# Executive Summary

Integrating Water Efficiency into Long-Term Demand Forecasting (project 4495)

## Key Findings

- Per capita water demand is declining due, in part, to water conservation and efficiency improvements resulting from standards and codes. Long-range demand forecasts should account for the impacts of efficiency standards and codes to more accurately predict future water demand.
- To account for efficiency improvements, forecasters should consider the various end uses of water by examining the stock and efficiency of appliances as well as behavioral aspects of water use, such as shower duration and frequency.
- Stock models are a series of mathematical equations that can help predict the turnover of older, less efficient devices and the increasing market penetration of efficient devices. This research focuses on methods for incorporating stock models into long-range demand forecasts.
- Stock models should rely on local data whenever possible, but in the absence of those data, they can reasonably use data from previous North American end-use studies.
- Through end-use analysis, stock modeling, and scenario testing, forecasters can anticipate the future impacts of standards and codes, as well as new water efficient technologies. Incorporating factors that are likely to affect per-capita water demand into demand forecasts will improve the reliability of future demand management and planning efforts.

## Background

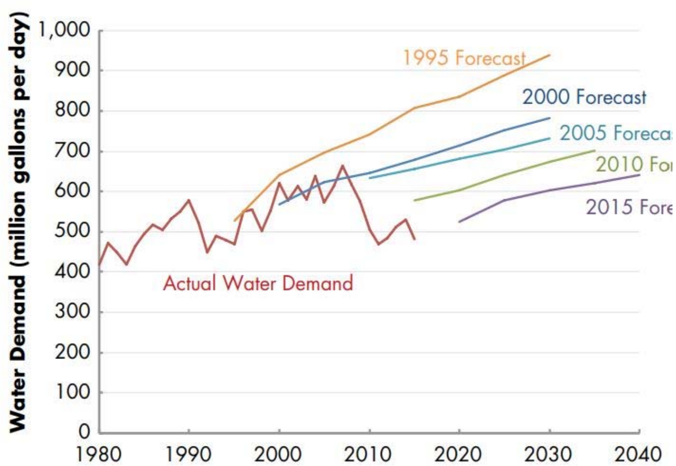
Municipal water demand varies over time in response to a variety of factors, including population, economic activity, demographics, and the implementation of conservation and efficiency measures. During the first half of the 20th century, national per capita municipal and industrial use generally increased, peaking in the 1970s at 370 gallons per capita per day (gpcd). However, by 2010, per capita water use had fallen by more than 40% to 220 gpcd (Donnelly and Cooley 2015). Reductions in per capita demand have been seen in communities across the United States. In some areas, these reductions are such that total water use has remained steady or even declined over the last several decades despite continued population and economic growth.

Several studies have demonstrated that a key driver in reducing per capita demand is the greater uptake of water efficient appliances and fixtures. This has been facilitated by a variety of tools, including direct financial incentives, such as rebates and vouchers; conservation-oriented pricing policies; regulations, such as codes and ordinances; and education and outreach programs. For example, the U.S. National Energy Policy Act of 1992 (EPAct; Pub. L. 102-486, 106 Stat. 2776 1992) adopted minimum efficiency standards for all toilets, urinals, kitchen and lavatory faucets, and showerheads manufactured after January 1, 1994. Standards and codes, like the EPAct, directly lead to improvements in the average efficiency of water using devices.

While efficiency improvements have played a central role in reducing per capita water demand, many water demand forecasts do not adequately account for these improvements and the resulting changes in per capita water usage. Indeed, in a survey of 94 utilities, Kiefer et al. (2016) found that while many utilities are interested in incorporating changing efficiency into demand forecasts, only 20 utilities actually included these factors in their forecasting. As a result, water demand forecasts routinely overestimate future water demand (Heberger et al. 2016; Figure ES.1).

Water planners and managers have a critical need to improve the reliability of long-term water demand forecasts. Inaccurate forecasts can create significant problems for utilities. Underpredicting future water demand can lead to water supply shortfalls, high short-term costs for some consumers, and the imposition of emergency cutbacks. Yet, overpredicting future water demand can lead to unnecessary and costly investment in unneeded infrastructure, including new sources of supply with potentially high marginal costs. Inaccurate forecasts can result in millions of dollars of expenditures, loss of consumer confidence and goodwill, and adverse impacts on system water quality and local economies.

The primary objective of this report is to help water planners and managers improve the reliability of long-term water demand forecasts by more accurately accounting for changes in manufactured product efficiency standards, conservation and efficiency requirements in building codes, new technologies, and third-party certification programs.




*Source:* Heberger et al. 2016.

