Decision Support Framework for Potable Water Systems Under Climate Extremes

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1. Decision context for Water Treatment Plants (WTP)

- **Challenges include:** changes in source water quality and quantity, financial burden of operations and upgrades, uncertainty surrounding water quality regulations, climate change and extreme weather events (extreme temperature and precipitation) (fig. 1)
- **Purpose:** This project seeks to create a decision framework for WTPs, in partnership with the Water Research Foundation. We completed a literature review of decision support systems (DSS) in WTP [1] and are engaging stakeholders to continue developing our framework.

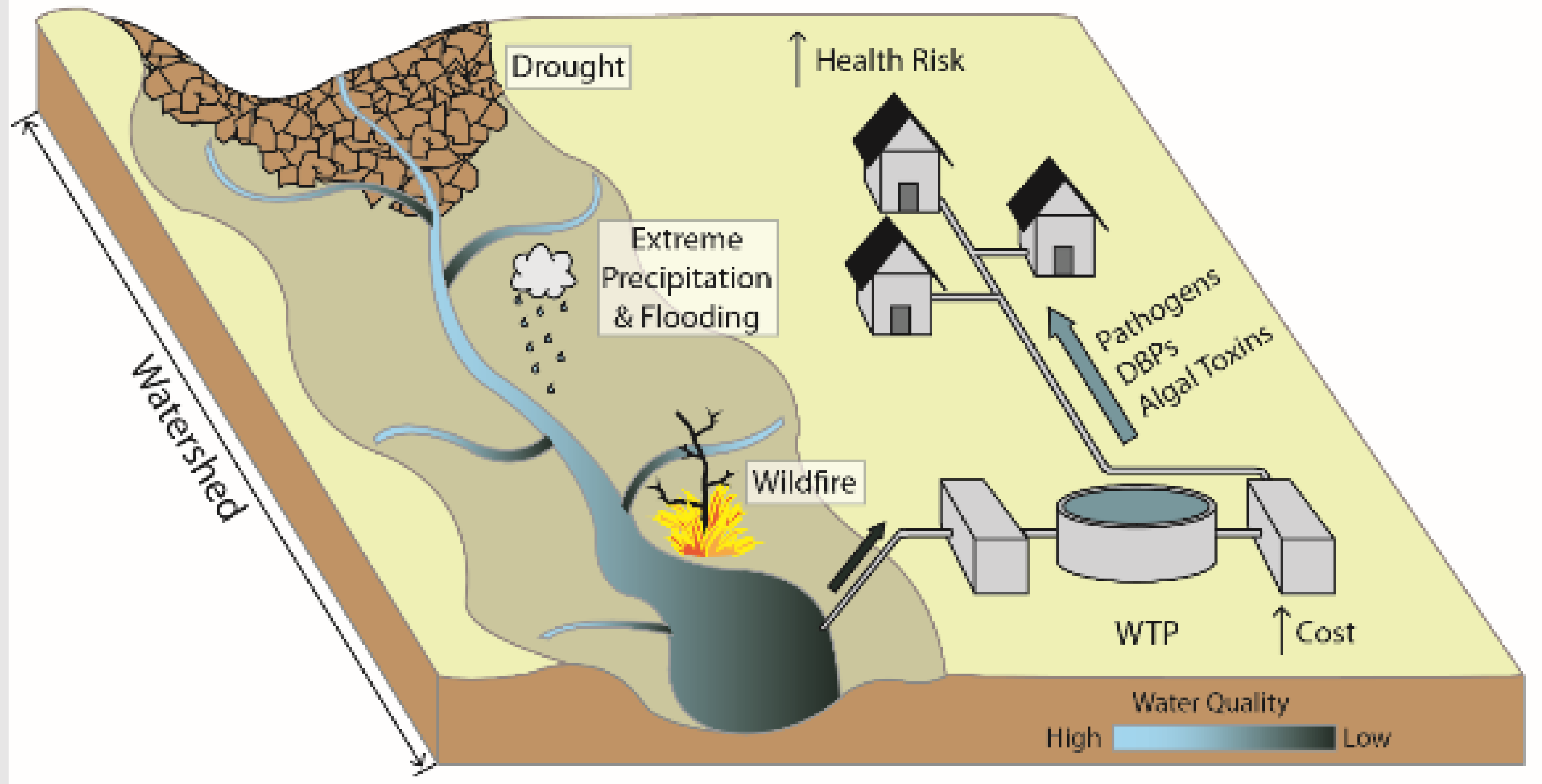

Figure 1. Schematic showing the effect of climate change and extreme weather events on drinking water quality. Degraded source water quality can lead to higher costs for WTPs and elevated health risk for consumers.

