Final Report
August 2015

High Resolution Energy Intensity Assessments: Maximizing Energy Savings in Water Conservation Program Design

CIEE Multi Campus Award POCP03-D10

Partners

California Public Utilities Commission (CPUC)

California Institute of Energy and Environment (CIEE)

Center for Water-Energy Efficiency, UC Davis (CWEE)

Background

California is currently facing an historic drought, and in response, the Governor of California recently declared an executive order (B-29-15) mandating statewide urban water reductions of 25% (Brown 2015). Further, California's water infrastructure is an emerging target for energy efficiency (EE) and greenhouse gas (GHG) emission reduction efforts (CPUC Rulemaking 09-11-014; California State Assembly Bill 32). Given the convergence of these policy initiatives to save both water and energy, it is more important than ever to understand the best options for achieving joint savings.

The water sector demands large amounts of energy. Upwards of 20% of the electricity and 30% of the non-power-plant natural gas used in California goes to producing, moving, treating, and heating water (Klein et al. 2005). While managing these integrated systems represent a statewide challenge, there is also a great opportunity to design targeted regional programs that jointly conserve both water and energy.

However, allocating EE and GHG reduction dollars to water efficiency programs requires clear, defensible methods for calculating the energy intensity (EI) of water, and reliable, verifiable monitoring of energy and greenhouse gas (GHG) emissions savings. This is no small challenge, because energy use varies significantly depending on where and when it's used within the water infrastructure (Spang & Loge 2013). No two water agencies are the same, so there's no one-size-fits-all EI number that can be given to a gallon of water.

A High-Resolution Approach

Given the complexity of water infrastructure networks, calculating system-wide EI from the top down obscures significant seasonal and spatial effects on energy. CWEE has developed a way to accurately represent the dynamic characteristics of water system EI by leveraging information from water utilities' Supervisory Control And Data Acquisition (SCADA) systems. SCADA systems provide operators with real-time control over the water infrastructure enabling them to manage flow and pressure across the network. Our approach repurposes SCADA data streams towards calculating and monitoring the energy consumed across the water system based on the network layout (Figure 1).

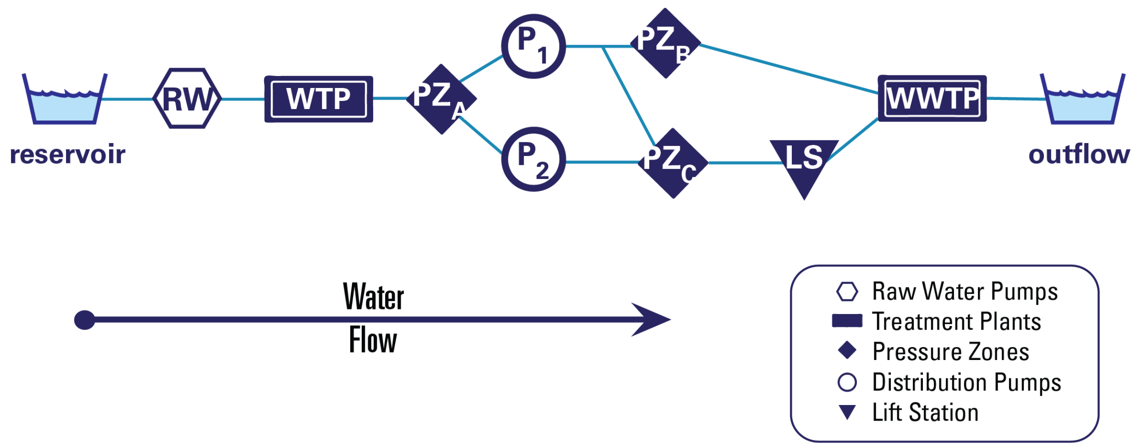

Figure 1. Example Water Infrastructure Schematic

We originally advanced the state of this art through a partnership with Pacific Gas & Electric (PG&E) and East Bay Municipal Utility District (EBMUD) by establishing a method for high-resolution assessment of the EI of water delivery. We worked with EBMUD to map and analyze the energy signature of water delivered throughout much of its service area, taking into account the seasonal energetic costs of treating water and pumping water over distances and elevations (Figure 2). We found that delivering a gallon of water to a home in the hills could require more than twelve times as much energy as it would take to deliver the same gallon to a home at sea level. Clearly, possessing such nuanced and specific data on EI has important implications for more effective targeting for water–energy conservation programs.

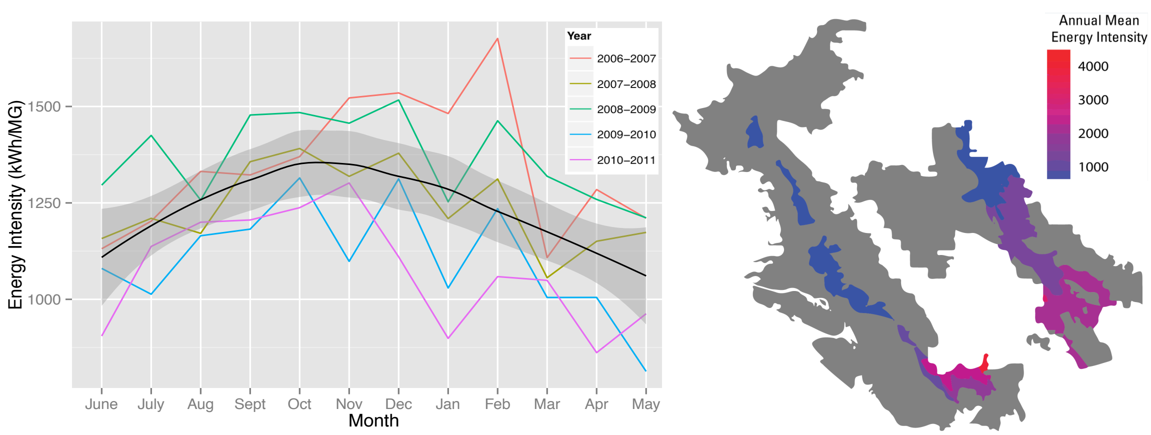

Figure 2. Seasonal and Spatial Energy Intensity Variation for East Bay MUD (kWh/MG)

After the EBMUD study, we sought to repeat and advance our approach with additional pilot studies of water systems, including the Los Angeles Department of Water and Power (LADWP), the San Diego County Water Authority (SDCWA), the Otay Water District, Burbank Department of Water and Power, and Austin Water. In discussions with the California Public Utilities Commissions, we realized that this portfolio of projects collectively represented an important opportunity to inform and advance the implementation of joint water and energy conservation programs across the state. A detailed understanding of how energy flows through various water systems could illuminate when, where, and how to secure cost-effective water-energy savings.