Figure ES.1 Comparison of Water Demand Forecast and Actual Water Demand in San Diego County, CA, Selected as an Example

## Approach

This report provides a discussion of the impacts of efficiency standards and codes on water demand, as well as practical guidance on incorporating water efficiency improvements into long-term demand forecasts. The researchers reviewed literature on incorporating water efficiency improvements from standards and codes into long-term demand forecasting from the water and energy sectors. In addition, informational interviews were conducted with experts and practitioners in both the water and energy sectors from the U.S. and Australia. Drawing on their experiences and expertise, this research provides examples and case-studies throughout the report to illustrate the application of these approaches.

The project team compiled a comprehensive dataset of voluntary and mandatory appliance standards and codes at the federal and state levels (where applicable) that are relevant for the residential, and commercial, industrial, and institutional (CII) sectors. Information on water use and product lifetime is presented in the appendices. The team also identified devices on the market that exceed current standards, and additional technological improvements that are likely for these devices. As described in the report, this information may be of use to analysts to inform demand forecasting scenarios.

This research provides detailed methods and resources for integrating efficiency improvements into demand forecasts. It describes in detail how stock models can be used to estimate the market penetration of efficient devices and the data requirements for stock models. It also highlights areas of uncertainty for stock models and, more broadly, demand forecasts. Additionally, the report provides two case studies to demonstrate the implementation of stock models and analysis of end uses. Finally, it concludes with practical guidance for water managers and consultants on how to integrate efficiency improvements into demand forecasts.

Given the emphasis of this report on standards and codes, the primary focus is on indoor residential uses of water. However, information on the CII sector is also included, as some end uses within this sector (e.g., clothes washers and pre-rinse spray valves) are affected by standards and codes. While outdoor water use is beyond the scope of this report, it can represent a significant use of water in many communities, and thus a discussion of methods and approaches for integrating outdoor efficiency improvements into different types of demand forecasts is included in Appendix C.

## Results/Conclusions

### Device Efficiency is Improving Over Time

Federal, state, and local appliance standards and building codes have led to increased uptake of efficient devices. In addition, there are numerous devices on the market that exceed current standards, and additional technological improvements are likely for many devices. Voluntary programs at the national, state, or local level can also increase the uptake of water efficient devices beyond required codes. Some of the most prominent national programs include ENERGY STAR, WaterSense, and LEED (Leadership in Energy and Environmental Design) certification. Devices that represent the cutting-edge technology of today may become tomorrow's standards. In 1957, the *National Plumbing Code Handbook* suggested a theoretical minimum for toilet efficiency of 2.6 gallons per flush (gpf) (Manas 1957, Whitford 1972). This "theoretical minimum" has been surpassed with standard toilets using 1.6 gpf and ultra-high-efficiency toilets using less than 1 gpf. Technological advancements are likely to continue improving device efficiencies beyond expectations for a wide range of devices.

### Efficiency Improvements Can Be Incorporated into Different Demand Forecasting Models

There are a variety of methods and models used to develop long-term water demand forecasts. These models vary greatly in their complexity; data requirements; and expertise, money, and effort needed to use them (Billings and Jones 2008, Donkor et al. 2014, Hillyer and Hofbauer 1998). Forecasting techniques can be broadly categorized into four major groups:

- Extrapolation models or time-series forecasts often use historical data to determine water demand per person or per account, which is then multiplied by future population to forecast total future water demand.
- Econometric and regression models are based on an examination of how various explanatory variables, such as water rates and income, are correlated with historical water use. These relationships are then used in combination with anticipated changes in the explanatory variables to forecast future water demand.
- Comprehensive end-use models estimate demand based on the various end uses of water (e.g., toilets, clothes washers, and showers). Water use for each end use is projected individually, based on an inventory of water-using appliances and fixtures and typical behavior patterns of usage, and is summed to estimate total water demand.
- Composite or hybrid models use more than one model type to estimate future demand, such as incorporating some end uses into econometric or regression models as a correction factor to account for efficiency.

As early as 1972, Peter Whitford concluded that basic extrapolation was not suitable for forecasting demand because it did not account for changing water use trends by specific end uses (Whitford 1972). Given continued implementation of appliance standards and building codes, as well as the adoption of new technologies and water-efficient practices, a simple extrapolation of current per capita use is likely to overestimate future demand. Likewise, most econometric models do not incorporate the changing stock and efficiency of devices into base models, but rather focus on the statistical relationship between historical water use and economic and climatic indicators.

To incorporate the expected impact from changing device efficiency, water utilities in the United States commonly use a hybrid approach, developing a baseline forecast using an extrapolation or econometric model and then subtracting a correction factor from that baseline to account for water savings from a set of efficiency improvements. The correction factors can include a robust analysis on the end uses of water, though this is not as common in U.S. utilities.

