Balancing Supply and Financial Risks in Water Utility Decision Making under Uncertainty

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Abstract: Water utilities seek to maintain high levels of water supply reliability while also meeting financial stability goals. Financial objectives such as keeping debt levels low and rates affordable can directly conflict with making investments in new infrastructure that ensure high levels of supply reliability. Water utilities have increasingly relied on borrowing via the bond market to support new investment; this makes meeting financial performance standards more critical to maintaining a high credit rating to secure lower interest rates. Balancing supply and financial objectives are challenging because of the uncertainties in demand projections and hydroclimatic conditions. In response to these challenges, utilities can deploy adaptive policy levers such as demand management and rate increases as a means of navigating future development paths that meet supply reliability and financial stability objectives. This research identifies development paths that achieve both objectives using a coupled water supply–financial model that is developed as a long-term planning tool for Florida's largest wholesale water provider, Tampa Bay Water Authority. The model is used to characterize the utility's ability to meet its supply reliability and financial stability goals under 1,000 different realizations involving variable conditions related to demand growth and hydroclimate. Financial stability is evaluated via measures of "credit-worthiness" (e.g., debt service coverage ratio) used by credit ratings agencies, which ultimately influence utility borrowing costs. Results indicate that achieving supply and financial goals simultaneously are only feasible through active management involving careful calibration of rate increases and demand management. **DOI: 10.1061/JWRMD5.WRENG-7164.**

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Introduction

Water utilities face the difficult task of balancing water supply reliability with the financial burden of supply infrastructure investments (Kane 2016) and how that burden may impact affordability for consumers. The importance of both objectives is highlighted in the 2023 American Water Works Association's (AWWA) State of the Water Industry survey report, with participants listing financing capital improvements and securing long-term water supply as top challenges (AWWA 2023). The overall cost of water supply projects has risen as federal support for the water industry has declined (prior to the enactment of the bipartisan infrastructure law), and water utilities are increasingly driven to rely more heavily on debt financing to pay for new projects (Gurevich 2022). Water utilities across the country are facing growing financial challenges as medium- to long-term estimates of water infrastructure investment exceed $100 billion annually (ASCE 2020). As a result, water utilities need to better balance their supply reliability goals and supply investment strategies, carefully considering the long-term financial implications of the latter, especially how the implications may impact their rate payers. Maintaining this balance has become more complicated as population growth, per capita water use, and weather patterns have become more unpredictable and introduced greater uncertainty into future supply and demand projections (Hao et al. 2025; Khatri and Vairavamoorthy 2009; Milly et al. 2008; Rachunok and Fletcher 2023; Rayburn 2008).

This uncertainty has ushered in a new era in water resource management planning, which has begun moving beyond the traditional deterministic "predict-and-plan" approach to now include more adaptive planning techniques (Gleick 2000; Quay 2015), particularly those that involve increased use of pricing and conservation. Development of more adaptive approaches has been cited as a way for utilities to avoid developing costly, but sometimes underutilized, supply infrastructure and instead focus on more flexible water

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supply options such as demand management and water transfers from other water users (e.g., agriculture, neighboring utilities) (Gorelick et al. 2018; Jenkins and Lund 2000; Krueger et al. 2019; Lund and Israel 1995). Demand management specifically has unrealized potential to maintain supply reliability while reducing the need for additional supply infrastructure (Beecher 1996; Cominola et al. 2021, 2023; Herman et al. 2014; Matrosov et al. 2013; White and Fane 2002). Nonetheless, water utilities must better understand the financial implications of increased reliance on adaptive actions. When used as a short-term drought mitigation tool, demand management actions could lead to sudden, intermittent, and unpredictable reductions in water sales revenue (Beecher 2010; Borgomeo et al. 2016). On the other hand, demand management can lower costs by reducing new supply investments in the long term, so quantifying these trends is important for making informed planning decisions. It may be especially vital to understand how moderate increases in customer rates can help improve the probability of maintaining the balance between supply reliability and financial stability.

Historically, financial planning has been based on projections of future demand growth, estimates of annual costs (such as payments for new supply projects), and then setting a customer rate that leads to revenues that recover costs (Beecher et al. 1993). Demand uncertainty, however, leads to revenue uncertainty. Given the large fraction of utility costs that are fixed (e.g., debt service), any deviations from expected revenues can result in budget shortfalls (Hughes and Leurig 2013). Rate setting has therefore become an even more important, and increasingly challenging, part of the balancing act that water utilities must engage in as they seek to fulfill the dual objectives of supply reliability and financial stability (Eskaf and Tiger 2014). An ideal rate structure would encourage demand conservation while meeting the revenue requirements of the utility and maintaining customer affordability standards, but this can be difficult to achieve in practice (Grinshpun et al. 2020; Olmstead et al. 2007).

While demand management can forestall new supply development, and perhaps even avoid it altogether in some cases, most water utilities will eventually need to invest in additional supply infrastructure. In this situation, evaluating the joint supply- and financial-risks of using an integrated portfolio comprised of demand management and new supply infrastructure becomes increasingly complex (Zeff et al. 2016). The few studies that have investigated methods of balancing these related risks in the context of integrated water supply planning have often focused on straightforward metrics such as project cost (often measured as net present value), changes in revenues (and/or costs) resulting from adaptive measures, with some tangential attention to customer rates (Gorelick et al. 2019, 2022; Trindade et al. 2020). While these are all important measures of financial performance, they also have thresholds that, if crossed, result in significant penalties for the utility, and these have rarely factored into earlier studies. These thresholds are typically computed as a function of a utility's revenues, debt obligations, and reserve holdings (e.g., debt service coverage ratios, bond covenants) and are closely watched by bond holders and credit ratings agencies to ensure that financial stability is maintained (Ajami 2018; Leurig and Diserio 2010; Scott 2011). Ratings agencies such as Standard and Poor's (SandP), Moody's, and Fitch evaluate the creditworthiness of many different organizations, with these ratings directly impacting the cost of borrowing (i.e., interest rates) (Raftelis 2005). A lower credit rating means a higher interest rate, and, given the capital-intensive nature of the water utility sector, in which debt service often comprises 50% or more of annual costs, the penalty for not meeting established thresholds for financial performance can be substantial (Hughes et al. 2014). Consequently, failure to consider these financial performance thresholds can lead to an incomplete analysis of a water supply planning pathway, as the balance between adaptive measures (e.g., conservation) and supply infrastructure has financial implications, as measured by debt service coverage ratio (and other metrics), which remains unconsidered (Leurig and Diserio 2010). It is also important to note that these financial performance thresholds are a focus of the financial units within most utilities, but that the siloed nature of most organizations means that they are rarely integrated into the models used by water supply planning personnel (Dell 2005). A standardized level of service concept has been proposed, which includes a system dynamic component that includes coupling water supply and financial modeling together to better illuminate trade-offs between supply reliability and financial stability (Gold et al. 2025).

In Gorelick et al. (2023), a novel model integrating consideration of the water supply reliability of two proposed supply projects with utility revenues and costs was developed to quantify trade-offs between reliability and financial performance, as measured by bond covenants. This research expands on that model to evaluate how uncertainty in demand growth affects the balance between supply reliability and financial stability for a water utility developing a long-term water supply and financial plan, which includes investments for capital improvement and new supply infrastructure. The specific objective of this research is to utilize the coupled financial and supply model to identify planning pathways and considerations that provide a high likelihood of simultaneously meeting supply reliability and financial stability goals through a combination of a controlled customer rate-setting policy and demand management to delay further supply infrastructure investment. This objective will be achieved by meeting externally imposed financial performance standards (e.g., bond covenants), and rate policies will be evaluated with consideration of customer affordability. The general objective is to show that using an integrated system dynamic approach to model long-term utility planning and investment can assist decision-makers in understanding the simultaneous supply and financial trade-offs across a range of uncertain future conditions.

This evaluation is conducted using the largest wholesale water utility in the southeast United States, the Tampa Bay Water Authority (TBW), as a test case. Tampa Bay Water plans to develop new supply infrastructure in response to demand growth expected through the late 2020s with concerns that additional supply infrastructure may be needed as soon as the early 2030s to meet projected demands. Understanding how uncertainty in demand projections will impact the future supply reliability and financial stability of TBW is vital to the planning process, as it provides information on the range of demands, and rates can be accommodated while still meeting supply and financial goals. Carefully calibrated use of adaptive measures such as rate increases and demand management actions can help TBW navigate their long-term planning challenges in a manner that will be similar for many water utilities. The results of this research should, therefore, provide insights related to the modeling of long-term water supply strategies that will be useful to mid- to large utilities currently addressing the joint challenges of maintaining supply reliability and financial stability in the face of uncertainty.

