Many-Objective de Novo Water Supply Portfolio Planning under Deep Uncertainty

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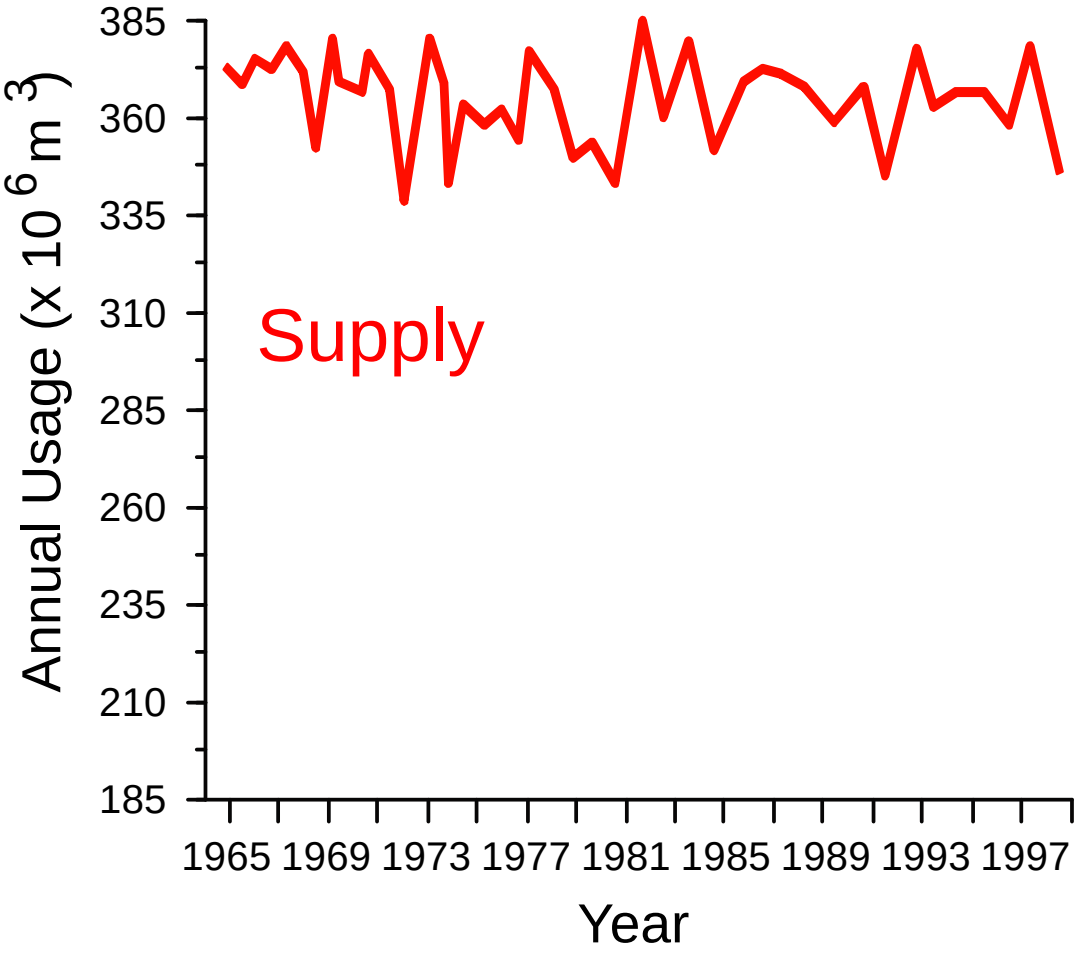
For additional information, refer to:

Kasprzyk, J. R., Reed, P. M., Kirsch, B. R., and Characklis, G. W., "Many-Objective de Novo Water Supply Portfolio Planning Under Deep Uncertainty." Environmental Modelling & Software, (In-Press).

Note:

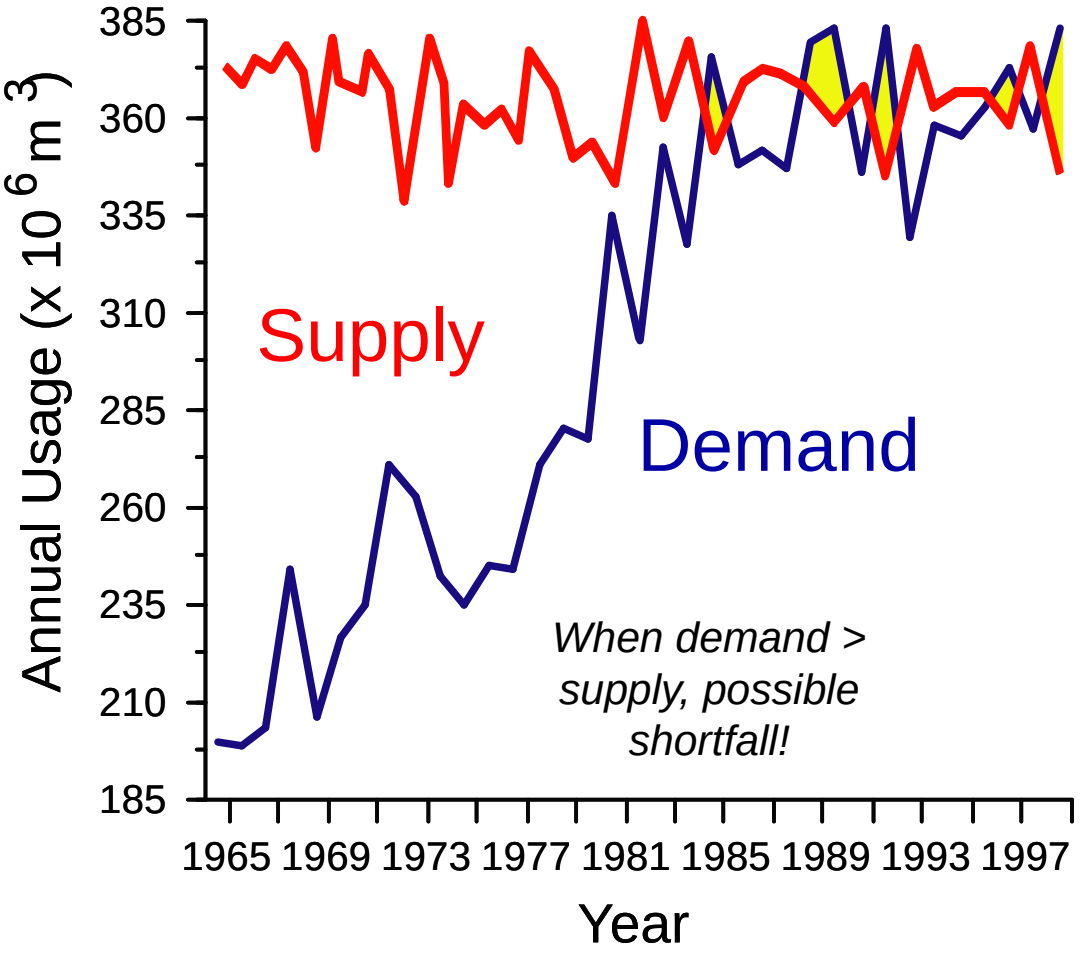
This presentation has been slightly modified from its original version in order to better suite the static nature of PDF format.

Water Marketing in Texas, USA



- Lower Rio Grande Valley
- Rapid urban population growth and high irrigation water use
- Existing water market with transfers from ag. to urban
- Research goal: help a **single city** use the water market more effectively

Water Marketing in Texas, USA



- Lower Rio Grande Valley
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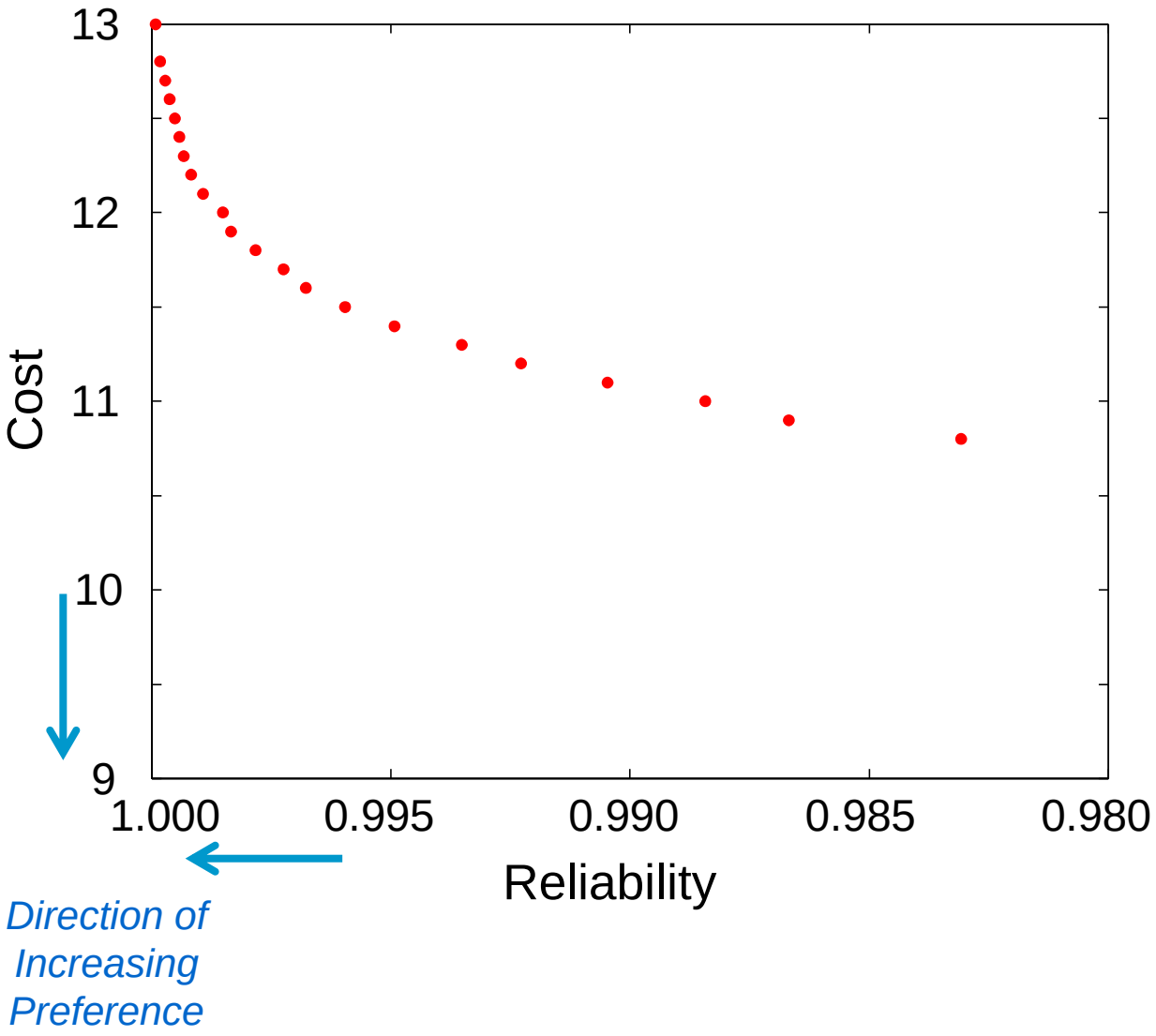
Water Marketing in Texas, USA

