# Let’s Think Outside the Box. Wait . . . What’s IN the box?—An Exploration of Water System Energy Efficiency

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## ABSTRACT

Studies show that water systems consume 10%-30% more energy than needed to meet the water demands of their customers. Obviously, water systems present a huge opportunity for efficiency programs, but efforts to date have largely missed the mark. Existing programs focus on improving individual pump station efficiency, gaining a few percentage points here and there. In reality, the key to conservation lies in understanding the flow of water and energy within the entire network. In 2014, Rocky Mountain Power and Cascade Energy initiated a program to pursue these opportunities. This paper will describe how utilizing a dynamic hydraulic model as an operations tool can “unwrap the box” to expose inefficiencies within the system network. Like other strategic energy management engagements, the program focused on helping operators make good decisions through facilitated discussions supported by hydraulic model illustrations. Why increase system pressure only to waste it through pressure reducing valves? Why pump water in a circle, looping the water back to the suction side of the same pump? Operators cannot answer these questions, and it’s not their fault! Given the miles of piping and the hundreds of junctions in the network, it’s impossible. Dynamic hydraulic modeling of the network, combined with effective energy management coaching and energy modeling expertise, can produce stunning results. In one case, two days of field work resulted in 32% (1,800,000 kWh) energy savings. Another reduced energy consumption by 11% (3,900,000 kWh) through a single management decision, once the costs of “business as usual” were understood.

## Introduction

Rocky Mountain Power (RMP), an investor owned electric utility serving portions of Utah, Idaho, and Wyoming, has been implementing energy efficiency programs for well over a decade. In 2013, an Energy Management offering was added to the suite of incentive options under RMP’s brand *watts*mart™. The offering aims to help customers reduce energy use through improved operations, maintenance, and management strategies. The $0.02/kWh incentive serves to offset customer time to implement the low/no cost actions with the goal, through program-funded technical assistance, to reduce customers’ annual energy usage and annual energy spend. The customer learns how to optimize the energy use of their existing equipment, without having to invest in capital expenditures.

The Energy Management offering ranges from basic Retro-commissioning, to Persistent Recommissioning, to the most involved partnership: Strategic Energy Management (SEM). Customer requirements of SEM include both executive-level sponsorship of a 12-24 month commitment and a designated staff member to act as the internal Energy Champion to lead their energy team. An added layer of flexibility for the program is the ability to offer SEM either to an individual customer or to a group of customers in a Cohort.

As *watt*smart program staff were deciding which sectors in Utah to approach about SEM, the water sector rose to the top as a growing, energy intensive sector best analyzed from the system level. In Utah, water services consume 7% of non-transportation energy (Larsen and Burian. 2012; UDWR 2012). As of July 1, 2016, Utah was the fastest growing state in the nation by percentage growth. (US Census Bureau). With increased population comes increased demand for water and municipal infrastructure. Thus, targeting energy efficiency within the water sector will pay dividends now and in the future. The water sector is also a non-competitive customer class whose members would be willing to work together in cohorts. As water utilities have complicated, interactive sub-systems; a conservative, risk-averse culture; and a mandate to deliver quality product no matter the cost; the *watts*mart team agreed that a comprehensive SEM approach would be best for this particular sector.

Cascade Energy and Hansen, Allen & Luce (HAL) were brought in by RMP to lead the Water SEM engineering and facilitation effort, with facilitation assistance by internal *watt*smart staff. Wattsmart staff initiated customer outreach and recruitment, and the first Water SEM project was started with a large water wholesaler in quarter two of 2014. The first Water SEM Cohort was initiated shortly thereafter with three water systems in quarter four of 2014, and the second Water SEM Cohort commenced with five water systems in quarter two of 2015, all systems located within roughly 60 miles of the Salt Lake City metro area.

