COMMERCE DEPARTMENT
ENERGY RESOURCES

Energy Efficiency Market Study:

Determining the Energy Efficiency Opportunity Potential at Minnesota Drinking Water Utilities

06/30/2021
Contract 157721

Conservation Applied Research and Development (CARD) FINAL Report

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ACKNOWLEGEMENTS

This project was supported by a grant from the Minnesota Department of Commerce, Division of Energy Resources, through the Conservation Applied Research and Development (CARD) program, which is funded by Minnesota ratepayers.

The authors would also like to acknowledge the electric utility personnel, drinking water utility personnel, and industry partners for their time and candid feedback related to the concepts presented in this report.

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Definition of Terms and Acronyms

AWWA	American Water Works Association
BOP	Best Operating Point
CIP	Conservation Improvement Program
DNR	Department of Natural Resources
E2	Energy Efficiency
GW	Groundwater
GPY (unit)	Gallons per year
kWh (unit)	Kilowatt-hour
MG (unit)	Million gallon
MGY (unit)	Million gallons per year
MnTAP	Minnesota Technical Assistance Program
MPARS	Minnesota Permitting and Reporting System
MRWA	Minnesota Rural Water Association
RO	Reverse Osmosis
SW	Surface water
VFD	Variable frequency drive
WM	Well metric
WTP	Water treatment plant

Executive Summary

Minnesota drinking water treatment facilities produced 138 billion gallons of water in 2017 which used an estimated 293 million kilowatt hours (kWh) of energy. This is about 0.5% of the electrical consumption in Minnesota, and about 1.3% of industrial electrical consumption in the State (State Electricity Profiles, 2019; State Electricity Profiles, 2017). This project evaluated the major types of electrical consumption within Minnesota drinking water treatment plants (WTPs), identified opportunities for increasing energy efficiency, and explored how electrical utilities may promote these opportunities as part of their Conservation Improvement Program (CIP).

This project started with a literature review to identify current practices in the drinking water treatment sector with respect to energy conservation and what is known about the topic. The second step was to interview a representative sampling of 15 drinking water utilities. These systems represented three size classes based on the amount of water produced per year, large (>500 million gallons per year, MGY), medium (50-500 MGY), small (5-50 MGY), and they represented five geographic areas of the state, the four quadrants of the state (southeast, southwest, northwest, & northeast) as well as the metro area. Interviews covered the structure and operation of the utility including how each utility uses electricity and what conservation opportunities they had considered, attempted, and implemented. Utility electrical data allowed the calculation of specific energy benchmarks for each water utility. Three companies that drill and maintain wells and service pumps were also interviewed to get their perspective on potential conservation opportunities.

Overall system specific energy, or the energy needed to produce one million gallons of water (kWh/MG), was calculated for 14 of the 15 sites interviewed. The specific energy for the three primary operations, acquisition, treatment and distribution, were also calculated for 13 of the 15 sites interviewed. One plant did not provide energy data and the treatment and distribution specific energy were combined for two sites due to complex interactions between the three primary operations. Specific energy estimates are presented in **Table 1** by system size, and in **Table 2** by plant configuration. In **Table 1**, where specific energy is based on just part of the group, the number of systems contributing to the average is given in parentheses.

Table 1: The average values of specific energy for each size category with average values for acquisition, treatment, and distribution. Values in parentheses are the number of each group contributing to the average.

Size	Number in class	Average (kWh/MG)	Acquisition (kWh/MG)	Treatment (kWh/MG)	Distribution (kWh/MG)
GW Small (5 – 50 MGY)	3	2,250	1,050	400	1,050
GW Medium (50 – 500 MGY)	4	1600	700	300 (2)	600
GW Large (> 500 MGY)	8	2,300 (7)	900	350 (5)	1000 (7)

Small and large plants in our sample were the most energy intensive, averaging 2,300 kWh/MG, with medium plants being the most efficient at 1,600 kWh/MG (28% less). The pattern for acquisition, treatment, and distribution steps followed a pattern of medium plants being most efficient followed by large plants and then small plants.

Table 2: The average specific energy for acquisition, treatment, and distribution for the different site configurations encountered.

Configuration	Number in Class	Acquisition (MG/kWh)	Treatment (MG/kWh)	Distribution (MG/kWh)	Overall (MG/kWh)
Treat at well	3	700	0	600	1,300
Filtration	8	1,000	400	900	3,300
Lime softening	3	750	350	1,350	2,350
Reverse osmosis	1	1,100	830	1,150	3,100

Looking at energy use by plant configuration, the reverse osmosis plant was the most energy intensive at 3,100 kWh/MG followed by lime softening plants at 2,350 kWh/MG (22% less), filtration plants at 2,200 kWh/MG (6% less than lime softening plants), with treat at the well plants being the most energy efficient at 1,300 kWh/MG (40% less than filtration plants). These trends are as expected based on the amount of complexity.

A third step was to evaluate five opportunities at five water utilities. The assessments focused on five major opportunities identified by the informational interviews (the numbers in parentheses denote the number of sites where each opportunity was analyzed and the last two were analyzed using statewide data):

- Well/pump rehabilitation (2)
- Pump efficiency optimization (3)
- Variable frequency drive (VFD) installation and optimization (2)
- Customer water conservation
- Water loss reduction

Energy Conservation Opportunity Results

Each section below provides a description of the energy conservation opportunity and the implementation and energy savings based on the informational interviews energy assessments.

Pump and Well Rehabilitation

Pump and well rehabilitation are maintenance activities performed on these sub-systems. Well rehabilitation includes maintenance performed on the acquisition wells including screen cleaning, drop pipe replacement or coating, air sparging, and other types of rock formation reclamation. Pump rehabilitation includes all maintenance performed on various pumps used in the water treatment process and typically includes replacement of key components of the pump such as wear rings, impellers, or bearings, or replacing the entire pump and motor. Pump rehabilitation typically applies to well pumps, as well as booster and distribution pumps and is a subset of well rehabilitation.