Alternatively, the energy sector in the United States and water utilities in Australia frequently use comprehensive end-use modeling. While not commonly used by U.S. water utilities, this approach allows utilities to forecast trends in water use for each individual end use and then add the individual end uses together to estimate total demand. These models include the impacts, for example, of weather and price, as well as changing device efficiency over time.

Regardless of modeling technique, analyzing individual end uses of water is one of the best ways to integrate efficiency improvements into water demand forecasts. These analyses can be used to determine the correction factor for extrapolation or econometric models or form the basis of a comprehensive end-use model. While the implementation of these analyses may vary, the underlying principles remain the same. In either case, water demand for each end use is estimated as a function of the stock of devices, efficiency or flow rate of devices, and water-use behavior.

## Stock Models Should Be Used to Characterize the End Uses of Water

Stock models are a series of mathematical functions used to model the changing distribution of devices in a given service area over time. Most commonly, they are used to estimate the uptake of efficient devices (and decreasing number of inefficient devices) from one year to the next. Stock models depend on understanding three key pieces of information: (1) the current number of devices and distribution of device efficiency in a given area, (2) the installation of new, efficient devices in new developments, and (3) the replacement of less efficient devices with newer, more efficient ones.

Within a stock model, the current stock distribution of device efficiencies is used as the starting point, or baseline. Because, by law, new buildings must be equipped with devices that meet or exceed current standards, new development effectively increases the number of efficient devices. This portion of the stock model relies on estimates of new development over time and the expected number of devices installed. The final, and arguably most complex, element of stock models simulates the turnover of devices in existing buildings as older, less efficient devices are replaced with more efficient models that meet or exceed current standards, either at the end of their useful life or sooner.

The rate of replacement of an inefficient device with a more efficient model strongly affects average device efficiency and total water demand. To model the rate at which a device fails and is replaced by a newer model, forecasters apply a decay function to the current stock of devices. Exponential decay functions, which assume that devices have an equal likelihood of failing each year, are commonly used by water analysts in the United States Despite widespread use, they are not accurate representations of device replacement because they imply that the greatest number of failures occur in year one, with a decreasing number of failures each year thereafter. There are several decay functions, such as lognormal or Weibull distributions, that better approximate our intuition (and limited observations) of how appliances and fixtures work: a few devices fail or are replaced before their design lifetime; many devices are replaced near the average lifetime; and some last much longer than the given average lifetime, producing a long "tail" in the distribution. Indeed, in Australia, a lognormal distribution of device failure is commonly used in stock models because it better matches the observed rate of appliance replacement.

One of the key parameters within stock models is the average lifetime of the device. With the lognormal and Weibull distributions, the average device lifetime and the variability (or spread) around the mean can dramatically affect the results of the stock model. In particular, average lifetime determines how quickly the current stock of inefficient devices is replaced by efficient devices, with a shorter assumed lifetime leading to a faster turnover of inefficient devices. Unfortunately, device lifetime and replacement rates are not well characterized.

## Multi-City Research Studies May Suffice Until Local Data Are Collected

In the United States, data are limited on the current stock of appliances and fixtures, efficiency of those devices, and water use behavior. However, there are two large datasets that aid in understanding the market penetration of efficient devices within selected utility service areas in North America: the Residential End Uses of Water Study (or REUWS) and the Residential Energy Consumption Survey (RECS). The REUWS was first published in 1999 (Mayer et al. 1999), and a follow-up study was published in 2016 (DeOreo et al. 2016). Both REUWS 1999 and 2016 were funded by The Water Research Foundation. While the REUWS 1999 and 2016 were not designed to be nationally representative, this project examined the REUWS 2016 data to better understand how the most recent multi-city average and city-specific data could be used to inform both stock modeling and behavior in communities across the United States. Because market penetration can be affected by a variety of factors, including the age of housing stock, the price of water, the presence and extent of active conservation programs, and socio-economic factors, the project team hypothesized that the market penetration of efficient devices and total water demand would vary dramatically between service areas, and therefore would lead to greater uncertainty when extrapolating data to other communities. Based on the team's analysis, it was concluded that, while REUWS 1999 and 2016 provide rich datasets, analysts should be cautious about extrapolating the averages from cities in the REUWS or data from another service area to their communities (Table ES.1).

Because water use data from service areas studied in the REUWS are not representative of communities not included in the study, water utilities should conduct local studies to obtain data for stock models and end-use analyses. Utilities use a variety of data collection methods to obtain reliable and representative information to inform their demand forecasts (either as input data or to calibrate or validate models). In addition, many utilities already collect data that may assist in demand forecasting, including detailed records of device rebates, direct installations, audits, and other conservation incentives that impact water demand. While these data are often collected for a purpose other than demand forecasting, they can provide valuable information. Compiling these records, along with billing data, into a single database can make it much easier to examine forecasting and water use trends.

