Beyond Optimality: Multi-stakeholder robustness tradeoffs for regional water portfolio planning under deep uncertainty

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1 Four urban water utilities seek “soft-path” approaches to drought management

Figure 1. In the Research Triangle region of North Carolina, water utilities have begun to explore the “soft path” of adaptive strategies to utilize existing infrastructure more efficiently [1]. Four utilities operate in the region: Durham, Raleigh, Cary, and the Orange Water and Sewer Authority (OWASA), serving Chapel Hill and Carrboro. Cary has the largest capacity-to-demand ratio, making it a source of transfer water in times of shortage.

2 We begin with a set of near-optimal water portfolios in the expected state of the world

Figure 2. In prior work [2], we performed multi-objective optimization of the utilities’ “soft-path” strategies, including demand restrictions and transfers. These strategies can reduce expected cost and environmental impact, but may increase variability in revenues and costs that are difficult for a regulated utility to manage. Solutions shown in color meet the utilities’ performance requirements, while solutions in gray do not.

3 Water portfolio planning must consider robustness in addition to optimality

Figure 3. The solutions above were optimized in the expected future state of the world. However, despite their optimality they are not guaranteed to be robust to exogenous uncertainty. We extend Many-Objective Robust Decision-Making [MORDM] [3] as part of a constructive decision-aiding framework for multiple regional stakeholders.

4 Portfolio performance degrades in alternate scenarios, defined by deeply uncertain factors

Figure 4. Deep uncertainties are variables for which probability distributions are unknown. We construct a sample of 13 deep uncertainties for the Triangle water supply system, including hydrologic and economic factors. These broaden the range of future states of the world that we explore, as shown at left.

5 Robust portfolios meet the utilities’ performance goals across many scenarios

Figure 5. Performance, measured by the water utilities’ four objectives, degrades dramatically when considering these alternate plausible states of the world.

Figure 6. We quantify the robustness of each solution based on the percentage of states of the world in which it meets the utilities’ expressed performance requirements [4]. We highlight the robustness of solutions A-D, and define four new solutions: R1, R2, R3, and R4, which are the most robust solutions for the four utilities respectively. Importantly, the solutions rank very differently across the utilities, indicating tradeoffs. Additionally, the larger cities of Durham and Raleigh exhibit low robustness even for their best solutions.

6 Controlling the rate of demand growth will significantly improve robustness

Figure 7. We seek to identify the causes of the poor robustness values in Figure 6, finding that the rate of demand growth is the key uncertainty controlling the utilities’ performance. We simulate mitigation of demand growth by calculating robustness across only those states of the world below a certain threshold. This improves the utilities’ robustness, particularly if demand growth can be held below 80% of the currently projected rate.

7 Robustness tradeoffs must be balanced between multiple regional stakeholders

Figure 8. As seen in Figures 6-7, the robustness of the four utilities forms a tradeoff (i.e., each utility can improve only by degrading another). We can explore this robustness tradeoff using parallel axis plots (A), or glyph plots (B-C). In both cases the color (yellow-blue) indicates the level of demand growth mitigation undertaken by the utilities. In (A), a sharp tradeoff exists between Durham/Raleigh and Cary, indicated by crossing lines. This indicates that the largest cities in the region may place stress on Cary, the supplier of transfer water. In (C), we isolate the nondominated solutions and highlight a compromise portfolio, “CM,” to balance robustness across the regional stakeholders.

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References