## The Water SEM Program Combines Technical Assistance, Organizational Coaching and Energy Tracking to Drive Energy Savings

The Cascade/HAL team worked together with each Water SEM participant to identify efficiency opportunities, implement them systematically, and track the resulting energy impact. The main components and tools used within the program are listed here, the more technical tools are described further in the next section:

- **Energy Map**: Each source of water is identified and the energy cost of water produced by that source is calculated. All other things being equal—water rights, water quality, water availability, and environmental impact, for example—the goal is to move production away from the high cost sources and towards the low cost sources.
- **Mass Balance**: Using the system’s historical production and demand information, the water flow in and out of each pressure zone and reservoir is calculated. Anomalies in the mass balance are the initial indicators of inefficient flow patterns.
- **Hydraulic Model Analysis**: The system’s hydraulic model is reviewed and updated if necessary, then used to identify its operating characteristics under different scenarios.
- **Energy Model**: A system-wide, top-down energy model is developed that describes the historic relationship between energy and system water production. The energy model allows the participants to compare “business as usual” energy use with actual energy use. Typically, three years of monthly water, temperature, and energy data is sufficient to build a model. Maintaining the energy model requires the participants to gather and provide water production information each month.

- **Energy Scan and Opportunity Register**: The Cascade/HAL team also performs on-site energy scans (scoping level efficiency audits) if the water utility has substantial infrastructure that is included in the energy model. Additionally, the three technical analyses are presented during energy team meetings that become something of a virtual energy scan. In both cases, energy efficiency measures are identified, prioritized, and added to the Opportunity Register for tracking.
- **SEM Coaching**: Finally, the team will provide individual coaching, assistance, and check-ins on a regular basis. In the early months, this is typically focused on energy team formation, policy setting, data gathering, etc. As the analyses are completed and the opportunity register starts to fill, the topic moves towards prioritization, implementation, staff engagement, and activating change. Towards the end, the check-ins are often about performance to date, digging into and recording the causes of savings and backsliding, and developing persistence strategies.

The Water SEM projects were initially funded as 18-month programs; six months to initiate changes, and twelve months of measurement and verification using the energy model. The timeline was adjusted if participants needed more time in a particular stage.

## A System Optimization Approach is more Holistic than Historical Energy Efficiency Efforts in the Water Sector

Traditionally, energy efficiency projects involving water systems have focused on improvements to individual pumps and pump stations. Rightfully so, since pumps impart the energy to move water from the source, through any treatment, and into the distribution system for delivery to customers under substantial pressure. For example, between 1990 and 1997, Southern California Edison performed over 28,000 water pump tests (Conlon et al. 1999). Unless a community is fortunate enough to be located relatively near and below its source water, pumping will generally comprise over 80% of the energy consumption of the system. (http://www.waterrf.org/knowledge/energy-management/FactSheets/EnergyMgt-EEPumping-FactSheet.pdf**)** Of the nine systems engaged in the Water SEM program, none had less than 85% of their total electricity consumption based in pumping.

Efficiency gains in pumping are typically derived from relatively costly projects: improving the mechanical efficiency of the pump with rebuilds, trims, or replacement; utilizing adjustable speed drives rather than control valves to regulate volume; replacing aging motors with high efficiency motors; or installing an additional pump to more efficiently meet reduced loads. Coating a pump's volute and impeller with low-friction coatings to restore surfaces and reduce wear has also been demonstrated to improve and maintain pump efficiency (Maier et al. 2009).

All of these efficiency measures ignore the complicated water systems that exist beyond the flanges of the pump. With the traditional approach, *the pressure and volume of water being moved by the pump is assumed to be both correct and necessary*. Furthermore, electric utility program staff, the energy efficiency experts, are not expected to question the operation of the water system and, with rare exceptions, would not feel comfortable suggesting operational changes that would impact either the volume or pressure requirements.

Perhaps more surprising, even if the program staff were to ask questions about whether the volume and pressure requirements were "correct," the water system operations staff would be hard-pressed to provide an answer. That is not due to complacency, ignorance, or insufficient training. Rather, it's because the tool that can provide the answer, the hydraulic model, has traditionally been used only for infrastructure planning and design efforts; it has not been used as a guide to improved operations.