- Three water supply instruments:
  - **Permanent rights**: traditional non-market supply (% of reservoir inflows)
  - **Spot leases**: immediate transfers of water, variable price
  - **Adaptive options contract**: reduces lease-price volatility (similar to European call stock option)
- Monte Carlo simulation with monthly timestep for 10-year horizon and extreme drought scenario, sampling uncertain historical data:
  - Reservoir inflows (allocations to rights)
  - Changes in reservoir level
  - Water demands
  - Lease pricing

Deep Uncertainty

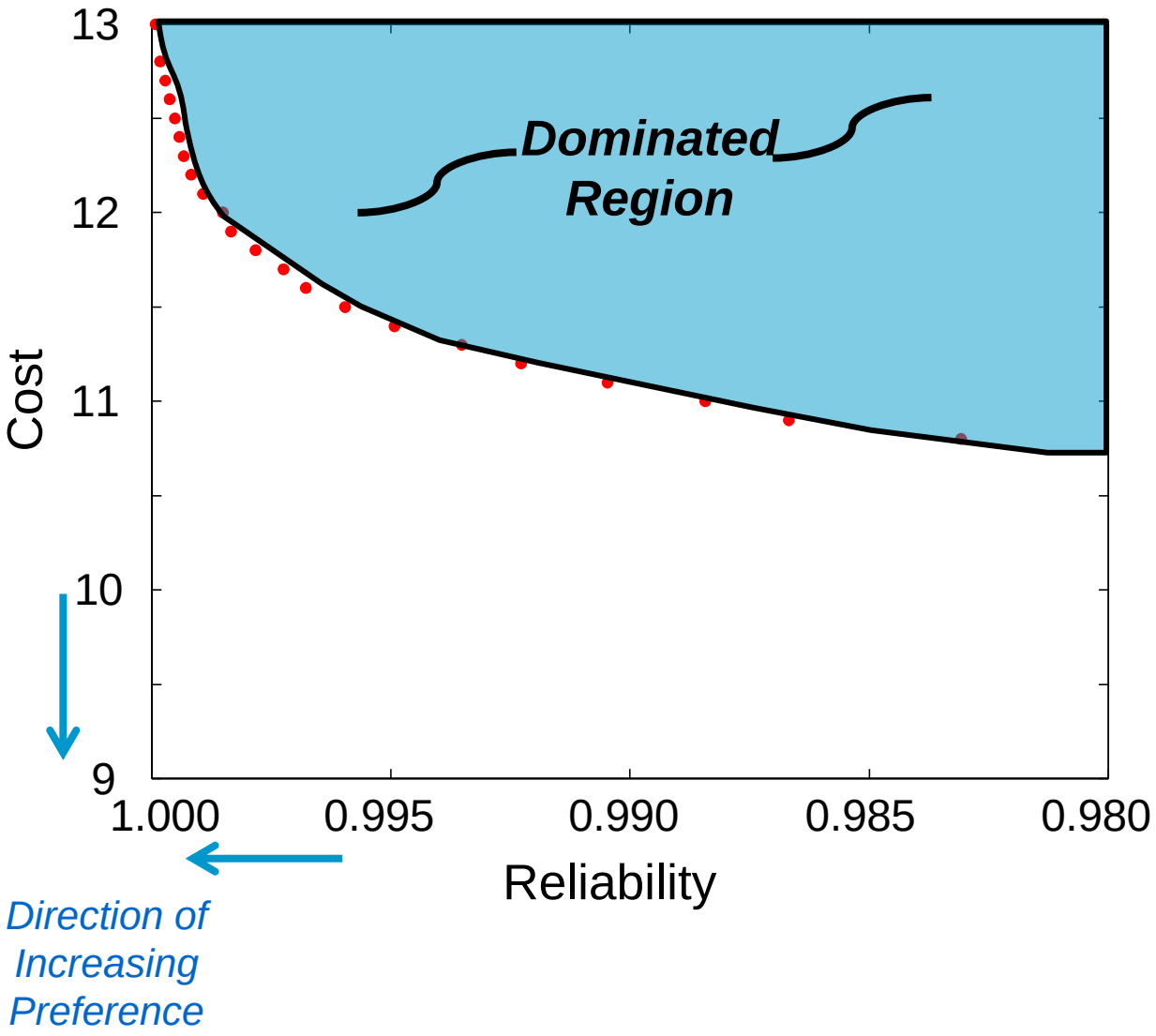
- Deep/Knightian Uncertainty originated with discussion in [Knight, 1921]
  - Decision makers cannot conceptualize every potential risk in addition to probabilities of those risks [Langlois and Cosgel, 1993]
- This work uses alternative formulations of a city's decision strategies to:
  - Develop robust solutions with good performance under many modeling conditions
  - Explore effects of decision makers' estimated probabilities on planning process

Multi-Objective Tradeoffs



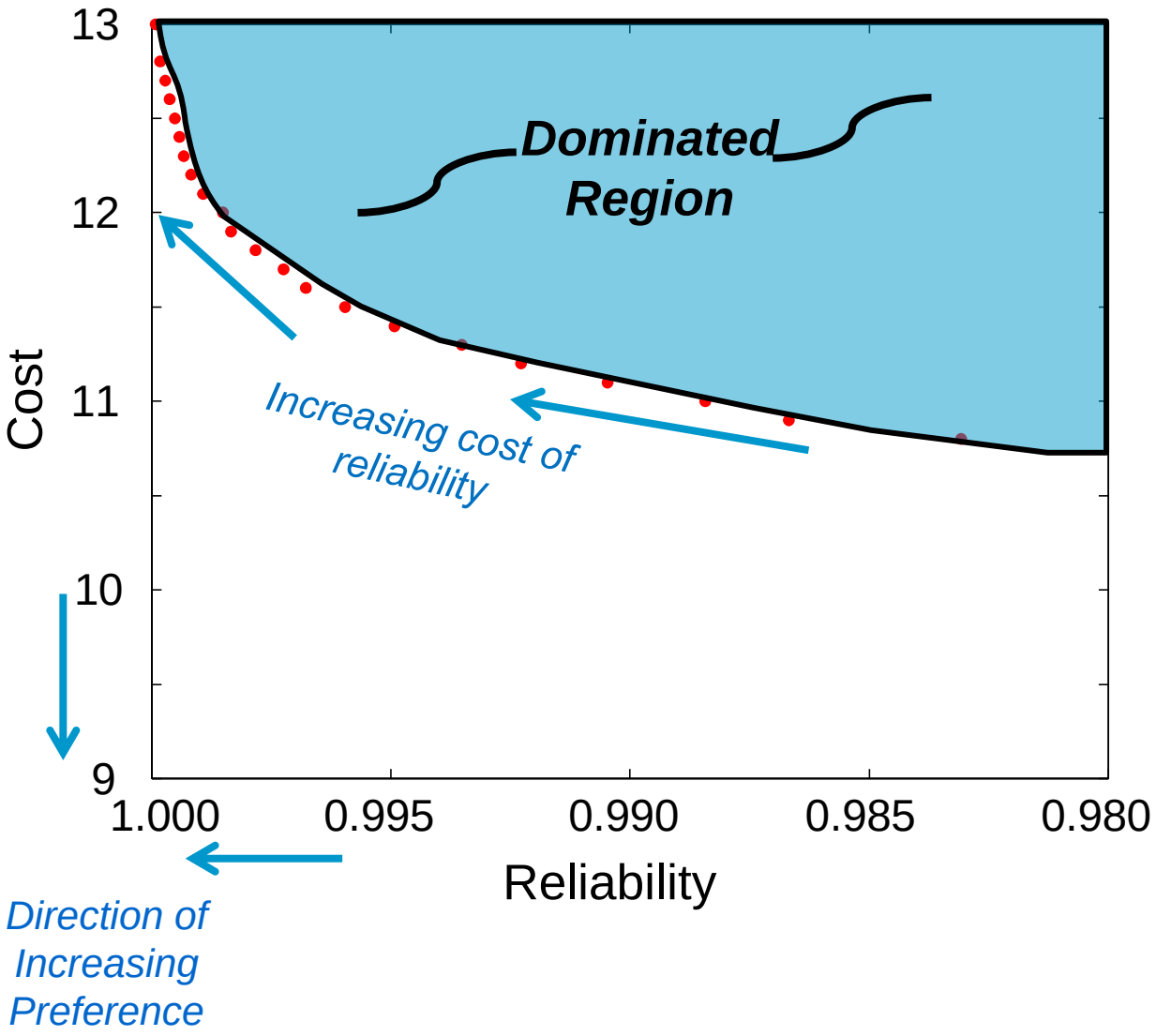
- Each point is a different water supply portfolio