2. DSS problem formulation

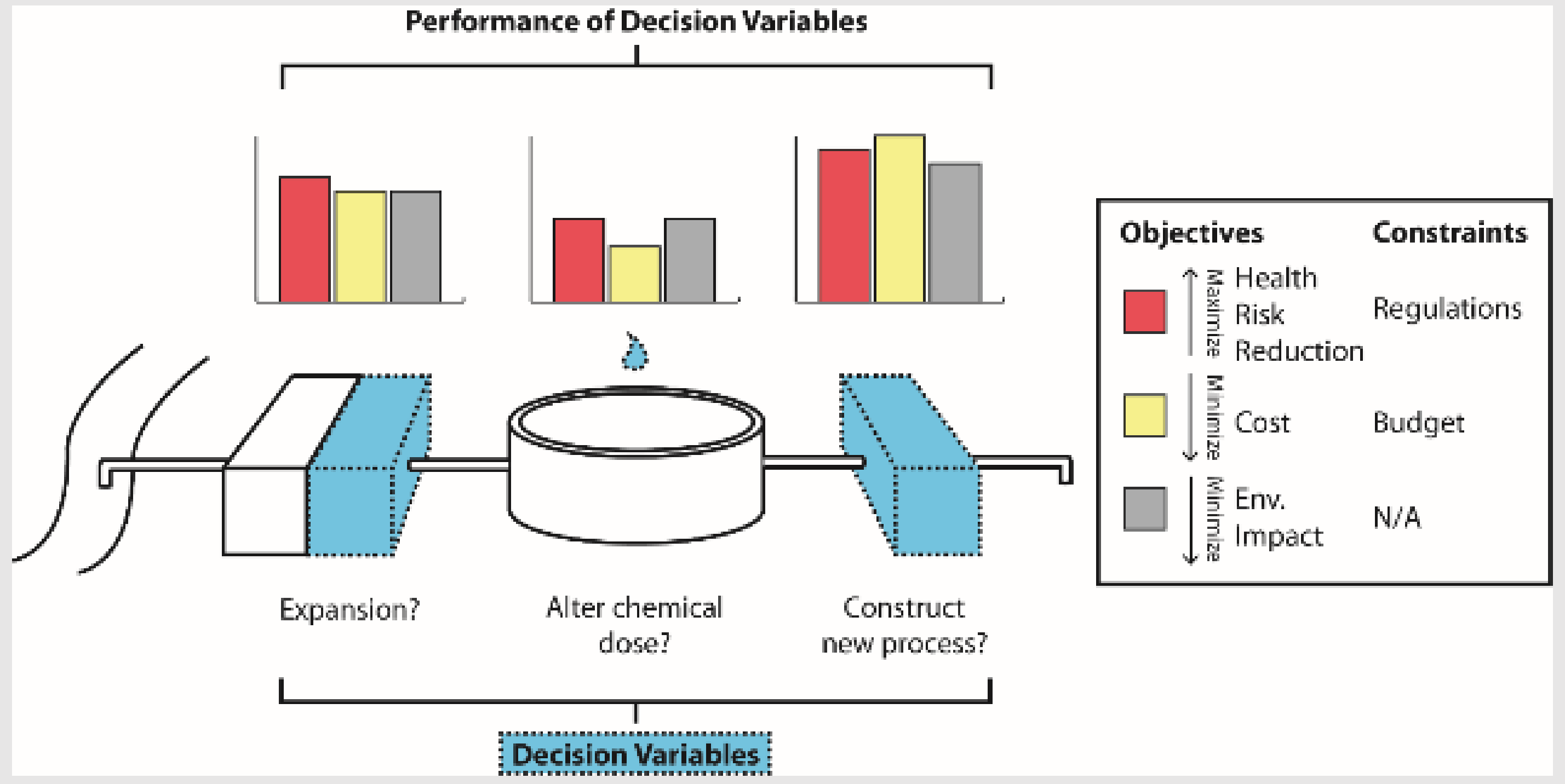

Figure 2. Illustration of the decision context of water treatment. The performance of decision variables can be measured as objectives and, to be acceptable to the decision maker, they cannot violate constraints. In XLRM terminology (see box 4) levers are equivalent to decision variables, and measures are equivalent to objectives and constraints.