Hydraulic models are digital representations of the water system, and modeling software was one of the early applications for programmable computers in the 1970's. Today, nearly every system is modeled, but we are only now beginning to use the model as an optimization tool to lower the energy footprint, improve water quality, and improve water service.

## Hydraulic Models are Traditionally Used to Plan Infrastructure Improvements to Meet Current and Future Conditions

Imagine a simple water system constructed to serve a small community (Figure 1). The water source is the town well, and water is pumped from the well into an elevated tank. A pipe runs from the tank into the community. The homes served by this system will all have pressurized water, and the pressure is set by the level of the tank. The area served by this tank is called a pressure zone. In this system, water flowrate, direction, and pressures at each point in the zone are easily determined.

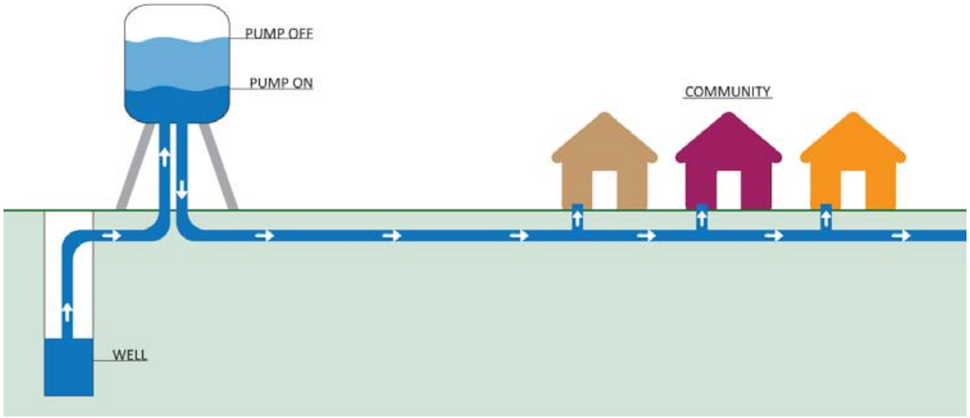

Figure 1. A simple water system. The pump fills the tank; the tank provides storage volume and maintains a narrow range of pressure for the system's customers.

As a system grows, it becomes much more complicated to determine what's happening within the system. For example, if homes are added to our model town that are built on higher ground, the existing tank can no longer serve them. In Figure 2, the network has grown by adding a booster pump and another tank. This creates another pressure zone, higher than the original zone. To add redundancy, a pipe from the higher zone is connected to the lower zone through a pressure reducing valve (PRV). In this way, if the pressure in the lower zone drops too much, water can flow back down from the higher zone to help meet demand. As shown in Figure 2, even within this simple system, it is already difficult to tell which direction water will flow in the mains, and it will depend on tank levels, water demand, and pump operations.

