Drivers of Urban Water (Un)Affordability During Droughts

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① Overview

Access to safe, affordable drinking water is a growing concern in both developed and developing nations. Empirical studies have found that access to affordable drinking water is inequitably distributed across racial and economic groups. Here, we present an approach to **characterize the impacts of droughts and drought management actions on household water affordability** and access utilizing a socio-ecological systems framework. This approach couples a basin-scale water resources systems model with econometric models of household water demand and behavior to predict how residential water users respond to water conservation and price signals, and how water use changes as a function of household socioeconomic status. We apply this framework to a retrospective case study of a California water system during the 2011-2017 drought. Results indicate that **droughts reduce water access and affordability and that the impacts are inequitably distributed across income classes**: water bills during droughts increase for low-income households and decrease for high income households. We find that system-wide access to affordable water as well as the inequity of any differences are dependent on the drought mitigation actions taken by utilities.

④ Key Insights

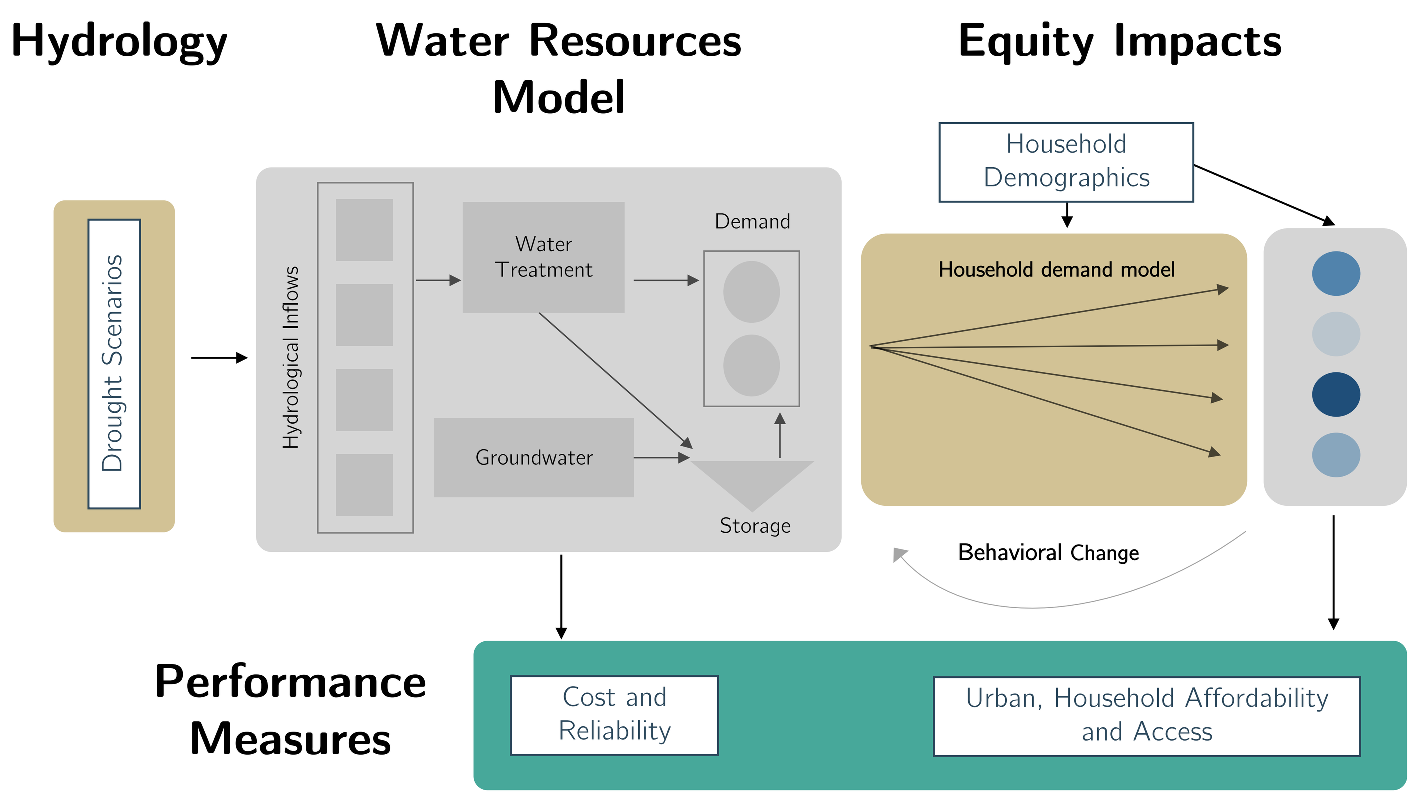
(1) **Droughts exacerbate water unaffordability** through surcharges. Intense droughts increase bills more than long droughts.

