Flushing Away Our Resources: A Closer Look at Toilets and Energy Conservation

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ABSTRACT

Water conservation programs garner energy savings through reductions in potable water consumption and wastewater generation. While the interrelationship between water and energy has been well established, there are still relatively few utility sponsored energy efficiency programs which specifically target energy conservation through water conservation. Furthermore, limited work has been done in our industry to attempt to quantify the societal benefits of such programs. In light of the ongoing drought conditions in the western U.S., such programs are lacking where they should be considered essential to any well-rounded portfolio. This paper explores the reaching impacts of one such program implemented by Truckee Donner Public Utility District (TDPUD) - the Water-Efficient Toilet Rebate/Exchange program. This program saves energy in both the water distribution and water treatment processes simultaneously by reducing potable water consumption and wastewater generation. Our paper presents findings and lessons learned from a recent impact evaluation of the toilet rebate/exchange program. More importantly, this paper communicates just how effectively a partnership between water and energy conservation can work to conserve our finite water resources while simultaneously contributing to energy efficiency goals.

Introduction

How many times per day does the average toilet get flushed? How much water does a toilet consume per flush? Why do we care? In 2006 the Department of Energy (DOE) published a report on the interdependency of energy and water (USDOE, 2006). In this report the DOE warns that policies and regulations in one can have dramatic impacts on the supply and availability of the other. Furthermore, with growing populations, increasing energy demands, and lingering drought conditions in the western U.S., both water and energy represent finite resources under increasing stress. Since the DOE report, studies have been performed at federal, state, and regional levels which contribute to a growing body of research on the *water-energy nexus*.[1] While the DOE and others focus on the broader relationship between energy and water, in California some research has been focused on specifically quantifying the energy needed to facilitate the drinking water cycle – e.g. the *embedded energy in water*. This paper contributes to the collection of knowledge on the water-energy nexus by presenting results from an impact evaluation recently performed for Truckee Donner Public Utility District (TDPUD) in which several water conservation programs were evaluated. More specifically, one of these programs, the Toilet Rebate/Exchange program, is used to demonstrate how effectively a partnership between water and energy conservation can work to conserve our finite water resources while simultaneously contributing to energy efficiency goals.

Water conservation programs are not a novel idea. Several California municipal utilities have well established water conservation programs for which they document energy conservation impacts (CMUA, 2015). Furthermore, in 2007, the California Public Utilities Commission authored a decision approving a joint partnership between California IOUs and local water agencies which enabled them to

[1] See (DOE 2014)

implement a series of pilot water conservation programs (CPUC, 2007). While not novel, water conservation programs funded by energy utilities, for purposes of energy conservation, are young compared to other Demand Side Management (DSM) efforts. As such there exists significant room for improvement and expansion in such programs as research improves our collective understanding regarding the interplay between the energy and water sectors – specifically in assigning magnitudes to the energy cost of water (*embedded energy* in water), and the water costs associated with certain energy generation technologies (*avoided costs* for the supply and treatment of potable water). The research presented in this paper focuses on the former, and contends that the latter be seen as a significant non-energy benefit when assessing the cost effectiveness of DSM efforts in water conservation.

How Toilets Save Energy

While this paper assumes that the reader understands these concepts, and therefore does not provide a full treatment of them, the water-energy nexus is summarized here as it relates to water/energy conservation opportunities in toilets.[2] The water consumed by toilets must first be conveyed, treated, and distributed to its location. Once flushed, the water must then pass through the sewage system and be distributed to a wastewater treatment facility before it can finally be released back into the watershed. A convenient diagram was published in (Klein, 2005) and is provided here in Figure 1 for the reader's reference. Each segment of this cycle requires energy, typically in the form of electric pumps, to facilitate water consumption at its end-use. The amount of energy required to supply, distribute, and then preform wastewater treatment varies depending on the technologies used throughout this process. A good summary of regional embedded energy magnitudes in California can be found in (GEI, 2010). The TDPUD Toilet Rebate/Exchange programs save energy by replacing existing, high volume, toilets with low-flush units - reducing the amount of water required to go through the cycle.