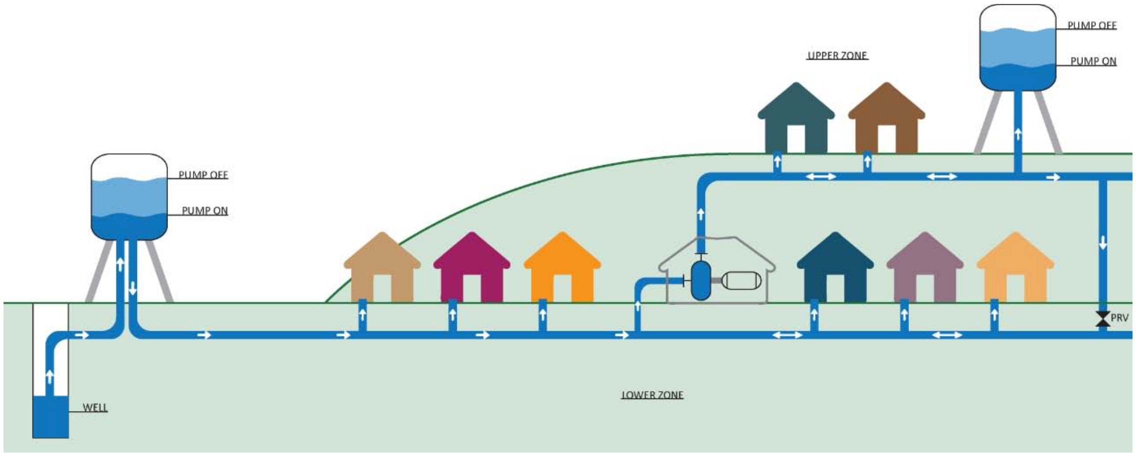

Figure 2. The simple system, now with an added booster pump, upper reservoir, and two pressure zones. The PRV allows water to flow back into the lower zone from the upper. The pressured (energy) embedded in the water is wasted as it flows past the PRV.

Most real systems are much more complicated. Figure 3 shows the network for an actual town of roughly 8,000 people which includes five pressure zones and over 1100 "pipes" (the usual metric for model size). The water model for Boise, ID (serving ~225,000 people), for example, consists of 37,500 pipes representing 1,200 miles of pipeline, 82 sources, 43 booster stations, 35 tanks, and 90 pressure zones.

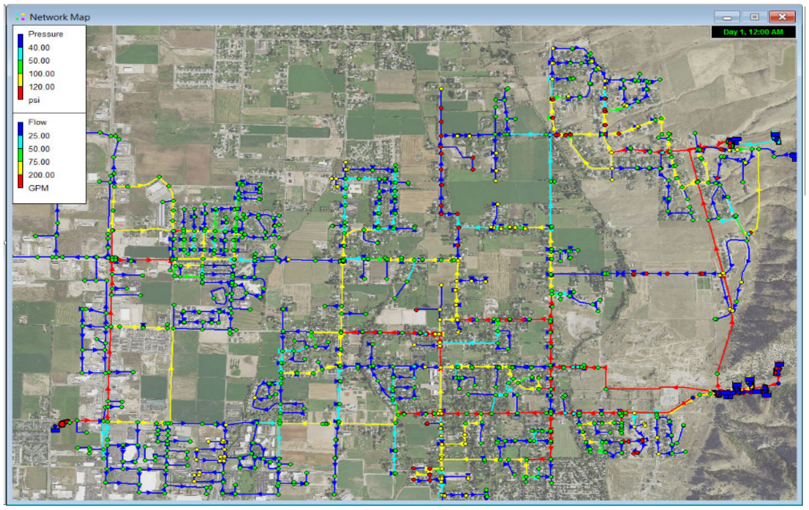

Figure 3. A modern water model for a small town of roughly 8,000 people. Colors indicate flows and pressures within the system at one point in time.

As network complexity grows, pressure and flow at any point can only be determined through iterative calculations. A hydraulic model, at its core, is simply a math program to quickly solve the multiple, simultaneous equations that define the conditions at every node (a piping junction, endpoint, connection to a tank or pump, etc.) in the network.

The traditional use of hydraulic modeling is embodied in the example above. The town's growth adds demand to the system. Hydraulic modeling helps the water utility determine whether the system can meet the peak demand and fire flow while maintaining minimum pressures, while also ensuring that the operating pressure range is not too high or too low for customers. This is called maintaining the “Level of Service.” By simulating average and peak demand scenarios now and in the future, engineers can determine which pressure zones will need more capacity, when new sources will be needed, and whether or how much new storage will be required.

## Extended-period Modeling as a Tool for Improving Operations

As illustrated above, a hydraulic model is a computer simulation that combines facilities (pipes, tanks, water sources, pumps, valves) with hydraulic conditions (water demands, time patterns, controls) to simulate and visualize water system behavior. A static or steady-state model is a snapshot of the system at a fixed time and condition; static models are fantastic planning tools. Again referring to Figure 3, the color coding within the network is used to illustrate the pressures and flowrates within each pipe under the modeled, static condition.