The coupled supply–financial planning model used in this study builds on system dynamics in long-term water utility planning, which emphasizes the interdependence of supply and financial systems within utility operations. Whereas conventional supply models are effective at modeling distribution operations for long-term planning, their integration with financial models that actually reflect the utility's budgeting and debt management processes allows for a richer evaluation of trade-offs across competing objectives across supply reliability, financial stability, and affordability. This theoretical approach has been validated in earlier applications (Gorelick et al. 2023), where coupled models successfully reproduced observed financial and operational dynamics to inform decision-making. In the

TBW context, this approach is particularly pertinent: TBW is committed to an initial supply investment and faces the prospect of additional projects that would increase long-term debt burdens. By simulating coupled supply and fiscal dynamics, the model clarifies how policy levers (e.g., demand management, the timing of capital expenditures, and incremental rate adjustments) change the timing and necessity of further investments, reshape revenue trajectories and covenant thresholds, and thus determine the utility's capacity to sustain affordability and financial resilience under uncertainty.

Methods

Study Area

TBW is a wholesale water utility provider located in the central region of the Gulf Coast of Florida (Fig. 1). The regional water supplier serves a population of over 2.6 million people through the provision of treated water to local utilities across six member governments. The member governments represent portions of Pinellas, Pasco, and Hillsborough Counties as well as three cities: St. Petersburg; New Port Richie; and City of Tampa. The TBW uses a diversified water supply portfolio, including 50% groundwater, 45% surface water, and 5% desalinated sea water, which combine to meet an average demand of 188 million gallons per day (MGD) [712 megaliters per day (MLD)] (TBW 2022b).

In 1998, TBW was established as a regional water supply authority through an interlocal agreement that resulted in TBW purchasing the groundwater production wellfields operated by the member government utilities. Today, TBW has 10 groundwater production wellfields governed by a consolidated well use permit that operates at a lower withdrawal limit than the member governments did, which contributed to the environmental recovery of the area (Asefa et al. 2014a). The reduction in permitted groundwater withdrawals resulted in TBW's need to invest in additional supply sources. In partnership with Veolia Water, TBW built a surface water treatment plant (SWTP) with a maximum capacity of 120 MGD (454 MLD) that treats an annual average of 90 MGD (340 MLD). The increased reliance on surface water adds greater supply variability to the system. One method TBW uses to reduce its vulnerability is through the 15.5 billion gallon (59 GL) C.W. Bill Young Reservoir. The Tampa Bay Desalination Plant also contributes to regional water supply and has a maximum production rate of 27 MGD (103 MLD), with a firm yield of about 16 MGD (61 MLD). Connecting TBW's supply and treatment infrastructure to the points of delivery for the six member governments requires over 150 miles (241 km) of transmission mains.

In 2020 TBW delivered 184 MGD (697 MLD) and in 2024 TBW delivered 199.1 MGD (754 MLD), this is an increase of 15 MGD in delivery over five years and future TBW demand projections anticipate continued growth with an annual average demand of 218 MGD (825 MLD) projected by 2040 (TBW 2022b). TBW has committed to investing in two new supply projects that will be added to the system by 2028. The first project is a 20 MGD (76 MLD) expansion of the SWTP, which, due to the variability of surface water, is projected to only add an average working capacity of 10–12.5 MGD (38–47 MLD). The second project is an expansion of the pipeline system that will bring an additional 65 MGD (246 MLD) of delivery capacity to Hillsborough County. The capital costs of these projects are $154 million and $415 million, respectively, and the high cost makes it impractical to pay for these projects upfront. This is often the case for many large supply projects and the reason that utilities rely on long-term debt financing, typically in the form of bonds, as the primary means of paying for them. The bond agreement between the issuer (TBW) and the bond holder includes requirements, often referred to as bond covenants, which must be met by TBW (or any bond issuer in general). The bond covenants for TBW, or any utility, involve metrics that compare a utility's revenues and its debt service payments, and these are described in detail in the section "Success Thresholds."

As with most utilities, each year Tampa Bay Water creates a 10-year finance plan for all of its capital projects, referred to as a

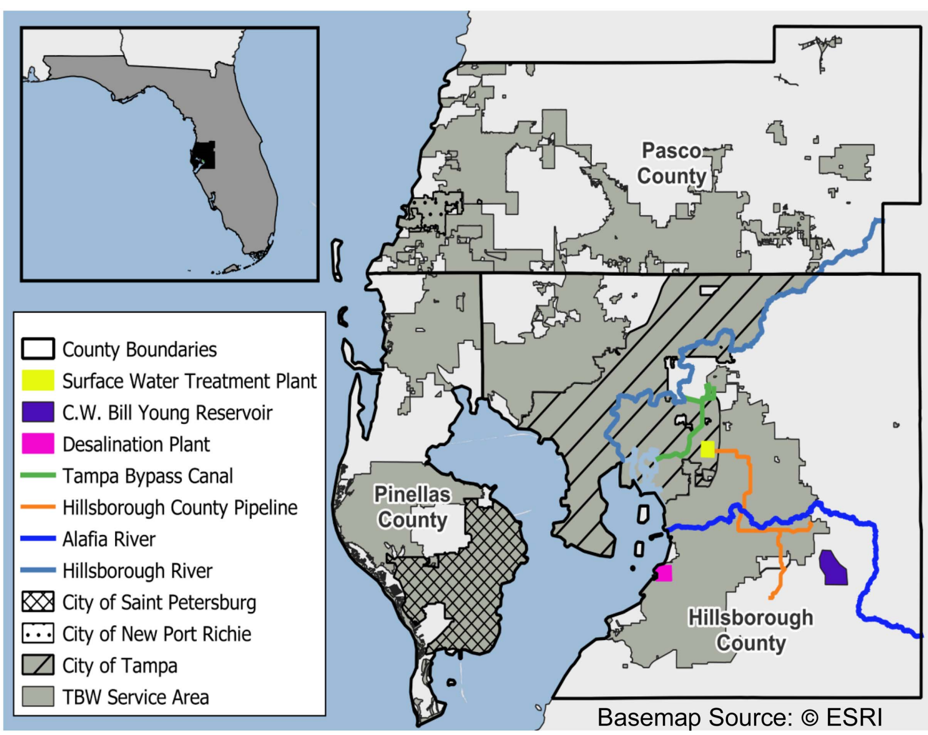

Fig. 1. The member governments, service areas, and components of the Tampa Bay Water Authority system. (Base map © Esri.)

capital improvement program (CIP). This program identifies approved capital projects, which include those for water supply, water quality, and infrastructure renewal and replacement. The cost of these projects is estimated and used to determine how each project will be financed, using one of its funds (capital improvement fund [CIF], renewal and replacement, and energy), direct use of its revenues, through the issuance of a new bond, or more often, by a combination of some/all of these. Between the years 2023–2029, TBW plans to issue four bonds, one every other year, to finance the supply projects and water quality project, along with some smaller capital improvements (TBW 2022a).

Modeling Framework

Coupled Supply and Financial Model Design

The coupling of a system-wide reliability evaluation (SWRE) and the financial risk assessment tool (FRAT) provides the ability to quantify TBW's water supply reliability, including new supply projects, as well as additional debt service from those projects, which is then translated into an impact on its financial metrics. In particular, the coupled model generates insights into the trade-off between the utility's supply reliability and financial stability, a trade-off that can then be altered via demand management actions or changes in its volumetric rate, adaptive strategies that can lead to the achievement of supply and financial goals.

This analysis focuses on the impact of new supply infrastructure projects TBW has decided to add to its system by the end of 2027. These projects include a pipeline to South Hillsborough County and expansion of its surface water treatment plant. To improve the chances of achieving supply and financial goals, the needed demand management targets and volumetric rate increases are established by separating the inputs into demand groups (high, medium, and low growth) and testing various volumetric rate policies (Fig. 2).

The 1,000 demand/hydroclimatic realizations are the inputs to the coupled SWRE–FRAT model framework. Slack variable outputs are used to determine the supply reliability for the TBW supply system with the new infrastructure (section "Supply Reliability Success Threshold"). There are 1,000 demand/hydroclimatic input realizations generated at a daily time step across 20 years. The same 1,000 daily water delivery output data sets are used as FRAT inputs, but multiple scenarios consisting of different volumetric rate policies can be applied to each in the FRAT component of the coupled model. This means for every volumetric rate policy there are 1,000 20-year records of financial outputs. The common identifier linking the inputs and outcomes is the demand/hydroclimatic realization ID (i.e., 1 . . . ,1,000). The ID is used to separate the outcomes into three demand groups based on the demand data from the realization. Four different volumetric rate policies are applied to the three demand groups. A threshold of success is then defined for supply reliability and the financial metrics, and the fraction of outcomes that meet all the thresholds provides information on which demand targets and volumetric rates can allow TBW to meet its supply and financial goals.