Multi-Objective Tradeoffs



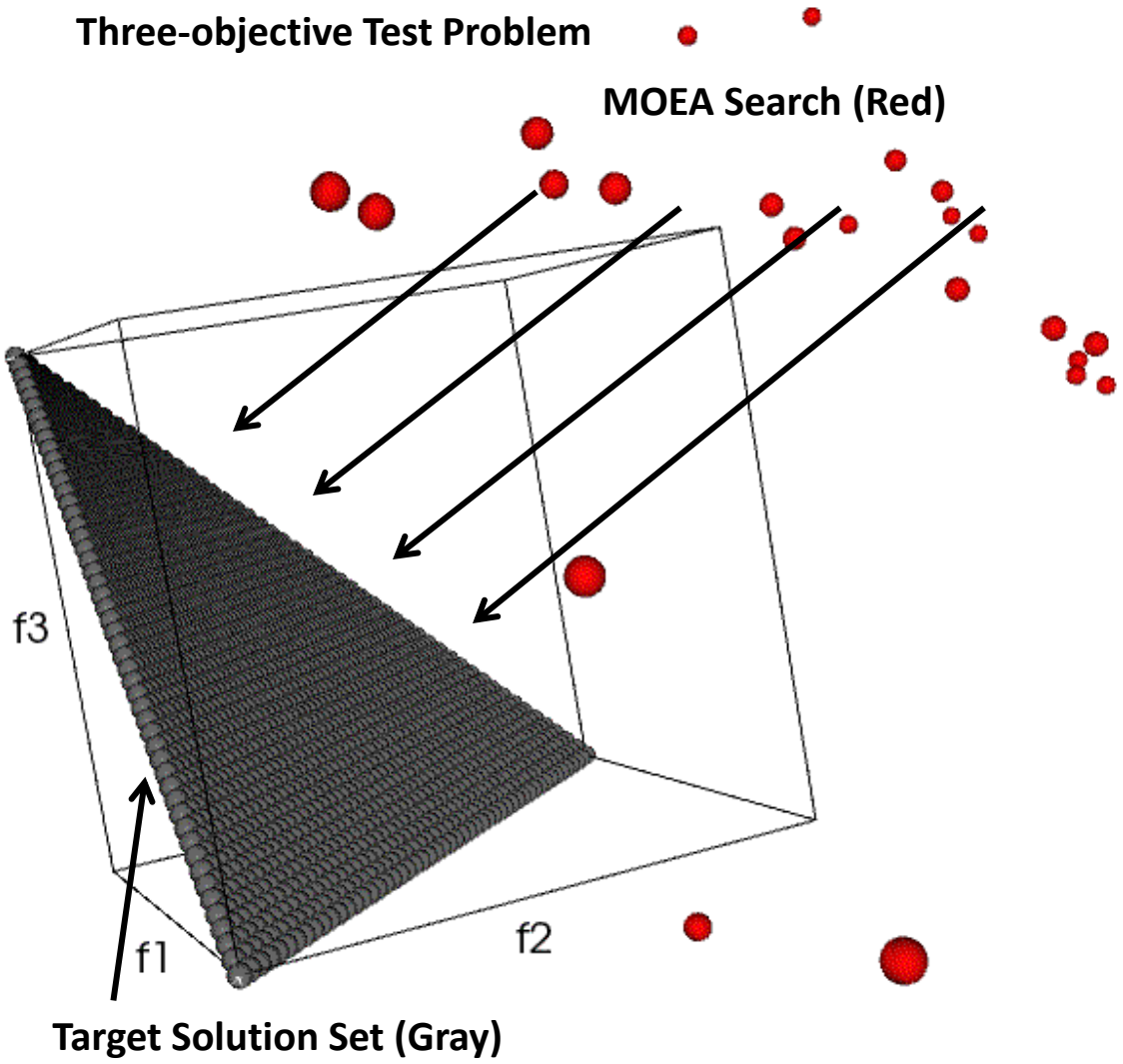
- Each point is a different water supply portfolio
- Non-dominated or Pareto set

Multi-Objective Tradeoffs



- Each point is a different water supply portfolio
- Non-dominated or Pareto set
- Shows increasing cost of added reliability

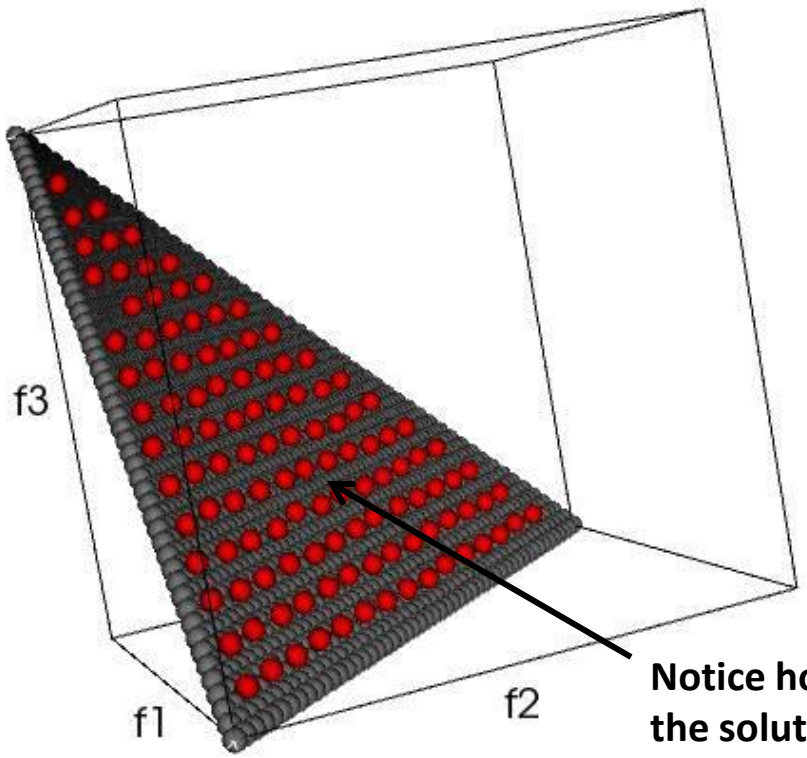
Many-Objective Search Illustration



- Multi-Objective Evolutionary Algorithms (MOEAs)
  - Intelligent search
  - Effective where other search techniques fail
- ε-NSGAII
  - Fast, efficient, effective
  - Can be used with supercomputers or desktop computing

Many-Objective Search Illustration

Three-objective Test Problem



Notice how it not only finds the solution, but also distributes itself across the solution.

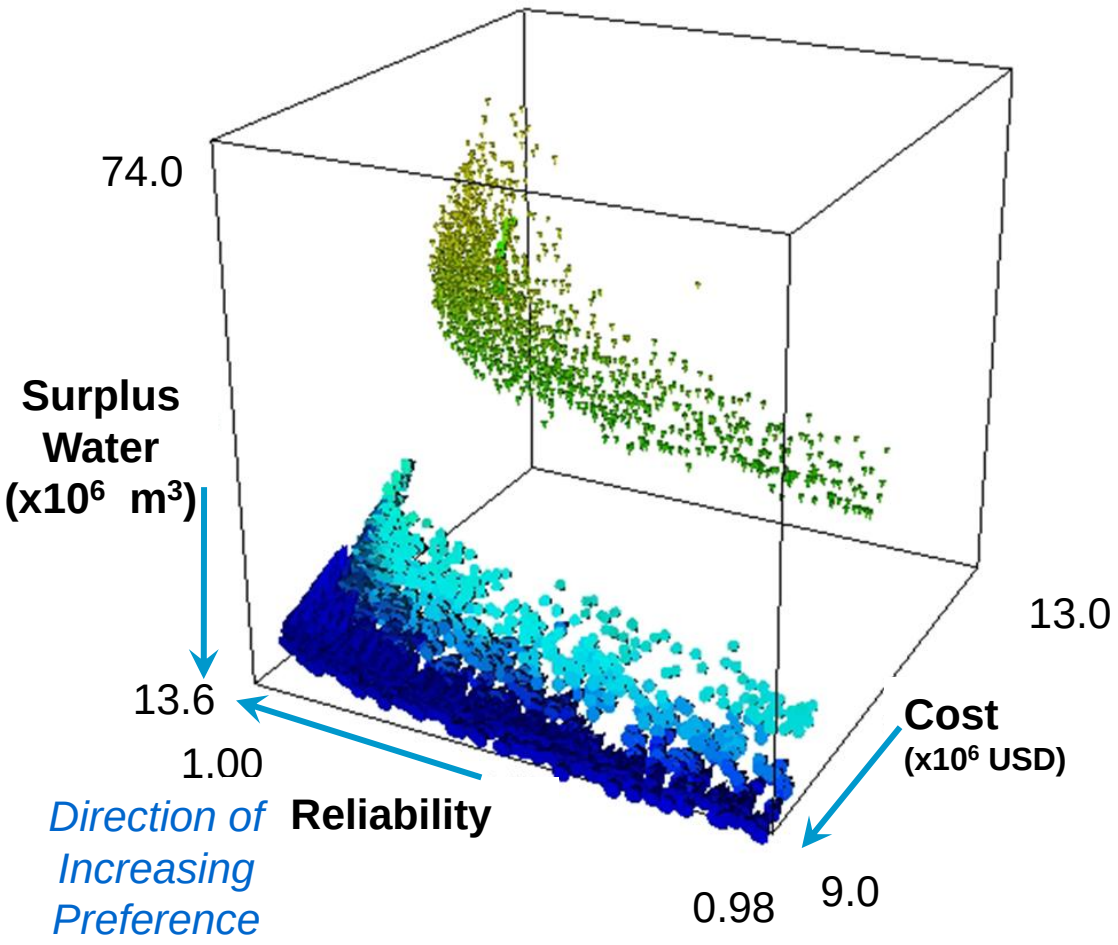
Multi-Objective Evolutionary Algorithms (MOEAs)