Project Tasks

The purpose of this project was for CWEE to combine the results of this portfolio of EI studies to inform the CPUC on building a program to facilitate joint water-energy conservation initiatives. With this information in hand, water utilities can enhance their efficiency directly by targeting conservation efforts and infrastructure upgrades, informed by the energy outcomes of their actions. A water conservation campaign or maintenance program directed at specific high-energy-intensity neighborhoods would thus yield outsized returns on energy reduction for the energy IOU partner.

A key output of this research would be the transparent assessment of the effectiveness of various water conservation programs to generate energy savings. By exploring a range of water conservation options, CWEE could apply its high resolution EI estimates to characterize the total energy saved through each program. Communicating this information effectively to the CPUC, water agencies, and energy utilities should help inform the design of statewide programs seeking to jointly conserve these critical resources in a cost-effective manner.

The four main project tasks are listed below:

> ***Task 1. Initiate Project and Provide Ongoing Management.*** Initiate project scoping meetings and finalize institutional agreements. Coordinate overall project efforts between CWEE, CIEE, CPUC, including regular conference calls.
>
> ***Task 2. Consolidate and Integrate Energy Intensity Studies.*** Integrate all EI study results conducted within PG&E, SCE, SDG&E and LADWP service territories. Design and develop a database to consolidate, organize, analyze, and visualize data from all four studies. Assess critical similarities and differences in EI characteristics for water agencies in the different energy serviced territories.
>
> ***Task 3. Assess Energy Savings of Water Conservation Programs.*** Collect data on various water conservation programs conducted by each water retailer. Calculate retrospectively energy savings for each water conservation initiative. Compare and discuss relative potential different types of water conservation programs in order to jointly optimize energy savings.
>
> ***Task 4. Prepare Final Report.*** Prepare final report including critical sections: Background, Assessment Objectives, Technical Approach/Methodology, Results, and Recommendations.

Project Results

This project provided an important opportunity for CWEE to synthesize information from existing EI studies and to advance our methodologies for conducting these analyses. While some of the tasks (as originally conceived) were difficult to achieve given external delays, we were able to make progress beyond what we thought possible in other areas of this research. More specifically, our ability to make cross-comparisons across multiple water agencies was significantly hindered by contracting delays with project partners; however, we were able to successfully redirect our efforts towards developing a standardized, web-based platform for EI analyses.

With the redirection of project effort towards software development, it is suggested that this final report is accompanied with a webinar to more fully demonstrate the functionality of the software program. The following section reviews the results of this project on a task by task basis.

Task 1. Initiate Project and Provide Ongoing Management.

The project team consisting of CWEE, CPUC, and CIEE coordinated and communicated as necessary to meet the needs of the project.

Task 2. Consolidate and Integrate Energy Intensity Studies.

A core component of this project was to compare the results of our EI analyses across water utilities in the State of California. While our EBMUD project (funded by PG&E) was completed in advance of this project, the other EI projects that were supposed to be conducted in parallel to this project were delayed significantly for reasons internal to those agencies. While the Otay project has now been completed, the LADWP project remains a work-in-progress. In the meantime, we have added Burbank Water and Power and Austin Water (Texas) to our portfolio of EI case studies, but have not yet completed these studies either.

Comparing energy intensities of water system component technologies

When looking at energy use across the project sites, we were able to make some direct comparisons across component technologies within the water systems, including water treatment plants and distribution pumps. Figure 3 below compares the range of monthly EI values for the water treatment plants (WTPs)[1] in the EBMUD and SDCWA-Otay studies using box plots[2].

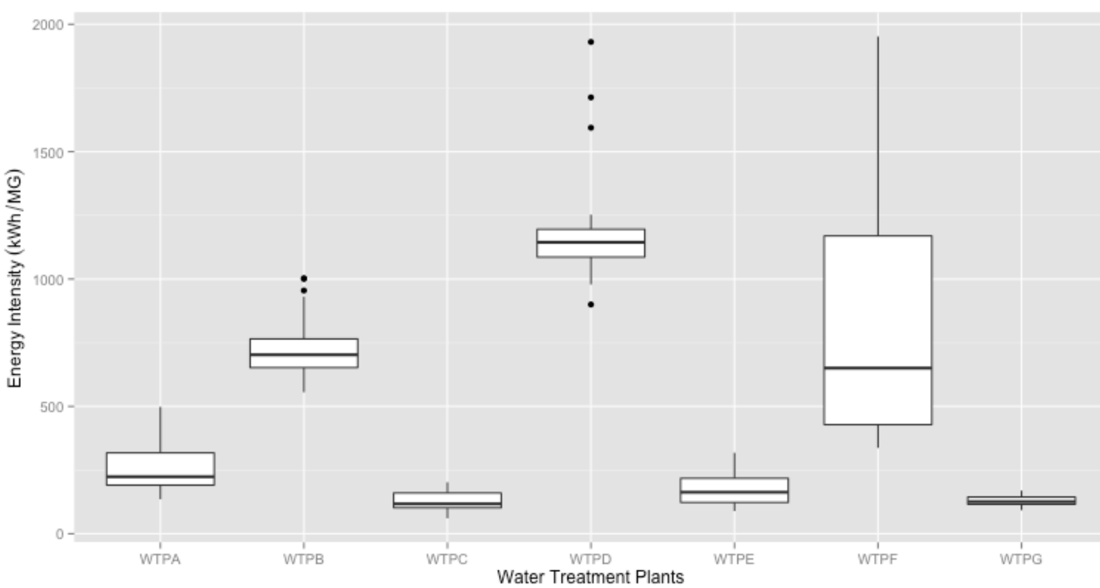

Figure 3. Energy intensity comparison of water treatment plants, EBMUD and SDCWA

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[1] The actual names of the WTPs were obscured ("WTPA", "WTPB", etc.) to protect privacy of the partner utilities.

[2] Box-plot graphics show the show the median value (thick black line), first and third quartiles (box), range (whiskers), and estimated outliers (points).

The graphic shows the broad variation in EI both between water treatment plants (mean values range from 125 to 1187 kWh/MG) as well as within the plants (WTP "F" demonstrates a range between 337 and 1952 kWh/MG). It is well documented that the EI of water treatment plants varies significantly according to the scale of the plant, the technologies deployed, and the quality of the source water (EPRI 2013), and this wide variation underscores the value of leveraging real-time data to characterize the water-energy relationship for these assets.