System-Wide Reliability Evaluation Model and Inputs

Tampa Bay Water assesses the reliability and future needs of its supply system with its own system-wide reliability evaluation (SWRE) model. This model evaluates various system-wide infrastructure configurations, including new and proposed projects, to estimate the level of reliability they might add to the system. Within an individual SWRE model run, the infrastructure capacity and the year in which it is added are prespecified conditions. The SWRE uses 1,000 realizations to provide daily output of system performance over the 20 year period, including reservoir levels, supply sources used, the frequency with which permits/capacity limits are exceeded; additionally, the SWRE model accounts for variability in streamflow and surface water, and through its optimized regional operation plan model (2.2.3), it simulates groundwater conditions to determine supply and distribution across the wellfields. The exceedances are tabulated daily as "slack variables" and provide the difference between water demanded and water delivered within the constraints of the system. The model utilizes the historic rainfall and streamflow data, which does not take into consideration shifting hydroclimatic trends caused by a changing climate. This is a boundary condition of the analysis, but it aligns with this study's near-term focus on investments this decade and TBW's primary source remaining groundwater. However, the use of Latin hypercube sampling to capture the region's internal variability yields a broad range of challenging hydroclimatic futures that exceed the extremes in the historical observed record. Demand and hydroclimatic inputs have predetermined daily values over the modeling period, and demand adjusts in response to weather within the demand model. However, within the financial model, demand does not dynamically react to hydroclimatic conditions, changes in rate policy, or periods of high inflation. All input data and scripts used in this study are publicly available in the GitHub repository (https://github.com/cmpetagna/Tampa-Bay), under the financial modeling directory. Full methodological details for the SWRE model and its inputs can be found in Gorelick et al. (2023) and Asefa et al. (2014a).

Operating Model System, Version 1 and Optimized Regional Operations Plan Model (Joint Modeling Components)

Tampa Bay Water's daily surface water operations and delivery strategy are simulated and optimized using two linked models. The first, the operating model system, Version 1 (OMS1), is a MATLAB-based routing model that determines how water from the Alafia River (directly) and the Hillsborough River (via the Tampa Bypass Canal) is allocated between the SWTP and the C.W. Bill Young Reservoir. During wet periods, OMS1 routes surplus water to the SWTP or reservoir; in dry periods, reservoir water supplements reduced river flows. Running concurrently with OMS1 is the optimized regional operations plan, a mathematical programming language (AMPL, Fourer et al. 2003). It identifies the most cost-effective daily water production and delivery strategy across TBW's member governments. Whenever total demands cannot be met within system constraints, the unmet volume is tracked via "slack variables." These slack variables account for any shortfalls in supply (Asefa 2015).

Probabilistic Demand Forecast (Input)

To generate synthetic demands, TBW uses a demand forecast approach that incorporates socioeconomic and weather variables to project demands across its six member governments. The six member governments are divided into seven water demand planning areas (WDPAs), with Hillsborough County divided into two regions: north and south. The modeling methodology is referred to as "rate-of-use-times-driver" and is applied to each WDPA, separately. The driver refers to a unit within one of three development sectors: single-family housing (SF); multifamily housing (MF); and nonresidential (NR). A variety of business, economic, and zoning data sources provide projections of explanatory variables that include growth of SF and MF units, NR square footage, real median household income, real marginal price of water, persons per household, housing density, fraction of reclaimed water use, NR use type, and weather conditions such as rainfall and temperature. These explanatory variables are used to develop an econometric model for each WDPA to determine the monthly rate of use and, from this, regional water demand.

Using 2017/2018 as a base year, the rate-times-driver-model creates a best-estimate long-term annual demand forecast to 2045. The

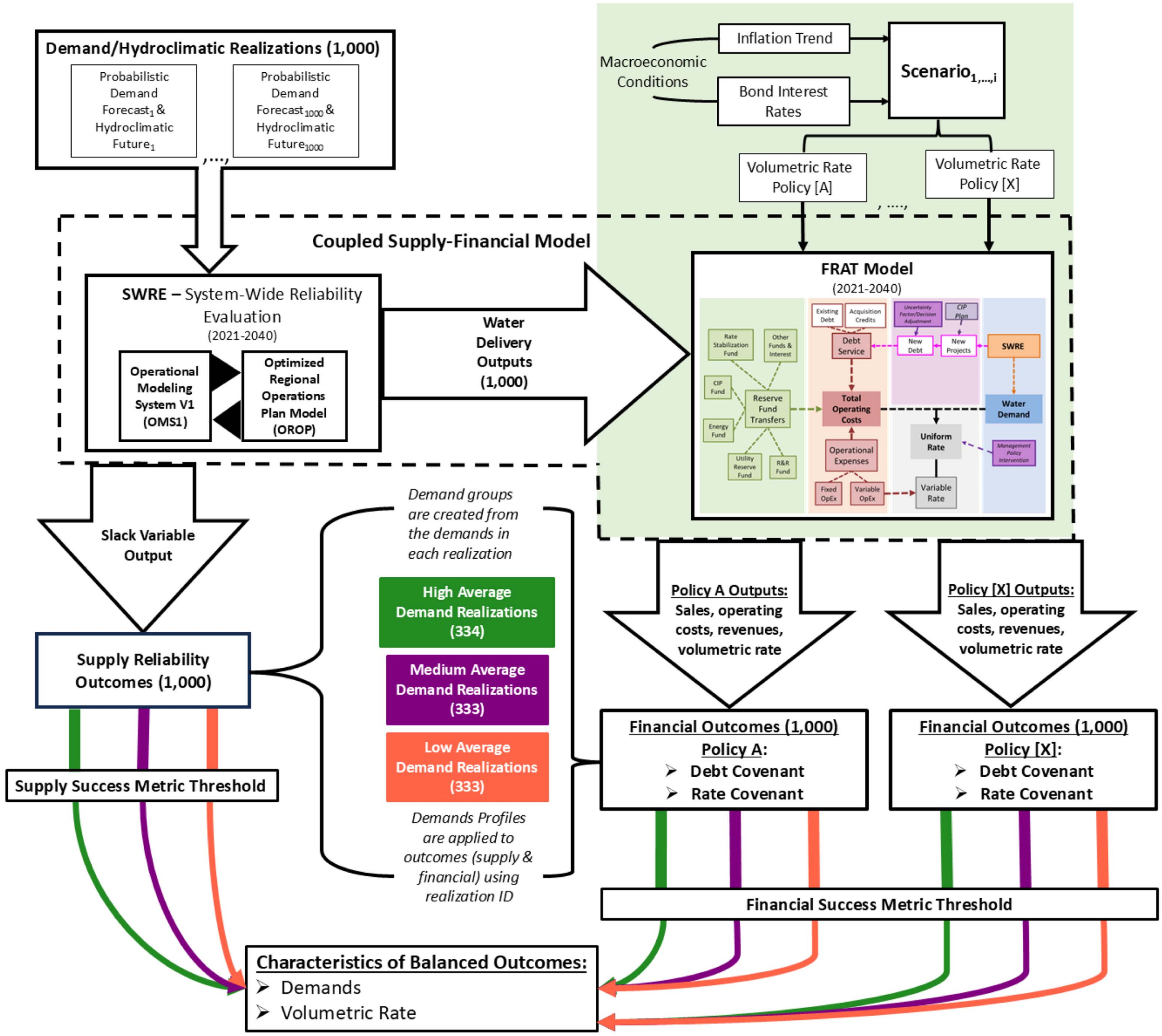

Fig. 2. Model flowchart. 1,000 realizations (demand/hydroclimatic condition combinations) are inputs to the coupled SWRE–FRAT model, which provides supply reliability and financial outcome data. Different volumetric policies can be tested against the 1,000 demand/hydroclimatic realizations. Success thresholds are applied to these outputs to determine which realizations meet both supply and financial goals ("balanced outcomes").

model is calibrated using data between 2001 and 2013 and using years 2014–2018 for validation. From this single forecast, a probabilistic set of monthly demands are created using a Monte Carlo simulation where the probabilistic demands are developed from a joint sampling of the historic variability of the exploratory variables in each driver. The sampling is implemented to create 1,000 20-year ensembles of monthly demand which are paired with 1,000 synthetic streamflow sets based on different hydroclimatic futures.

Hydroclimatic Futures (Input)

Synthetic streamflows are generated using the flow modeling system, Version 2 (FMS2), developed by Hazen and Sawyer. The first component of FMS2 is a rainfall model used to generate ensembles of rainfall time-series for gauge locations in the Alafia and Hillsborough watersheds at nearby St. Leo, Plant City, and the Cypress Creek Wellfield. The St. Leo and Plant City models were developed using 106 years of monthly rainfall data, and the Cypress Creek Wellfield model was developed with 30 years of data. The rainfall models are created using seasonal variants of Gaussian mixture models, an adaptation of hidden Markov models. The historical records at each site are separated by month such that there are 12 separate time-series used to determine and fit to three potential climate states: drier-than-normal; normal; and wetter-than-normal (Asefa et al. 2014b). The outputs of the rainfall model are then used in another component of FMS2, which generates synthetic streamflows.