In this section the reader is first provided with a brief background of research that has been published for California utilities to date on the embedded energy in water before the evaluation findings are presented for TDPUD specifically.

[2] A comprehensive treatment of the water-energy nexus can be found in (Klein, 2005) and (USDOE, 2014).

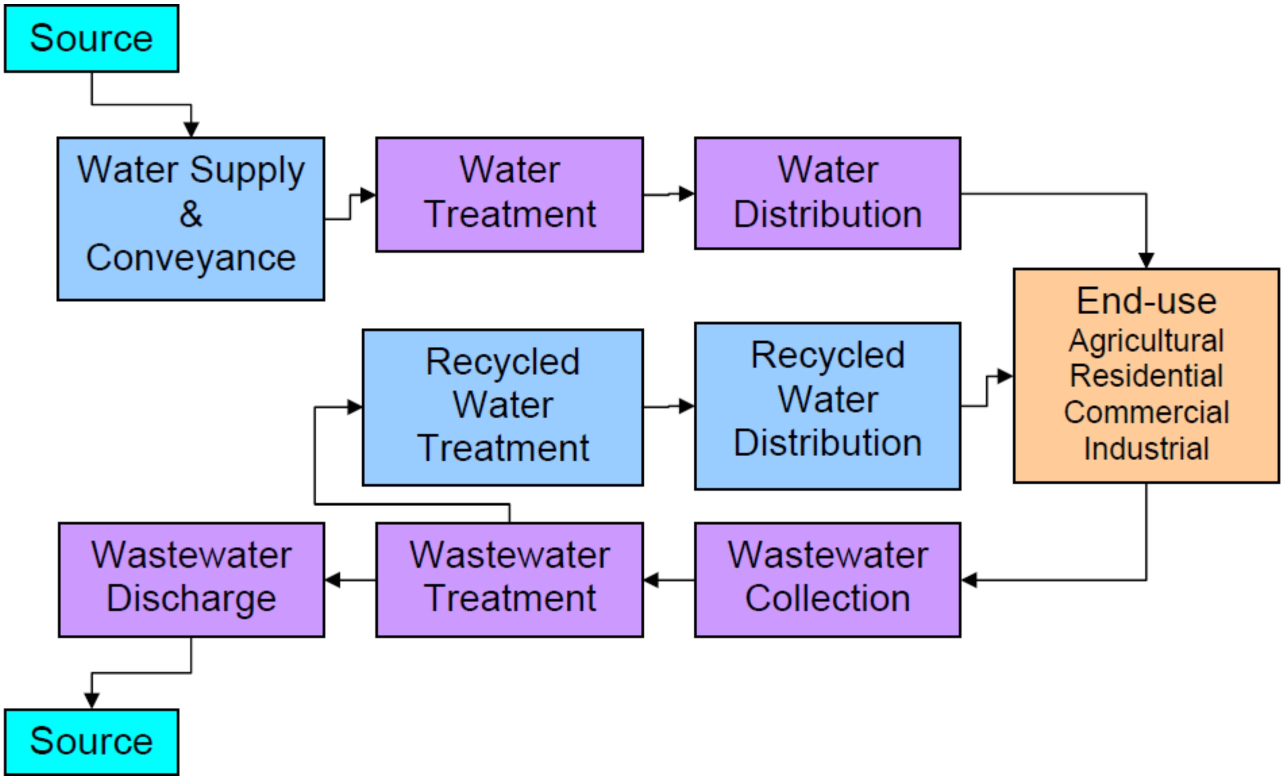


Figure 1. Water Energy Cycle

Previous Research for California Utilities

Several research efforts have been sponsored in California with the objective to both characterize and quantify the interconnectedness between water and energy. The first research effort was published by the California Energy Commission (CEC) in 2005 which established a baseline estimate for the embedded energy content of water in California. The primary finding (Klein, 2005) was a pressing need to improve coordination between the energy and water sectors. Attention was drawn to the need to revise the regulatory environment such that energy and water utilities not focus solely on the cost of their own processes.