An extended-period model, or more commonly extended-period simulation (EPS), on the other hand, simulates dynamic system behavior over a period of time, for example, a 24-hour day. This allows one to actually “see” tanks filling and draining, pumps turning on and off, pressures fluctuating, and flows shifting in response to demands. Figure 4, below, shows time-series charts from an example 24-hour simulation. They show i) system-wide flow balance (water consumption and production) and ii) water pressure fluctuation over the course of the modeled day at two different locations.

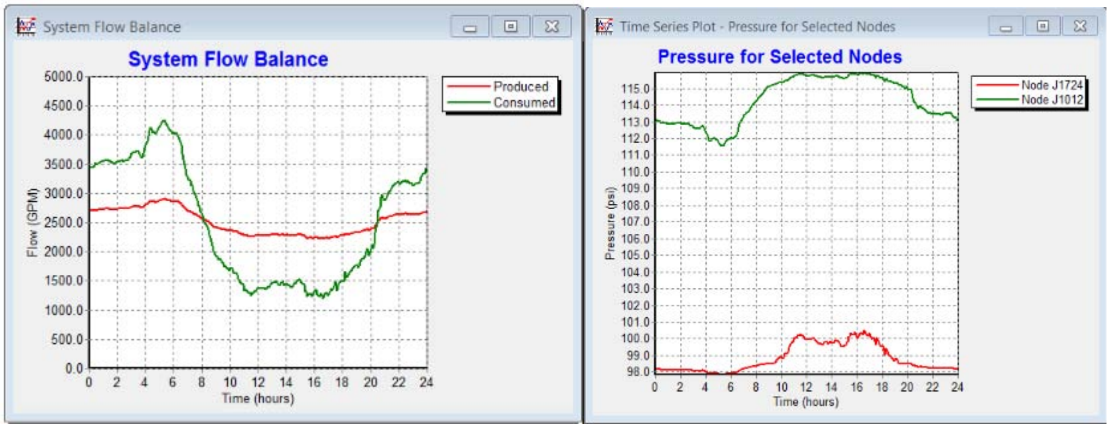

Figure 4. EPS charts showing i) System Flow comparison between the production source and the collective consuption of the system (left) and ii) Pressure trends over the course of a single day of two measurement points (right).

An EPS can be used to simulate new operating scenarios, replicate existing behavior to determine the cause of known issues, and identify previously unknown issues. Note, for example, the high pressures between 10 a.m. and 6 p.m. on Node J1012 (upper line on the right hand pressure chart). This corresponds to the period of low water demand in the middle of the day. Conversely, low pressures correspond with high water demand in the early morning and late evening. In this case, the EPS model confirmed the operators’ gut feeling and provided additional insight that was not previously possible. Until flow and pressure meters are physically built into pipelines, an EPS provides the only way to visualize where the water is going—an invaluable resource for water system optimization and energy management. Seeking to understand the system in terms of energy, through the model, is one of the first steps to achieving an optimized system. The model helps identify energy inefficiencies and safely test the performance of operational changes or capital improvements before they are implemented in the real system.

The beauty of the EPS, and why it fits so well with an SEM approach to energy reduction, is that much of the inefficiencies that are identified can be "fixed" with simple control adjustments, management decisions, routine maintenance, and changes in the operators' behavior rather than expensive capital projects.

## Efficiency through Water System Optimization

The underlying assumption in the value of facility-specific equipment upgrades is that the facility lies along the most energy-efficient water delivery path. This is not always true, and there may be a better way to deliver water. Much like a navigation system with built-in traffic monitoring can show the most efficient delivery route, the EPS model analysis can also show the most efficient path for delivering water where needed. And, it shows where current set points, controls, and valve positions are inhibiting the most efficient scheme.

By looking beyond individual equipment or facilities, water system optimization aligns the three areas of concern—hydraulic performance, water quality, and energy efficiency—across the entire system (Jones and Sowby, 2014). See Figure 5. Built on the EPS model analysis, water system optimization reveals efficiency opportunities not apparent to the O&M staff or even through traditional static modeling. A water system is, in a sense, a distributed facility, with components spread throughout a city; to optimize the system, all components must be considered. The main opportunities associated with water system optimization come from considering the whole supply scheme and seeking the most energy-efficient path for water delivery that still satisfies the Level of Service.