A typical maintenance plan includes pump/well rehabilitation every 7-10 years which was analyzed at two sites during the assessment phase. Savings of 7-8% of acquisition energy were identified. This type of maintenance procedure should be implemented wherever it is not currently being followed (53% of utilities based on interview results). None of the interview sites were planning pump maintenance based on specific energy monitoring which is likely to yield a 1-2% decrease in acquisition energy use.

Pump Efficiency Optimization

Pump optimization involves finding the combination of pumps that provides the greatest energy efficiency possible for the system's configuration. This opportunity is most applicable to systems with several pumps that serve the same purpose, such as multiple wells or redundant distribution pumps. Selecting the optimal combination of pumps for operation can potentially save 3 to 7% of an individual drinking water utility's energy consumption.

Customer Conservation

Customer conservation provides energy savings through customer water savings. Items such as low flow toilets and showerheads, smart irrigation devices, and other household appliances use less water than what was previously installed. The water saved from customer conservation leads to less water pumped and treated at the WTP, which in turn saves energy used to produce excess water. Nine water utilities with strong customer water conservation programs were responsible for 71% of customer water conservation achieved in Minnesota between 2017 and 2019. These strong programs achieved water savings of 0.5-2% per year per site. The small number of cities providing strong water conservation programs indicate that much of the state could still benefit from a water conservation program.

Water Loss Reduction

Water losses include all water that is acquired from a water source but is not delivered to a customer. This includes water lost by leaks while distributing water, water lost during treatment processes, as well as hydrant flushing/use. The energy savings are proportional to the amount of water saved with the specific energy used as a conversion factor. The average leak rate at the sites interviewed was 11% and the Department of Natural Resources (DNR) target is 10%. This indicates an average opportunity of 1%, but leak rates much lower than 10% are attainable since 1/3 of the sites interviewed at or below leak rates of 5%.

Variable Frequency Drive Installation and Optimization

VFDs on pumps can increase energy efficiency by allowing a pump to run at its optimal point (best operating point). They can also eliminate throttling large pumps to achieve the desired flow rate. VFDs were installed on most of the pumps identified during the interview process, but they generally appeared to be used to reduce wear on pumps or as a soft start. Using VFDs to eliminate throttling can reduce pump energy by 30% but this does not appear to be a common opportunity for the sector as many sites have already implemented this savings measure. Due to many WTPs having implemented

VFDs, a widely available opportunity for the sector is to use VFDs to optimize the pump's best operating point to save 1-3% of pump energy.

Miscellaneous Energy Efficiency Measures

Heating and space conditioning are not a large opportunity for the sector overall, however the impact on small facilities can be significant where the structure is rarely occupied. It also more generally applies to well houses which are typically uninsulated and unoccupied. One small water utility showed that reducing the thermostat set point to 60°F saved 15% of the energy used.

Electric Utility Support of Conservation Opportunities

Table 3 shows the statewide energy saving potential for each opportunity, in order from most to least potential savings.

Table 3: Summary table of opportunities and their statewide potential.

Opportunity	Percent of State Water Utilities Available	Estimated Savings	Estimated Sector Energy Saving (kWh/yr)
Pump Efficiency Optimization (PEO):	**N/A**	**N/A**	**25,000,000**
PEO: Well Pump Selection	87%	5%	14,000,000
PEO: Distribution Pump Selection	87%	0.7%	2,200,000
PEO: Pump Redesign	10%	600 kWh/MG	8,300,000
Well/Pump Rehabilitation	**53%**	**6%**	**9,300,000**
Water Loss Reduction (WLR):	**N/A**	**N/A**	**3,500,000**
WLR: Distribution Leak Repair	95%	2.5-31% of losses	2,400,000
WLR: Hydrant Repair	96%	0.4-2.3% of losses	180,000
WLR: Treatment Losses	87%	2.3-43% of losses	890,000
WLR: Pressure Control	15%	1.4% of losses	31,000
WLR: Storage Mixing	15%	0.6% of losses	2,000
Customer Conservation (CC):	**N/A**	**N/A**	**2,700,000**
CC: Irrigation	94%	N/A	1,200,000
CC: Residential Appliances	94%	N/A	1,500,000
CC: Other	94%	N/A	85,000
VFD Optimization	**60%**	**1.5%**	**1,900,000**
Statewide Total	**N/A**	**N/A**	**42,000,000**

Pump efficiency optimization and well/pump rehabilitation showed the greatest potential for statewide energy conservation with modest savings potential and a fairly large number of potential sites. The identification of sites with greater potential for pump efficiency optimization are those with greater than five wells. For well/pump rehabilitation, sites without an existing plan for rehabilitation will provide the greatest potential. A requirement for incentivizing these opportunities is the measurement of specific energy for the pumps involved. During the interview process, no sites had the robust electricity monitoring that these two opportunities would require and would likely need to be incentivized by the electric utility. This system could emulate how compressed air leak audits are incentivized currently by electric utilities: an initial audit is completed to identify leaks and the audit is paid back once leaks are fixed. This ensures that energy savings are occurring from the investment by the electric utility. In a similar fashion, monitoring equipment could be installed to aid in pump efficiency prioritization and well/pump rehabilitation and could be paid back if efficient pumps are utilized or well/pump maintenance is completed.

Water loss reduction and customer conservation showed the next greatest potential for savings with a relatively high number of facilities in the state not currently with active plans for either and relatively high potential energy savings. This opportunity is easily identified with DNR data on leak rates and could be incentivized on a per leak fix basis similar to current compress air leak programs. A leak rate of 10% or less is recommended by the DNR and any sites above that would be good initial targets for outreach. To identify sites that could benefit from customer conservation, the water use per capita and the specific energy could be used as a way to identify higher opportunity as higher per capita use would indicate more opportunity for customer conservation and a higher specific energy would indicate a larger incentive to reduce water use. Rebate programs offered by the water utility, could be partially funded by the electric utility on a per gallon basis which can be converted to energy savings using the specific energy (kWh/MG).

The final two opportunities identified were related to VFD operation and had the lowest statewide potential. VFDs were commonly found on well pumps in drinking water treatment plants, but optimization is rare – they are mostly used for demand rather than energy reduction. Identification of optimization activity is more challenging than the other opportunities, requiring an in-depth assessment of water utility operation. Since these opportunities have a smaller statewide potential, they should be reserved for special cases.