(2) **Demand-side solutions** (curtailment) lead to **biggest bill differences across groups**, but are almost always lowest cost

(3) **Temporary solutions** (market water purchases) create **variability in water bills**

(4) **Demand hardening** exacerbates impact of droughts on affordability

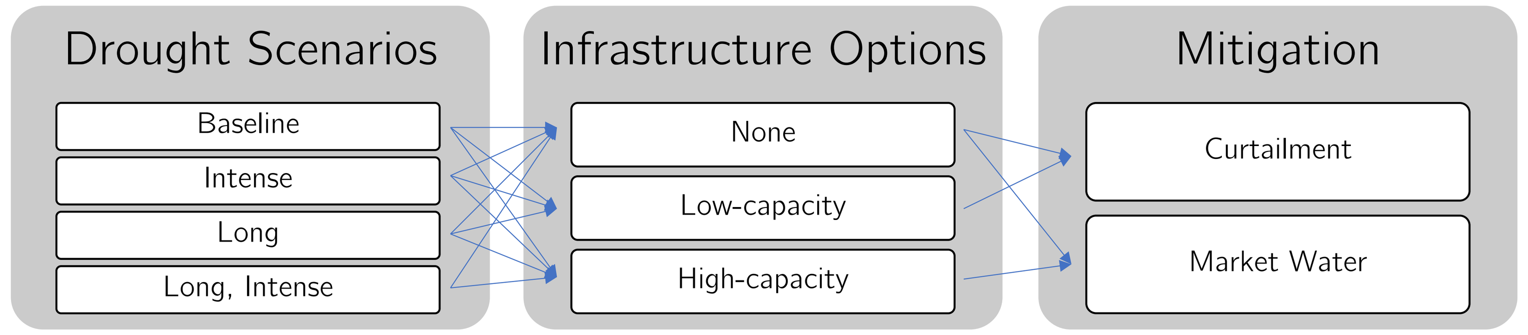
② Framework & Case Study



Model Overview: Framework for quantifying household water affordability. Our model simulates the operation of a utility and calculates total utility cost increases and the resulting changes in water rates which result from building infrastructure, mitigation activities, and changes in water use. The model **estimates residential household water demand for 16 classes of home,** adjusted for household **size, income,** and **behavioral response** to price signals.

$$D^t = \sum_c d_c^t \, m_c \left(\frac{P^{t-1}}{P^{t-2}}\right)^{\epsilon_p} \left(\frac{Y_c}{Y_{\mathrm{MHI}}}\right)^{\epsilon_y} H_c$$

Household Demand Model: We estimate total residential water demand using an **econometric demand model** based on Cardoso & Wichman 2021. **Price and income** elasticities (0.1 and 0.43 respectively) are utilized to adjust water demand based on changes in water price and income.