When comparing the EI of the distribution pumps[3] between EBMUD, the Otay Water District, and Austin Water (Figure 4) we see a similar level of variation between the pumps (average energy intensities range from 117 to 2036 kWh/MG) and exhibited by individual pump operation. The differences in pumping EI is generally a function of flow, pressure head, and efficiency, all of which can vary from pump to pump within a water district making it difficult to estimate a universal EI value for distribution pumps (EPRI 2013).

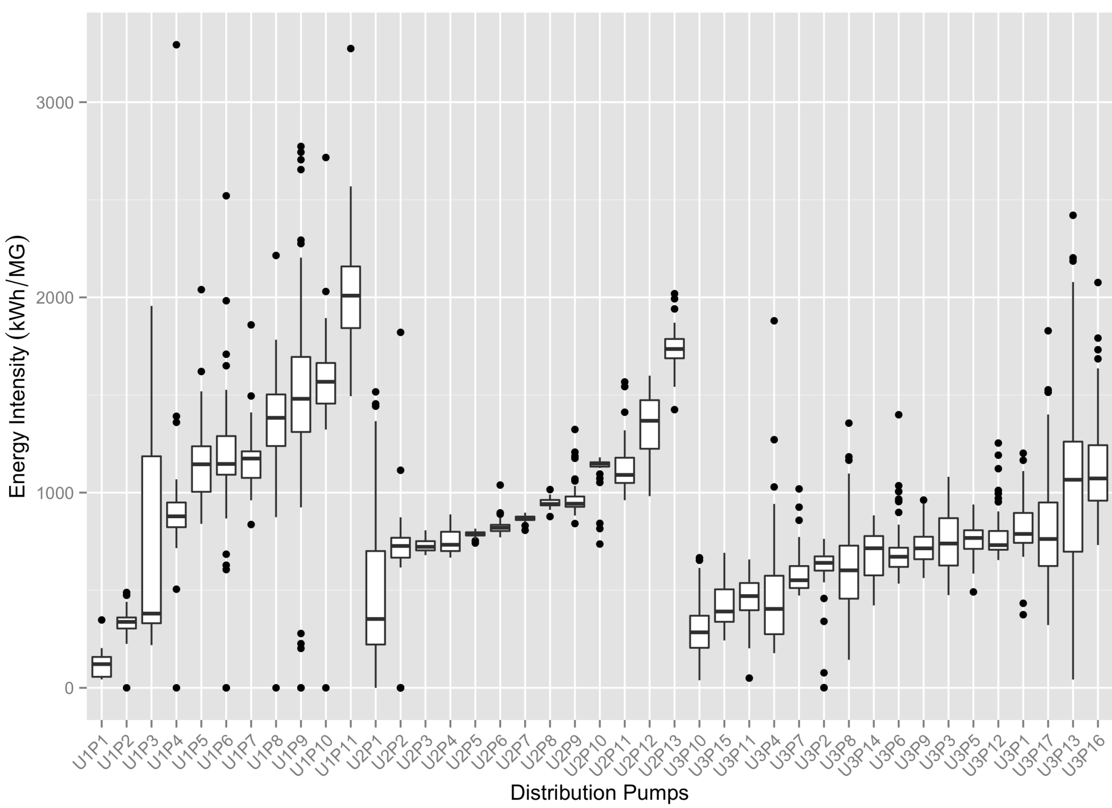

Figure 4. Energy intensity comparison of water distribution pumps, EBMUD and Otay

The previous figures are showing a representation of energy intensities by broad technology type. As we extend our studies in this area, we will aim to further benchmark these results by technology subtype and scale of operation (e.g. MGD design capacity). This will provide a greater ability to normalize and cluster the EI calculations, which will

[3] The actual names of the distribution pumps (e.g. "U1P1" refers to "Utility 1 Pump 1") were obscured to protect privacy of the partner utilities.

make it easier to identify assets that are performing within an optimal or suboptimal range for that particular technology and/or use case.

Complexity of water data

Given the wide variation in the quality, availability, and format of the relevant data at our partner water agencies, we realized early on in the project that integrating the data and scaling up the analysis was going to require significant effort. Figure 5 provides an example of how data can be highly fragmented with hourly data distributed across individual daily files within monthly and then yearly folder hierarchies. For this particular agency, we had to invest a significant portion of our project effort on stitching together these individual files to have a single continuous view of time series data for each individual asset.