In total, the opportunities identified above have a statewide potential of 42,000,000 kWh per year. More than half of that total is contained in the pump efficiency optimization opportunity, hinting at relatively small savings for the rest. These savings values likely do not warrant a full program devoted to this industry, but other options exist such as combining with wastewater treatment facilities to cover a larger sector or combining utility service areas, or forming partnerships between water and electric utilities.

Background and Approach

Delivery of clean drinking water to Minnesota residents is a local government service critical to public health and economic development, and delivering this service is energy intensive. The energy intensity of the process contributes to overall costs for the service borne by municipalities and paid by businesses and households. Published resources cite widely different energy cost ranging from 25% to as high as 80% of all operating costs for water production and distribution (Lane, 2009; Energy Efficiency in Water and Wastewater Facilities, 2013). Some of this difference may be due to geographic location within the U.S., water source (aquifer or surface water), scale of production as well as the age and operability of facility equipment. National energy intensity averages of 1,800 kWh/MG for groundwater (GW) and 1,400 kWh/MG for surface water (SW) sources have been reported, with wide variation around the average for different regions and individual water utilities (Cantwell, Water and Wastewater Energy Best Practice Guidebook, 2006). A higher energy intensity of 2,010 and 2,160 kWh/MG has been reported in Wisconsin for ground water and surface water, respectively (Cantwell, Water and Wastewater Energy Best Practice Guidebook, 2016). No information on the amount of energy used by drinking water treatment plants (WTPs) in Minnesota was found, however if the Wisconsin averages are representative of Minnesota drinking water supply infrastructure, the state could be using as much as 240,000,000 kWh for groundwater procurement and 139,000,000 kWh for surface water supply based on 2017 use rates. This would be around 0.1% of the 67,153,580,000 kWh of retail electrical sales in Minnesota for 2017 (State Electricity Profiles, 2019).

Little work has been done in Minnesota to evaluate energy use at drinking water utilities, and nationally the focus has been on very large utilities that comprise facilities serving populations greater than 100,000. Of the 658 water supply facilities in Minnesota, four fall into this category. In terms of efficiency opportunities, discussion is very general, such as improve motor efficiency, or use automated controls. A preliminary analysis of one Minnesota facility identified pumping efficiency variations of up to 30% from wells drawing from the same depth and that greater utilization of more efficient wells could save 8% of water utility energy. Given the large number of water supply facilities in Minnesota and the significant energy intensity of the process, this project sought to develop an energy efficiency approach to the water supply industry to maintain progress on state energy goals.

This project focused on:

- Confirming electrical energy use and intensity for procurement, treatment and supply of safe, clean drinking water in Minnesota.
- Identifying energy conservation opportunities.
- Quantifying the energy savings potential throughout the state.
- Identifying which opportunities were already supported by electric utilities or fit the ability of electric utilities to support.

The project started with a review of available literature to ascertain baseline information on water supply energy efficiency including industry benchmarks and current practices. Next, process operations were evaluated through a number of phone interviews and site visits for a representative cross-section of sector facilities and sector partners, to discuss energy use and energy efficiency opportunities with water supply operations staff and others familiar with the industry. This work sought to identify opportunities for cost effective energy efficiency across the sector as well as to identify operational best practices, scope variations across operations and develop possible checklists and tools for use to screen for energy efficiency options in water supply systems. Using these pieces of information collected during the interview process, in-depth site assessments were conducted to estimate the potential savings for each of the identified energy efficiency opportunities. This was then scaled up to encompass the entire state and provide a clear picture to water and energy utilities where the energy efficiency opportunities exist for the drinking water supply sector.

Project outputs include:

- Energy footprint for well operation, treatment and distribution
- A rough estimate of energy use across the Minnesota water supply system
- Quantification of variation in pumping efficiency, and the causes of the variation
- Identification of cost-effective energy conservation opportunities within the water supply system
- An estimate of the energy impact of system leak & losses
- Identification of practices that improve well energy efficiency
- Expected energy savings from implemented energy efficiency opportunities
- Identification of opportunities that electric utilities currently support, as well as can best support through their Conservation Improvement Program (CIP) program

Drinking Water Utility Identification and Characterization

There are 658 cities in Minnesota with Department of Natural Resources (DNR) permits for withdrawing water for municipal use as potable water; 634 cities used 120 billion gallons per year (GPY) of ground water; while 24 cities used 66 billion GPY of surface water in 2017 (Minnesota Water Use Data, 2018). Of these cities, 627 have groundwater permits, 17 have surface water permits, and 11 have both. Minneapolis and St. Paul account for nearly 70% of municipal surface water use and 25% of all municipal use. There are 59 aquifers that municipal groundwater is drawn from in Minnesota. The following characterization of the drinking water treatment sector was conducted to provide a baseline for selecting interview and assessment sites.

Size Characterization

Table 4 shows the distribution of drinking water facilities in Minnesota by annual volume use categories for water produced from ground water and surface water sources. The use categories were used as a tool for analyzing the sector. 97% of the drinking water produced by groundwater facilities comes from the 245 facilities producing more than 50 million gallons per year (MGY), and more than 99% is produced by surface water utilities larger than 10 MGY. This project evaluated plants in the 10-5000 MGY production range with the smallest plant evaluated producing 16 MGY and the largest producing 4,300 MGY. This group of plants accounts for 74.5% of drinking water produced by Minnesota municipalities. Larger plants like the Minneapolis and St. Paul utilities (25% of water produced) were omitted because of the time it would have taken to review these large operations and because the largest utilities have a greater ability to evaluate energy opportunities using their own engineering staff. Smaller utilities likely don't spend enough on energy to justify changes in operations – a 10 MGY plant might spend $5,000/yr on electricity.

Table 4: Distribution of Minnesota Drinking Water Supply Facilities by 2018 Production Volume (Minnesota Water Use Data, 2018).