3. Review of existing literature on DSS for WTP

- Categories of WTP DSS
  - Physically-based models (PBM), simulations based on fundamental physics and chemistry. Often coupled with optimization (Fig. 3)
  - Statistical models (SM), represent systems based on data and probability distributions
  - Artificial intelligence (AI), systems designed to mimic human reasoning: knowledge-based systems (KBS, Fig. 4), Bayesian networks (BN, Fig. 5), and artificial neural networks (ANN, Fig. 6)

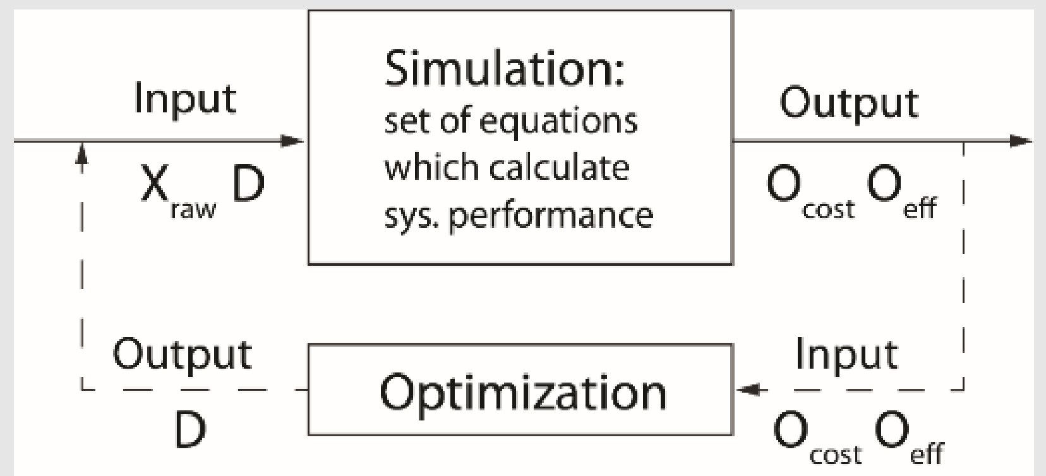

Figure 3. PBS with optimization

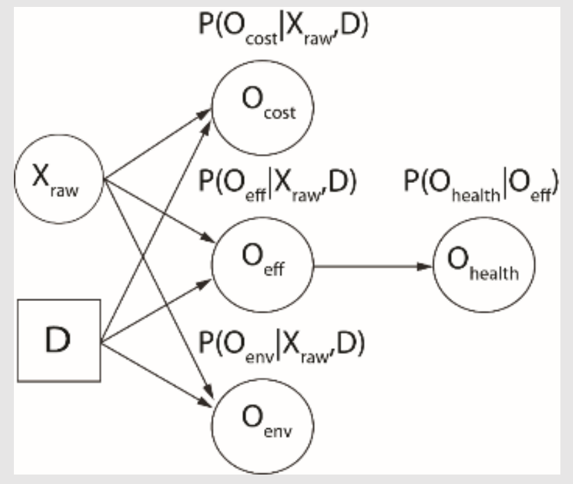

Figure 5. BNN, a probabilistic model of the relationship between water quality and decision