**Table ES.1 Mean, Median, Minimum, Maximum, and Relative Standard Deviation from Median (RSD%) between Cities in the REUWS 2016 Study**

| | Mean of cities | Median city | Min city average | Max city average | RSD % between cities | Significant differences between cities (# of differences out of 9 cities) |
|---|---|---|---|---|---|---|
| Total Indoor Water Use (gpcd) | 58 | 58 | 50 | 71 | 11% | YES (3) |
| Shower Length (min) | 7.8 | 7.9 | 7.0 | 8.4 | 8% | YES (3) |
| Number of Showers (pcd) | 0.72 | 0.73 | 0.59 | 0.82 | 13% | YES (4) |
| Showerhead Efficiency (gpm) | 2.1 | 2.1 | 1.9 | 2.4 | 7% | YES (5) |
| Faucet volume use (gpcd) | 11 | 11 | 9.5 | 13 | 10% | NO |
| Faucet events (pcd) | 23 | 24 | 19 | 25 | 11% | NO |
| Faucet volume (gpe) | 0.57 | 0.55 | 0.48 | 0.74 | 15% | YES (8) |
| Toilet events (pcd) | 5.5 | 5.6 | 4.8 | 5.9 | 6% | NO |
| Toilet efficiency (gpf) | 2.6 | 2.6 | 2.3 | 2.9 | 7% | YES (2) |
| DW events (pcd) | 0.10 | 0.10 | 0.06 | 0.15 | 40% | YES (3) |
| DW efficiency (gpe) | 6.3 | 6.3 | 5.9 | 6.5 | 1% | NO |
| CW events (pcd) | 0.32 | 0.33 | 0.26 | 0.39 | 12% | YES (3) |
| CW efficiency (gpe) | 31 | 30 | 27 | 35 | 9% | YES (4) |
| Bathtub events (pcd) | 0.07 | 0.06 | 0.03 | 0.13 | 50% | YES (4) |
| Bathtub efficiency (gpe) | 20 | 20 | 18 | 25 | 4% | NO |
| Leaks (gpcd) | 7.8 | 6.9 | 5.4 | 12.0 | 37% | YES (4) |

Notes: DW = dishwasher, CW = clothes washer. Significant differences between cities are measured by $p < 0.05$ that two or more cities of nine cities studied vary from each other. Fort Collins was removed from analysis in DW and CW events and efficiency due to a database error. Units are minutes (min), per capita per day (pcd), gallons per capita per day (gpcd), gallons per minute (gpm), gallons per event (gpe), and gallons per flush (gpf).

An important shift has occurred in Australia from a focus on ownership data to sales data. Initially, Australian forecasters relied on cross-sectional national and statewide surveys to inform the ownership of appliances and device types. However, they have been increasingly relying on sales data, which provide a much better indication of how device ownership is changing over time. Cross-sectional ownership survey data can then be used for validating the outputs of the device stock models, providing improved confidence in the modeling basis. This shift is described in more detail in the case study in Chapter 10.

Recent utility investments in automated meter reading (AMR) and advanced metering infrastructure (AMI) may provide additional data collection opportunities. AMR allows utilities to collect meter readings through an automated system, and AMI allows for even greater automation by using a communications network to collect water use data (Rettie et al. 2016). While AMI allows for more frequent water use data (collected hourly or daily, rather than monthly) than traditional meters, these data are still too coarse to be disaggregated into most end uses. However, researchers have suggested that, in the future and with the right technology, utilities will be able to get more accurate end-use data by collecting data on a shorter time resolution and using advanced disaggregation algorithms (Arregui 2016). For example, researchers and utilities in Australia and elsewhere have been working on new, automated classification methods for disaggregating household water use signals based on "machine learning" (Stewart 2015). Machine learning would provide a means for water utilities to increase the sample size and resolution of end-use measurement data collection programs, while simultaneously reducing their costs.

## Guidance and Recommendations

### Improve Forecasting Methods

Accurate demand forecasts are essential for utilities to adequately plan for the future. Many demand forecasting methods were developed when per capita demand was relatively stable, and thus forecasters could simply extrapolate population and water demand. However, since the 1980s, per capita demand has been declining and, as a result, new, more complex models are needed. To improve long-term demand forecasting, the following actions are recommended:

#### Examine the Accuracy of Demand Forecasts and Monitor Trends in Water Use

Many long-term water demand forecasts developed over the past 30 years have over-predicted water demand. Through interviews, however, the researchers found that utilities and consultants do not regularly revisit old forecasts to assess their accuracy. While forecasters regularly update the input data for their models, many do not examine the underlying assumptions and the degree to which projections match actual demand. Rather than simply updating input data, forecasters should examine the underlying trends, the assumptions within the models, and the degree to which past projections match actual demand. Assessing accuracy and updating demand forecasts can dramatically improve future predictions, largely because the underlying assumptions about per capita or per unit water use are no longer correct.