Use category (MGY)	# GW Cities	GW MGY	% MG	# SW Cities	SW MGY	% MG
>5000	0	0	0%	2	46,765	25.1%
3000-5000	4	13,475	7.2%	2	8,514	4.6%
1000-3000	26	46,070	24.7%	4	7,609	4.1%
500-1000	35	25,208	13.5%	1	820	0.4%
100-500	110	24,506	13.1%	10	2,514	1.3%
50-100	70	5,007	2.7%	3	274	0.1%
10-50	219	5,005	2.7%	1	47	0.0%
5-10	83	604	0.3%	1	10	0.0%
<5	87	203	0.1%	0	0	0%
totals	634	120,078		24	66,553	

Well Depth

From data supplied by the Department of Natural Resources (DNR), 86% of municipal ground water is drawn from wells that are drilled to total depths of 100 to 700 feet; 6% is drawn from wells that are less than 100 ft deep, and 8% is drawn from wells that 700 to 1200 ft deep. Two complicating factors related to well depth are:

1. total well depth does not correspond to static water level, and
2. when a well pump is turned on the water level in the well decreases.

Both these water levels are generally known to the well operator, but they are not broadly available for analysis and study of the potential energy implications.

No study of energy intensity of Minnesota drinking water utilities was found during a thorough review of the literature. The state's B3 tool for energy benchmarking of state buildings included energy for only 10 utilities (Buildings, Benchmarks & Beyond, n.d.). The average energy intensity for this group was 1,870 kWh/MG, assuming all energy was electrical, with a range from 137 to 3,180 kWh/MG. These are consistent with national numbers although the low end of the range seems unreasonably low.

Operational Style

There are three main operations a WTP performs: acquisition, treatment, and distribution. Distribution is the largest portion of energy usage, estimated by an American Water Works Association (AWWA) research Foundation report to account for an average of 66% and 86% of total energy usage for groundwater and surface water, respectively (Carlson & Walberger, 2007). Acquisition uses the second most energy, using an average of 33% for groundwater and 9% for surface water. Treatment only accounts for 1% of energy usage for groundwater and 5% for surface water. The relative energy use of each of these operations, as reported by AWWA Research Foundation, is shown in **Table 5**. A MnTAP assessment on a groundwater treatment plant revealed that 52.5% of the site's energy is used for distribution, 45% is used for acquisition, and 2.5% is used for treatment.

Table 5: Percentage of energy usage within different treatment systems (Carlson & Walberger, 2007).

Water source	Groundwater (1,800 kWh/MG)	Surface Water (1,400 kWh/MG)	MnTAP assessment (2,200 kWh/MG)
Acquisition	33%	9%	45%
Treatment	1%	5%	2.4%
Distribution	66%	86%	52.5%

The AWWA report also included information on treatment objectives. The primary objective of water treatment is disinfection. Other significant objectives include treating for turbidity, taste and odor, and organic carbon, although they were only noted in one-third to one-half of the survey's responses. Methods of treatment vary in energy intensity. The range of treatment methods used in Minnesota and their frequency is not available in literature and was a main focus of the interview process.

Drinking Water Utility Interviews

To understand the drinking water sector in Minnesota, 15 water utilities were categorized and selected to be representative of the sector. These 15 sites were selected to evenly distribute these sites geographically and provide a cross section of the sector based on size, water source, and geographic location.

Selection

Size and Geographic Location

Using data from the Minnesota DNR's Permitting and Reporting System (MPARS) and Water Conservation Report System (developed by Energy Savings Platforms, LLC or ESP) data sets, cities were sorted by system size and source type. Plants were defined by size using the following transition points: small, 10 to 50 MGY; medium, 50 and 500 MGY; and large, 500 to 5000 MGY. Any WTP that pumped less than 10 MGY was excluded before starting analysis. This removed 171 cities - 25% of water systems and 0.4% of municipal water pumped in Minnesota in 2017. We also ignored the very largest systems producing >5,000 MGY (0.3% of systems, 25% of the volume). We judged that understanding these systems would consume more time than we had available; opportunities applicable to the middle group of systems might also apply to the largest; and these largest systems have engineering staff that are likely already looking at energy conservation opportunities. Of the cities remaining, 541 (95%) use groundwater and 22 (5%) use surface water. Our target of interviewing 15 water utilities required only one surface water site in order to properly represent this distribution.

To ensure that the list of cities chosen was representative of the state, cities were also sorted into five geographical regions: northwest, northeast, southwest, southeast, and metro, to account for geographic variations in source water quality.

Well Metric (Well Depth)

Most cities have multiple wells that pump different amounts of water from different aquifers at different depths. Capturing this level of complexity in a single metric for each city was used as an energy use surrogate assuming water pumped from a deeper well will require more energy to overcome the static head and vice versa for a shallow pump. This led to the creation of the well metric (WM) criteria which is a volume-weighted average of well depth for a given system. The metric finds the average depth that water is drawn from by first calculating the individual well production in million gallons per foot depth (MG/ft depth). A sum of these values is then used to calculate a volume-weighted average of the foot depth water is pumped from for a given system. This metric was then divided into 5 categories that each represent 20% of the total number of sites. Although the WM was originally intended to estimate the relative energy intensity of the WTP under the assumption that energy intensity increases for deeper wells, this is not accurate because the water level in the well is not necessarily dependent on the drilled depth of the well. Total well depth was the best available data at the time of selection and was used accordingly.

A large sized surface water plant was arbitrarily selected for interview, and fourteen cities utilizing groundwater sources were selected to create a list equally divided by size, WM category, and geographic location. Cities with the same well metric in either a single size category or in the same geographical area were avoided – for example, a WM of 4 from the large GW group was not selected from the same region as a WM of 4 from the medium GW group. However, 4 cities declined to participate and 7 more did not respond so new cities were added to replace them. Replacements were found using a process similar to that used to create the original list. Small cities were the most difficult to find willing participants, as operators often had other duties that left them with minimal time for participation in a study. To address this, the small city category was further refined to only include cities with a population of more than 500.