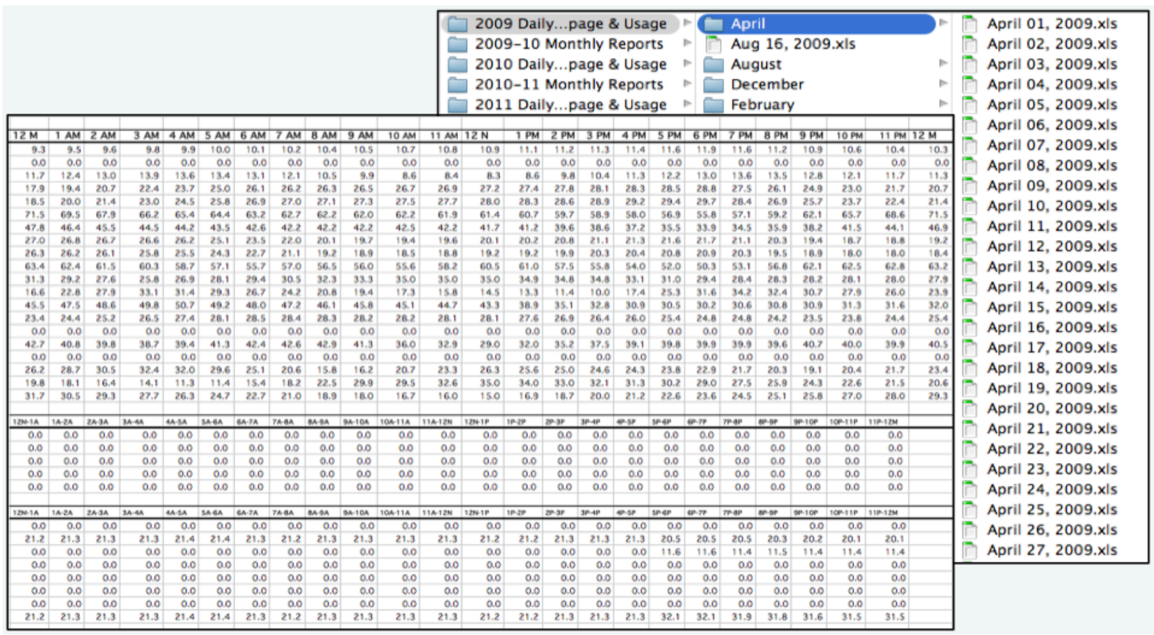

Figure 5. Data complexity – fragmented files in fragmented folders

Based on our consistent confrontation with "the data problem", we decided to invest significant effort into the elaboration of a computational software platform to streamline and harmonize EI analysis. We uploaded all existing data for our projects into a database/platform specifically designed to handle time series data for integration at multiple levels of resolution. This included organizing the data itself according the physical structure of the water network (e.g. the asset framework) as illustrated in the Figure 1 example. Once the data was organized in a consistent format, we were able to develop a range of analytics to gain improved visibility into the water-energy relationship at our partner water utilities.

Static to dynamic data exploration

Our first programming goal was to build our EI analytics into a web-based server, so that the water utilities (and the partner energy utilities) could gain dynamic access into the EI estimates. In this case, "dynamic" refers to the user's ability to select EI results for specific assets (or specific sets of assets) by month and year. This approach would produce a distinctly more valuable deliverable to our utility partners – an easily accessible portal for exploring their own data in high-resolution as opposed to a static (and almost instantly outdated) project report.

For examples, Figures 6 and 7 are screenshots of the software platform where the user can compare flow, energy consumption, and EI for individual pumps (Figure 6) or for sets of pumps to enable instant cross-comparison (Figure 7). To provide further flexibility for the user, we made the data associated with any particular visualization downloadable for further analysis by the user in the program of their choice, e.g. Microsoft Excel.

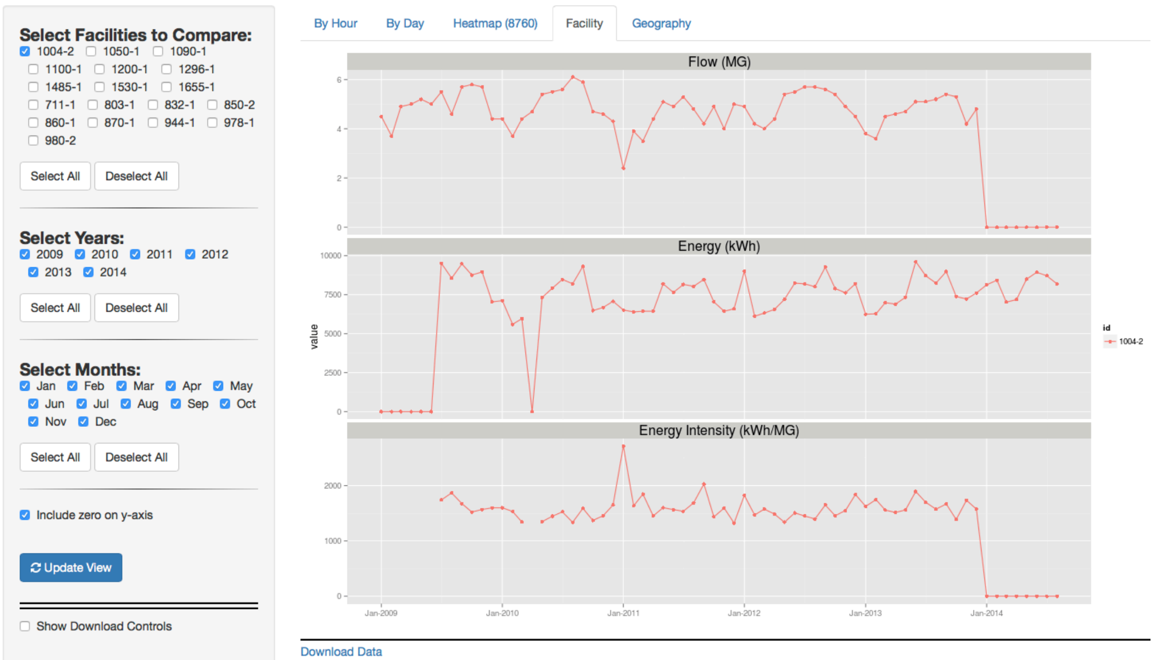

Figure 6. Time series flow, energy, and energy intensity data for a single pump

Figure 7. Comparison of time series flow, energy, and energy intensity for multiple pumps

We provided similar capabilities to the user for exploring the spatial components of the EI analysis. Using the same methodology as we applied to EBMUD, we calculated the cumulative EI by pressure zone for the Otay Water District and presented the results via the web portal. The user selects the timeframe for their desired results, and the interface then builds maps to present the average EI (kWh), water consumption (MG), and embedded energy (kWh) for each of the pressure zones in the study (Figure 8).

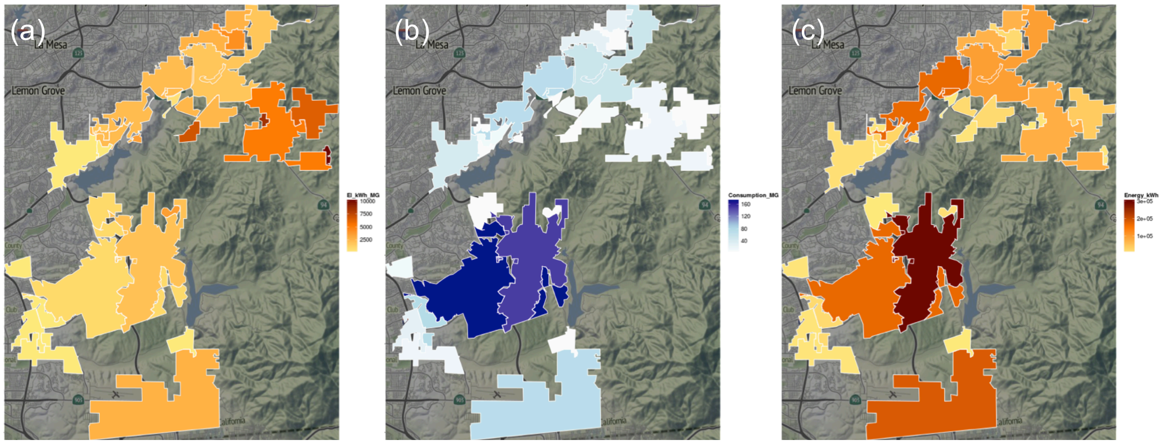

Figure 8. Maps of (a) energy intensity, (b) water consumption, and (c) embedded energy by pressure zone in the Otay Water District

Standardization and comparability

While the web-based analytical tool makes the results of each individual study more accessible and compelling, it will also provides a framework for standardizing the results and making comparisons across multiple EI studies. This analysis would be similar to the results presented in Figures 3 and 4, but with additional data aggregation and benchmarking capabilities. For example, a water agency could choose to compare the energy performance of one if its pumps to pumps with similar characteristics at other water agencies (with the identity of the other water utility obfuscated from the perspective of the user). This functionality has not yet been built into the platform, but we aim to integrate this capability into the menu of analytics at the completion of our EI projects currently being built out within the platform (including LADWP, Austin Water, and Burbank Department Water and Power).

