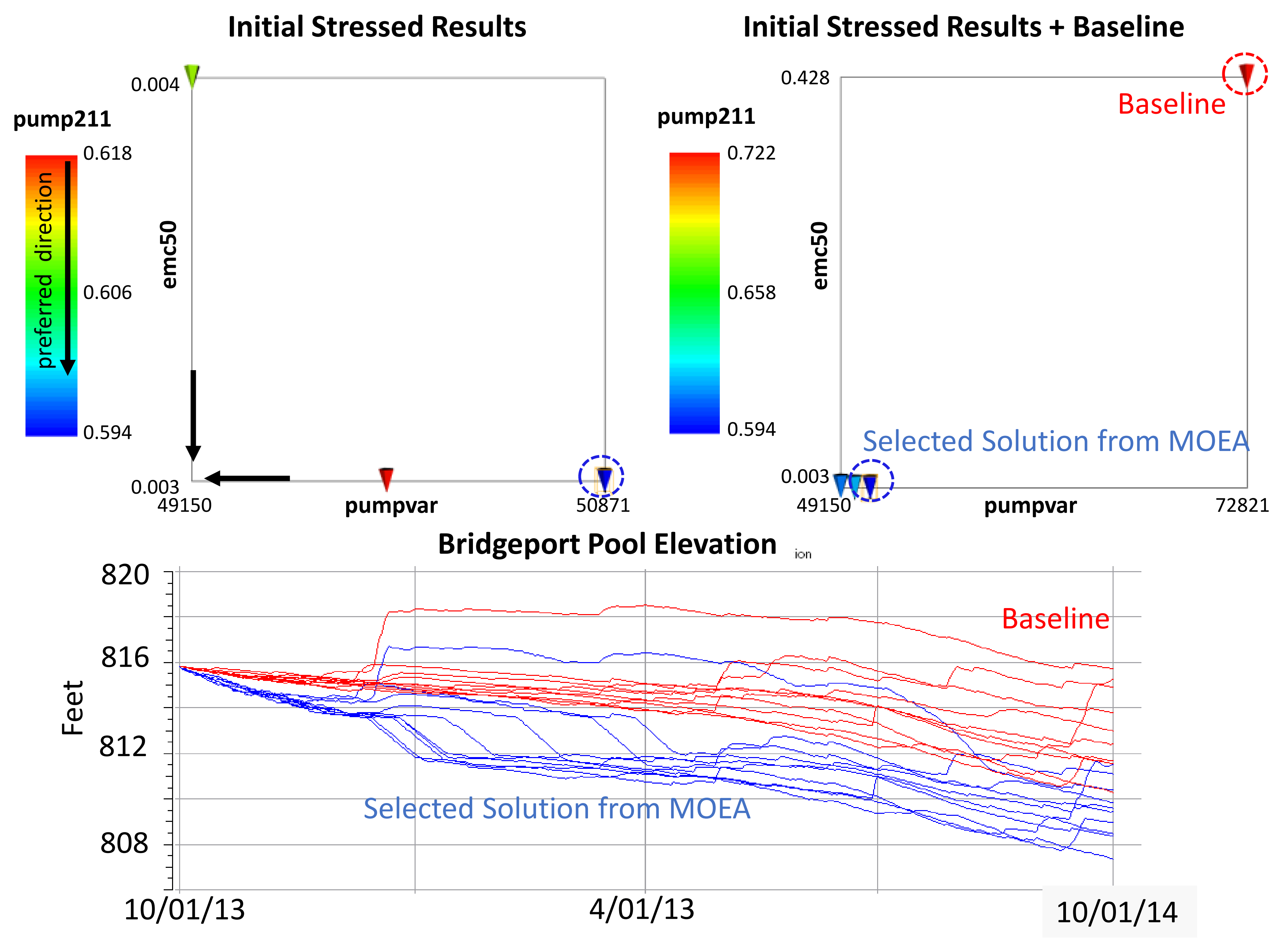
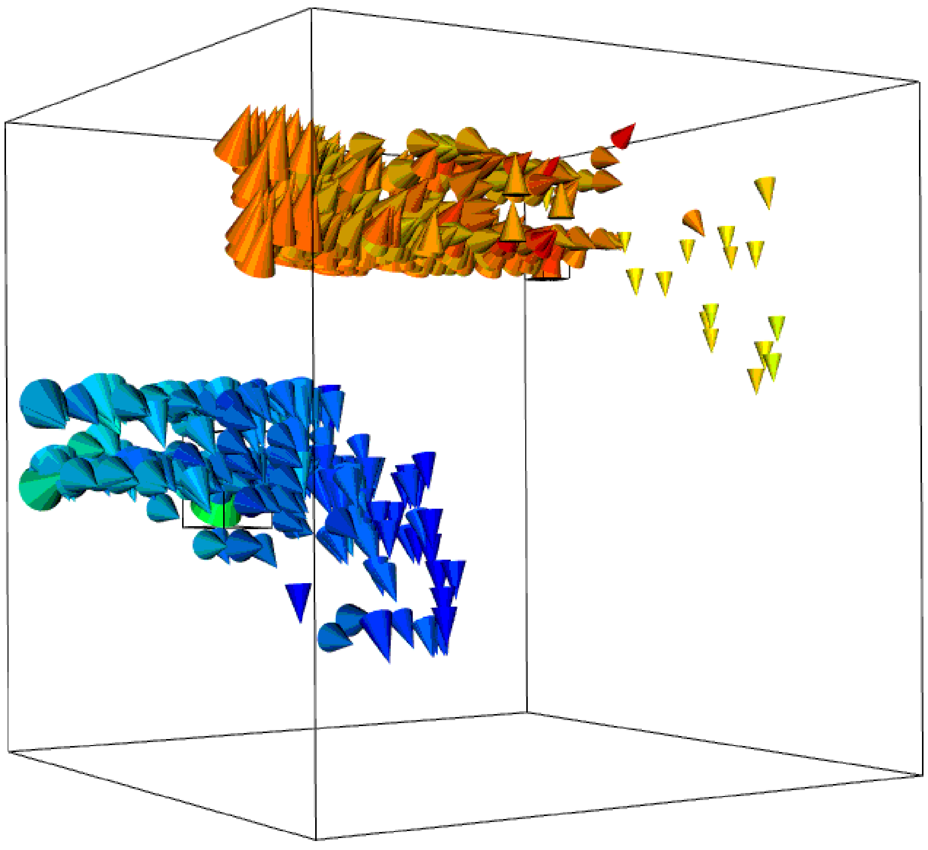
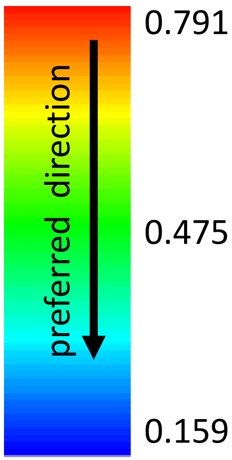