Final Site Selection

The final list of cities included one surface water site, one that used a combination of surface and groundwater, and thirteen groundwater sites. Of these sites, there were three small, five medium, and seven large sites. Three sites are located in the metro area, four are in the northwest, three are in the southwest, two are in the northeast, and three are in the southeast. **Table 6** shows the distribution of 14 groundwater plants based on size and geography. **Table 7** shows the distribution of plants selected based on the distribution of the well metrics.

Table 6: The number of water utilities interviewed in 3 size categories and five geographical regions of Minnesota with totals for each category.

Size Category	Metro	NE	NW	SE	SW	Total
GW Small (5-50 MGY)	1	0	1	0	1	**3**
GW Medium (50-500 MGY)	0	1	1	1	1	**4**
GW Large (>500 MGY)	2	1	1	2	1	**7**
Total	**3**	**2**	**3**	**3**	**3**	**14**

Table 7: Well metric category with calculated well metric in parenthesis. Data is arranged with respect to pre-determined size class and geographical region.

Size Category	Metro	NE	NW	SE	SW
GW Small	**5** (435 ft)		**4** (293 ft)		**3** (200 ft)
GW Medium		**1** (95 ft)	**4** (427 ft)	**4** (489 ft)	**1** (109 ft)
GW Large	**3** (398 ft) **3** (356 ft)	**2** (288 ft)	**1** (143 ft)	**5** (519 ft) **5** (506 ft)	**4** (432 ft)

Other Interviews

Interviews with three electric utilities were conducted near the end of the project and interviews with two well drillers as well as representatives from the Department of Natural Resources and the Department of Health were conducted around the time of the water utility interviews. Five electric utilities were contacted for interviews, but only three responded. This was similar for both the water utility interview recruitment process as well as the well driller recruitment process, many sites were contacted but only a fraction responded favorably.

Interview Procedure

Interviews with WTPs were done over the phone or onsite. An interview script was drafted to ensure that the information gathered was as consistent as possible. First, a general understanding of the site's operation was gained for acquisition, treatment, and distribution of water. Then information on the plant's maintenance and focus on energy efficiency was gathered, including past efforts and future plans for energy efficiency upgrades. Interviews were typically closed with a conversation regarding nonrevenue water losses and customer conservation efforts. The interview script is included in **Appendix B: Interviews**.

For phone interviews, all data that could not be communicated over the phone or was not readily available to the operator was requested to be sent electronically after the interview. For in person interviews, much of these data was collected while on site. A few of the in-person interviews included a tour of the facility. Pictures were taken of relevant equipment and occasionally suggestions were made to adjust operation for higher energy efficiency.

Results

Process Overview and Plant Configurations

The operation of the WTPs interviewed varied greatly, but three main parts were present in all systems – acquisition, treatment, and distribution. Acquisition includes acquiring water from its source, with either a well pump or a pump that draws from a surface water source. Treatment is any process used to treat water, mainly to disinfect and remove impurities. Distribution is the delivery of water to the customer, including pumping from treatment, water towers, and booster pumps. **Table 8** describes the water system configurations identified during the interview process.

The simplest configurations included three sites (112 – 4,550 MGY) that had no formal treatment plant – well pumps move water from the aquifer to the elevated tower or reservoir and chemicals such as chlorine and anti-corrosion chemicals are added in-line. The remaining 12 systems had one or more centralized treatment plant serving all or portions of the service area with distribution pumps transferring water from the treatment plant to the distribution towers and reservoirs. Eight systems (seven groundwater and one surface water; 17 – 2,530 MGY) have filter treatment to remove suspended and dissolved solids and then add chemicals for corrosion control and disinfection. Three systems (two groundwater and one mixed surface water and groundwater) have lime softening before chemical addition. And the most sophisticated groundwater treatment system used reverse osmosis and bio-filtration to remove dissolved solids and balance the delivered water hardness.

Table 8: Water system configurations encountered.

Number & Size	Acquisition	Treatment	Distribution	Variations
3 plants: 112, 550, 4550 MGY	Wells	Chemical addition at well	Well to tower, then gravity	
7 plants: 17, 43, 85, 205, 614, 1028, 1180 MGY	Wells	Filtration & chemical addition	High Service pumps to towers	Various media and pressure filters; filter aeration; & distrib. booster pumps
1 plant: 2530 MGY	River	3 trains – rapid mixing, flocculation, & chemical addition	High Service pumps +booster	
1 plant: 1605 MGY	River & well	Lime softening, ozone disinfection	High Service pumps	
2 plants: 48, 2580 MGY	Wells	Lime softening & chemical addition	High Service pumps	Distrib. booster pumps
1 plant: 667 MGY	Wells	Reverse osmosis + biofilters	High Service pumps	

Acquisition, Treatment, Distribution Overview

Acquisition pumps (both well and surface water) typically operate on a schedule that ensure equal run hours. However, higher quality water can result in a well being used more heavily than another. This means that a less efficient well may be used more heavily to avoid higher treatment costs or to ensure the water produced meets all quality standards. Two of 15 sites monitor well energy efficiency and optimize their well usage – both were in the large size category described in the section **Size Characterization**.

More advanced treatment is typically driven by need or desire to improve water quality or taste. Treatment methods varied from the simple chemical feed to more complex methods such as ozonation or reverse osmosis. One of the most complex treatment systems was seen in the surface water site, in which they had three different treatment trains that were run at different times of the year – experience had shown lower operating cost with some of the systems as a function of incoming water temperature. The treatment systems with filters generally require wells to pump to a slightly greater height or have their own pumps to provide the driving force through the filter. This is generally a small energy draw, although this energy use becomes significant for reverse osmosis. Filters also require backwashing for cleaning. One system with three geographically separate treatment plants added new facilities as the city grew and demand increased, while others have added booster stations or water towers as the city expanded.

Distribution systems varied little from site to site consisting of one of two configurations: 1) water was pumped to a water tower and distributed via gravity to the system (most common), or 2) water was pumped into the system, at delivery pressure with some excess water filling a water tower for times of increased demand. For sites with no treatment plant, the well pump used for acquisition raised water to storage reservoirs for distribution. The operation of distribution pumps, generally referred to as high service pumps, was typically used on a set rotation schedule. It was uncommon for operators to monitor the energy efficiency of distribution pumps. Booster stations were common in cities that had significant changes in elevation.