In terms of standardization, we have also developed a tool to expedite the specification of the water system network, i.e. the sequencing of treatment plants and pumps in the network that allows us to trace the cumulative energy embedded in water deliveries. This effort is one of the most resource-intensive requirements of our high-resolution approach to EI analysis. Thus, any improvements we can make to expedite this process will dramatically improve the scalability of our approach.

One key advancement in our program has been the development of an application that allows the user to graphically draw out the water network, which is then formalized as computationally linked nodes within a database (Figure 9). As we refine this tool, we hope that it will enable our partner water agencies to specify their own network structure and thus remove a major barrier to the widespread replication of our high-resolution methodology for EI characterization.

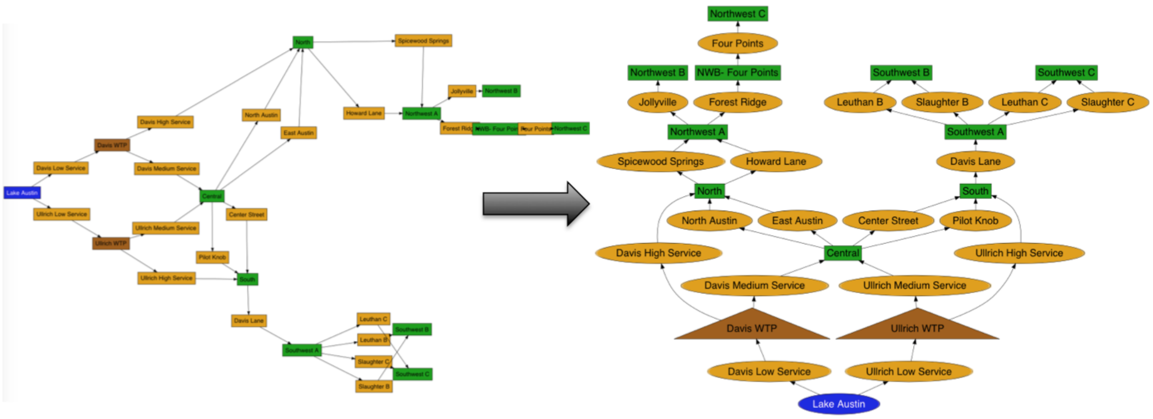

Figure 9. Example of manually-drawn water system asset framework converted to optimized network graphic

Task 3. Assess Energy Savings of Water Conservation Programs.

The purpose of characterizing the EI of a water system in high-resolution is ultimately to be able to predict with confidence the amount of energy that will be saved as a result of a water conservation program. For this portion of the research, we originally sought to consolidate existing data on the implementation and effectiveness of past water conservation programs. However, we encountered a lack of consistent and sufficiently detailed information on conservation programs, and as a result transitioned our approach to building our own water use and energy consumption modeling tool, described below.

Utility applications for monitoring system-wide water use

The first application provides the water utility with a quick assessment of monthly water savings relative to an annual baseline (Figure10). In this example, the water utility is able to compare monthly use in 2014 relative to 2013, as well as overall annual conservation (in green) – a statistic directly relevant to the Governor's current Executive order to reduce statewide urban water consumption by 25% relative to the 2013 baseline.

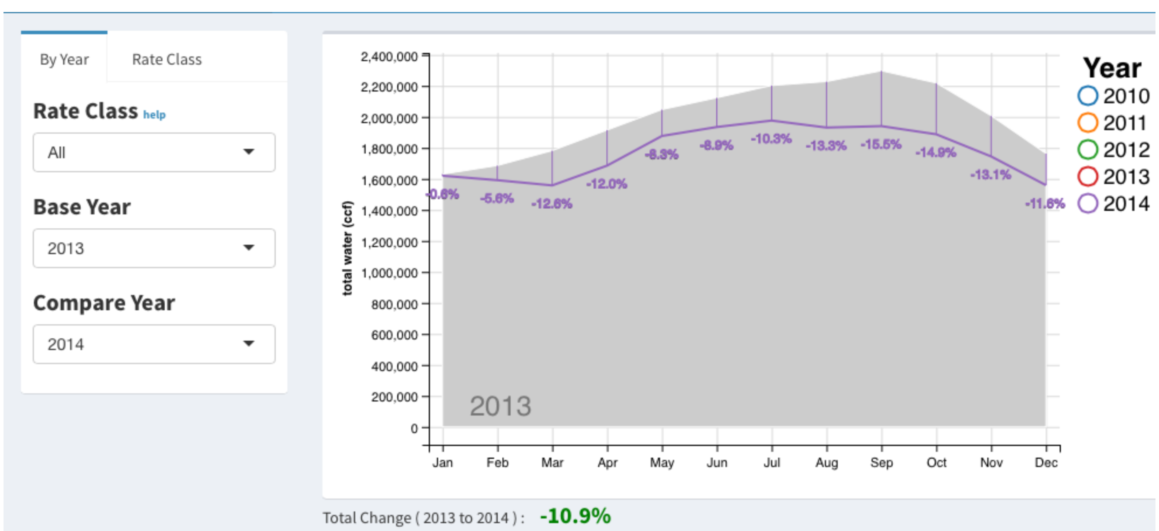

Figure 10. Total monthly water conservation achieved relative to a baseline year

This same application allows the utility to drill down on this same metric by individual user class (Figure 10) as well as quickly view overall consumption by user class for any given year (Figure 11).