Initial Stressed Results
Initial Stressed Results + Baseline
pump211
0.618
0.606
0.594
preferred direction
0.004
0.003
emc50
49150
pumpvar
50871
pump211
0.722
0.658
0.594
0.428
0.003
emc50
Baseline
Selected Solution from MOEA
49150
pumpvar
72821
Bridgeport Pool Elevation
820
816
812
808
Feet
Baseline
Selected Solution from MOEA
10/01/13
4/01/13
10/01/14



Visualizing objectives

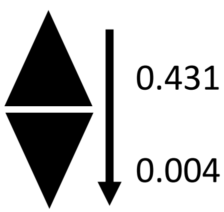
pump211



System-wide Metrics

Color shows the amount of time there is high pumping (*pump211*)

emc50

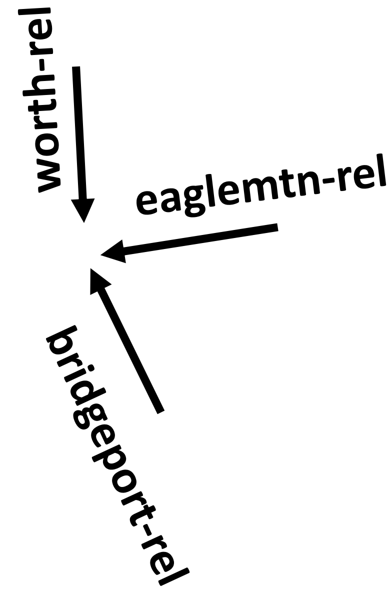


Orientation shows *emc50*, the amount of time that there is more than 50 mgd of supplementation to Eagle Mountain