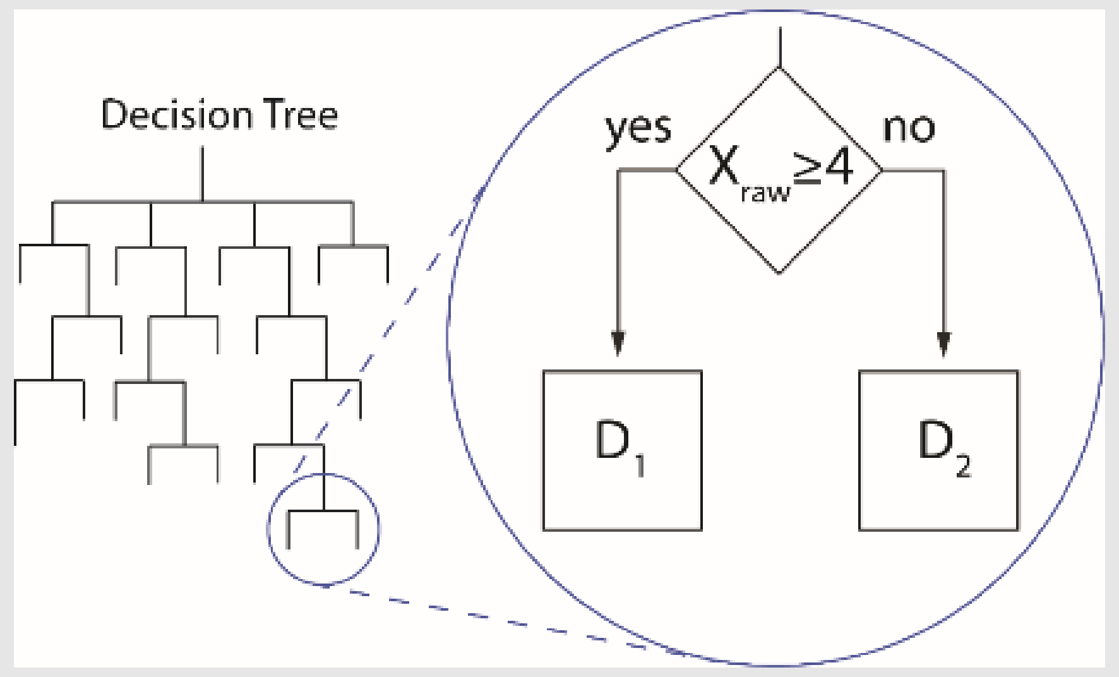

Figure 4. A branch of KBS, in which a choice between decisions is based on the raw water quality (X_{raw}) at a plant