The second component uses a seasonal multivariate linear regression model (SMLR), which consists of two submodels: one for the wet season (June–September); and one for the dry season (October–May). To capture the impacts of historic climate variability on streamflows, the submodel parameters are developed using 30 years of historic rainfall and streamflow data. The SMLR uses the synthetic rainfall data as inputs to generate synthetic monthly streamflows for the Hillsborough River, TBC, and Alafia River (Hazen and Sawyer 2010; Wang et al. 2020, 2022). The monthly streamflow data

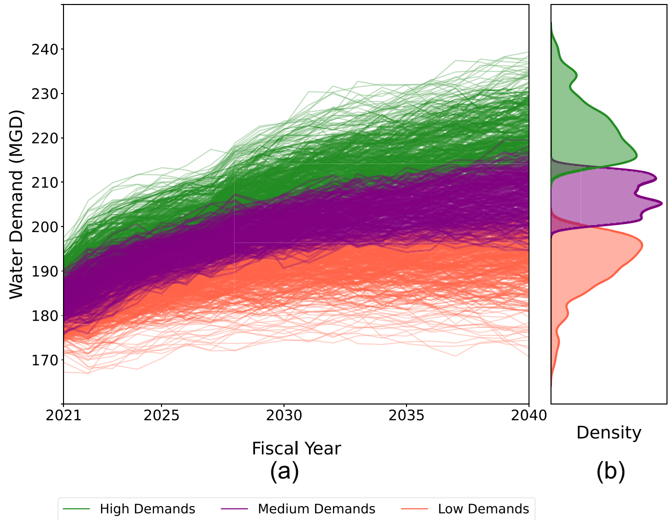

Fig. 3. The 1,000 synthetic demand realizations, categorized into high, medium, and low demand groups based on the average annual demand over the simulation period: (a) demand time-series from 2021 to 2040; and (b) distributions of the average annual demand for each group. Demand group classifications are based on the average annual demand for each realization: low demand (<194 MGD), medium demand (194–203 MGD), and high demand (>203 MGD).

are disaggregated into daily data for use in the daily operations model. The disaggregation is done using a multivariate nonparametric disaggregation procedure that is similar to the *k*-nearest neighbor method (Lall and Sharma 1996).

Demand Groups

To determine how variability in demand growth over time impacts supply and financial performance, demand realizations are categorized into three demand groups: low; medium; and high. The average of the monthly demands across the 20 year planning period was calculated for each realization. The average demand instead of average growth rate is used because when the modeling period starts, the annual daily demand average of the realizations varies between 165 (625) and 200 MGD (757 MLD) and does not affect the annual demand growth rate for each of the realizations. Therefore, if demands were grouped by average demand growth rate, there are instances of realizations that begin with a high annual daily demand average and exhibit low demand growth on average across the 20 years, yet overall demand still exceeds supply capacity and vice versa. Instead, annual average demand is used to establish targets to be met by demand management (the actual active actions for achieving demand management are not explored in this work). The 1,000 realizations in each volumetric rate policy are divided into the three roughly equal groups such that 333 realizations fall into the low group [average demand <194 MGD (734 MLD)], 333 in the medium third [194 MGD (734MLD)] ≤ average demand <203 MGD (768 MLD)], and 334 in the high third [average demand ≥ 203 MGD (768 MLD)] (Fig. 3).

Financial Risk Assessment Tool

The FRAT is a Python-based forecasting model that simulates the budgetary flows of TBW revenues and costs and does so in a manner that conforms with its accounting practices. The FRAT model utilizes daily water delivery outputs from SWRE to simulate water sale revenues for each fiscal year (coincides with the water year from October to September) over the modeling period, 2021–2040. Water sales are generated from the volumetric sale of treated water charged at the volumetric rate per 1,000 gal and the sales of untreated water to the City of Tampa. Revenues and operating costs, which include debt service payments, are compiled at the end of each simulated year and then reconciled with the previous year's simulated budget resulting in financial outcomes (actuals) for the current fiscal year (Fig. 4) being modeled (i.e., there are 20 years of modeled actuals).

The FRAT model then simulates the budgeting process for the next fiscal year, which includes estimating operating costs, water sales, revenues, and transfers between funds. During the budgeting process, the volumetric rate (referred to as "uniform rate" by TBW) is set using the estimated total operating costs and water deliveries for the next fiscal year. Total operating costs (referred to by TBW as the annual estimate) include the utility's debt service, which is the sum of previously issued debt and new debt used to finance projects for supply expansion, water quality improvement, or for renewal and replacement of existing capital. The budgeting process takes into consideration the required reserve fund balances, needed to maintain bond covenants, and account for the necessary revenue deposits that may be needed the next year to meet those requirements. During the actual TBW budgeting process, water sales revenue for the next year is estimated based on short-term projected demand data (not the same projected demands used in SWRE for long-term planning, but the short-term demand projection for budgeting purposes follows a similar process described in the section "System-Wide Reliability Evaluation (SWRE) Model and Inputs"). To estimate water sales revenue FRAT uses the "water delivered" in the fiscal year and a growth rate multiplier.

The volumetric rate ($ per 1,000 gal.) is calculated for the upcoming fiscal year by dividing the projected total operating costs by next year's projected annual demand. There are two components to TBW's volumetric rate: a fixed rate component; and a variable rate component. After subtracting the variable operating costs (associated with power and chemicals) from the total operating costs, the member governments are charged a monthly portion of the remaining balance based on the fraction of the previous year's water demand relative to total TBW demand from the previous fiscal year. The variable rate is the product of the ratio of the budgeted variable cost to the total operating costs and the volumetric rate charged per 1,000 gal. of water delivered.

For this study, several parts of the FRAT model were added to and/or modified compared to Gorelick et al. (2023). One of the modifications changes the way in which new debt service is considered. In Gorelick et al. (2023), debt service was included based on the supply infrastructure scenario considered within SWRE, with an estimate of the project's cost and an assumed interest rate and maturity period for the debt. Additionally, only new debt service associated with supply infrastructure was considered in the earlier model, meaning that a significant portion of total expected debt service (65%), which includes TBW's funding of capital improvement projects not related to supply, was not included in TBW's future operating costs. Including all future debt, regardless of project type, is important not only because total debt service is part of the calculation of financial stability metrics (Section 2.3.2), but also because it is common practice among water utilities to rely on debt to cover the cost of major capital improvement projects, especially as federal funding for these projects has declined (Ajami 2018). In addition, the characteristics of anticipated future bonds can now be modified within FRAT to account for changing interest rates, timing of bond issuance, and the length of bond maturity. Moreover, since TBW seeks to keep the amount of annual debt service within a range of $80 to $120 million, the bond agreement with issuers also specifies how many years TBW can delay

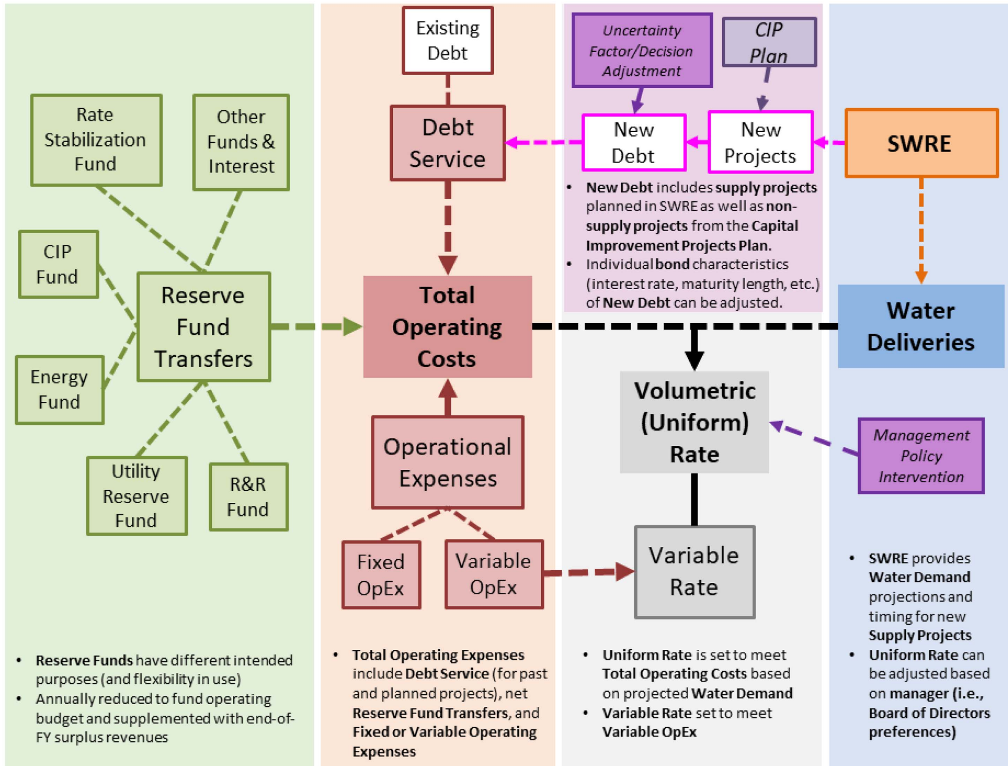

Fig. 4. Components of the financial risk assessment tool, which uses water delivery outputs (blue) from the SWRE model (orange) and the estimated total operating costs (red) to determine a suitable volumetric rate (gray).

principal payments, which is another decision variable that can now be modified within FRAT. Bond characteristics and the ranges of values considered in this research are described in more detail in Section 2.3.3.