pumpvar

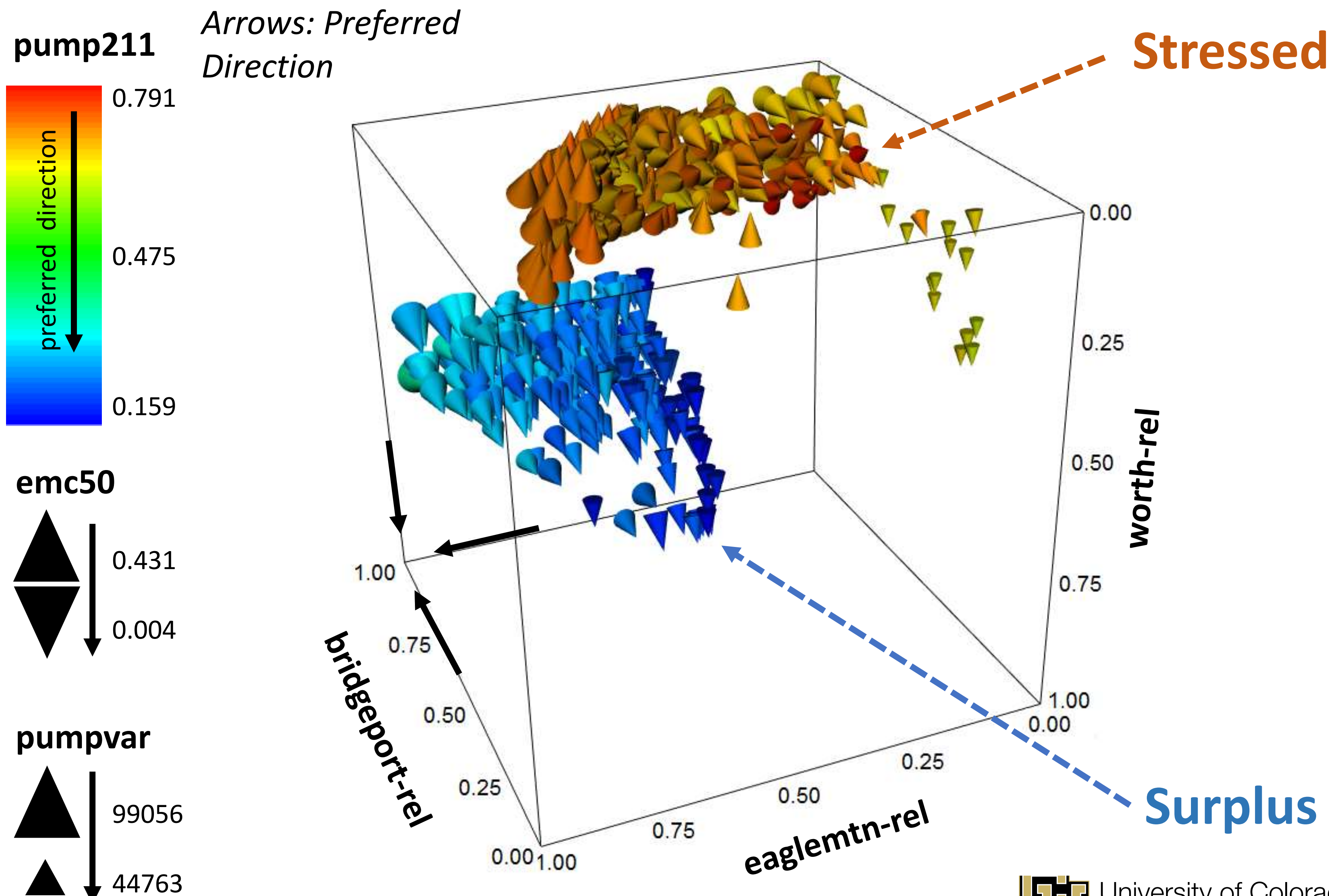
Size shows *pumpvar*, a measure of variance of pumping.

Individual Reservoirs



Spatial axes show reservoir reliabilities, which calculate the amount of time storage is above desired targets.