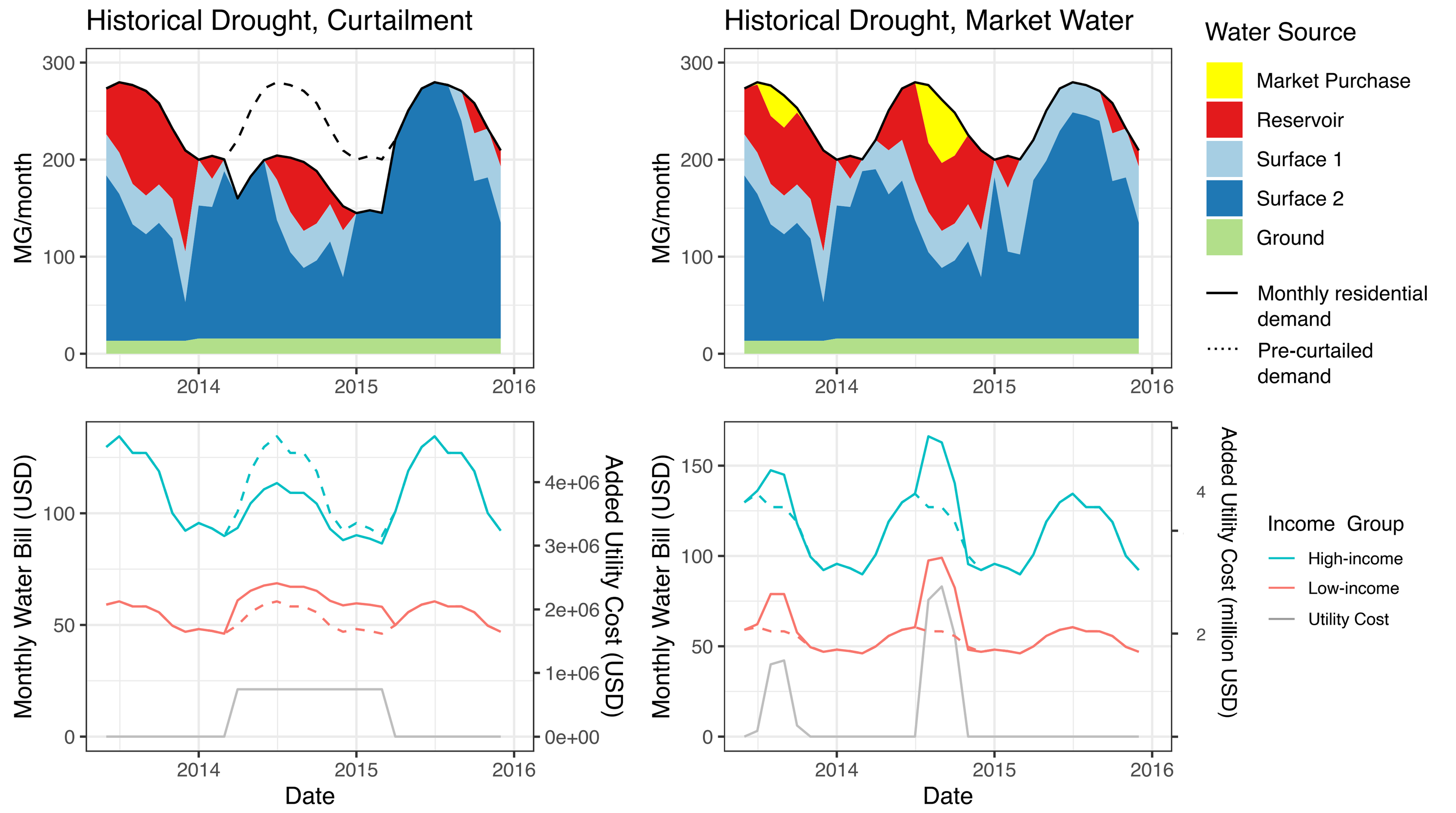


Scenarios: Four drought scenarios are generated based on the 2011-2016 drought in California: (1) baseline, historical drought, (2) intense drought 1.5x standardized anomalies, (3) long drought, 2x length of baseline. Low and high-capacity infrastructure options (+180, +900 MCM/yr respectively) can be built at a cost of \$20.4 and \$115 million. Mitigation occurs through **supply side** (Market Water) or **demand side** (Curtailment) and leads to a revenue-neutral rate surcharge

Study Area: Santa Cruz is a city on California's Central Coast with a fully locally-sourced water supply. The city has three primary surface water allocations which supply 95% of urban water demand, and a small groundwater well operation. The city manages one reservoir (Loch Lomond) primarily to supply drinking water, with a small environmental flow requirement.