- Intelligent search
- Effective where other search techniques fail

ε-NSGAII

- Fast, efficient, effective
- Can be used with supercomputers or desktop computing

Many Objective Analysis – Avoiding Myopia

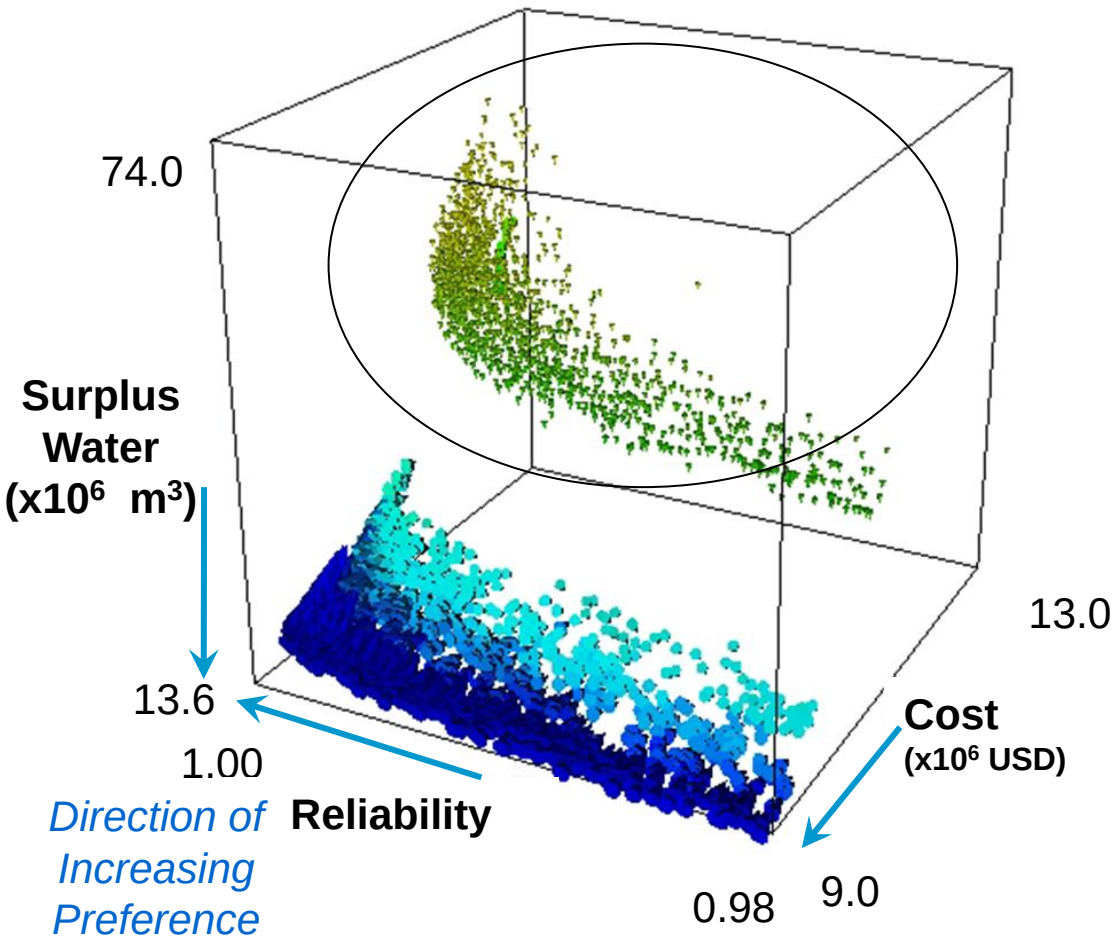


- Discovery of solutions that reduce costs and surplus water, and improve reliability
- Find groups of solutions not known a priori

Legend
Size: Volume of Leases
Orientation: Volume of Exercised Options
Color: Volume of Permanent Rights
low — *high*

[Kasprzyk et al., 2009, Water Resources Research]

Many Objective Analysis – Avoiding Myopia



- Discovery of solutions that reduce costs and surplus water, and improve reliability
- Find groups of solutions not known a priori
  - Rights-dominated

Legend
Size: Volume of Leases
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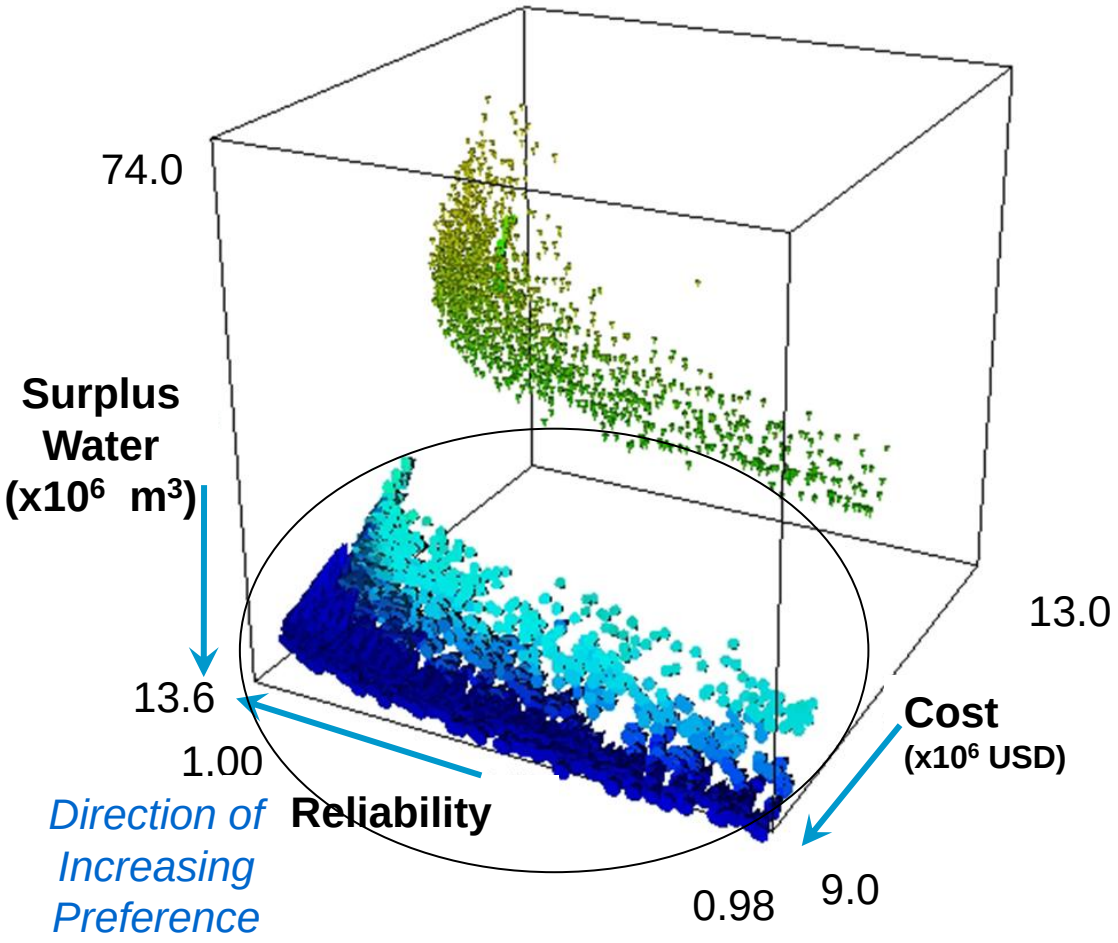
Many Objective Analysis – Avoiding Myopia