Variable Frequency Drive Overview

Variable frequency drives (VFDs) were commonly found installed on acquisition and distribution pumps. Many systems use a VFD as a soft start to avoid shocking the geologic formation or increasing pump and motor wear. A soft start initiates operation at a low speed and gradually ramps up to the desired operating speed. This is in contrast to a hard start with a direct line connection to the motor, which starts the pump at the full operating speed without any build up. This also typically requires a large initial power draw to get the pump moving, which increases the demand for the hard start motors.

VFDs were used at one system to avoid throttling a well pump that needed to run at a lower speed to produce the correct flow rate for the filtration system. An alternative solution would have been installing a smaller pump. However, a smaller pump can leave a system vulnerable to not meeting demand should other wells go down or in case of a fire emergency. This option is not desirable when the retrofit cost is greater than adding a VFD.

There were very few instances of operators using a VFD to vary the speed of a pump in order to match demand, but it was common for VFDs to be run at a set speed, and to run longer if more volume was needed. One operator ran their VFDs as slow as possible in order to reduce demand charges, while others ran their VFDs at or close to full speed to maintain their desired capacity. VFD operation was inconsistent across the sites interviewed, but VFD installation was common.

Electric Energy Benchmarks

We received electrical meter data for 13 of 15 sites and calculated an overall system energy intensity, as well as estimated energy intensity for acquisition, treatment and distribution. Energy intensity estimates are presented in **Table 9** by system size, and in **Table 10** by plant configuration. One plant did not provide energy data and there were two where the estimate for treatment and distribution energy intensity were combined because of the complexity of separating electricity used for the three primary operations.

Acquisition energy includes the energy required to pump water into treatment operations. Treatment energy represents energy for processes between acquisition and distribution, including both treatment processes and pumps that move water between processes or pressurize filters. However, a WTP's energy for the treatment building is typically all metered together, making it difficult to separate the energy used by high service pumps for distribution. In **Table 9**, where energy intensities are based on just part of the group, the number of systems contributing to the average is given in parentheses. Distribution energy includes energy required to pump into the system from treatment as well as any energy for booster pumps or reservoirs. The majority of sites did not have distinct distribution energy, so energy was estimate based on pump parameters and runtimes for distribution pumps. For sites with no treatment plants, treatment energy is assumed to be zero. In this case, the same pump is used to acquire the water and to distribute it, and estimated fractions of acquisition and distribution energy based on the proportion of functional well depth to the height of the reservoir or tower above the wellhead.

Table 9: The high, low, and average values of energy intensity for each size category with average values for acquisition, treatment, and distribution. Values in parentheses are the number of each group contributing to the average.

Size	Number in class	High (kWh/MG)	Low (kWh/MG)	Average (kWh/MG)	Acquisition (kWh/MG)	Treatment (kWh/MG)	Distribution (kWh/MG)
GW Small (5-50 MGY)	3	2,950	1,250	2,250	1,050	400	1,050
GW Medium (50-500 MGY)	4	2,150	950	1600	700	300 (2)	600
GW Large (>500 MGY)	8	3,100	1,600	2,300 (7)	900	350 (5)	1,000 (7)

Small and large plants in our sample were the most energy intensive, averaging 2,300 kWh/MG, with medium plants being the most efficient at 1,600 kWh/MG (28% less). The pattern for acquisition, treatment, and distribution steps followed a pattern of medium plants being most efficient followed by large plants and then small plants.

Table 10: The average energy intensity for acquisition, treatment, and distribution for the different site configurations seen in kilowatt hours per million gallons.

Configuration	Number in class	Acquisition	Treatment	Distribution	Overall
Treat at well	3	700	0	600	1,300
Filtration	8	1,000	400	900	2,200
Lime softening	3	750	350	1,350	2,350
Reverse osmosis	1	1,100	830	1,150	3,100

Looking at energy use by plant configuration, the reverse osmosis plant was the most energy intensive at 3,100 kWh/MG followed by lime softening plants at 2,350 kWh/MG (22% less), filtration plants at 2,200 kWh/MG (9% less than lime softening plants), with treat at the well plants being the most energy efficient at 1,300 kWh/MG (40% less than filtration plants). These trends are as expected based on the amount of complexity, but surprisingly, when just treatment energy is considered, the energy intensity of the filtration and lime softening plants is reversed. As such the overall energy intensity of these two types of plants is likely driven by factors other than configuration, such as size.

For sites that provided monthly data for both energy and water flow, energy intensity was also calculated for winter and summer, presented in **Table 11**. Summer was considered to be May through September, while winter included the remaining months. Once summer and winter intensities were found, a difference was calculated and used to calculate a seasonal metric that compares the seasonal difference to the yearly intensity. This metric was used to determine the effect climate has on energy intensity. For all sites that provided seasonal data, specific energy was higher in the winter than in the summer. However, more energy is typically used in the summer due to higher volumes of water being produced. The extent of the increase in energy intensity varied greatly between plants, from as low as a 1% increase to as much as an 86% increase.

Table 11: Specific energy estimates for each of the size classes and for winter and summer months.

Size	Overall Specific Energy (kWh/MG)	Summer Specific Energy (kWh/MG)	Winter Specific Energy (kWh/MG)	Summer to Winter Change (%)
Small	2,500	1,400	2,600	86
Medium	1,600	1,200	1,700	42
Large	2,200	1,600	2,100	31
Overall	**2,100**	**1,450**	**2,100**	**45**

Four sites reported changing operation during the winter. Pumps were sometimes run longer at lower speeds in order to reduce the amount of time water was stagnant in pipes or reservoirs to avoid freezing.

Water Conservation

Water Conservation can reduce the volume of water that needs to be produced, and that can reduce the time pumps and equipment operate, thereby reducing energy use. Water conservation can occur within the drinking water operations (acquisition, treatment and distribution) and reduces water that never reaches or is paid for by the customer (non-revenue water). This is often referred to as conservation or loss reduction before the meter. Water conservation can also occur at the customer, or after the meter.