#### Incorporate Stock Models and End-Use Analysis into Demand Forecasts to Capture Future Efficiency Improvements Resulting from Standards and Codes

Efficiency standards and codes at federal, state, and local levels will continue to dramatically reduce the water use of many common residential and commercial devices. Examining the changing stock, efficiency, and behavior in specific end uses of water allows forecasters to integrate efficiency improvements in different sectors over time. While end-use analysis requires a large amount of data, understanding how end uses of water are evolving over time is essential for incorporating standards and codes, and their associated efficiency improvements into long-term planning. These improvements can be incorporated into demand forecasts using a correction factor or, alternatively, a comprehensive end-use model that sums all major end uses of water. Comprehensive end-use modeling simultaneously includes the impact of price, income, and weather with the changing efficiency of devices, and thus can better capture the impacts of standards and codes alongside econometric factors.

#### Integrate Uncertainty into Demand Forecasts

The future is uncertain, and thus many factors that affect water demand are uncertain. Developing multiple scenarios and more complex uncertainty analyses can provide insights into the range of possible future outcomes. Scenario testing allows forecasters to speculate on, for example, the potential impact of ultra-high-efficiency devices or skyrocketing growth on future water demand. When making decisions about whether new supplies are necessary, high growth may show there is negligible risk of water shortage despite limited utility involvement. Or, scenarios that include a more rapid uptake of efficient devices could indicate that new supplies could be avoided through demand management programs.

Using uncertainty analyses, such as Monte Carlo simulations, forecasters can elucidate a statistical chance that an outcome may occur. The combination of all extreme outcomes is highly unlikely, and uncertainty analysis can quantify the risk of each scenario. There are readily available plugins that allow analysts to add Monte Carlo simulation to any spreadsheet model. The result would be a probabilistic range of outputs rather than a single, deterministic estimate. The probabilistic range will better inform utilities on whether to move forward with securing new supplies and/or demand management options.

## Incorporate Stock Modeling into Demand Forecasts

A bulk of this report focuses on developing increasingly complex stock models to simulate changes in demand resulting from the uptake of efficient devices over time. These models describe the distribution of devices and their associated water use on an annual basis. Demand forecasts can incorporate stock models to estimate the impact of changing water efficiency over time in a variety of ways. Regardless of demand forecasting method, stock modeling principles remain constant. To improve stock models, the following actions are recommended:

### Determine More Realistic Device Lifetimes

The average product lifetime is one of the most important parameters within stock models, as it determines how quickly the current stock of inefficient devices is replaced by more efficient models. While manufacturers may advertise a product lifetime, the advertised lifetime may not be accurate. Toilets, which have an assumed lifetime of 20 to 30 years, are an oft-cited example of a device that regularly outlasts its assumed device lifetime. Detailed studies in the water sector are needed to better characterize device lifetimes.

### Develop More Realistic Replacement Distributions

It is assumed that when a device fails, it will be replaced with an equivalent or a more efficient model, as required by the new standards. Therefore, the rate of replacement strongly affects average device efficiency and total water demand. While limited data are available, the lognormal distribution better fits the existing data and our intuition about how devices are likely to fail. Studies in Australia find that the observed rate of appliance replacement better matches a lognormal rather than an exponential decay function, and as a result, lognormal distributions are commonly used in stock models in Australia. This research recommends using replacement rates with lognormal decay functions rather than exponential decay. Additionally, it is recommended that more data on replacement rates and efficiency distributions for specific devices be collected.

### Use Data to Calibrate or Validate Stock Models

Market penetration surveys and sales data can be used to ground truth device replacement rates, validate models, and calibrate models. Using data from high-resolution flow monitoring, forecasters can acquire a baseline understanding of the market penetration of efficient devices. Models can then be either verified or corrected to better reflect these data, and therefore provide an accurate baseline for the model. The single time point of a high-resolution flow monitoring, however, does not allow forecasters to calibrate the replacement rates over time. Multiple time points are needed.

## Determine Current Market Penetration of Efficient Devices

### Region Specific Data Are the Most Valuable and Can Be Collected Using In-person Assessments and High-Resolution Flow Monitoring Studies

Data from research conducted throughout the U.S. are not always representative of individual cities because local conditions are highly varied. Water utilities can conduct local studies to acquire data for end-use analyses and demand forecasts. Perhaps the most valuable data come from high-resolution flow trace analyses that use advanced data loggers to provide flow rates over time to determine water use efficiency and behavior. These analyses can provide a baseline understanding of actual water usage by end use in a given area.

High-resolution flow monitoring is expensive and, therefore, many utilities will need to rely on collecting information through traditional household surveys via phone or web. It is suggested that traditional household surveys include in-person assessments for at least a subset of customers in order to understand specific end uses of water and device efficiency. Without the in-person assessments, it is difficult to compare modeled and survey results.