Each segment within the water-energy cycle illustrated in Figure 1 has an associated energy intensity (e.g. Kilowatt-Hours per Gallon) for which (Klein, 2005) provides a base estimate. Subsequent research efforts were sponsored by the PIER Program[3] to hone the initial estimates for California utilities (NAV, 2006). The results are re-published in Table 1 for each water cycle segment. These values represent the current best estimate for the embedded energy in water for California utilities. Note that "MG" is used in this report to denote 10^6 Gallons of water.[4]

[3] The Public Interest Energy Research Program (PIER). This program is managed by the CEC to conduct public interest research.

[4] Million Gallons

Table 1. Revised California Water -Cycle Energy Intensity Estimates by Segment

Cycle Segment	Indoor Use (kWh/MG)[5]		Outdoor Use (kWh/MG)	
	Northern Ca	Southern Ca	Northern Ca	Southern Ca
Water Supply & Conveyance	2,117	9,727	2,117	9,727
Water Treatment	111	111	111	111
Water Distribution	1,272	1,272	1,272	1,272
Wastewater Treatment	1,911	1,911	0	0
Regional Total	***5,411***	***13,022***	***3,500***	***11,111***

In the remainder of this section the authors build upon the above research to provide specific embedded energy estimates for Truckee Donner Public Utility District.

The Truckee Donner Public Utility District is located just northwest of Lake Tahoe in Truckee, Ca. At an elevation of 5,817 ft Truckee is located near the Sierra Crest and receives significant snowfall in the winter and enviable summer and fall temperatures. TDPUD was established in 1927 to provide electric services to the local community. Water services were added in the 1940s. Currently the PUD has approximately 13,145 electric customers and 12,586 water customers. It is also one of California's few winter peaking utilities.

Current Research for Truckee Donner Public Utility District

The water-use cycle in Truckee is overseen by three agencies. Truckee Donner Public Utility District is responsible for conveyance, treatment, and distribution of potable water, the Truckee Sanitary District (TSD) collects wastewater and distributes it to the wastewater treatment facility, and the Tahoe Truckee Sanitary Agency (TTSA) treats the wastewater before finally discharging it into a soil aquifer treatment system. The evaluation of TDPUDs DSM programs included primary data collection and analysis of the energy intensities for the water-use cycle segment overseen by each of these agencies. The embedded energy in water for the TDPUD water district was then quantified by combining the findings for each segment.

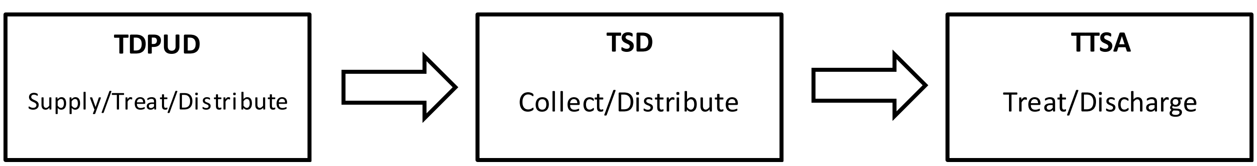


Figure 2. Organizational Responsibilities for Truckee Area Water Cycle

Energy Intensities for TDPUD. The District acquires its water from aquifers within the Martis Valley groundwater basin area. Water is transported to Truckee's higher elevations through a series of pump stations and is stored in water tanks throughout the community. Given the depth of these wells, the process of pumping water from the aquifers is significantly larger than the energy required to treat and transport the water once on the surface. The energy intensities of these segments were quantified together using metered data on pumped water volumes and utility energy use for the 2014 calendar year.

[5] Note that there are some significant differences in the energy intensities between Northern and Southern California. This is due to differences in water supply sources and technologies. Southern California is more reliant on remote water sources (e.g. significant conveyance) and energy intense water purification technologies.

TDPUD operates 10 wells and 16 booster stations which collectively provide potable water to the District's water customers. The District is organized into three *zones* based on elevation (e.g. the pumping power required to distribute water to these areas). The electric power consumed by the wells and booster stations, along with the calculated energy intensities for each component, are provided in Table 2. Note that in 2014 TDPUD supplied approximately 1.43 Billion gallons of water.