Nine of the 13 systems providing information had “non-revenue water” loss rates below 10%, as shown in **Table 12**. Non-revenue water includes any water acquired that does not reach a customer and is not billed, including water lost during treatment and during distribution. Typically, loss rates were less than 10%, which is the standard set by the DNR. Four systems had loss rates above the 10% threshold suggesting opportunities for conservation exist. In the most extreme case seen, one site had an estimated loss rate of 43%, although many causes of water losses were unknown due to a lack of monitoring. The majority of sites named hydrant flushing and main breaks as the primary causes of nonrevenue water losses. A few sites used proactive approaches to reducing water losses, which included annual leak detection surveys as well as wrapping newly installed or repaired pipes with polyethylene to reduce corrosion.

Table 12: Water loss rates and per capita use rates by system size.

Size	Water Loss Rate	Gallons per Capita
Large	18.5%	39
Large	15.6%	44
Large	10.0%	60
Large	8.3%	45
Large	7.9%	61
Large	7.5%	75
Large	5.4%	50
Large	3.8%	47
Medium	42.8%	33
Medium	7.2%	50
Medium	2.0%	121
Small	8.3%	46
Small	4.8%	73

The piping for most systems was either cast iron or ductile iron. Cast iron piping was typically older piping and was no longer being installed for new developments or repairs. Ductile iron was common for repairs and new development, as were different types of plastic piping, such as PVC or C900 pipes. Cast iron piping appeared to be more susceptible to leaks and failures, although it is unclear whether this is due to the material or the age of the pipe.

There was a wide range of approaches to customer conservation. Eight cities had information on conservation on their websites, typically providing information on locating leaks in the home or identifying surface leaks on roads. Another common method of promoting customer conservation was to send out information in bills. Some cities contact customers if their water usage is significantly higher than previous billing periods as a way to catch customer leaks. Three sites offer a rebate program for select appliances or have a program planned. Tiered rate structures are also used to encourage larger customers to conserve water. A barrier for customer conservation is the loss of revenue, although WTPs typically encourage customer conservation regardless of revenue loss due to energy conservation and acquisition limits.

Only two sites actively monitored their energy usage, and some system operators did not see their energy bills directly. Typically, sites review their electric bills to ensure they are not significantly higher than expected, but do not monitor the usage of individual pumps or other equipment. The sites that monitored the energy usage of individual pumps typically did so to determine their efficiency and in turn optimize their operation.

Energy Conservation and Barriers to Implementation

The most common method of improving energy efficiency was rehabilitating wells. Well rehabilitation includes repairing or replacing the well pump and its parts, as well as removing sand from the well itself or repairing its casing. Removing sand keeps sand from being pumped up with water, which can cause significant wear on the pump and its internal parts, resulting in lower energy efficiency or replacement. A well's casing can also become damaged. Other methods to improve energy efficiency were optimizing VFDs, improved lighting and HVAC, and using coatings on internal parts of pumps. Coatings can reduce wear on moving parts and smooth them for increased energy efficiency, as well as protecting against corrosion.

The major barrier identified during the interview process, for water utilities to implement energy efficiency projects, was cost. This affirms the overall pretense of this study and increases the need for electric utility incentives or outside funding. Two secondary barriers were data availability and time to review and complete upgrades. These secondary barriers were primarily seen in small to medium sized plants that did not have dedicated water treatment plant staff (one staff member was responsible for many city-wide functions).

Drinking Water Utility Assessments

Selection

Sites were recruited based on the data they could provide and the opportunities they were able to fulfil. This approach was specifically conducted with utilities that participated in the informational interviews since data had already been acquired for these sites. The assessment sites (AS) are listed in **Table 13**, including other parameters for comparison. No assessments were conducted with an on-site portion due to the COVID-19 pandemic, therefore data quality and quantity was crucial.

Table 13: Assessment site list with utility parameters for each.

Plant	Acquisition	Treatment Method	Flow (MGD)	kWh/MG	kWh/yr
WT4	Wells/aquifer	Lime softening/Multi-media filter	7.1	2,400	6,100,000
WT10	Wells/aquifer	Minimal (chlorine, fluorine, polyphosphate)	12.5	1,600	6,900,000
WT8	Wells/aquifer	Aeration/Multi-media filter	0.23	2,300	177,000
WT14	Wells/aquifer	Iron & Manganese precipitation; filtration	3.4	2,500	1,400,000
WT2	Wells/aquifer	Minimal (chlorine, fluorine, polyphosphate)	0.31	970	99,000

The literature review identified 12 possible best practices (see **Table 27**) which were then vetted for their application to WTPs in Minnesota through the interview process. These 12 best practices were compressed into eight potential opportunities described in **Table 14** which were then prioritized based on potential impact for energy conservation in Minnesota WTPs. Column two lists the number of assessments of each opportunity that were targeted, and column three lists the water utility targeted for analysis of the specific opportunity, either because the utility had implemented the opportunity, or they appeared to have enough data to allow for the simulation of opportunity implementation. Two identified opportunities were not chosen for analysis: optimizing treatment, because the treatment portion of energy consumption is small compared to acquisition and distribution pumping; and misc. energy efficiency (E2) because both of these were small consumers of energy and these were opportunities electric utilities were already familiar with. Six opportunities were analyzed in detail to quantify their electrical saving potential and feasibility. Pump selection and optimization was evaluated as part of three water utility assessments. Pump rehab and customer conservation programs were evaluated as part of two assessments. Well rehab and reducing system losses were evaluated as part of a single assessment each. Head reduction was also evaluated in a single assessment, but this was folded into a discussion on VFDs and pump optimization.

Table 14: Assessment opportunity selection process.