### When Region-Specific Data Are Not Available for Market Penetration, Water Use Data and Studies from Other Locations Can Provide Valuable Information but Will Produce a Wide Envelope of Potential Future Water Demand

The Residential End Uses of Water Study (REUWS) is useful for understanding the end uses of water in detached single-family units in North America, and it provides essential information on water use and device efficiency for utilities included in the study (Mayer et al. 1999, DeOreo et al. 2016). For utilities that cannot conduct more localized studies, the REUWS data can provide a helpful baseline. For many cities, the technology and behavior of specific end uses did not vary. However, there were several cities that had different average efficiencies for devices, such as toilet and clothes washer efficiency.

When using the data from REUWS, it is important to understand and characterize the uncertainty. For some end uses, the variability between cities was relatively high. Additionally, this is likely the minimum variability for the end use components because the study only includes single-family homes in metropolitan areas. The uncertainty is greater in areas where housing types or demographics differ from the study regions, such as rural areas or those with a large proportion of multi-family homes. Data from the REUWS 1999 and 2016 should not be applied to multi-family households and should be used with caution for single-family homes.

### Models Based on Housing Age and Implemented Standards Can Provide Estimates of Water Use for Specific End Uses but Need to Be Calibrated and Validated

In the absence of adequate real-world data on the current distribution of devices, analysts have developed models to estimate the market saturation of efficient appliances and fixtures. These basic stock models generally rely on U.S. Census Bureau data on housing age. It is difficult to recommend whether these models are useful in predicting the market penetration of efficient devices. In the limited examples available, they appear to fit observation fairly well. However, caution should be used in implementing these models without verification or calibration data from surveys and high-resolution flow monitoring.

## Improve Data Collection and Management

### Organize Available Data from Billing, Conservation, and Forecasting Efforts from All Divisions within The Water Utility

Many utilities do not consolidate data from customer billing, conservation programs, and forecasting for use by multiple departments. However, the availability of diverse datasets is essential for incorporating device efficiency into demand forecasts. Especially helpful data sources from conservation programs include detailed records of device rebates, direct installations, audits, and other conservation incentives that impact water demand. Kiefer and Krentz (2016) suggest improving classification for water customers by more consistently classifying customer information, improving information on customer characteristics, and more frequently collecting water use information. Compiling this information in a single database with the associated billing data can make it much easier to update conservation plans and examine forecasting and water use trends.

### Collaborate with National and State Government, as Well as Local Energy Utilities on Data Collection and Analysis

Nationwide surveys should be performed on a regular basis to better understand patterns of water and energy conservation and use. The Department of Energy's Residential Consumption Survey (RECS) provides a good example of a national data source with regional information (U.S. EIA 2015b). Data are collected from a nationally representative sample on a semi-regular basis (approximately every five years); however, data only include limited information on clothes washers and dishwashers. Questions on water use and water-using devices could be inserted into the U.S. Census Bureau's American Community Survey or the Department of Energy's RECS. Questions on water usage would be useful for both the energy and water sectors, especially because there is a strong relationship between energy and water use. An additional question on toilets would greatly inform the water sector, and would likely add little additional cost.

Because energy utilities are regularly conducting market penetration and energy use studies, water utilities should consider broad partnerships with local and state energy utilities to collect the necessary baseline data for water demand forecasting. Individual states or consortia of energy utilities regularly conduct market studies to determine the penetration of efficient energy-using devices and conservation potential. For example, the Northwest Energy Efficiency Alliance and the New York State Energy Research and Development Authority conduct a wide variety of studies on building stock and market penetration of efficient devices. This aids in both energy forecasts and in conservation potential studies.

Some energy utilities are already collaborating with water utilities on audits that could inform demand forecasting. Maddaus et al. (2016) describe a successful collaboration in California between Pacific Gas and Electric (a large energy utility) and 34 local water utilities to conduct joint water and energy audits, with auditors trained for both energy and water. Similarly, SoCal Gas and West Basin Municipal Water District have partnered on audits for commercial kitchens (Cooley and Donnelly 2013). Energy companies are typically better funded and conduct audits more frequently, and there is an opportunity to build on existing, successful programs. Such programs should be expanded, and a data management and sharing should be a large component of those programs.