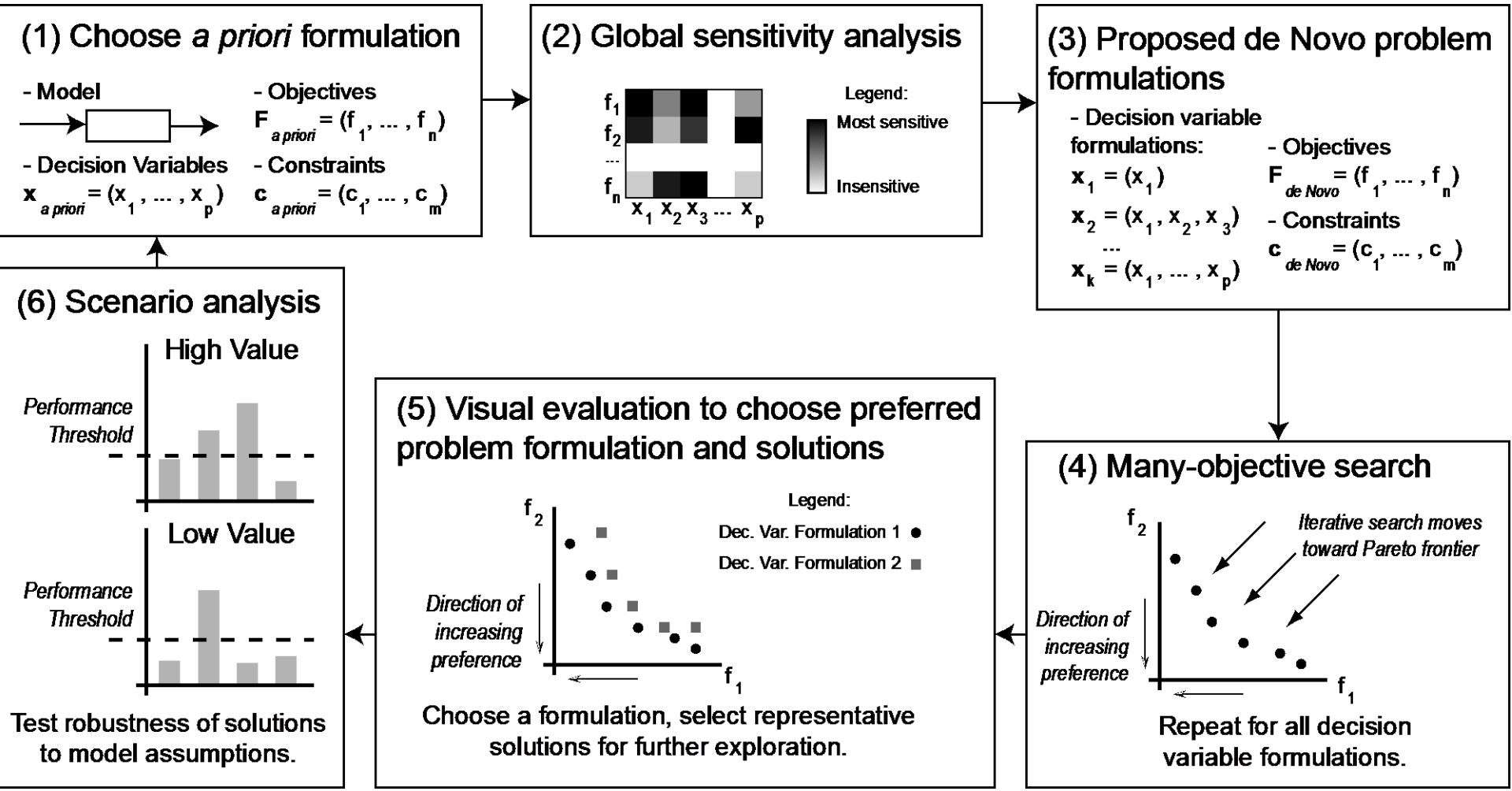


- Discovery of solutions that reduce costs and surplus water, and improve reliability
- Find groups of solutions not known a priori
  - Rights-dominated
  - More market use

Legend
Size: Volume of Leases
Orientation: Volume of Exercised Options
Color: Volume of Permanent Rights
low — *high*

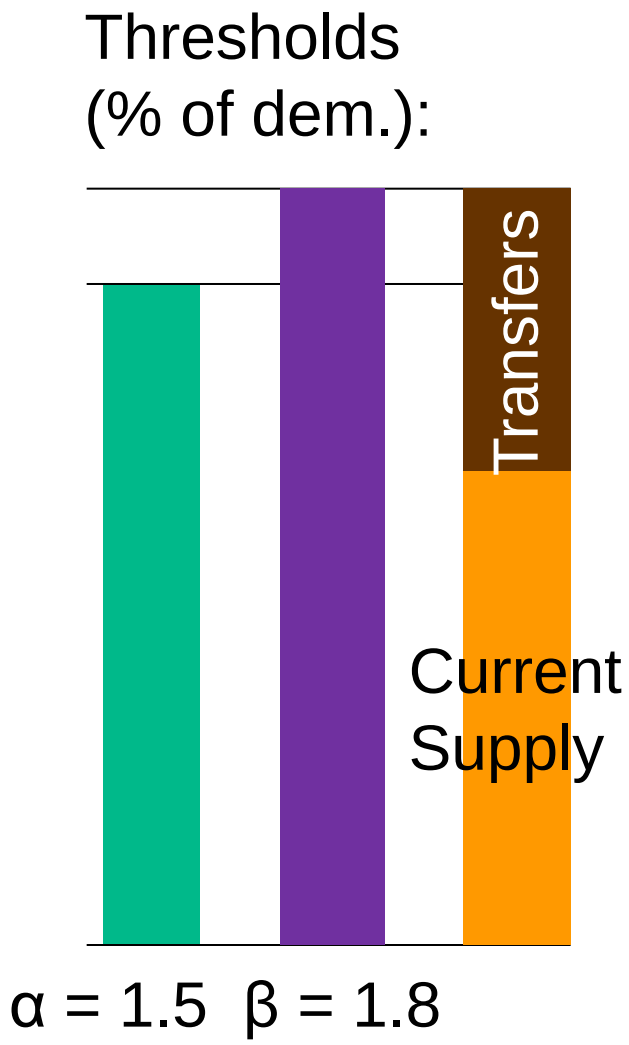
[Kasprzyk et al., 2009, Water Resources Research]

de Novo Planning Framework

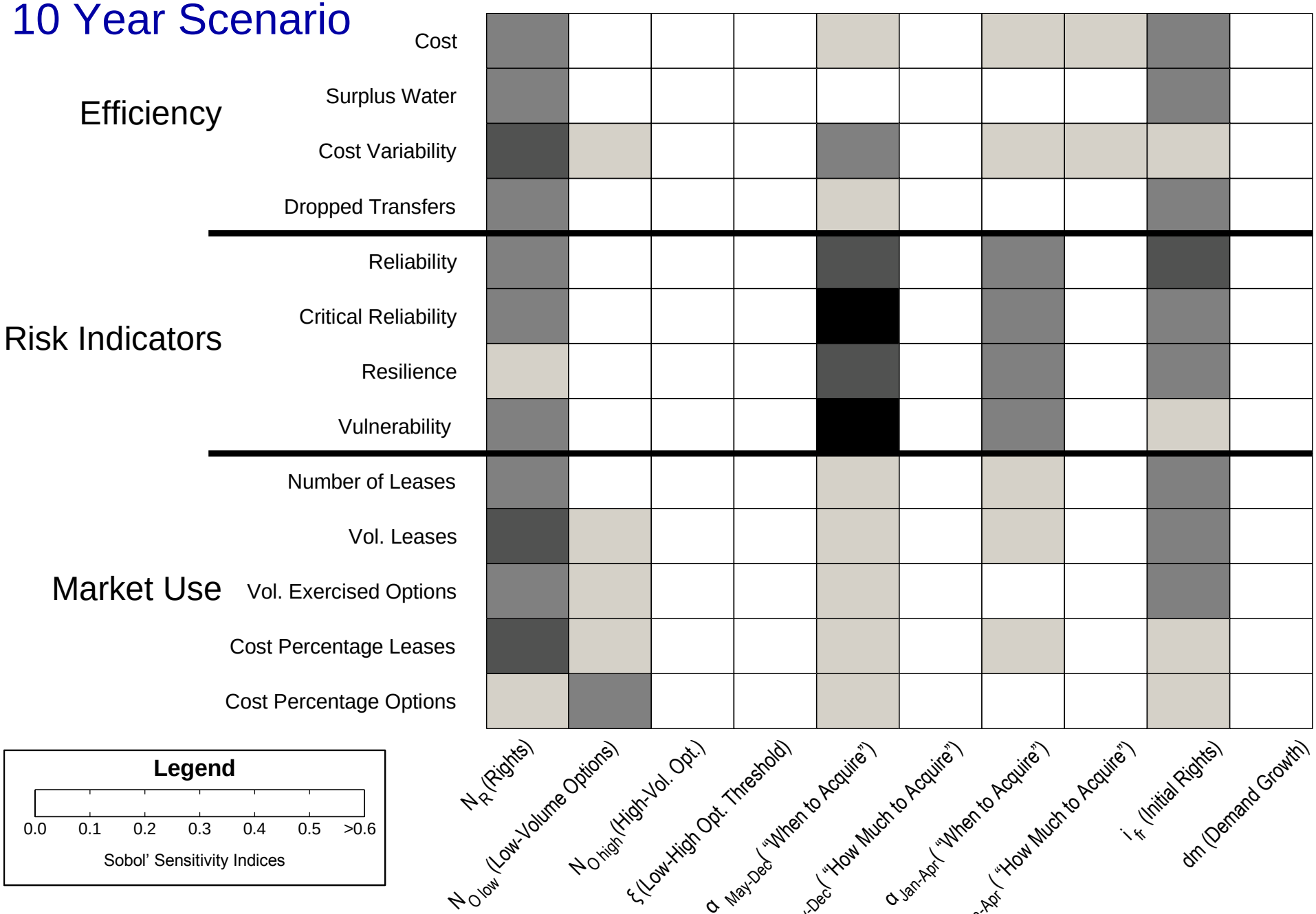


A priori formulation: Decision Variables

- Permanent rights
  - N_R = Volume of rights
  - Allocated pro rata based on reservoir inflows
- Adaptive Options Contract
  - $N_{O,low}$ = Low-volume alternative options volume
  - $N_{O,high}$ = High-volume alternative options volume
  - ξ = Threshold for deciding between high/low
- Anticipatory Thresholds
  - $(\alpha, \beta)_{May\text{-}Dec}$ = "When", "How Much" for May-Dec
  - $(\alpha, \beta)_{Jan\text{-}Apr}$ = "When", "How Much" for Jan-Apr
- Figure: If current supply is less than "when" threshold, purchase such that you meet "how much" threshold