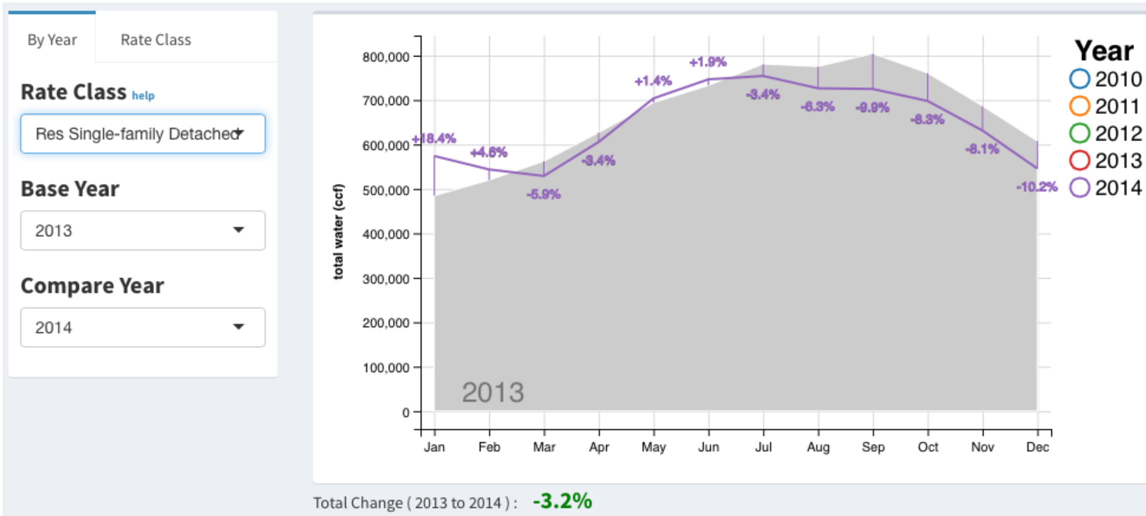

Figure 10. Monthly residential single-family water savings relative to a baseline year

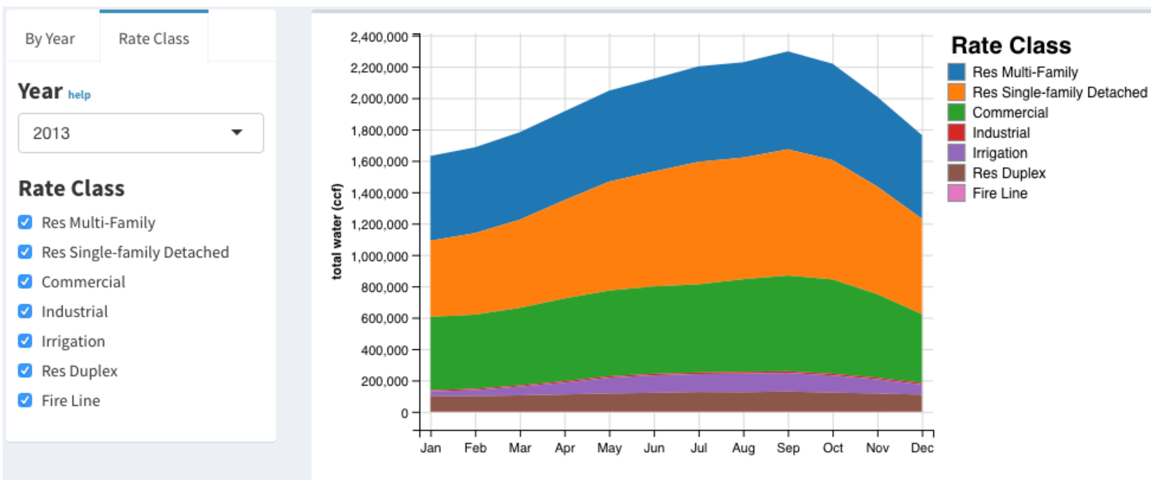

Figure 11. Monthly water consumption by user class

Utility applications for estimating water conservation and energy savings

To link water use to energy savings, we built a tool for the water utility to estimate energy savings associated directly with water conservation by individual customer class. In the example provided in Figure 12, the energy savings (both electricity and natural gas in this example) associated with a 25% reduction in water use in the residential and commercial sectors is projected.

We currently provide three different estimates of energy savings in this application. The first estimate, the “aggregated” utility estimate, is based on using an annual energy intensity for the entire water utility. In other words, the total energy consumption at the water utility (including gas since there is one gas-powered pumping station in this example utility) is simply divided for the utility by total water delivered. The second, “Navigant” estimate is based on a system-wide energy intensity estimate derived from the CPUC Water-Energy Calculator 1.04 (built by Navigant Consulting) that provides baseline energy intensity estimates by hydrologic zone, type of source water, and technology deployed. The final "CWEE" estimate is based on CWEE's methodology of disaggregated monthly estimates of energy intensity by pressure zone within the water utility service territory.