Table 2. Summary of Estimated Energy Intensities for TDPUD Water Supply and Distribution

	Annual Electricity [kWh]	**Energy Intensity [kWh/MG]**
Pumping & Treatment	3,519,629	2,460
Distribution	3,159,516	2,208
Overall	6,679,145	4,668

It is of interest to note that the energy intensity of the water supply/distribution system varied over the course of the year, with the minimum intensities occurring between May and June. While the overall energy intensity was 4,668 kWh/MG, the evaluation found that the average monthly energy intensity was 5,044 kWh/MG with a minimum and maximum of 3,248 kWh/MG and 6,600 kWh/MG respectively. This, along with the monthly energy consumptions for the supply/distribution system, is illustrated in Figure 3. The monthly water pumping volumes closely follow the monthly pumping energy consumptions.

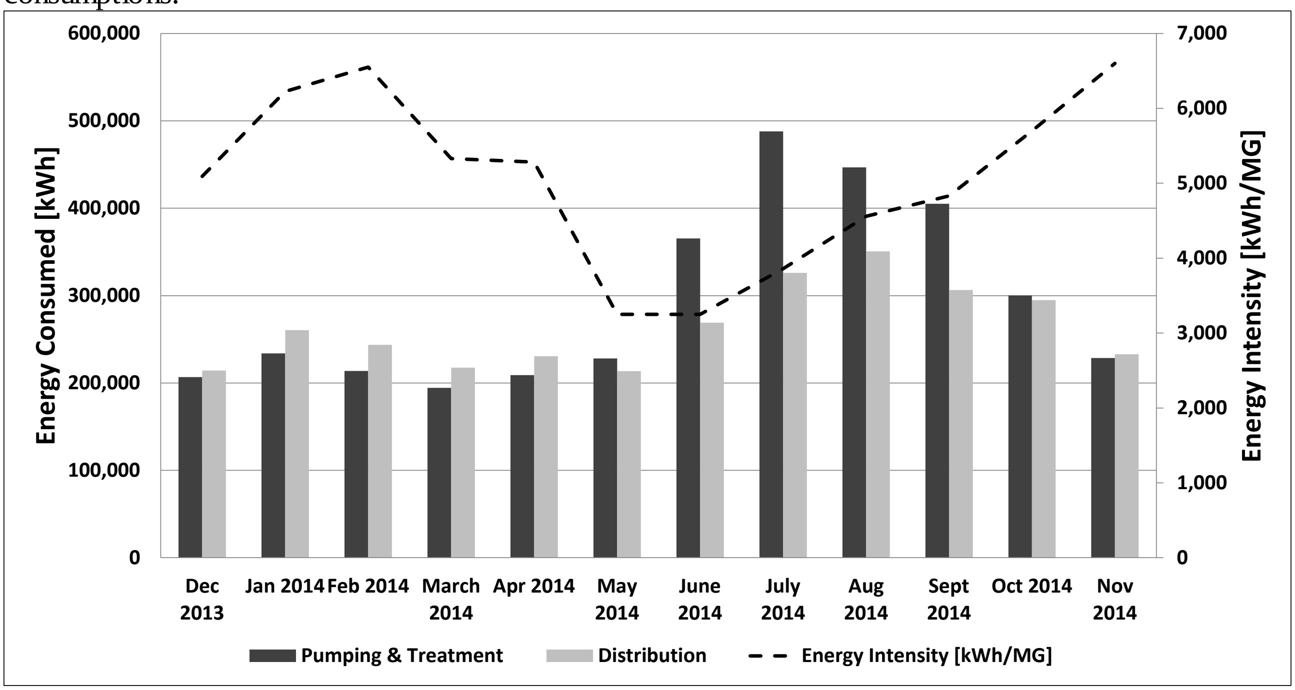


Figure 3. Monthly Variation in Energy Consumption and Energy Intensity for Water Supply System