Success Thresholds

We operationalize "successful" and "unsuccessful" realizations using a satisficing measure: a realization is successful only if it simultaneously meets the supply-reliability and financial thresholds, as described in the following. Rather than seeking a single optimal trade-off, this approach evaluates whether each realization falls inside an acceptability domain defined by explicit bounds on supply and fiscal outcomes. This satisficing/robustness framing is standard in decision-making under deep uncertainty (Herman et al. 2015).

Supply reliability success threshold. In each realization, success in meeting supply reliability goals is achieved by avoiding 30 consecutive days in which demands are not fully met, thus necessitating pumping in excess of groundwater pumping permits, a condition identified by evaluating slack variable output from SWRE. If demand is not met for 30 consecutive days at any point during a realization, a "critical shortfall" is said to have occurred, and the realization is labeled as "unsuccessful" with respect to meeting TBW's established supply reliability goals. Realizations in which supply shortfalls occur for less than 30 consecutive days are assumed to be managed by TBW and its member governments through a combination of short-term usage restrictions or supply augmentation actions (TBW 2017; Wang et al. 2019). We define the critical shortfall in terms of consecutive days because TBW diversified supply portfolio and emergency operational measures can typically mitigate short interruptions (e.g., one to two days), but sustained shortages have materially different operational and financial implications. A 30 day threshold therefore captures sustained, operationally significant shortages rather than transient fluctuations and aligns with prior agency planning practice (Wang et al. 2022).

Reliability is presented in terms of the percentage of successful realizations in each fiscal year and is further broken down by demand group (high/medium/low), such that for each fiscal year reliability ($SR_{Dr,FY}$) is calculated as

$$SR_{Dr,FY} = \frac{1}{D_r}\sum \lambda_{r,FY} \tag{1}$$

$$\lambda_r = \begin{cases} 1 & C_{r,FY} < 1 \\ 0 & \text{else} \end{cases} \tag{2}$$

where D_r = the total realizations in the demand group; and C_r = the annual number of critical shortfalls.

Financial reliability success threshold. Demand uncertainty makes long-term planning and the achievement of supply reliability and financial stability goals more challenging. This goes beyond understanding how revenues are being impacted, to include the use of financial benchmarks that provide a more comprehensive picture of a water utility's financial health using the types of metrics employed by credit ratings agencies. Two financial metrics are typically used to assess water utilities' financial health, including TBW's. The first is the debt covenant (C_{debt}), which is the ratio of net revenues to the sum of a utility's debt service and deposits to several funds needed to ensure smooth long-term functioning of the utility, such that

$$C_{\text{Debt},FY} = \frac{\text{Net Revenues}_{FY}}{DS_{FY} + \text{Deposit}_{CIF,FY} + \text{Deposit}_{R \text{ and } R,FY}} \tag{3}$$

where C_{Debt} = fiscal year FY is the ratio of net revenues for the FY over the sum of the debt service (DS) and budgeted annual deposits into the capital improvement fund (CIF) and renewal and replacement fund (R and R).

The second metric is the rate covenant (C_{rate}), which is the ratio of the sum of net revenues and reserve fund balance over its debt service payments, such that

$$C_{\text{Rate},FY} = \frac{\text{Net Revenues}_{FY} + \text{Reserve Fund}_{FY}}{DS_{FY}} \tag{4}$$

where net revenues = the sum of annual water sales, nonsale revenues, unencumbered funds from the previous fiscal year, and any funds withdrawn from the utilities rate stabilization fund minus the deposits to the various funds required to satisfy the rate covenant and total operating costs. The reserve fund is a savings fund, which is not used to fund projects; for TBW, the allowed reserve fund minimum is sufficient to cover 10% of yearly budgeted revenues.

To meet the requirements of TBW's master bond resolution, an agreement between TBW (the wholesaler) and the six member governments, TBW's debt covenant ratio must be at least 1.0, while its rate covenant ratio must be at least 1.25 at the end of each fiscal year. If either ratio drops below these thresholds, it is an indicator of financial risk and could lead to a credit rating downgrade, which would likely result in TBW paying higher interest rates on future bonds. Success in meeting these covenants is tracked for each fiscal year throughout a realization and across the low, medium, and high demand groups.

Financial Risk Assessment Tool Scenarios

The bond interest rates TBW is expecting for its four upcoming bond issuances in 2023, 2025, 2027, and 2029 are applied to the 1,000 demand/streamflow realizations. The bond amounts and timing are provided in TBW's (2023) capital improvement program plan (TBW 2022a). Between the years 2027–2032, the total annual debt service payments will be over \$100 million, putting TBW in a financially vulnerable position. One of the conclusions of Gorelick et al. (2023) is that the volumetric rate set in 2021 needed to be raised to increase the chances of meeting financial performance goals (established by bond covenants); however, increasing the volumetric rate sufficiently such that financial goals are always met results in very high rate increases in some years. Rapid increases not only run counter to TBW's traditional rate setting policies, which seek to provide price stability for customers and have resulted in maintenance of the same rate from 2011 to 2021 (TBW 2018), but also introduce concerns over affordability (Patterson and Doyle 2021). Therefore, this analysis applies four different volumetric rate policies as a means of identifying the degree to which each improves financial outcomes, which can then be weighed against concerns over rate stability and affordability. The volumetric rate policies A/B/C/D set an upper limit on the rate increase that TBW can impose each fiscal year such that: (1) annual rate increase is capped at 1%; (2) at 2%; (3) at 3%; and (4) at 4%. The financial performances of the rate policies are then compared. Supplementary Table 1 provides information about the interest rate of each bond, year of issue, and the capped annual percent increase associated with each volumetric rate policy.

Successful Demand Management Pathways

Success in meeting financial performance goals ($FS_{Dr,FY}$) is described relative to TBW's maintaining debt and rate covenants above the prescribed thresholds in each fiscal year, such that

$$FS_{Dr,FY} = \frac{1}{D_r} \sum \lambda_{r,FY} \tag{5}$$

with the success rate of the debt covenant measured relative to a threshold of 1.0, and the success rate of the rate covenant relative to a threshold of 1.25, such that

$$\lambda_r = \begin{cases} 1 & C_{\text{Debt},FY} \geq 1.0 \\ & \text{and} \\ & C_{\text{Rate},FY} \geq 1.25 \\ 0 & \text{else} \end{cases} \tag{6}$$

Table 1. Summary of modeled scenarios, outcomes, and decision maker considerations

Scenario	Description	Outcome
Low demand outcomes (<200 MGD)	Fig. 7 shows that, in low-demand scenarios, rate and bond covenants fail to be met in many realizations and for many years. Fig. 8 shows ratepayers consistently paying the cap of the rate policy year-after-year.	In this scenario, the anticipated demand growth that motivated the supply investments fails to materialize. Even when ratepayers are paying the maximum allowable annual increase in each policy case, the resulting revenues are inadequate to satisfy the utility's financial targets. Consequently, meeting the prescribed financial goals would necessitate higher year-over-year rate increases.
High demand outcomes (>220 MGD)	With the exception of Rate Policy A, Figs. 7 and 8 show that financial goals are being met by the utility, but the supply reliability goals are not.	This scenario indicates that demand may exceed the supply investments, and the utility would want to consider additional investments in supply in later years. In real world terms, the additional investment is not without risk as those demands may never be realized.
Median demand outcomes (<220 MGD)–Policy B (≤2%)	Maintaining demand levels between 200 and 220 MGD helps the utility meet its supply reliability goals without having to immediately add another infrastructure investment after the 2028 supply additions. With Rate Policy B, the rate increase never goes above 2%, but there are a few years when the rate and bond covenants are not being met.	If demand can be contained within this range, supply metrics are met without consideration for having to invest in additional supply projects. The comparison of these rate policies comes down to what a utility decision maker feels more comfortable with. For Rate Policy B, rates will never increase above 2% each year and the utility risks certain circumstances may prevent them from meeting the rate and bond covenants in some years (Fig. 7). Conversely with Policy C, the utility must consider if the extra increase in rates and potential burden on rate payers is worth no risk in not meeting the debt and rate covenants.
Median demand outcomes (<220 MGD)–Policy C (≤3%)	In this scenario, supply reliability and financial goals are met, but there is a higher increase in rates compared to Policy B.	

Tampa Bay Water's performance in terms of meeting its goals with respect to all three metrics (supply reliability, debt covenant, and rate covenant) is measured as the number of realizations (out of the total in each demand group) that meet or exceed TBW's established performance thresholds for each metric. These are reported for each fiscal year over the planning period and are described in results by means of pie charts showing successful and unsuccessful realizations. A pie chart is presented not only for each individual metric in each year but also in terms of years that meet performance standards in all three areas in the same year.