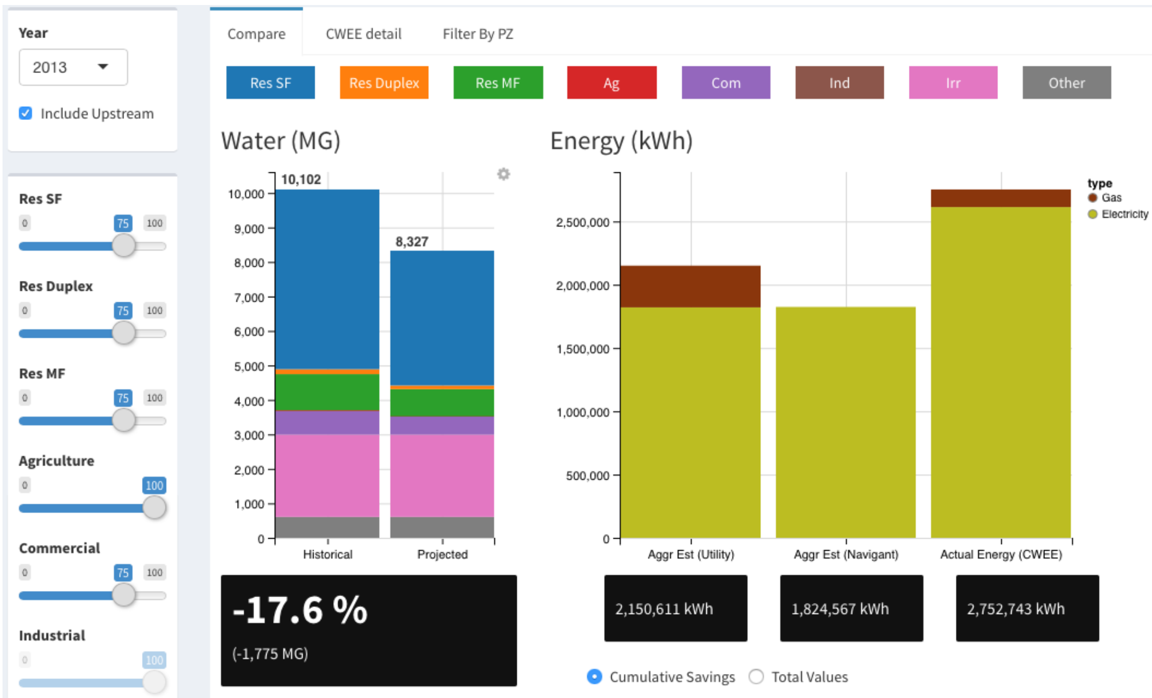

Figure 12. Energy savings from percentage water use reductions by customer class as estimated by three different EI methodologies ("Aggregated", Navigant, and CWEE)

As Figure 12 shows, the three methodologies produce different estimates of energy savings. The estimates differ for a number of reasons, the most important include the following:

- *Utility-specific vs. regional estimate:* The "aggregated" and the CWEE approach use actual data from the water utility, whereas the Navigant estimator is based on generic regional values. While the Navigant approach does provide a reasonable rough estimate of EI, it is destined to be less accurate than the other two methodologies that rely on real water and energy data from the utility. Further, since Navigant deploys a "top-down" approach, it fails to identify other unique characteristics of the water utility, such as the use of natural gas to power some pumping operations as provided in the given example. Since the "aggregated" and CWEE approach both use real data, the use of natural gas is correctly specified in the EI estimate.
- *Aggregated vs. disaggregated approach:* The "aggregated" and the CWEE approach will generate roughly the same overall estimate of energy intensity for the water district. However, since the CWEE approach differentiates EI by pressure zone, it allows for more specific energy savings by customer type. In other words, it accounts for the fact that customer types are distributed unequally across the service territory, so the energy savings from water conservation will be influenced by location of customer types within pressure zones of differing energy intensities.

- *Isolated vs. networked specification:* The "utility" approach neglects to take into account the interconnectivity of the water utility to other water providers, and thus neglects to include the associated upstream energy intensity. The Navigant approach allows for specification of imported water from the large conveyance projects across the State as well as local deliveries, but these estimates suffer from the same lack of specificity as the technology estimates with Navigant's regional approach to EI. Meanwhile, the CWEE approach directly accounts for the energy intensity of imported water that falls within the same investor-owned energy utility (energy IOU) territory as the water utility itself. In the example provided, the water utility imports water from a regional water wholesaler as well as a local, adjacent water agency (both in the same energy IOU territory as the water retailer). This upstream energy intensity can be easily turned on or off in the web-based analysis (using the "Include Upstream" check box directly under the year menu). In the example provided in Figure 12 above, upstream energy intensity is included and the resultant energy savings projections are roughly 25% higher than produced by the other two methodologies.

Based on the qualities described above, the CWEE approach provides more accurate estimates of the energy saved from system-wide conservation efforts. However, there is a significant additional advantage to the CWEE approach in that it allows the utility to target conservation efforts towards particularly energy intensive pressure zones. Figure 17 shows an interface where the utility manager is able to select individual pressure zones for targeted conservation efforts. In this example, the top 50% of pressure zones with the highest EI values has been selected.

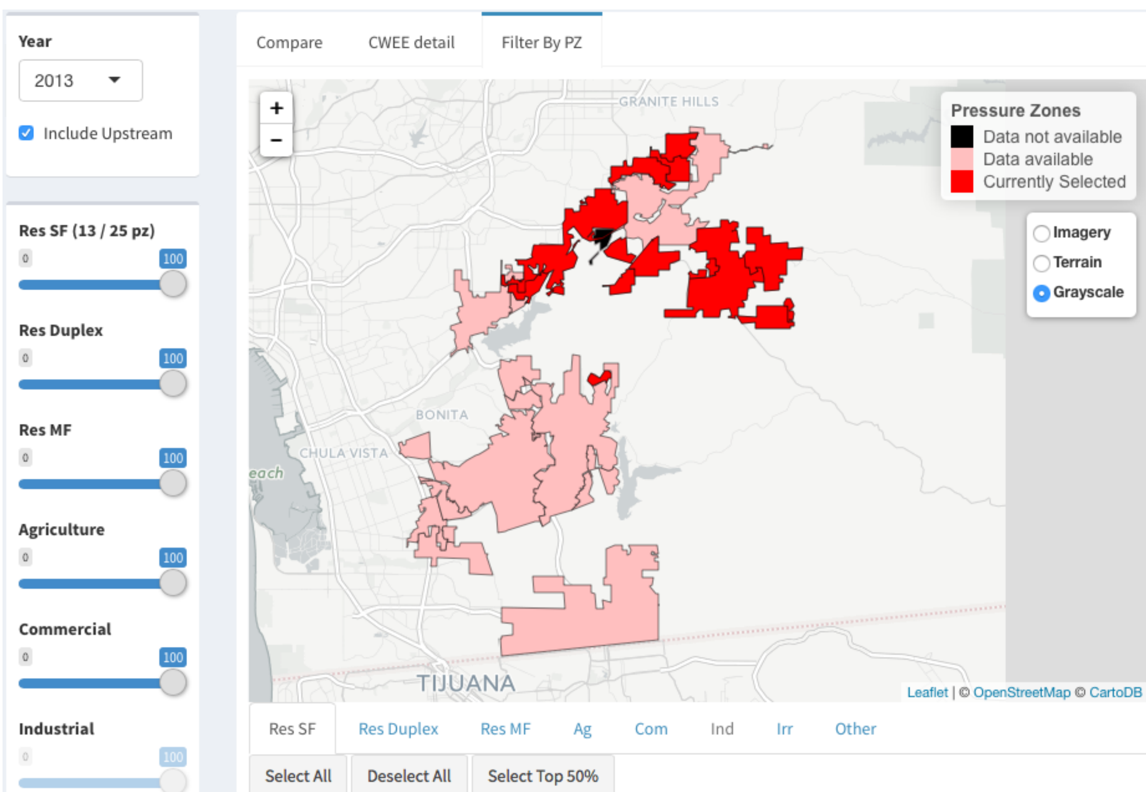

Figure 17. Application interface for targeting specific pressure zones for conservation initiatives

Figure 18 provides an estimate of the energy savings achieved if the water utility were to roll out the same conservation program as before (25% reduction in residential and commercial sectors) but only in the most energy intensive pressure zones (as selected in Figure 17). Since the "aggregated" and Navigant EI methodologies do not have the capabilities to differentiate EI by pressure zone, they significantly underestimate the energy savings achieved from water conservation in these targeted pressure zones as compared to the CWEE approach. The CWEE methodology estimates total energy savings (1600 MWh) as roughly two times greater than the other two approaches (950 and 800 MWh).