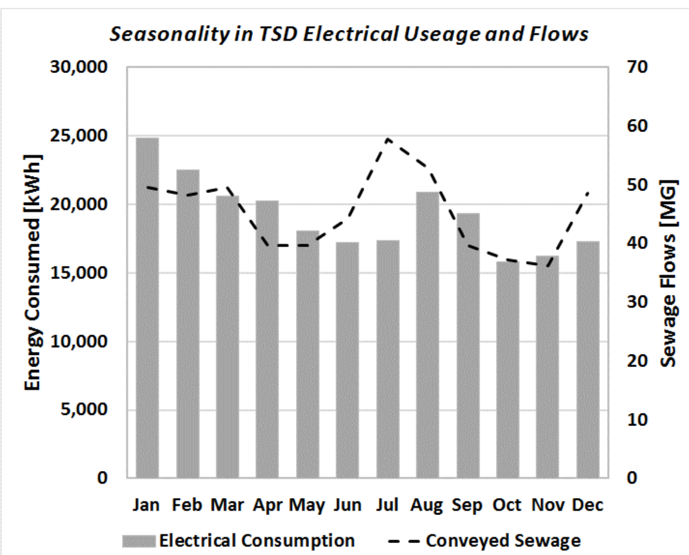
Energy Intensities for TSD. The Truckee Sanitary District maintains and operates 300 miles of gravity pipeline, 9 miles of pressure pipeline, and 40 lift stations. While the primary contribution to this system comes from residential customers, a handful of small businesses and restaurants also contribute to the wastewater flows. The collection system is monitored/controlled using computerized telemetry and flow metering from which data was collected to quantify the energy use intensity for this segment.

Two years of monthly electrical consumption and sewage flow histories[6] were analyzed to derive the energy intensity of sewage conveyance in the Truckee region. The average annual consumption[7] and calculated water energy intensity are provided in Table 3.

Table 3. Summary of Estimated Energy Intensities for Truckee Sanitary District

	Annual Electricity [kWh]	Energy Intensity [kWh/MG]
Sewage Conveyance	230,534	429

Some seasonal variation in energy consumption and sewage flows was observed in the data. The peak energy consumption occurs during the winter months of January and February; however, sewage flows show a peak in July and August. These differences in seasonality account for much of the variation seen in the embedded energy for TSD. Figure 4 illustrates the seasonality observed in TSD's energy consumption and sewage flow data. It also demonstrates that there is some scatter in the correlation between energy consumption and conveyed sewage (e.g. the energy intensity). This study did not include a more detailed analysis of this data to identify specific sources for this scatter. Currently it is expected that much of this scatter is generated by differences in the seasonality of sewage flows for regions within TSD's service territory. Due to the significant topography of the Truckee region, some communities require a number of pumping stations while others are almost entirely gravity fed.



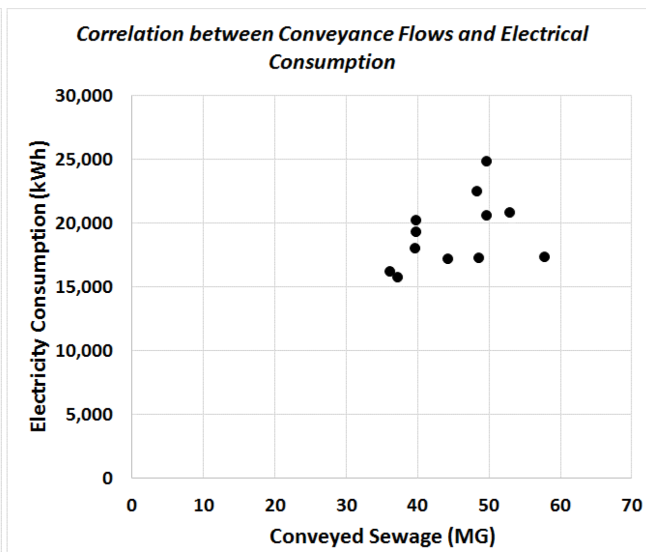


Figure 4. Summary of Trends Observed in Water & Energy Use for TSD

Energy Intensities for TTSA. The Tahoe Truckee Sanitation Agency provides regional wastewater treatment services to communities around Lake Tahoe, Ca. through five sewage collection districts – of which TSD is one. Wastewater is treated at a water reclamation plant located in Martis Valley, just east of the Town of Truckee. Electrical consumption and plant influent rates for the most recent two year period[8] were reviewed to estimate the energy intensity of TTSA's water treatment process. The results are shown in Table 4.