Success in meeting supply reliability goals is a function of infrastructure capacity (which varies over the planning period as new supply capacity is added) and demand growth. Understanding how the supply reliability of the system can be maintained via demand management can help a water utility decide whether to delay or even forego the development of new infrastructure (Boyle 2014). While this analysis does not identify specific demand management programs or their effectiveness, it does provide insight into what levels of demand management would be required to meet supply reliability goals. This information could then be used in combination with knowledge of a given demand management action's effectiveness to make decisions regarding which action(s) to implement. Similarly, running this analysis over different volumetric rate policies provides valuable information for assessing the ability of each to allow TBW to meet its financial performance goals. Thus, TBW's ability to make choices regarding demand management and pricing represents adaptive decisions it can use to meet its supply reliability and financial stability objectives in the face of hydrologic and demand growth uncertainty.

Results

The consequences of the uncertainty in demand projections and hydrologic conditions are captured across the 1,000 realizations that are input to the coupled SWRE–FRAT model, generating estimates of TBW's supply and financial performance in each realization. In the results that follow, the demand trends in the realizations are divided into high/medium/low groups and are used to evaluate how demand influences supply and financial performance. Tracking the demand groupings and the resulting volumetric rate increases across realizations allows for an improved understanding of the financial and/or demand management decisions (or levers) that TBW can use to improve its ability to reach both its supply and fiscal goals.

Supply Reliability

Supply reliability in TBW's system is dominantly influenced by demand growth, with higher future demands leading to substantially lower supply reliability (Fig. 5). The percentage of successful realizations (blue) varies by demand group and the percentage of realizations that contain at least one critical shortfall (groundwater pumping exceeding permitted capacity for 30 consecutive days) each year are depicted in gray. In 2028, the South Hillsborough pipeline and SWTP expansion are completed and improve supply reliability across all three demand groups (high, medium, and low). Even with these supply project additions, however, the high demand realizations still lead to a much higher rate of supply shortfalls over the postproject portion of the planning horizon, while the low demand realizations show high supply reliability.

Demand Groups and Volumetric Rate Policy Combinations

Supply reliability is arguably the most important measure of a utility's operational performance, but high levels of reliability are often achieved through investment in new supply projects, which can have countervailing effects on a utility's financial performance in the form of higher debt service and increases annual operating costs, which must then be covered by revenues largely generated by volumetric water sales. Maintaining the balance between debt service and revenues is critical for meeting debt and rate covenant thresholds, which determine a utility's credit rating and future borrowing costs. For Rate Policy A, analyzed in Fig. 6, growth in TBW's volumetric rate is limited to no more than 1% each year. Such limits on rate increases can leave the utility financially vulnerable, particularly if they are accompanied by low demand, both of which constrain revenues and result in fewer realizations in which TBW successfully meets its financial goals. The high demand realizations, on the other hand, have a lower supply reliability, but increased water sales lead to a higher percentage of realizations that exceed debt and rate covenant success thresholds. This is especially evident during the years when TBW is most financially vulnerable (2027 to 2032) due to increased debt service. Even among the high demand realizations, the probability of successfully achieving financial performance goals is still relatively low during this period, indicating that limiting rate increases to 1% annually frequently fails to generate enough revenue to meet debt and rate covenant thresholds.

The bottom row of results in each demand grouping indicates the percentage of realizations simultaneously meeting/exceeding all three performance thresholds, such that a successful realization involves debt and rate covenants being met and no supply shortfalls. Success in meeting all three performance goals is relatively low, approaching 60% in all demand groups even after the supply projects are added, but low demand leads to a higher percentage of realizations (e.g., 80% in 2026) achieving performance goals across all years.

Raising the limit on annual rate increases from 1% (Rate Policy A) to 2% (B), 3% (C) or 4% (D) has a significant impact on the fraction of realizations meeting all three performance goals (Fig. 7). This is due to the improved success in meeting the debt and rate covenants, as meeting supply reliability goals is not impacted by rate increases. The percentage of realizations meeting the single supply reliability goal in Fig. 7 (shown as a dashed line, coincident with other time series in high and medium demand results) acts as a ceiling on the percentage achieving success relative to all three performance metrics simultaneously.

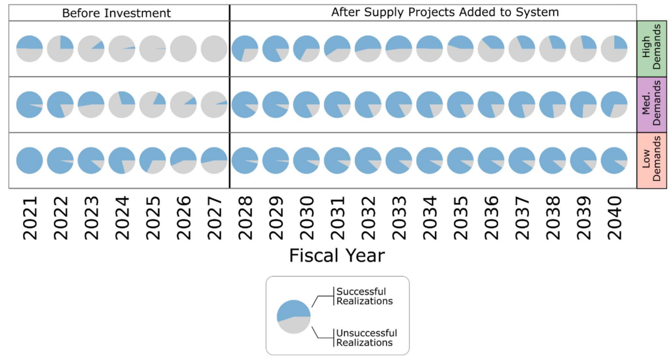

Fig. 5. Supply reliability outcomes across 1,000 demand realizations over the planning horizon (2021–2040), separated into high, medium, and low demand groups. Each pie chart represents the proportion of realizations that successfully meet supply reliability thresholds (blue) versus those that experience critical shortfalls (gray) in each fiscal year. The vertical line at 2028 marks the addition of planned supply projects (South Hillsborough pipeline and SWTP expansion), which improve supply reliability outcomes across all demand groups.

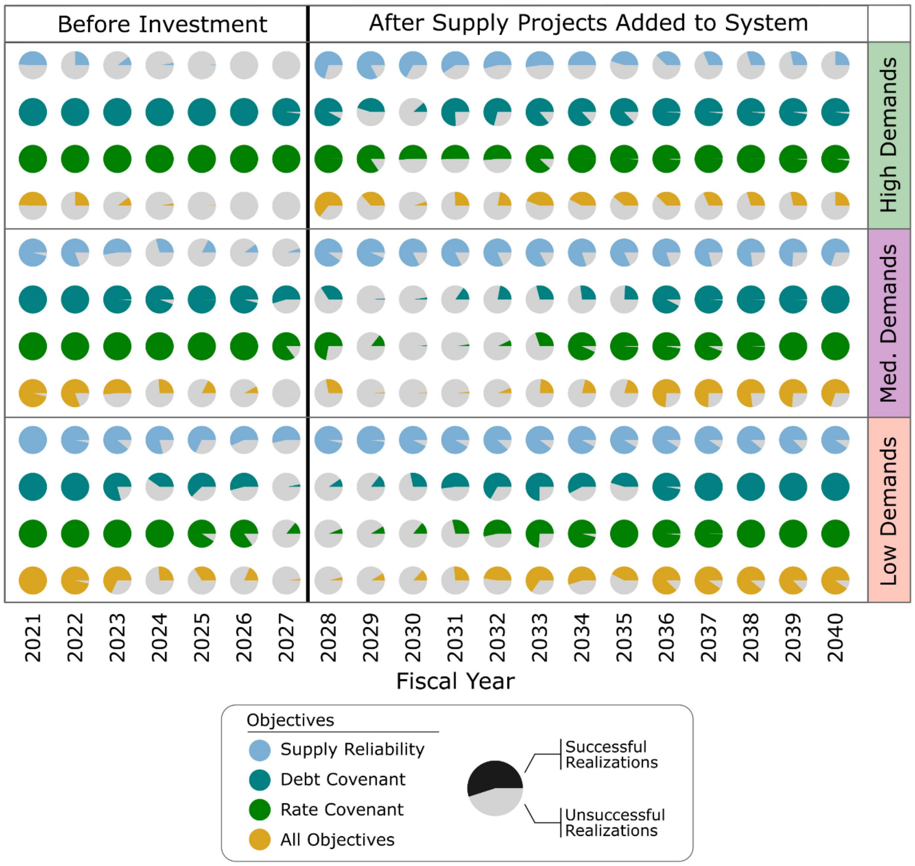

Fig. 6. Annual success rates for achieving supply reliability (blue), meeting debt covenant requirements (teal), rate covenant requirements (green), and all three objectives simultaneously (gold) across 1,000 demand realizations, categorized by high, medium, and low demand groups. Each pie chart represents the proportion of successful (colored) versus unsuccessful (gray) realizations in each fiscal year. The vertical line at 2028 marks the addition of new supply projects.

Rate Policy A has the lowest annual rate increases (≤1%) and the lowest level of success across all three demand groups, as the low limit in annual volumetric rate increases leads to many realizations in which financial performance goals are not met. Policies B, C, and D allow for higher rate increases and thus often lead to meeting financial goals when high demand growth is experienced. Under these rate policies, success in meeting all three performance goals is limited by the relatively low percentage of realizations meeting supply reliability goals. As demands decline (i.e., medium and low demand groups), the fraction of realizations meeting financial performance goals declines and leads to greater differentiation among pricing policies B, C, and D. In the case of Rate Policy D, in which the volumetric rate is allowed to increase by up to 4% annually, financial performance goals are met with increasing frequency, such that, even in the low demand grouping, it is mostly supply reliability that limits the percentage of realizations that meet all three performance standards simultaneously. The supply reliability limitation has the smallest impact on the low demand group realizations and therefore the highest chance of meeting all supply and financial goals. This suggests the high potential impact of demand management and provides target levels for any demand management program (i.e., reach levels described by the low demand grouping); however, it is important to understand how much the volumetric rate needs to be increased for a balance between meeting supply and financial goals to be achieved.