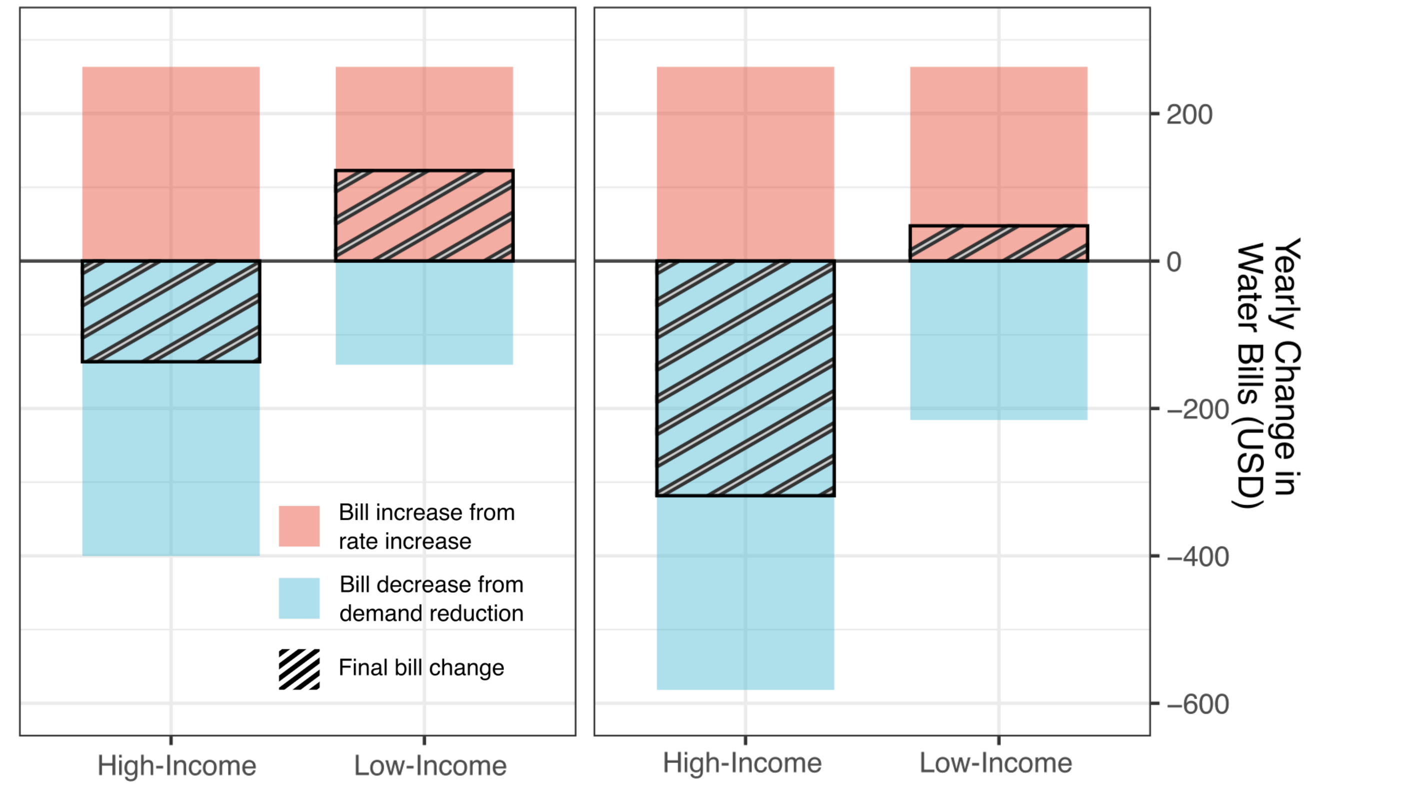
③ Results

Drought Scenarios & Mitigation Strategies



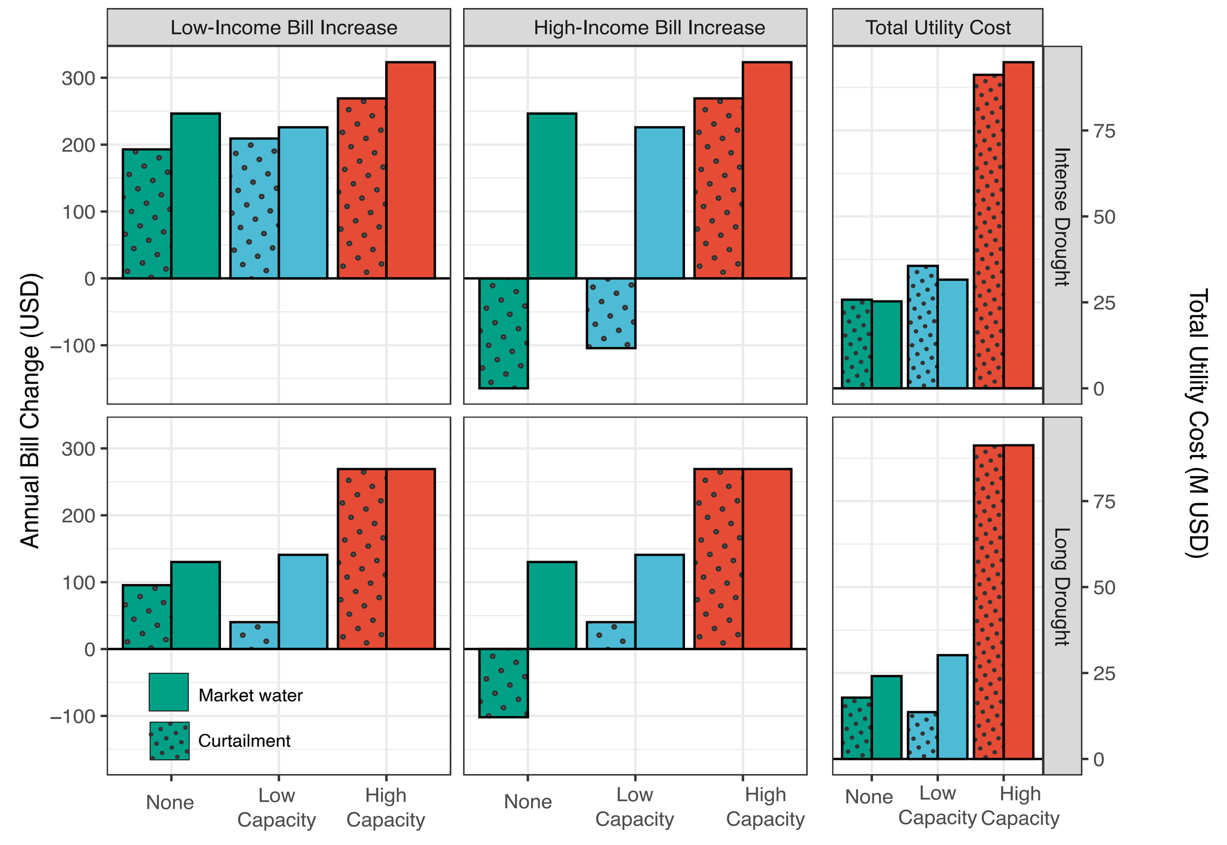
Historical drought scenario for the years 2012-2016 showing the impact of curtailment (left) and market water (right) mitigation strategies. Stacked area charts (top) show the water from each source used to meet demand (solid black line). Costs to low-income (red), high-income (green) and utility (gray) shown in over time (bottom row).