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[6] 2013 through 2014

[7] Note that this is a two year average.

[8] 2013 and 2014

Table 4. Summary of Estimated Energy Intensities for Tahoe Truckee Sanitation Agency

	Annual Electricity [kWh]	Energy Intensity [kWh/MG]
Sewage Conveyance	7,748	5,883

Influent rates were used in this calculation because better data was available for plant influent then for plant effluent. It is assumed that the rates are equal. Figure 5 shows the monthly variations in electrical consumption and influent flows. It is unsurprising that the two-year average seasonal variations seen in the wastewater influent match those seen in TSD's conveyance flows (Figure 4). Given the consistency of the waste water treatment process less scatter is observed in the correlation between electric usage and influent flows (e.g. the observed energy intensities).

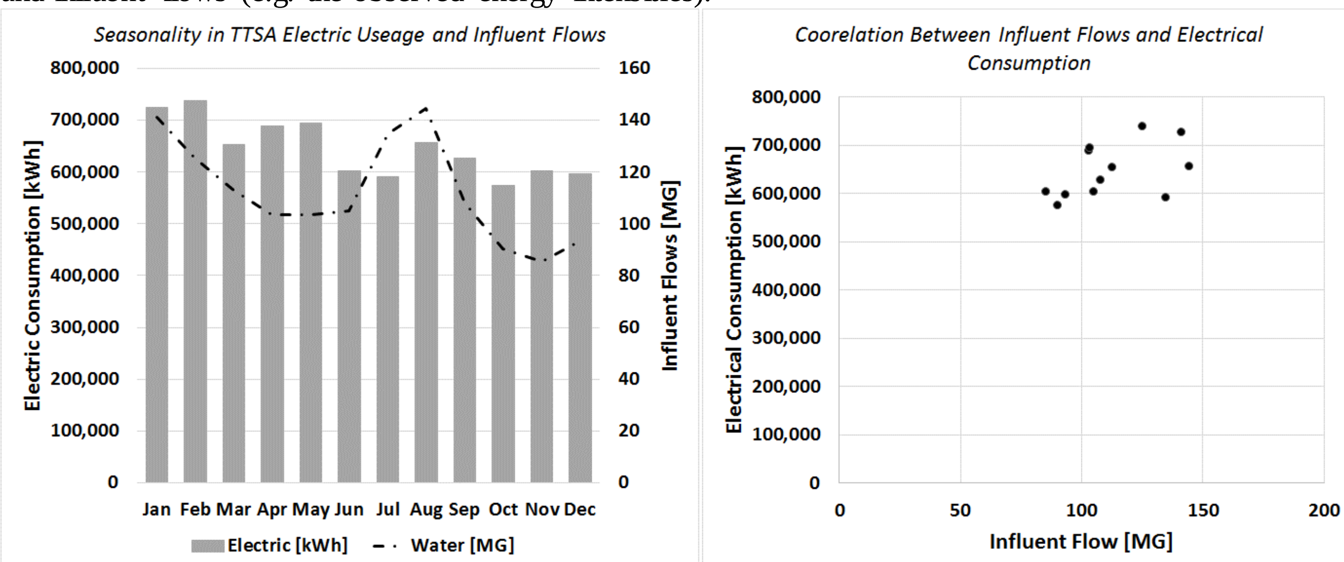

Figure 5. Summary of Trends Observed in Water and Energy Use for TTSA

Embedded Energy for Truckee Region. The calculated water intensities are provided in the previous sub-sections for each component in the water-cycle for the Truckee region. These are summarized and aggregated below to calculate the overall energy requirements (embedded energy) for drinking water in the Truckee region. Two estimates are provided for the embedded energy of water – one for indoor water and another for outdoor water. The difference between these numbers accounts for the fact that water used for outdoor purposes (e.g. irrigation, car washes, etc.) does not get distributed back to the wastewater treatment plant for processing and discharge.