As a result, it is important to understand the combination of demand and volumetric rate conditions that lead to a higher fraction of successful realizations. The demand range in which TBW is estimated to achieve high levels of success in meeting supply and financial reliability goals (yellow) hovers between 180 (681) and 220 MGD (833 MLD) after the supply projects in 2028 are added (Fig. 8). Supply reliability goals are met in the demand range between 200 (757) and 220 MGD (833 MLD) with a lower volumetric rate than realizations in which demands are in the range between 180 (681) and 200 MGD (757 MLD). These differences become more pronounced between Rate Policies B (annual rate increases ≤2%) and C (≤3%). The larger volumetric rate increase required under low demand realizations could raise concerns over customer affordability, especially for realizations where there is an annual increase of 3%–4% for many consecutive years, such as Rate Policy D, which may be burdensome to lower income households. It is crucial for water utilities to fully understand the "Goldilocks Zones" (e.g., the yellow cluster observed after the implementation of the "28 supply project"), in order to meet supply and financial objectives within each policy framework. This consideration is exemplified by Rate Policy C, in which the increase in rates relative to Rate Policy A may be justified by the higher percentage of realizations successfully meeting financial goals, particularly among low demand futures. However, Rate Policy C may be the highest a water utility could reasonably implement, such that any increase in the percent of successful realizations using Rate Policy D (annual rate increases ≤4%) would be impractical given affordability concerns. The rate policy implications on the demand groups described in Fig. 8 provide a detailed depiction of the trade-offs between demand and supply

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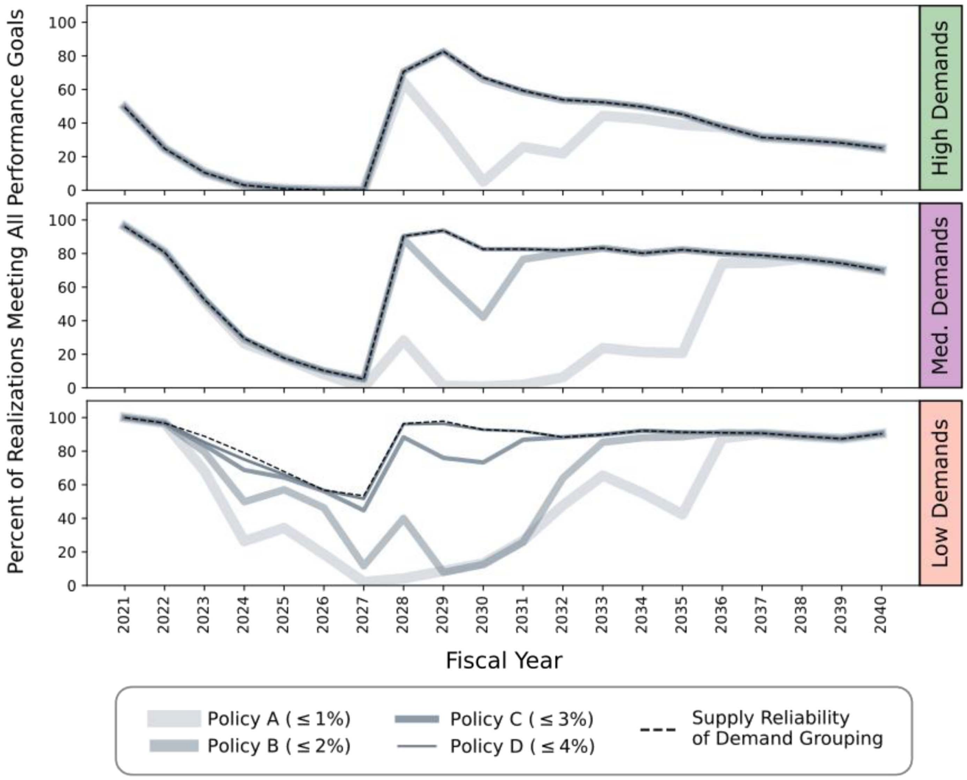

Fig. 7. Percentage of realizations meeting all three performance goals (supply reliability, debt covenant, and rate covenant) under different volumetric rate policies, categorized by demand group (high, medium, and low). The dashed black line represents the supply reliability success rate for each demand group, which serves as an upper limit on achieving all objectives. Four rate policies are compared: Policy A (≤1% annual increase, light gray); Policy B (≤2%, medium gray), Policy C (≤3%, dark gray); and Policy D (≤4%, black).

reliability and the rate increases necessary to maintain financial stability while still maintaining affordability.

Discussion

These results provide insights useful in the design of planning pathways that increase the ability of a water utility achieving the balance between supply reliability and financial stability, as it navigates uncertainty in demand growth and hydroclimatic conditions. Using a coupled supply and financial model, several Goldilocks Zones are identified as described by a combination of demands and rate policies, which lead to a high probability of meeting supply reliability and financial goals while maintaining rates at affordable levels. Previous research has typically evaluated a water utility's financial health in terms of expected revenues, sometimes with attention to revenue variability but rarely in terms of the financial metrics that drive utility decision-making, such as bond covenants. Attention to these metrics provides better insight into the relationship between supply and financial operations because covenants take into consideration multiple aspects of a water utility's financial performance often with a focus on some combination of debt service payments and revenues. For Tampa Bay Water, its debt and rate covenants include revenues, reserve funds, funds for maintaining existing infrastructure, and debt service, such that tracking all of these throughout the planning period requires a more detailed and highly integrated modeling framework. Further, when observing the links between supply reliability and financial stability, it is important to include consideration of a utility's accumulated debt, not just the additional debt of an individual investment (e.g., supply project). This is becoming increasingly important as more water utilities struggle to reconcile the costs of maintaining and/or replacing aging infrastructure, estimated to be in the trillions of dollars at the national scale (ASCE 2020). Uncertainty over future water demand and growing pressure to keep rates at an affordable level only add to the challenges of identifying successful development pathways (Qureshi and Shah 2014).

The appropriate balance between demand management and customer rates will vary for individual water utilities, but once the 2028 supply project is added to TBW's system, a demand management target range of 200–220 MGD (757–833 MLD) (medium demand group range) would help maintain TBW's supply reliability without having to develop another new supply project immediately after the 2028 supply investment. Conversely, a demand management strategy would likely require accompanying volumetric rate increases to meet financial goals, and affordability concerns will limit the range of rate increases considered (Patterson and Doyle 2021). Table 1 summarizes the trade-off between affordability considerations and meeting financial and supply reliability performance metrics, which is perhaps most clear when considering a rate policy that caps the annual increase at either ≤2% (Rate Policy B) or ≤3% (Rate Policy C). Whereas one decision-maker may think a 3% annual increase is too high, another may consider doing so to increase the probability of meeting all performance metrics is justified. Thus, there is a need for decision-makers to identify and understand the trade-offs required to reach the Goldilocks Zone for a utility in which demands and rates allow for supply reliability and financial goals (i.e., bond covenants) to be met, especially in the face of significant uncertainties in demand growth. Estimating the direct affordability impacts of TBW's wholesale rate adjustments is beyond the scope of this study because wholesale changes are mediated through each member