### Develop a National Dataset and a Clear, Consistent Labeling Scheme for Water-Using Devices, Similar to Australia's WELS, Such That Customers Can More Easily Identify the Water Usage of Their Devices

A national labeling scheme for water-using devices would also make data collection easier by informing residents about their devices. In the U.S., utilities are able to glean some information from ENERGY STAR or WaterSense labeled devices. However, these labels do not rate all devices and therefore do not provide an easy way to determine water efficiency by those surveyed. By contrast, in Australia, the Water Efficiency and Labeling and Standards (WELS) scheme identifies water use from many residential devices, regardless of efficiency level. While WELS was primarily designed to inform customers on water efficiency and encourage conservation, it has served to improve household surveys by clearly rating in-home devices with a one- to six-star rating. A similar WELS scheme in the U.S. would likely improve survey reliability.

### Compile State/Regional Estimates for Sales Data and Market Penetration

Market and product sales data on all water-using devices are needed. Product sales data can provide a more forward-looking view of the evolving market share of efficient technologies, especially for those devices that are more efficient than required by federal or state standards. In addition, when using sales data, forecasters do not need to track and analyze new housing developments separately from devices replaced in existing homes or businesses. The stock models can account for changing efficiency, device lifetime, and consumer choice based on the sales volume of efficient devices in recent years.

Data on sales are available from market research firms, but it is not a trivial task to process these data and convert it into meaningful information that can be used in forecasting. Similarly, market data can be collected as shipment data or aggregate sales data. Rather than relying on each water utility to compile these datasets, an industry association or coalition of associations could serve as an efficient source of compiled information if they purchased market, shipment, and/or sales data, processed it, and provided it as a service to water utilities. While it is often challenging to obtain comprehensive sales data, utilities should begin putting resources into purchasing sales data from market research groups on water-using devices. Companies with data available for free or for purchase are outlined in Appendix F.

### Create a Standardized Database for Data on Water-Usage and Customer Classifications

Comparing data between utilities on water usage is essential for understanding broad trends in both residential and non-residential water usage. Coomes et al. (2010) conducted an extensive study on water usage trends in North America and found it was difficult for researchers to compare data between utilities and analyze water usage trends because there are differences in how customers are classified and how data are stored. Kiefer and Krentz (2016) recommended that the industry develop standardized water customer classifications and keep a historical record of water use and billing information. Dunham et al. (2017) examined available datasets in the U.S. and recommended data requirements that can be used for a Federal Water Demand Survey. The project team echoes the authors' recommendation that a standardized data management framework be developed so that utilities and researchers can more easily examine and compare data.

## Improve End-Use Analysis for Outdoor Water Use and Commercial, Industrial, and Institutional Sector

End-use analysis is typically applied to indoor residential uses and, less frequently, to specific end uses in the commercial, industrial, and institutional (CII) sector and outdoor water uses. Increasing data collection and improving methods for CII and outdoor water uses would dramatically improve end-use analysis within those sectors and overall demand forecasting. The following are recommended:

### Evaluate Trends and Improve Data Collection Methods for Outdoor Water Usage

Outdoor water use can represent a significant portion of total municipal water use, especially in hot, dry areas. There are no national standards and codes that affect outdoor demand, but landscape ordinances and voluntary standards may become more common. A growing number of communities have adopted regulations affecting outdoor demand, such as restrictions on filling swimming pools or limits on turf area. Whether from ordinances, voluntary conversions, changes in yard size, or warmer temperatures, outdoor water use is changing. Utilities should begin monitoring trends in outdoor water use.

Remote sensing is the next frontier to monitor trends in outdoor water use, especially in the western U.S. where landscapes are irrigated. Remote sensing data can offer water utilities an unprecedented capability to develop fine-grained, spatially granular models of outdoor water demand and, critically, how targeted interventions, such as soil moisture monitoring devices and landscape conversions, could reduce outdoor demand.

### Evaluate Water-Use Trends for the Commercial, Industrial, and Institutional Sector

Water-use trends for the CII sector are still largely unknown. Most Australian and U.S. water utilities have adopted a much more simplified approach to modeling demand for non-residential properties. Analysts often disaggregate water use by sub-sectors (e.g., schools, hotels, or public parks), but do not disaggregate by end use. Because of the variety of activities among commercial water users, their water use is not as amenable to being broken down into a small number of categories and simulated with simple computer models. Utilities should develop classifications for CII that can allow forecasters to differentiate water use behavior and devices (Kiefer et al. 2015).

Analysis of end uses within the CII sector, including both stock models and behavior, can be conducted by collecting and incorporating behavioral metrics and market penetration data for sub-sectors of CII. There are sub-sectors within the CII sector that can be more easily modeled than others. For example, commercial office water consumption, like residential water consumption, is comprised of a limited set of end uses that are readily conducive to end-use analysis. Kiefer et al. (2015) recommend conducting CII customer surveys to determine the presence of various end uses. These surveys can provide the baseline for stock models and assist in estimating device turnover. The demand forecasting models must be modified to correct for behavioral and other differences between residential and non-residential sectors, such as market penetration and behavioral metrics (e.g., average daily usage based on business days). In addition, it is generally thought that the lifetime of devices in a commercial setting is shorter, as they are subject to heavier and more frequent use.