Table 5. Summary of Embedded Energy Content of Water for Truckee Region

	Indoor Water [kWh/MG]	Outdoor Water [kWh/MG]
TDPUD	4,668	4,668
TSD	429	0
TTSA	5,883	0
Overall	10,980	4,668

Water and Energy – A Successful Partnership

The previous section in this paper demonstrates that energy impacts garnered through water conservation are both clear and quantifiable. While one may appeal to an ethical imperative as sufficient justification for water and energy conservation programs; this section demonstrates that water conservation programs can also be justified through cost effectiveness testing alone. This point is illustrated using the results from a recent impact evaluation of the Toilet Rebate/Exchange programs implemented by TDPUD. However; before this can be shown, the traditional metrics for success (e.g. the standard list of cost effectiveness tests) need to be refined such that the results value both water and energy impacts.

How to Measure Success. It was mentioned in the introduction that the water and energy sectors need to be better integrated such that valuation of each resource (and its infrastructure) can account for its impact on the other (Klein, 2005). Any integration of this sort will require creative and practical applications on many levels though one specific application is an inclusion of water resource costs (and benefits) in the current cost effectiveness models for DSM programs. [9] The most common cost effectiveness tests currently used to assess DSM program success are:

1. Program Administrator Cost Test (PAC)
2. Total Resource Cost Test (TRC)[10]
3. Participant Cost Test (PCT)
4. Ratepayer Impact Measure Test (RIM)

It is outside the scope of this paper to give a complete overview of the above cost effectiveness tests and a comprehensive treatment can be found on each, including formulae, in (CPUC, 2001). For the purposes of this paper it is assumed the reader has at least basic understanding of the components involved.

One particularly important benefit leveraged by most of the listed tests is the avoided cost of energy generation. In the context of energy conservation this represents the relative amount it would cost a customer to purchase the avoided energy through expansion of generation facilities or acquisition of a new supplier. It is typically used to estimate the fair market value for energy and, while this concept is well developed and applied to energy conservation, its analogue in the water sector is only now being advanced. When applied to a water utility this represents the cost to increase water production/conveyance/treatment capacity to meet additional demand. Typically this is estimated using a Fixed Charge Rate which includes the following components (NAV, 2014):

1. Asset Depreciation
2. Asset Life
3. Return on Equity
4. O&M Expense
5. Interest Expense

The inclusion of this metric is paramount to ensure fair valuation of water conservation impacts which avoid both the need to expand energy generation resources, and water supply, distribution, and

[9] This is currently being reviewed in California for inclusion into the E3 Calculator model used by utilities to estimate program/portfolio cost effectiveness using a "bottom" up approach.

[10] Sometimes called the "Societal Cost Test".

treatment infrastructure. Given the costs associated with water capacity improvements, the addition of avoided water costs has a significant impact on program cost effectiveness. This is illustrated at the end of this section by comparing the results of each cost effectiveness test for the TDPUD Toilet Rebate/Exchange program with and without their inclusion.

It should also be noted that additional non-energy benefits (NEBs) are garnered through water conservation activities - the clearest of which are positive impacts on regional eco-systems competing for the same water resources. However; such NEBs are more difficult to quantify in as straight-forward a fashion as the avoided costs discussed above. This is in part due to a subjective element in the valuation of regional eco-systems and the impact(s) on society any degradation of these eco-systems may impart. This is mentioned here to inform the reader that additional benefits are actualized through water conservation that are currently not considered in the cost effectiveness test results provided below and that more work is required to better quantify the interactions (e.g. costs and benefits) associated with water conservation

Cost Effectiveness of an Actual Program. The cost effectiveness test results are provided here from a recent evaluation of the Toilet Rebate/Exchange program implemented by Truckee Donner Public Utility District. These results are provided to demonstrate that water conservation programs can be considered cost effective elements to a well-rounded DSM portfolio – particularly in the western US where prevailing drought conditions have left water resources at record lows.