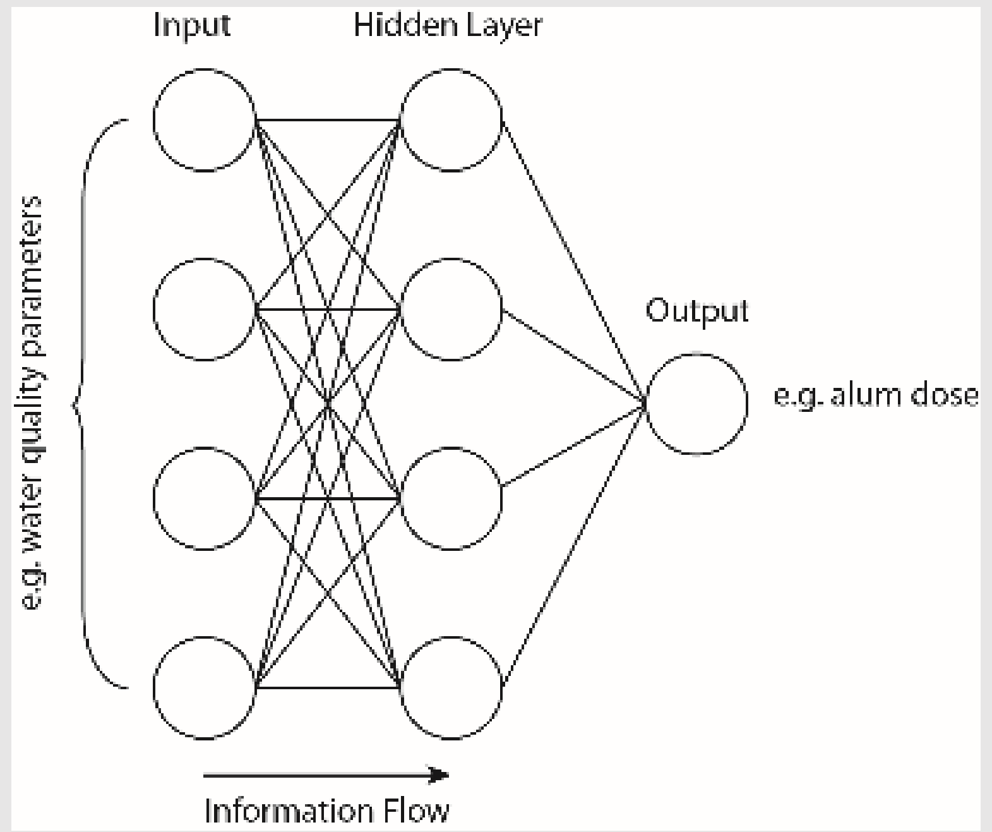

Figure 6. ANN to predict a decision of optimal alum dose

- **Analysis of existing DSS:** Predictive models (ANNs and some SMs) can aid in day-to-day decision-making (e.g., selecting optimal coagulant doses). Optimization using PBMs can inform designs and do not require much data. KBSs can help operators troubleshoot under new situations. BNs explicitly acknowledge uncertainty.
- **Recommendations** for future DSS work
  - *More accurately reflect the practical needs of WTPs* and focus on real-world application
  - *Explicitly handle uncertainty* including sensitivity analysis
  - *Incorporate nonstationarity*, especially with regard to extreme weather events and climate change
  - *Represent multi-objective tradeoffs* including minimizing cost, system failure, health risk, and environmental impact
  - *Use standardized terminology* to minimize confusion (e.g. confusion between risk assessment and decision support)

4. Our upcoming workshop will solicit feedback from decision makers on important DSS components.

- Our research has 3 components: (i) initial workshop to create a problem formulation for the DSS (ii) application of DSS for Fort Collins, CO (iii) final project workshop to disseminate findings. For more on the workshop-based participatory framework see Smith et al (poster in this session)
- Initial workshop plan
  - **Introduction and Initial Presentation**: Introduce the broader project
  - **Kickoff Question:** Utilities will name the long-term challenges facing their organization
  - **Scoping into XLRM Framework:** Participants will be asked to list uncertainties (X) within their system, the decision levers (L) or management plans that can be used to achieve the stated objectives, the relationship (R) that map actions to outcomes, and measures (M) that quantify the system performance (see Table 1).
  - **Desired Features:** Elicit the desired features that would have to be represented within the problem formulation and simulation model.
  - **Wrap Up:** Discuss expectations for further communication

Table 1. Anticipated responses from the XLRM scoping exercise

Component	Sample Responses
Uncertainty (X)	“we don’t know to what extent algal blooms would change if temperatures increase by 1 degree C”
Levers (L)	“we decide to add advanced treatment to reduce our levels of disinfection byproducts” “we will pay upstream farmers $XXX to add cover crops to decrease the sediment load into the plant”
Relationships (R)	“we use a pilot plant to test new configurations for our system” “we use a physically based model for our treatment plant”
Measures (M)	“we want to minimize operational costs associated with droughts” “we would never allow turbidity levels to exceed XXX as it would violate regulation XXX.”

5. Summary of challenges: WTPs under deep uncertainty

- Difficult to apply paradigms of decision making under deep uncertainty to a field in which modeling is often based on data-based systems
- Potable water systems are a coupled system that includes WTPs, watershed hydrology, and water distribution systems
- Participatory approaches that engage with stakeholders are promising because they can help scope the methods to be most useful

Reference: [1] “A critical review of decision support systems for water treatment: Making the case for incorporating climate change and climate extremes” WJ Raseman, JR Kasprzyk, FL Rosario-Ortiz, J Stewart, B Livneh, In Revision at *Environmental Science: Water Research and Technology.* **Acknowledgments:** This work was supported by the U.S. Environmental Protection Agency “National Priorities: Systems-Based Strategies to Improve the Nation’s Ability to Plan and Respond to Water Scarcity and Drought Due to Climate Change”, Grant No. R835865. The contents of this manuscript are solely the responsibility of the grantee and do not necessarily represent the official views of the US EPA.