10 Year Scenario



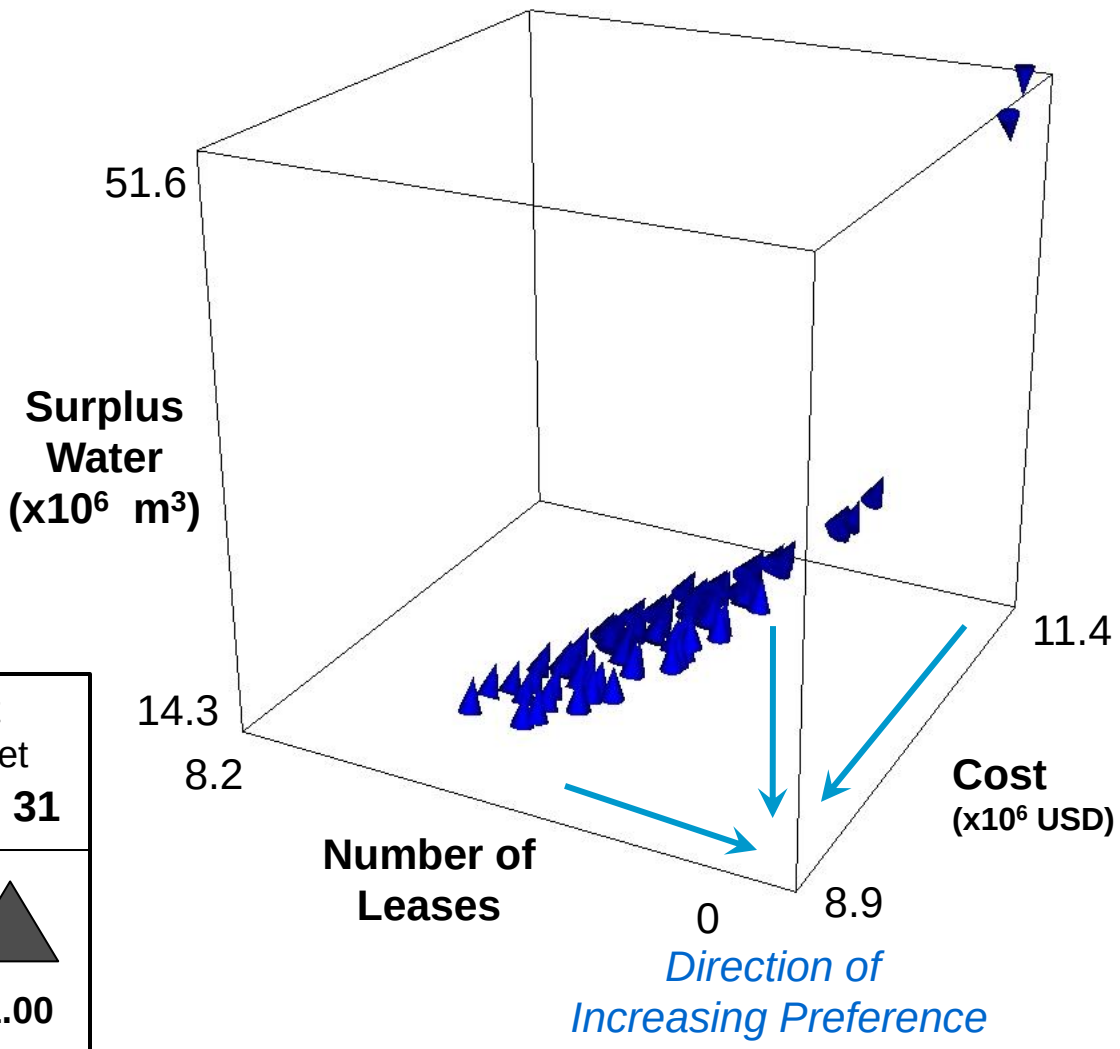
Analysis of Added Model Complexity

Case	Volumetric Decisions	Strategy Decisions
I	N_R, N_O (single-volume)	α: **both** "when / how much to acquire"
II		$\alpha_{\text{Jan-Apr}}$, $\alpha_{\text{May-Dec}}$
III		$\alpha_{\text{Jan-Apr}}$, $\alpha_{\text{May-Dec}}$ "when" $\beta_{\text{Jan-Apr}}$, $\beta_{\text{May-Dec}}$ "how much"
IV	N_R, N_{Olow} , N_{ohigh}, ξ (adaptive opt.)	

Note: Case IV used in a priori formulation

Many-Objective Tradeoffs: Case I

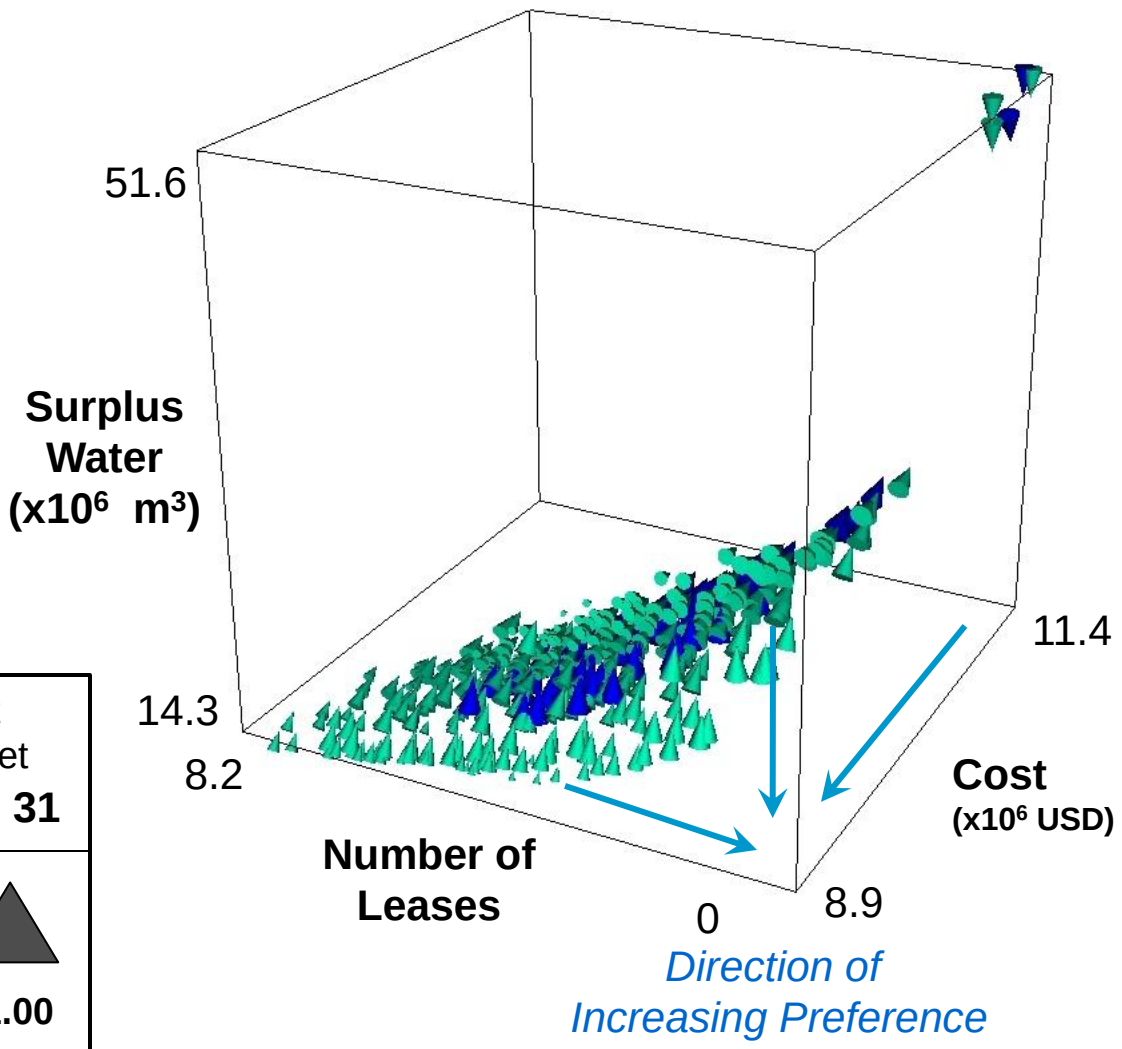
- Limited flexibility: market controlled by one threshold
- Solutions exhibit a range of properties (market use vs. permanent rights)



Color: Model Case	**Orientation:** Cost Percentage in Market
I II III IV	**0** ▼ *Down to Up* ▲ **31**
Size: Critical Reliability	▲ *Small to Large* ▲
Legend	**0.99** **1.00**

Many-Objective Tradeoffs: Case II

- Added flexibility (late-year vs. early-year thresholds)
- Slightly larger range than model case I
- Lower number of leases, cost, and surplus