The evaluation applied IPMVP Option A,[11] partial-retrofit isolation (EVO, 2014) to estimate the gross water conservation impacts attributable to the Toilet Exchange/Rebate program using the following equation:

$$\Delta Gal = F_{Person/Day} * N_{People} * (V_{Pre} - V_{Post}) * 365 \qquad (1)$$

ΔGal	Represents the gallons of water conserved
$F_{Person/Day}$	Is the number of toilet flushes per person per day[12]
N_{People}	Is the number of persons per household/toilet[13]
$V_{Pre/Post}$	Is the volume per flush (pre and post)[14]

Based on the program population data, the average toilet replacement conserved water usage by approximately 7,200 Gallons per year per toilet. Note that the assumptions applied in Formula 1 were identified through secondary literature and local demographic data available in the most recent census. The 2014 the program replaced 511 toilets with low-flow alternatives. This conserved approximately 3.7 MG/year of household water consumption. Once a reasonable estimate was available for annual water impacts, the evaluation applied its findings presented in the previous section regarding the embedded energy in water (.0063 kWh/Gal) to estimate the gross annual energy conservation impacts for this program – approximately 40,618 kWh, or 79 kWh per Toilet. The Net-To-Gross survey identified a free-ridership rate of 10% for the program which was applied to get a net savings estimate for both water and energy conservation totals. The gross and net impact evaluation results are provided in Table 6

[11] International Performance Measurement and Verification Protocol
[12] This evaluation assumed 5.1 flushes per person per day (AWWA, 94)
[13] This evaluation assumed 2.56 persons per household (based on 2009-2013 American Community Survey 5-Year Estimates for Truckee, Ca).
[14] Based on manufacturer specifications.

Table 6. Gross and Net EM&V Results for Toilet Exchange/Rebate Program

	Water Impacts (MG/Year)	Energy Impacts (kWh/Year)
Gross	3.7	40,618
Net	3.3	35,989

Each of the cost effectiveness tests were performed for the program using the best available avoided cost estimates for both the electric and water utility. The avoided cost estimates for electricity were derived from primary data provided by TDPUD, however; given the dispersed nature of the water system, and lack of relevant literature, the avoided costs for water are based on a recent research study sponsored by the CPUC for the State of California (NAV, 2014). For the purposes of this paper, the evaluation team prepared two different versions of the cost effectiveness tests to demonstrate the impact that the avoided water costs have on program cost effectiveness estimates. Avoided water capacity costs were estimated using the avoided water capacity cost model calculator (NAV, 2014) for the North Lahontan region which output $4.94 per avoided CCF of water.[15] We also note that the program administrative costs were approximately $115 per toilet and program equipment/rebate costs approximated $130 per toilet. The cost effectiveness calculation results are compared in Table 7.

Table 7. Summary of Cost Effectiveness Tests

	No Avoided Water Costs	All Avoided Costs
PAC	0.2	0.2
TRC	0.2	1.9
PCT	1.5	1.5
RIM	0.2	1.6

Impact of Avoided Water Capacity Costs. It can be seen by comparing the values in Table 7 that the inclusion of avoided water costs makes a significant difference in how one might assess the success of this particular program. In particular, the Total Resource Cost test results (a popular metric by which program effectiveness is measured) increased from a value of 0.2 to 1.9. In the absence of the avoided water costs this program is considered not cost effective. However; the full impact of the program is not considered without accounting for the reduced infrastructure needs (avoided costs) in both resources – energy and water.

Conclusions

It is well established that water conservation activities also result in energy conservation impacts. Furthermore, establishing the magnitudes of these energy impacts (e.g. the embedded energy in water) is a relatively straightforward data analysis exercise. The results for the Truckee region water-cycle presented in this paper fall well within the expected ranges established by previous research studies for the California Investor Owned Utilities. While this was an important first step, it is insufficient on its own to establish an integrated approach in valuation of water conservation efforts (in the DSM context). As demonstrated by the cost effectiveness test results provided in Table 7, if additional key benefits and costs are recognized in current cost effectiveness models an effective a partnership between water and energy conservation can work to conserve our finite water resources while simultaneously contributing to energy efficiency goals.

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[15] Calculator outputs are in units of $M/MGD capacity per year and converted into $/CCF for use in this study.

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