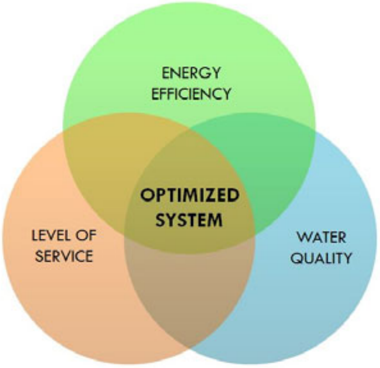

Figure 5. An optimized system satisfies the Level of Service, while maintaining or improving water quality and reducing the energy footprint.

Water system optimization leverages the hydraulic model to inform several strategies for improving energy efficiency. The examples below, all in Utah, come from RMP Cohorts as well as work performed by HAL outside RMP's programs:

**Preserve energy already embedded in the water.** Each time water goes through a pump station, energy is added, and each time water goes through a pressure-reducing valve (PRV) or flow-control valve (FCV), energy is wasted. Efficient water delivery preserves the embedded energy (pressure) from pump stations, wholesale connections, and gravity supplies. For example, Centerville City, Utah now uses the pressure from its wholesale connections to effectively bypass its own pump station (HAL, 2017). In some cases, capital projects are required to preserve this energy. A new gravity pipeline in Spanish Fork has reduced the water system's energy use by 29% (HAL, 2017). Two other bypass projects are planned in North Salt Lake and Granger-Hunter Improvement District that together will save 750,000 kWh per year (HAL, 2017).

**Utilize Storage.** Most systems underutilize their storage capacity. Figure 6, below, shows a typical system's response to water demand. As demand picks up, water production increases. Little of the system's storage capacity is being utilized, the tank levels fluctuate very little, and the water production rate peaks at around 42,000 GPM at 9 p.m.

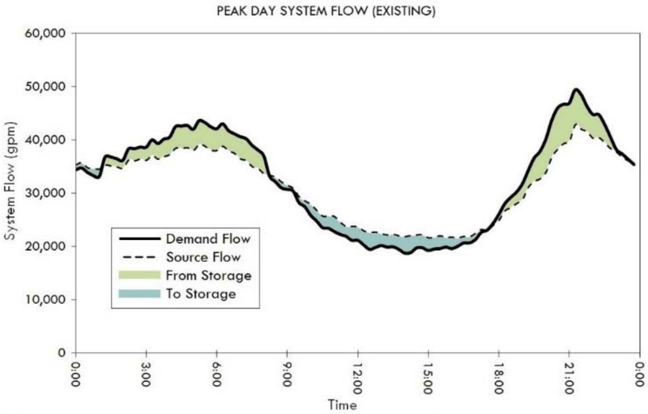

Figure 6. A typical water system tends to match production to consumption.

Figure 7 shows the same system with an idealized production schedule. Here, water production is held steady at about 32,000 GPM, and the peaks of demand are met by letting storage tank levels fall. The tanks are refilled during low demand period between 9 a.m. and 8 p.m. Not only does this reduce operating horsepower (and associated demand charges), less total water is moving through the system during peaks. This reduces the effect of bottlenecks within the system and lowers pressure spikes for customers in those areas. Additionally, moving water in and out of the tanks reduces water aging with an improvement in water quality. All three components of an optimized system are met.

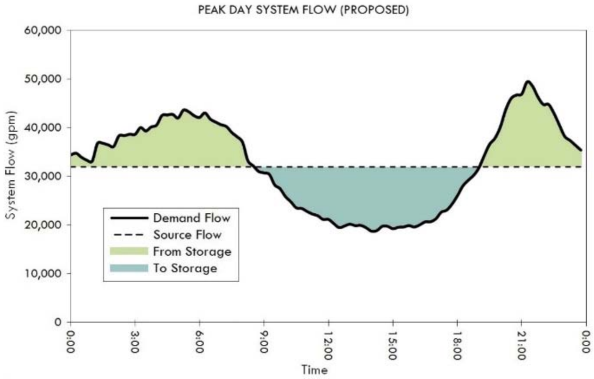

Figure 7. Ideally, production would remain relatively constant, and the systems storage volume would be used to meet peak demand periods.