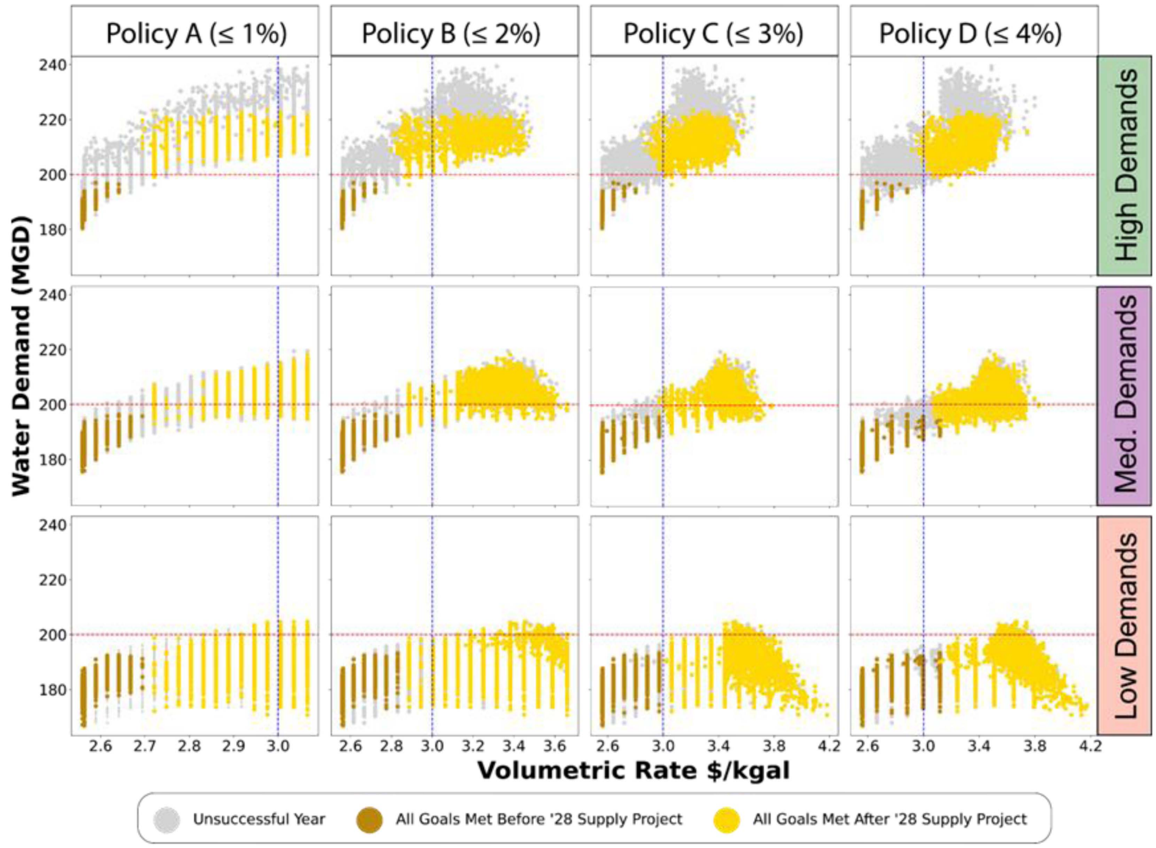

Fig. 8. Demands categorized by group (high, medium, and low) and volumetric rates of realizations that meet all three performance goals before the 2028 supply projects are added to the system (brown) and after (yellow). Years in which one or more goals is not met are gray. A blue vertical line and a red horizontal line mark the $3/kgal volumetric rate and 200 MGD water demand, respectively, for comparison across policies and demand groups. Rate Policy A caps the annual volumetric rate increase at 1%, Rate Policy B is 2%, Rate Policy C is 3%, and Rate Policy D is 4%.

government's retail pass-through mechanisms and billing structures. As a result, retail-rate outcomes and the impacts of burden on low-income households will vary across jurisdictions (Patterson, Bryson and Doyle 2023). TBW's current wholesale rate is approximately $2.64 per 1,000 gal. A 2%–3% wholesale rate increase adds about $0.05–$0.08 per 1,000 gal (TBW 2025). For a typical household using roughly 4,200 gal per month, this corresponds to an increase of approximately $0.22–$0.33 per month if the full increase is passed through in the volumetric charge (TBW 2023). Although an average 2%–3% annual wholesale increase may be justifiable for the TBW service region, the impacts on individual households depend on retail pass-through mechanism as well as household income and consumption patterns. TBW's reliance on comparatively inexpensive groundwater tends to reduce the wholesale share of retail bills, so modest wholesale increases (e.g., 2%–3% per year) translate into smaller changes in household bills than would be observed in surface-water-dependent systems (Hughes et al. 2025). Nonetheless, distributional impacts on vulnerable households remain possible; a detailed assessment therefore requires a household-level analysis that links retail-billing structures or pass-through schedules to demographic indicators and is recommended for future work.

Since the daily demand and hydroclimatic realization inputs are predetermined across the 20 year modeling period, the volumetric rate does not directly influence the demand outcomes. While urban demand for water tends to be relatively unresponsive to price, adding consideration of price elasticity of demand into the modeling framework would provide an added dimension. The independent nature of the hydroclimatic and demand inputs also means that there is no accounting for a potential negative correlation between regional precipitation and demand. Given that the majority of TBW's supply comes from groundwater, whose availability is not likely to be overly affected by year-to-year fluctuations in precipitation, this limitation does not seem likely to have a large distorting effect, but for utilities more dependent on surface water, this could be a more important factor. In addition, the 30 year record of historical hydrologic observations does make it difficult to capture extremes while also limiting the ability to detect any shifts in rainfall trends. As a result, future research in this area might focus on better characterizing the impacts of prolonged dry conditions, especially if TBW begins to move away from primary reliance on groundwater. A general consideration for future work is to incorporate projection-based climate change scenarios into the supply model to assess their influence on the coupled supply–financial dynamics. In this study, we instead use a 1,000-member Latin-hypercube ensemble sampled from historical streamflow and precipitation records to robustly stress-test system performance across a wide range of plausible near-term scenarios; these results are therefore intended to probe short- to midterm vulnerability rather than to represent long-term resilience. We chose this approach because, over our 2020–2040 planning horizon, internal climate variability, rather than multimodel mean climate change signals, dominates the range of plausible regional hydroclimatic extremes (Lehner and Deser 2023; Lehner et al. 2020). Projection-based, nonstationary assessments remain important for multidecadal planning and for systems that rely heavily on surface water; future work should therefore couple climate change projections to the present supply–financial framework.

Conclusion

Maintaining high supply reliability is the top priority for water utilities but balancing that objective with financial stability has become increasingly important and difficult to achieve. Coupled modeling of supply reliability and financial metrics over long-term planning horizons allows for the identification of demand growth and customer rates that will lead to meeting goals in both areas, information that can guide demand management and rate increase decisions. These findings highlight the importance of identifying the Goldilocks Zone in which demands and rates are carefully calibrated to allow for supply reliability and financial goals to be met. Decision-makers must understand the trade-offs inherent in choosing different rate-increase policies and demand management levels, especially amid uncertainties in demand growth, affordability constraints, and rising debt burdens.

Future areas of exploration of the Goldilocks Zone could include additional trade-off considerations. These might involve exploring temporary depletion of certain reserve or rate stabilization funds to reduce the impact of additional debt and lower the customer rate increases required to meet utility financial goals. Other trade-offs could include limiting the number of capital improvement projects a water utility performs such that it meets bond covenants. Using the levers of rate increases and demand management to arrive in the Goldilocks Zone allows for greater flexibility in efforts to effectively balance new supply investments and demand management strategies while still meeting financial performance standards.

Utilities worldwide face competing pressures: aging infrastructure; constrained water supplies; the need to schedule capital investments without burdening ratepayers; and political and regulatory demands to keep rates affordable. These objectives frequently conflict, making it difficult for utilities to achieve them all simultaneously. A coupled supply–financial modeling framework renders these interactions explicit, uncovers previously unrecognized trade-offs, and identifies policy levers that link operational outcomes to fiscal health. A central policy implication of our analysis is that utilities should consider institutionalizing more frequent, incremental rate adjustments; for example, via prespecified fiscal triggers or automatic adjustment mechanisms, to preserve financial capacity while advancing infrastructure renewal, supply reliability, and affordability objectives over time. These results, and more importantly, the type of integrated supply–financial modeling described in this work, have broad implications, as more utilities seek to balance supply reliability and financial stability in the face of future uncertainty and rising debt burdens. For Tampa Bay Water, the utility's annual debt service obligations will be highest between 2027 and 2033, as it plans to issue four bonds over the next six years. Understanding the interplay between moderate rate adjustments and effective demand management will help the utility ensure water supply and fiscal goals are maintained and potentially delay the need for additional infrastructure (and therefore additional debt service), until it becomes essential. The importance of adaptive planning can be viewed from a historical context, such as the temporary drop in demand TBW experienced during the 2008–2010 housing market downturn (TBW 2018). By coordinating incremental rate strategies and demand management measures, there is more flexibility in the timing of even more supply project investment, which can protect TBW's revenue base should a similar event occur during their high debt obligation period.

Data Availability Statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request. Code used to model and reproduce supply and financial modeling results is available in an online repository.

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Author Contributions

Christina Petagna: Conceptualization; Data curation; Formal analysis; Investigation; Visualization; Writing – original draft. Dan Li: Data curation; Validation; Visualization; Writing – review and editing. David E. Gorelick: Conceptualization; Data curation; Investigation; Methodology; Software; Validation; Writing – review and editing. David F. Gold: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Software; Writing – review and editing. Trevor Amestoy: Data curation; Investigation; Software; Validation; Visualization; Writing – review and editing. Lillian Lau: Data curation; Investigation; Software; Validation; Visualization; Writing – review and editing. Tirusew Asefa: Conceptualization; Data curation; Methodology; Resources; Software; Supervision; Writing – review and editing. Hui Wang: Conceptualization; Data curation; Methodology; Resources; Software; Supervision; Writing – review and editing. Sandro Svrdlin: Resources; Supervision. Patrick M. Reed: Conceptualization; Funding acquisition; Project administration; Resources; Supervision; Writing – review and editing. Gregory W. Characklis: Conceptualization; Funding acquisition; Project administration; Resources; Supervision; Writing – review and editing.

Supplemental Materials

Table S1 is available online in the ASCE Library (www.ascelibrary.org).

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