Behavioral Response to Price Signals



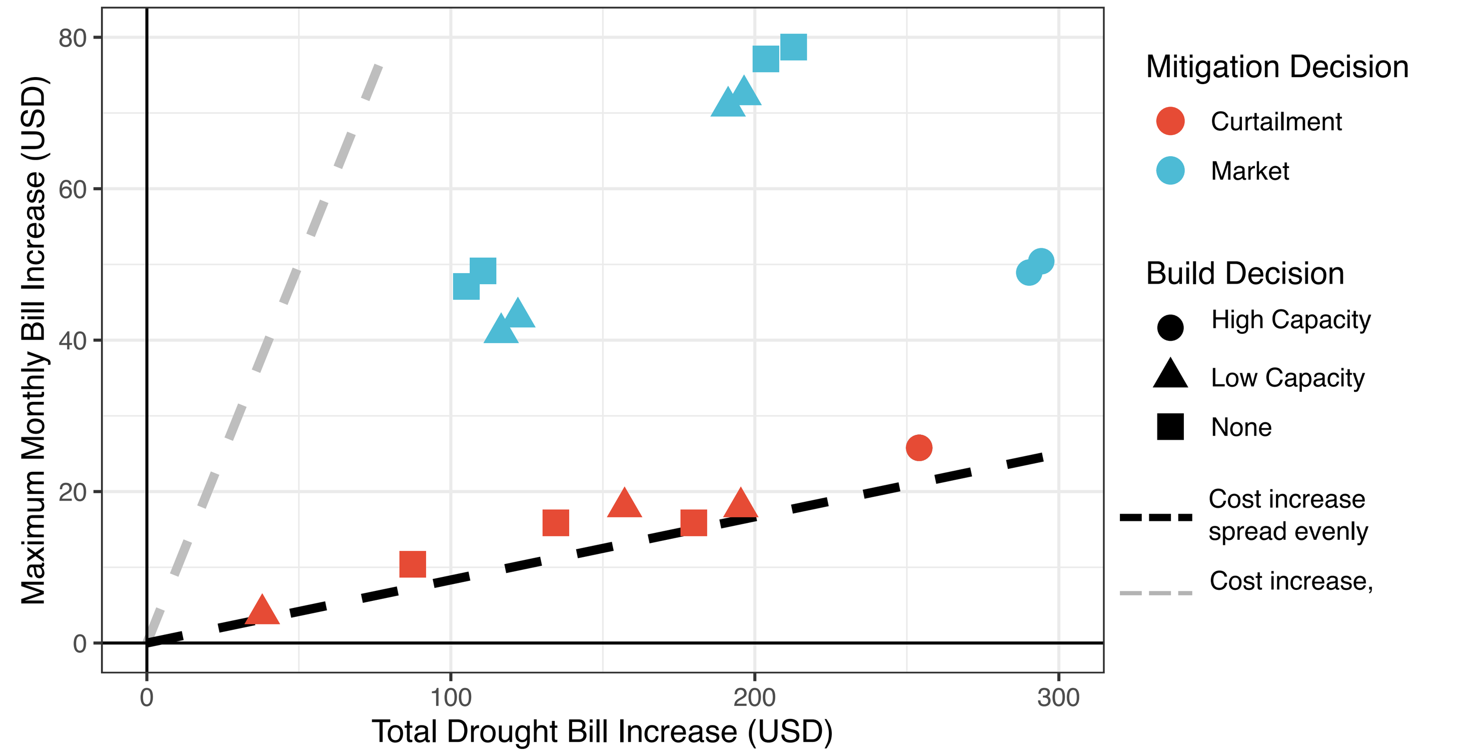
Behavioral Response to Price Signals: Low-price responsiveness (left) and high-price responsiveness (right) are modeled using high and low price elasticity. Red bars show the total annual bill increase which occurs as a results of **drought surcharges** for high and low-income households. Blue bars shows the **cost reduction which occurs with a reduction in household water** use due to curtailment and price responsiveness. Striped boxes show the net change in annual bills for high and low-income households.

Household Affordability and Total Cost



Household Affordability and Total Cost: Total cost increase per year during a drought for low-income households (left), high-income household (center) and utilities (right) during an intense drought (top row), and long drought (bottom row). Colored bars correspond with infrastructure options and dotted or solid bars mitigation actions.

Total and Maximum Bill Increases



Total vs. Maximum Bill Increases: Total bill increases are shown plotted against the maximum bill increases in any one month. Colors and shapes show scenarios. The dashed gray line shows the worst-case bill increases in which all increase is applied in one month, and the black line shows the best case, evenly spread bill increases. Key insights are the impact supply vs demand-side mitigation has on maximum vs. total bill increases, and the **information potentially lost by focusing on only totals or maximums.**