**Minimize energy additions.** As much as possible, water should be delivered directly to its intended pressure zone to minimize energy additions. When water sources are at low elevations, for matters of initial cost and convenience, water utilities often construct large pump stations to lift water to the top of the system and then let it cascade down to lower pressure zones through PRVs; this “leaping” wastes the energy that was embedded by pumping. In “looping,” the PRVs are not properly set, and water can be pumped in circles between two or more adjacent pressure zones. A more efficient arrangement is to pump water to each pressure zone successively and to set PRVs low enough that water is not regularly flowing through them. A hydraulic model helps determine the proper settings.

Some service areas may be over-pressurized, whether by pumping or by gravity. Separating these areas into a new pressure zone can save significant energy. In 2013, Logan, Utah, implemented a new pressure zone at a lower elevation by reducing the heads on two wells and installing PRVs between zones (Jones et al. 2015). For the past three years, the water system has experienced an average 28% reduction in energy costs. As an added benefit, reducing pressure also reduces water use (less water flow at each faucet) and water loss (each leak releases less water from the system). Logan’s energy savings were accompanied by a 17% reduction in water use (HAL 2017).

**Prioritize low-cost water sources and facilities using the Energy Map.** Each water source or facility has an energy footprint: the kilowatt-hours (energy) and kilowatts (demand) to produce, treat, or pump a unit of water. Water utilities that do not know these values may realize significant savings by creating an Energy Map and prioritizing the most efficient water sources in each pressure zone. All other things being equal, the lowest-cost source should be favored.

## Water SEM Program Results in Significant Savings and Deeper Customer Engagement

The Water SEM program has produced significant energy savings amongst many of the participants. The results for each project are shown in Figure 8 below:

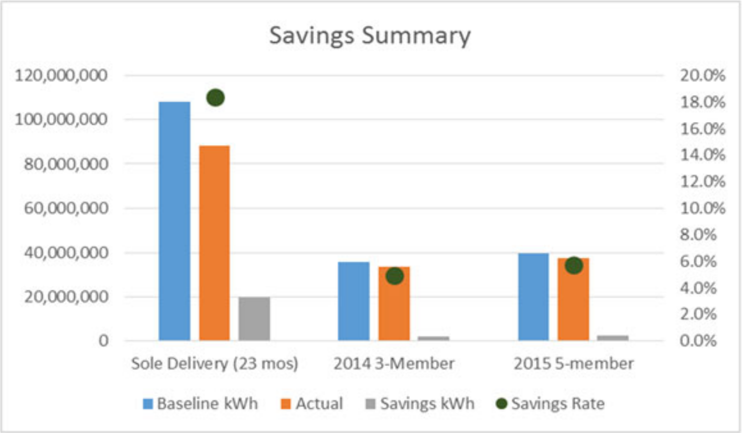

Figure 8. Baseline, Actual, and kWh Saved for RMP's Water SEM participants.

Some opportunities are easily identified, yet successful implementation requires a level of trust between the participant and the SEM team that can only be developed over time. During the course of the Water SEM, Jordan Valley Water saved 3,900,000 kWh in one year by utilizing the Energy Map to prioritize operations, and it cost them almost nothing (UDEQ, 2015). The Water SEM program's influence on this change was providing a clear accounting and cost for the "business as usual" source selection. The second year outperformed the first, with total two-year savings just under 20 million kWh.

On the other hand, some opportunities take effort to find, but once understood, can be implemented in almost no time. Following recommendations from the hydraulic model analysis, North Salt Lake adjusted its PRVs in just one afternoon and reduced its energy consumption by 30%. This is another case where the operators "had a feeling" that the water was looping, but it was only after watching the EPS simulation that they could see where and why it was happening. This gave them the confidence to make the change, knowing that the change would not negatively impact their customers.