## Anticipate the Future

### Anticipate Future Standards and Codes

Most forecasters are unwilling to speculate on what the future may hold. Yet, we know that manufacturers continue to develop new and more water-efficient products. Looking at the history of water efficiency, it seems likely that there will continue to be innovation and greater water savings over time. Many of the current state codes or WaterSense standards are likely to become more widely adopted in the future. These hypothetical standards can be incorporated into forecasts as scenarios. It would behoove forecasters to examine how these standards are likely to affect total water demand.

### Investigate AMI Technologies for Collecting Water Data

There is a growing movement to install automated meter reading (AMR) and advanced metering infrastructure (AMI) as a replacement for traditional water meters. AMR allows utilities to collect meter readings through an automated system, and AMI allows for greater automation by using a communications network to collect water use data (Rettie et al. 2016). Utilities using AMI have much more detailed information about water use than previously, when meters were read monthly or less frequently. AMI technology now allows for hourly or daily water use data, which can improve tracking and billing, as well as inform peak demand and leak detection.

In the future, there may be additional opportunities for these devices to be used for short-term, high-resolution flow monitoring. The short-term high-resolution flow monitoring can provide a more robust understanding of the stocks and efficiencies of appliances and end uses of water. As technology improves, these technologies are likely to become less expensive, and data management will become less time consuming. Further research is needed on improving the frequency of data collection from AMI and to determine the price point at which utilities would be able to save money by installing "smart meters," for example through expedited residential meter reading and through faster leak detection. This should be an active area of investigation.

**Related WRF Research**

| Project Title | Research Focus |
|---|---|
| Advanced Metering Infrastructure: Best Practices for Water Utilities (project 4000) | This project provides a roadmap for decision-making, project success, and demonstrable business success for utilities considering advanced meter infrastructure/automated meter reading projects. |
| Evaluation of Customer Information and Data Processing Needs for Water Demand Analysis, Planning, and Management (project 4527) | This study identified the data collection and information management needs for water utilities, including both short- and long-term information requirements of managers and planners, as well as the needs of other local, regional, state, and federal agencies that depend on collection and analysis of municipal water demand data. |
| Long Term Water Demand Forecasting Practices for Water Resources and Infrastructure Planning (project 4667) | This project aims to describe models, methods, and practices currently used to forecast long-term demand in support of water resources and infrastructure planning and management. The project will evaluate how current practices have evolved over time; the accuracy and effectiveness of different forecasting approaches; and how forecasting models, methods, practices, and communications influence decisions. about utility plans and actions. Recommendations will be developed to improve the role and effectiveness of demand forecasting practices and communication strategies on water resource and infrastructure planning and decision-making. |
| Methodology for Evaluating Water Use in the Commercial, Institutional, and Industrial Sectors (project 4375) | This project developed and tested a methodology to collect standardized data to determine commercial, institutional, and industrial end uses of water. This methodology can be used by utilities of various sizes to collect end use data for demand forecasting, rate design studies, benchmarking, and conservation program planning. |
| North America Residential Water Usage Trends Since 1992 (project 4031) | This project quantifies changes in residential water use patterns to determine the recent macro-level trends across North America. It discusses how the water use trends affect distribution system operations, water quality, rates, revenue, and long-term planning. |
| Planning and Implementing CIS and AMR/AMI Projects (project 4583) | This project identified typical water industry activities and best practices related to selecting, implementing, using, and upgrading key customer service technologies, from a meter-to-cash perspective, with a focus on Customer Information Systems, Automated Meter Reading, and Advanced Metering Infrastructure capabilities. |
| Residential End Uses of Water, Version 2 (project 4309) | This project serves as a comprehensive update to WRF's 1999 Residential End Uses of Water study. This update includes more varied site locations, hot water end use data, more detailed landscape analysis, and expanded water rates analysis. This project focused solely on single-family residences. An Access database containing all of the end use water events recorded during the 2016 study, along with the survey response data, historic billing data, and other data obtained for each study site, can be utilized as a basis for further research. |

| Related WRF Research | |
|---|---|
| **Project Title** | **Research Focus** |
| Uncertainty in Long-Term Water Demand Forecasting (project 4558) | A literature review, survey, and workshop were conducted to prepare a comprehensive summary of the uncertainties related to forecasting long-term water demand for resource and infrastructure planning. The report describes the uncertainties utilities face in long-term demand forecasting, and presents strategies to manage these uncertainties. |
| Water Use in the Multi-Family Housing Sector (project 4554) | This research developed practical strategies for estimating multi-family water use to more easily allow utilities to categorize, estimate, and forecast water use for prominent multi-family water use categories. |

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**Project 4495**

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