Legend

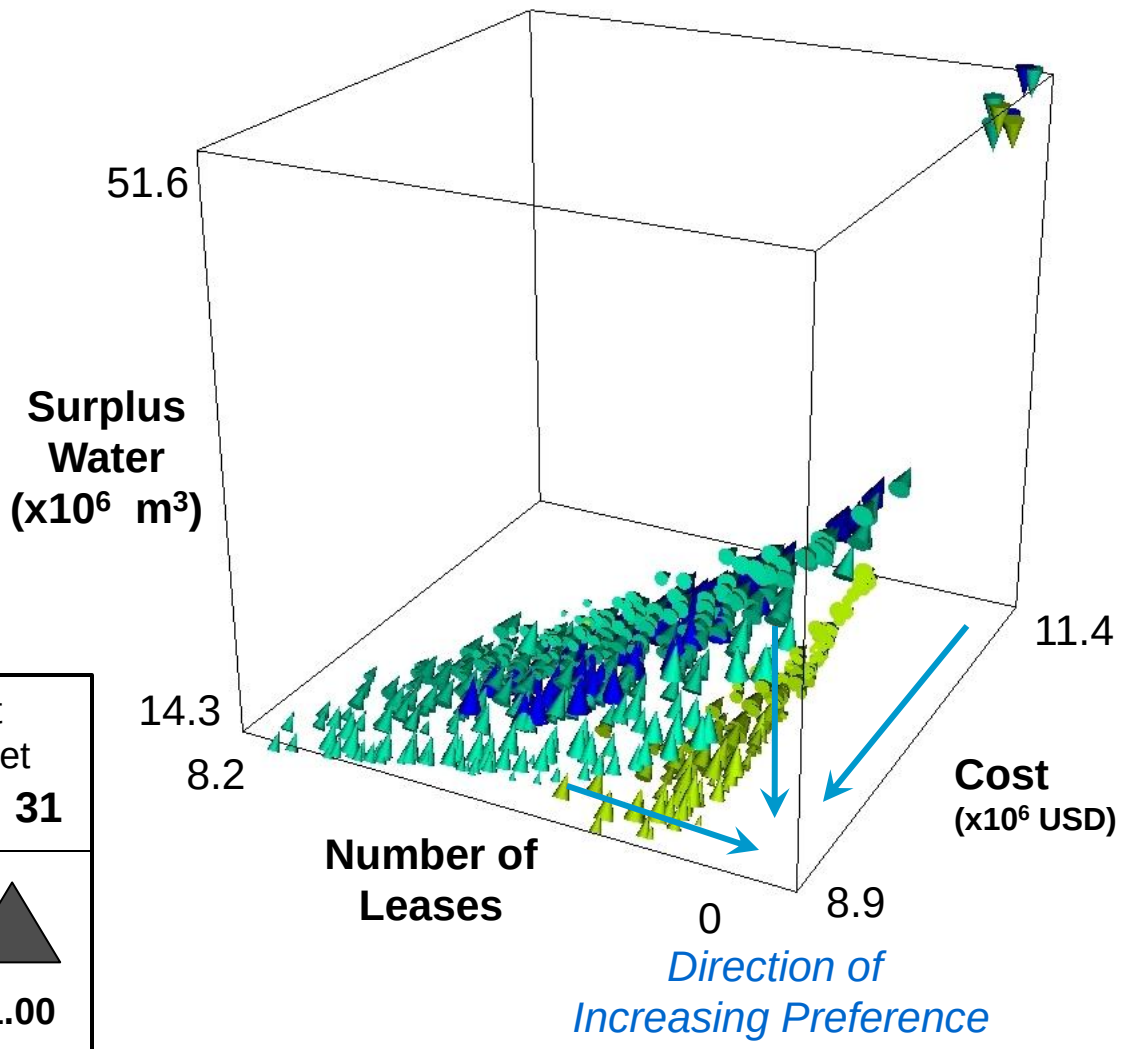
Color: Model Case — I II III IV

Orientation: Cost Percentage in Market — **0** ▼ *Down to Up* ▲ **31**

Size: Critical Reliability — ▲ *Small to Large* ▲ — **0.99** to **1.00**

Many-Objective Tradeoffs: Case III

- Separate supply/demand ratio for volume of water acquired
- Lower costs with less percentage of cost in the market



Color: Model Case

I II III IV

Orientation: Cost Percentage in Market

0 ▼ *Down to Up* ▲ **31**

Size: Critical Reliability

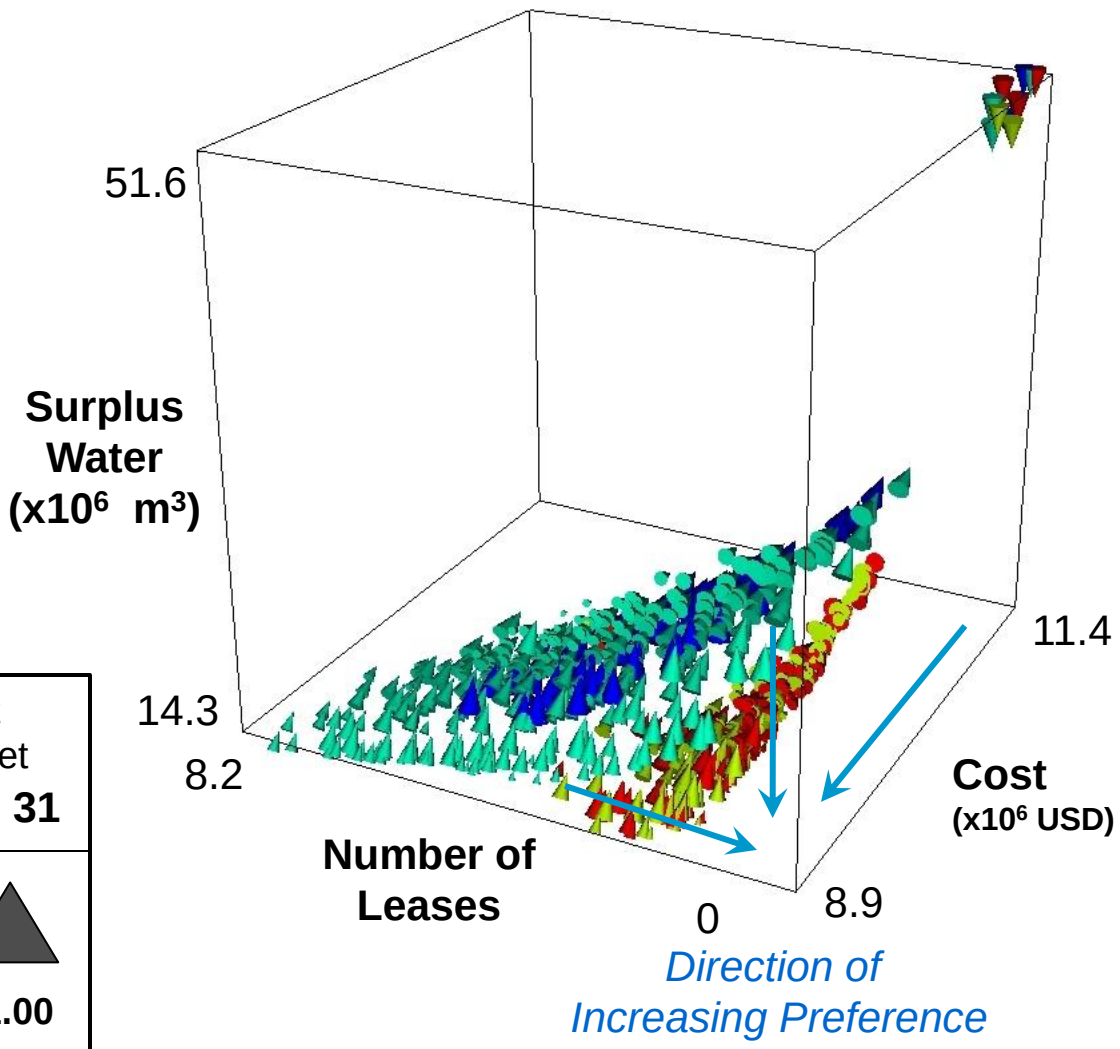
▲ *Small to Large* ▲

0.99 **1.00**

Legend

Many-Objective Tradeoffs: Case IV

- Case IV adds the adaptive options contract
- Similar objective performance to Case III