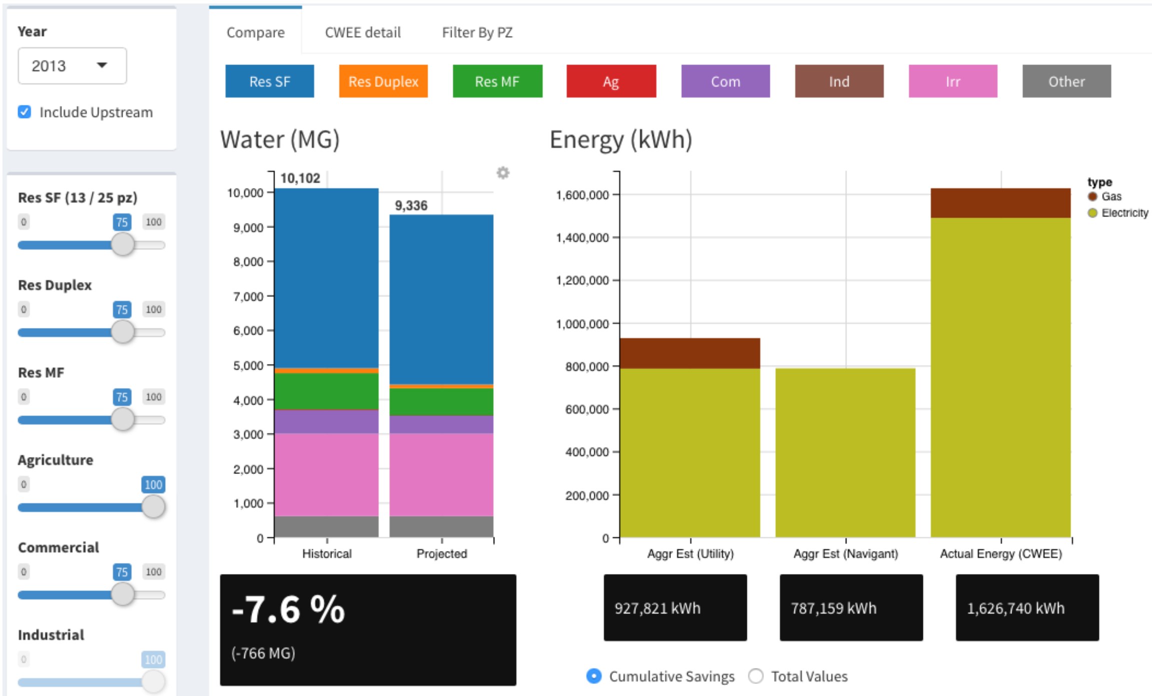

Figure 18. Energy savings from water use reductions by customer class in pressure zones targeted for high energy intensity. The energy savings are calculated using three different EI methodologies ("Aggregated", Navigant, and CWEE).

This ability to target conservation efforts towards pressure zones with higher energy intensity has important implications for the cost-effectiveness of joint programs between water and energy utilities.

In addition to providing more accurate estimates of energy savings from water conservation and the ability to target high energy-intensive pressure zone, the CWEE approach provides a framework for monitoring and verifying water and energy savings. Once the asset framework is specified within the database structure, water and energy data can continually be integrated and analyzed to track ongoing water and energy consumption. As programs are implemented, these "live" data streams can be leveraged to compare actual water and energy resource use relative to anticipated consumption as a result of the program intervention. This monitoring and verification capability is an essential component to funding and scaling out successful joint water-energy initiatives.

Task 4 – Final Report

A draft final report was completed and shared with all project partners at the end of June, 2015. In conjunction with the final report, CWEE has also agreed to present a webinar on the functionality of the web-based EI analysis platform for all interested parties. The webinar is yet to be scheduled, but will likely be scheduled for July or August 2015.

Conclusion

From our comparison of methodologies for estimating EI ("aggregated" utility method, "Navigant" regional method, and the CWEE high-resolution method), we conclude that a high-resolution approach should be used whenever possible. This approach allows for improved estimation of energy savings from water use efficiency by leveraging real data from the water utility and accurately accounting for the actual operational conditions of network assets (e.g. pump efficiency and treatment operations), the geographic distribution of different customer classes (i.e. different customers will have different EI values associated with their home pressure zone), and by directly specifying the EI associated with regional and local water imports.

By integrating high-resolution data from across the water network to develop a disaggregated estimate of energy intensity, the project partners can access the following key capabilities:

- Accurate estimation of the water and energy savings based on where water use efficiency technologies are adopted in the water utility service area;
- Advanced and flexible benchmarking of water use, including by rate class and pressure zone;
- Ability to direct their water conservation investments towards service areas that will return the greatest amounts of both water and energy resource savings;
- Capacity to establish monitoring and verification of water and energy savings post-adoption of water use efficiency technologies, using the same data framework as established for the original EI estimation.

Over the course of the project period, the project tasks shifted away from the original plan to perform a meta-study of EI results from multiple water agencies and towards the development of computational analytics and software solutions for calculating and understanding EI. This adaptation was a necessary result of the unforeseen delays in many of our EI studies, which are still ongoing in many cases. However, the focused development of analytical platform has provided us with the opportunity to develop and advance key functionalities of our EI calculation methodology, including:

- scaling our high-resolution EI characterization to more water utilities more quickly,
- producing dynamic results accessible by multiple users,
- delivering advanced capabilities for monitoring and estimating energy savings from water use efficiency,
- and eventually, enabling a robust ability for cross-comparisons of EI between water utilities as more case studies are completed and integrated into the platform.

We believe this project significantly advanced a number of promising analytical tools for water utilities to optimize decisions at the complex water-energy interface. The centralized data platform we developed is immediately useful for conducting EI analyses and water-use benchmarking, but also has great potential to improve information flows and advance decision-making capabilities more broadly at water utilities. We look forward to continuing our work towards this mission and gratefully acknowledge the CPUC and the CIEE for providing the funding essential to these efforts.

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