Stressed & Surplus: Results



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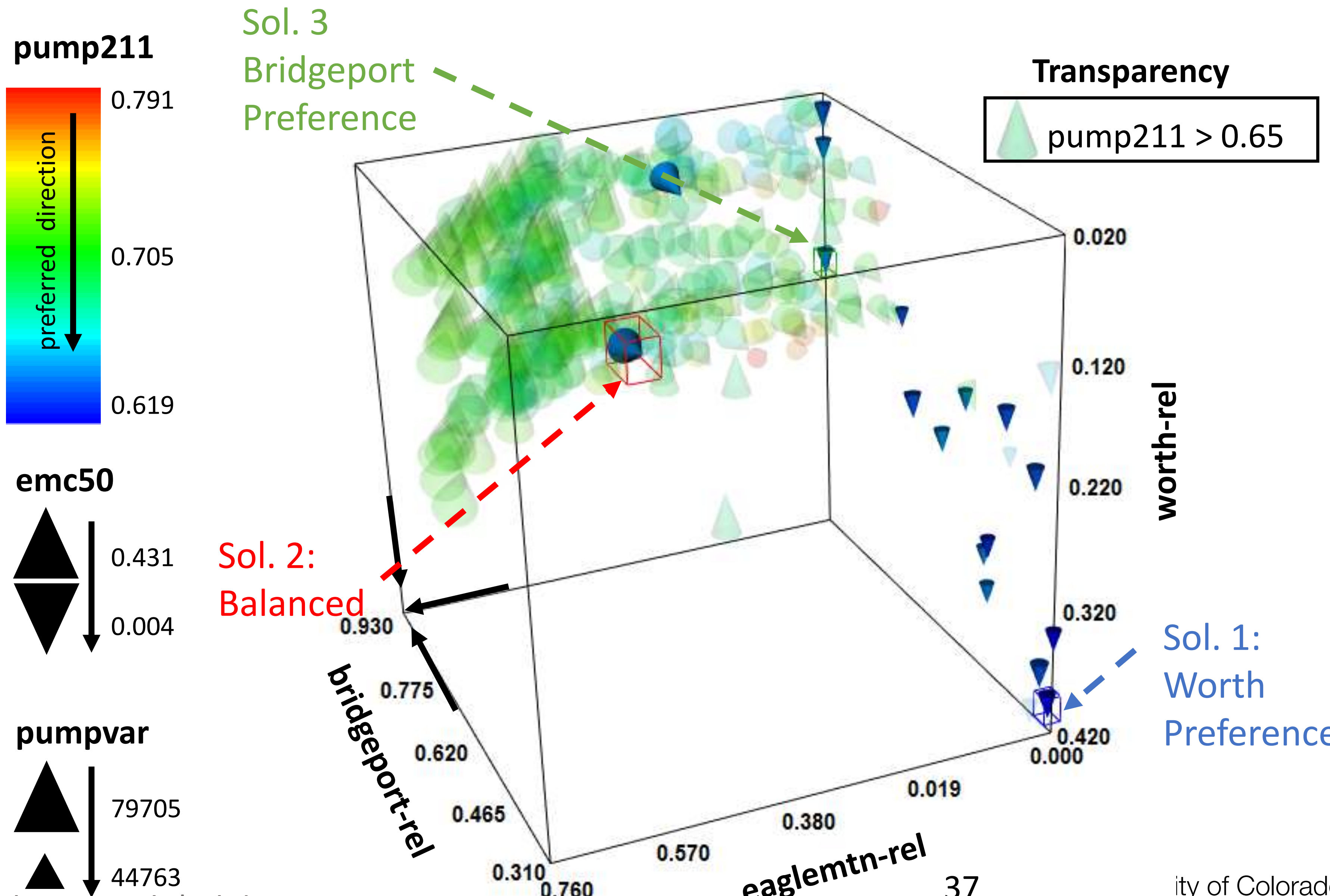
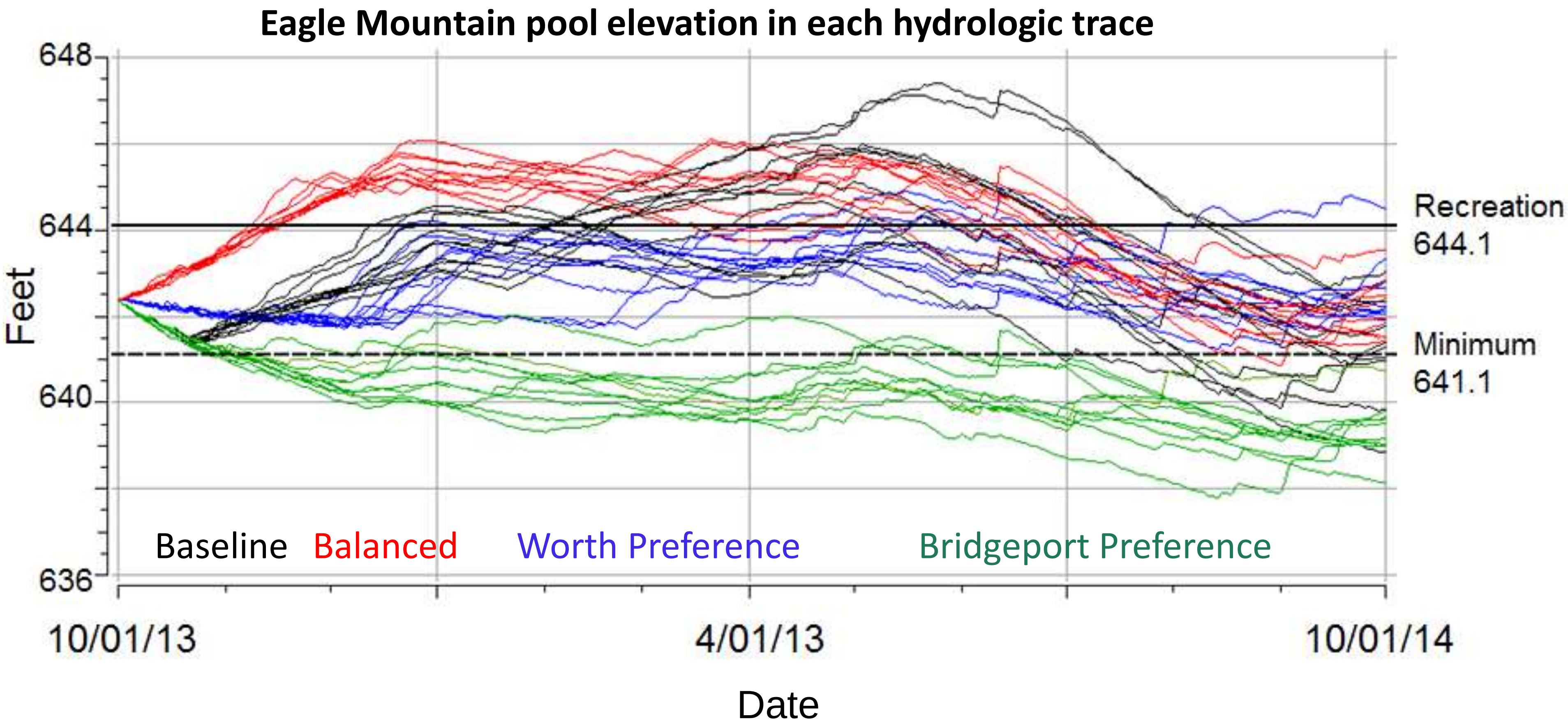
Stressed: Set Exploration