## Lessons Learned and Suggestions for Success

Single-customer SEM projects can be more risky than cohort offerings because the costs are not spread over several participants, and the benefits are wholly dependent on one organization's ability and willingness to embrace change. Here, the approach of focusing engineering services on one large water customer worked because of a low level of program risk. Due to the high energy intensity of the customer, the team was confident that a cost effective level of savings would be achieved compared to project cost. Engineering services also helped the large customer affect cultural change within their organization because they had enough contracted time to invest in education and technical skill advancement of executive-level staff and operations-level staff, both being vital to project success.

For SEM cohorts, the approach of mixing small- and medium-sized customers together worked for the most part because success of the Cohort is measured by the total energy saved at the group level. If commitment or energy savings potential of one system languished, the commitment and energy savings potential of other systems in the Cohort tended to "float" the group total.

The risk of underperformance can be mitigated by recruiting. A strong recruiting process to identify truly interested customers is key to success. Additionally, a focused conversation around customer commitment at the beginning of the SEM project is helpful. RMP uses a document called the "Customer Commitment Letter" that the executive sponsor and the energy champion sign at the beginning of the engagement. This letter helps the program to have something to reference in cases where customer commitment needs to be reinvigorated over the extended timeframe of the SEM project.

Regarding the data-intensity of SEM and SEM Cohort engagements, it is an important but significant effort for the electric utility, the engineering firm, and the customer to keep energy data current and accurately show progress of the SEM project. Data tracking is especially significant for water systems due to the sheer number of electric meters that water systems tend to have, as compared to, the one or two meters typically required for a wastewater facility. RMP designated internal administrative staff to respond to the monthly usage data requests by Cascade/HAL. Cascade/HAL then worked to update each customer's energy performance chart as a way to show customers how action items taken in the previous month positively, negatively, or neutrally impacted their energy usage. This visibility of data helped customers stay committed to the engagement and learn how different actions affected their system.

At times, the results of source selection activities can mask the impacts of efforts taken within each individual source. For example, selecting the most efficient pump in a treatment plant's raw water line-up is an energy saving measure, but using the plant instead of a lower cost source overshadows the good work of the operators. To help identify these efforts, periodic feedback from the participant is critical. The feedback allows the program team to know which actions on the Opportunity Register had been completed to understand how these decisions impacted the various energy drivers. Cascade utilizes a software program called SENSEI® which helps to automate and dashboard this energy tracking effort. As the program matured, the energy model was refined to better account for how system-level decisions can impact energy savings in water systems. The *watts*mart program feels this was a great lesson learned that Cascade can take forward when working with other water systems in the future.

## Conclusion

Rocky Mountain Power targeted the water sector for savings through Strategic Energy Management due to the sector's energy intensity, projected growth, and organizational suitability for a cohort approach. Partnering with its contractors Cascade Energy and Hansen, Allen & Luce, one individual and two cohort-based projects have been completed. The program has provided RMP's customers energy and cost savings, improved level of service, and on-going enthusiasm for continued improvement and participation in the *watts*mart program offerings.

The Water SEM program produced significant savings towards RMP's conservation goals in just over three years. Since 2014, RMP has booked savings from four systems resulting in 14.3 million kWh and over $560,000 saved through low- and no-cost operational changes. These systems provided approximately 38 billion gallons of potable water to their customers each year. Seven additional systems will have savings booked this year, with provisional savings of 2.4 million kWh and $219,000. These systems provide nearly 50 billion gallons of water per year. By utilizing Mass Balance, Energy Maps, Energy Models, and the Extended Period Simulation, system operators and managers were given a window into their previously hidden networks. Combined with SEM coaching and connecting actions with energy impact, the operators and managers have learned repeatable and persistent methods to optimize their systems and minimize energy intensity as part of their everyday strategies.

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