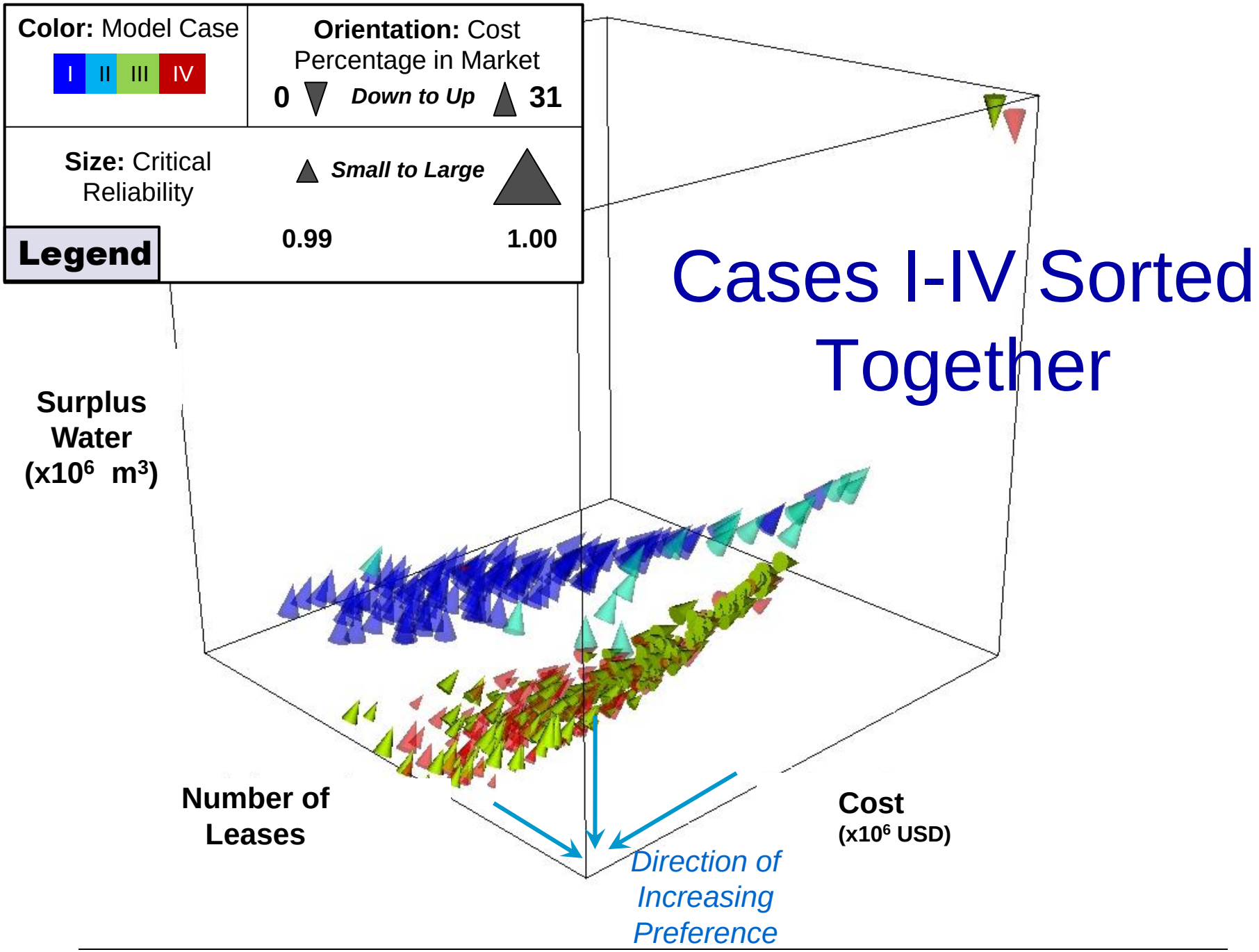
Legend

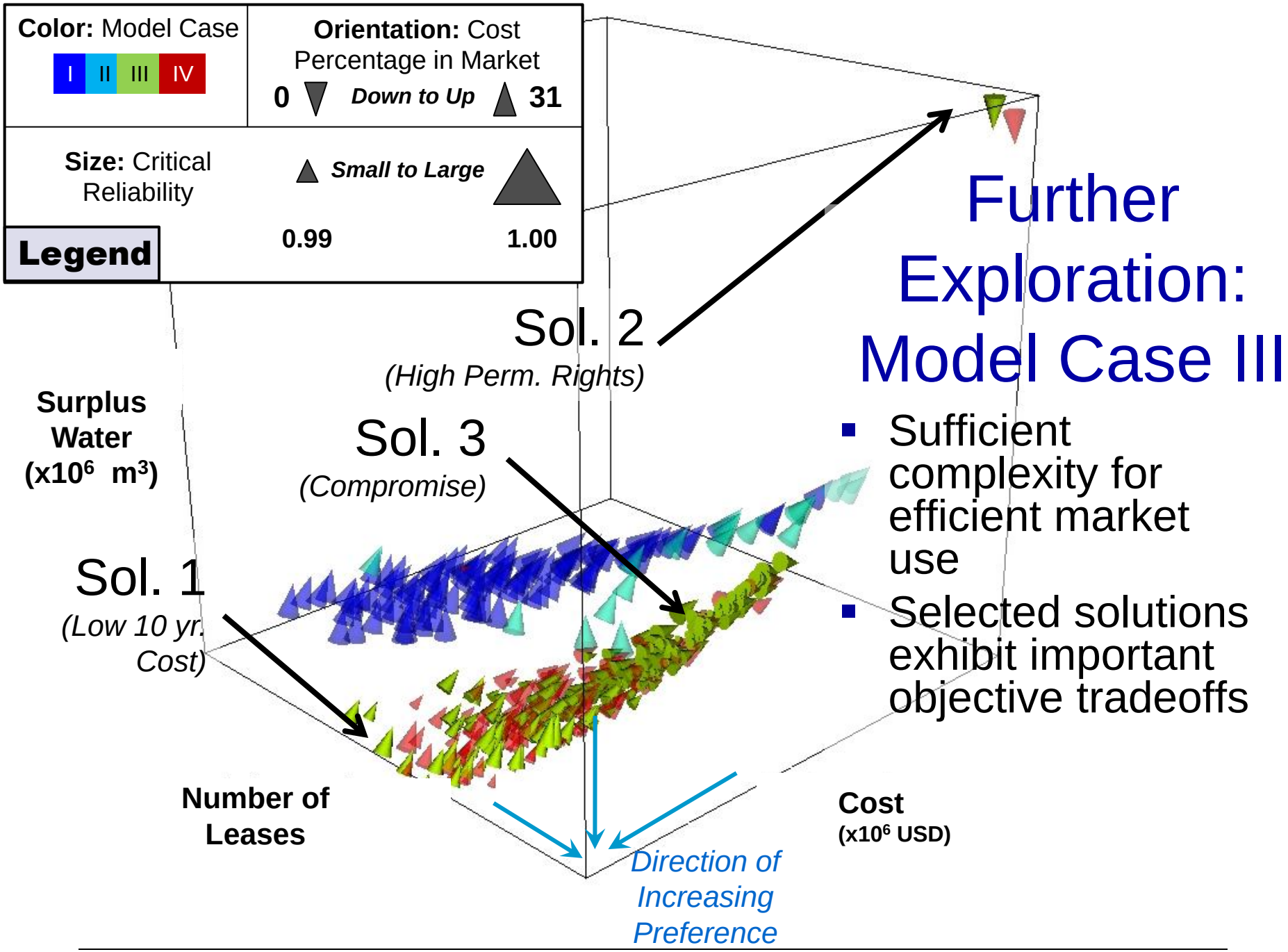
Color: Model Case — I II III IV

Orientation: Cost Percentage in Market — 0 ▼ *Down to Up* ▲ 31

Size: Critical Reliability — ▲ *Small to Large* ▲ — 0.99 to 1.00

Cases I-IV Sorted Together





Further Exploration: Model Case III

- Sufficient complexity for efficient market use
- Selected solutions exhibit important objective tradeoffs

Scenario Analysis with Drought

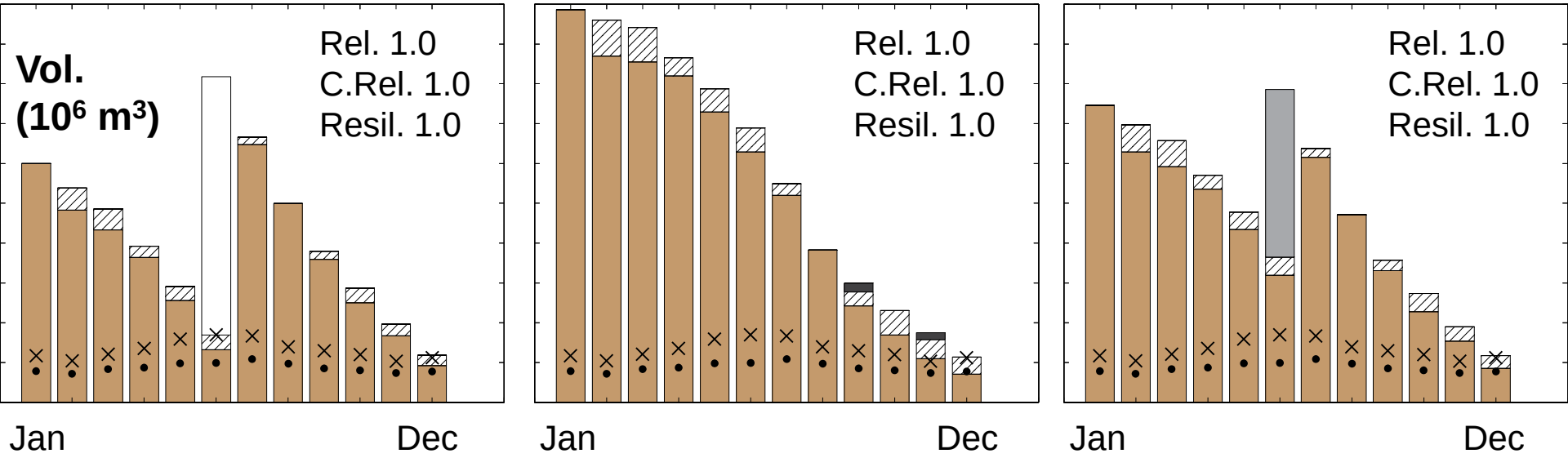
- Drought scenario tests robustness of portfolio values
  - Maximal demands with minimal reservoir inflows
  - This maximizes error since city uses **expected** supply and demand to determine market use
- Initial condition: percentage of rights in supply account
  - Optimization in prior section assumed a single value for initial water in drought
  - In scenarios, initial condition changes as a proxy for failures in the prior planning period

Initial Rights: 40%

Sol. 1
(Low 10 yr. Cost)

Sol. 2
(High Perm. Rights)

Sol. 3
(Compromise)



Month

Legend

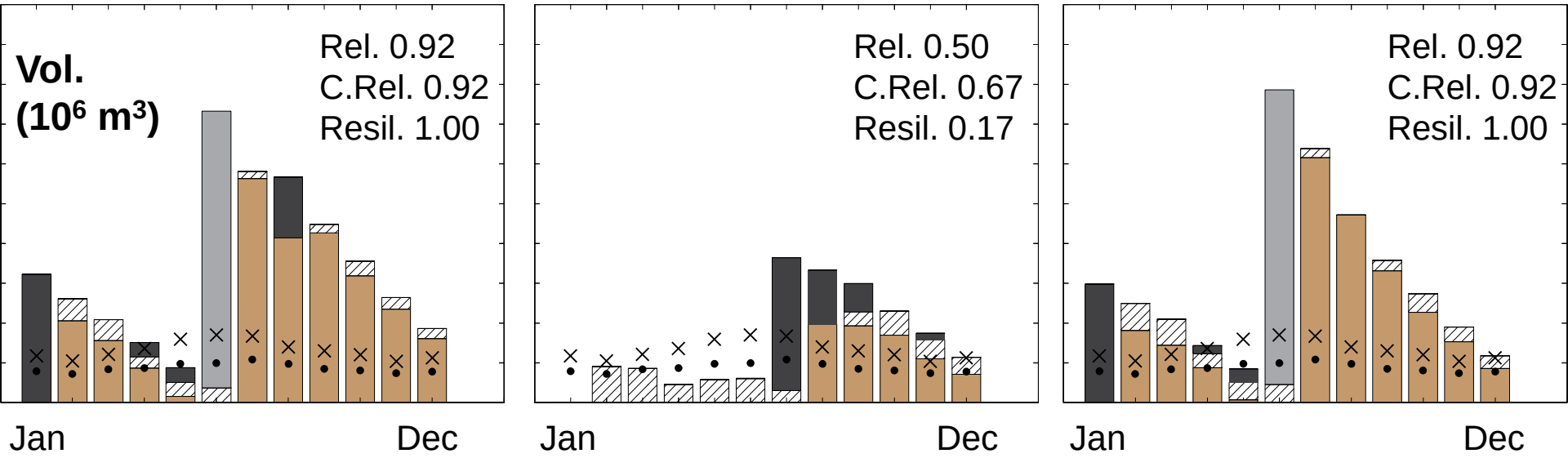
- Carry Over
- Rights
- Lease Purchases
- Exercised Options
- Actual Demand
- Projected Demand

Initial Rights: 0% (no water at start)

Sol. 1
(Low 10 yr. Cost)

Sol. 2
(High Perm. Rights)

Sol. 3
(Compromise)



Conclusions

- The work supports a dynamic view of decision variables, objectives, and constraints
  - Sensitivity analysis, many-objective search, and visual analytics together showed effectiveness of moderate complexity formulation
- By exploring the implications of using estimated probabilities and violating model assumptions, we test the **robustness** of solutions
  - Future work will link the de Novo framework with robust decision making efforts

Thank you! Questions?
Paper in press: Kasprzyk et al., Environmental Modelling and Software

References

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