Other plotting mechanisms in the simulation model help us explore the results.



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	Sol.150	Sol.87	Sol.77	Baseline
Objectives				
emc50	0.016	0.243	0.008	0.428
pump211	0.619	0.646	0.645	0.722
spill	0.000	0.000	0.000	0.000
pumpvar	51738.585	70175.718	52401.700	72821.251
bridgeport-rel	0.320	0.720	0.930	0.930
eaglemtn-rel	0.000	0.430	0.000	0.000
worth-rel	0.400	0.160	0.170	0.170
Decision Variables				
emzone1	645.860	644.814	644.179	644.100
emzone2	647.164	645.362	644.425	644.100
emzone3	647.518	647.949	647.044	648.100
bpzone1	813.691	815.747	820.036	821.000
bpzone2	817.985	819.614	827.152	826.000
bpzone3	830.056	832.790	828.873	836.000
emtrigdry1	641.425	641.390	641.155	643.100
emtrigdry2	641.457	641.809	641.195	645.100
emtrigdry3	645.994	644.666	642.058	647.100
emtrigav1	642.076	642.675	641.281	641.100
emtrigav2	642.780	642.965	641.839	643.100
emtrigav3	644.380	643.871	642.674	645.100
emtrigwet1	641.100	641.115	641.201	641.100
emtrigwet2	641.137	641.194	641.258	643.100
emtrigwet3	641.821	642.669	647.266	645.100
emcrate1	48.076	200.000	28.399	150.000
emcrate2	46.898	197.008	2.836	100.000
emcrate3	18.813	194.292	1.202	75.000
worthlev1	590.410	590.236	590.366	590.000
worthlev2	590.783	590.411	590.492	591.000
worthlev3	590.985	590.442	590.761	591.500
worthlev4	591.108	590.516	591.345	592.000
worthlev5	591.256	590.677	592.836	593.000
worthlev6	591.475	590.744	592.836	593.000