Energy Conservation Opportunity Categories	Assessments Planned	Assessments Completed
Pump rehab (procurement, distribution, other) – replace, rebuild	2-3	WT4, WT10
Pump selection/optimization – select efficient pumps/wells; trim impeller; VFD speed; right size;	2-3	WT4, WT10 WT14
Well rehab – clean screen; clear debris; enhance recharge	Up to 2	WT4
Head reduction – coatings; reservoir levels; well levels; pipe diameter; pipe smoothness	Up to 2	WT2
Reduce water production by reducing losses – methods to identify and quickly repair leaks, prevent leaks through selection of pipe materials or repair processes	Up to 2	WT8
Reduce water production by reducing customer demand - efficient fixtures; irrigation	Up to 2	WT4, WT10
Optimize treatment – select eff train; ozonation efficiency; blending rates; membrane P/yield	0	N/A
Misc. E2 – lights; HVAC; ventilation rates; air compressor use & operation	0	N/A

Assessment Procedure

Each site assessment focused on different opportunities, shown in **Table 14**, above. The general procedure for each assessment included gathering the necessary data from each site, analyzing those data with respect to the specific opportunity identified, and presenting the site with a concise report outlining the findings. Gathering the data was completed via email and phone calls due to the restrictions of the COVID-19 pandemic. No site visits were completed after 3/16/2020 due to stay-at-home orders and University of Minnesota travel restrictions. Each site assessed had strict visitor policies, further reducing the ability to conduct on-site assessments. The data collected from each site typically included electric utility bills, water volume pumping summaries, and pump specifications (power, voltage, pump curves, runtime). With these data, each specific opportunity was analyzed with input from operators at each site.

The savings for pump and well rehabilitation were determined using specific energies for each well or pump, calculated from electric meter data and pump flow rate data. The average specific energy before pump or well maintenance was compared to the average specific energy after pump or well maintenance. The difference in the specific energy was then used to calculate an energy savings value. At WT10, averages were done on a monthly basis, and at WT4, they were done on a yearly basis. This was driven by available data from each site. Both of these sites had previously implemented pump and well rehabilitation schedules, so the analysis was savings verification.

Analysis for the pump efficiency optimization opportunity was completed using specific energy data, similar to the pump and well rehabilitation calculations. For pump efficiency optimization, well pumps were ordered based on specific energy and the wells with the lowest specific energy were prioritized. From these monthly reprioritizations, a new energy use was calculated and compared to the actual energy use to yield a monthly energy savings. The process for WT14 was slightly different, as a focus on utilizing shallower wells was analyzed due to the configuration of the treatment system.

Verification of savings at WT2 was analyzed using pump run times and power rating and validated previous predictions made in the interview with WT2. Analysis for VFD optimization was difficult due to the lack of reliable pump curves and the inability to conduct testing on-site. Estimates were presented based on anecdotal evidence from the interviews and previous work completed by the authors.

For the customer conservation and water loss reduction opportunities, state-wide data was used for analysis because the best information from targeted assessment sites turned out to be identical to the DNR dataset provided. The dataset provided by the DNR from their Water Conservation Reporting System was used for these opportunities as it provided a much larger sample size and allowed for broader conclusions.

Many of the analyses performed for these opportunities were to verify the savings of previously implemented energy saving initiatives and emphasizes the utility of the identified opportunities. Each of the five opportunities were identified by real-world examples of successful implementation and are not solely theoretical in nature. For more detail on the specific assessments completed, see **Appendix C: Assessment Summaries** and for more information on the compiled results for each opportunity refer to the next section, **Drinking Water Utility Electric Conservation Opportunities**.

Drinking Water Utility Electric Conservation Opportunities

Pump/Well Rehabilitation

Well rehabilitation includes maintenance performed on the acquisition wells including screen cleaning, drop pipe replacement or coating, air sparging, and other types of formation reclamation. Pump rehabilitation includes all maintenance performed on various pumps used in the water treatment process and typically includes replacement of key components of the pump such as wear rings, impellers, or bearings, or replacing the entire pump and motor. Pump rehabilitation typically applies to well pumps, both submersible and vertical turbine, as well as booster and distribution pumps and is a part of the well rehabilitation process.

Two types of management plans for pump maintenance were to replace well pumps every 40,000 hours or inspect pumps every 7 years. These types of plans reduce risk of pump failure while many times (but not always) reducing overall energy use. This is the most common type of management plan with the main object being system reliability – energy performance is almost never part of the equation.

Another management plan is to monitor pump health with specific energy, or the energy needed to pump a specific volume of water (kWh/MG). When this value starts to increase, the pump and motor should be inspected, as the energy required to pump the same amount of water is increasing, and there is likely wear on the pump components.

Pump rehabilitation applies to all water utilities as pumps are used at each water utility, and roughly 95% of water utilities acquire water via wells implying that well rehabilitation is needed at every drinking water treatment plant. Pump rehabilitation applies to both acquisition pumps (well pumps and intake pumps) as well as distribution pumps alike, but well pumps and intake pumps likely have a greater potential for savings as the water pumped is lower quality, possibly containing sand or other particles which can accelerate pump wear.

Based on the data collected from the 15 interview sites, 47% of sites currently have a maintenance plan for pump rehabilitation, but typically these include inspecting pumps every 7-10 years to decide if the pump needs maintenance. Results based on a smaller subset of sites (2), some level of replacement is necessary at the 7-10 year threshold with total pump replacement occurring every two to three cycles, although submersible pumps tend to be replaced every cycle. Extrapolating these data to the rest of the state, roughly 53% of the 658 drinking water treatment facilities in the state are not rehabilitating pumps on a prescribed schedule, and none of the sites interviewed were rehabilitating pumps based on energy use, pointing to a major opportunity gap in the state.

Savings from a previously instated well pump replacement schedule of every 40,000 hours was 8% of acquisition energy used at the site assessed. This analysis was completed at WT10 and included 18 of the 30 wells (pump replacement did not occur in the other 12 wells in the period where data was available). This only included well pumps and did not include maintenance to the well itself as pump replacement was the only maintenance performed in the time that data were available. Savings realized by rehabilitating wells at WT4 was 8% of acquisition energy and included 6 of the 15 wells (for similar reasons to WT10). The average specific energy savings from WT10 was 114 kWh/MG and was 69 kWh/MG for WT4. These values lead to an overall sector potential of 9,300,000 kWh/yr.

Although these numbers show modest savings, they were only calculated for a set rehabilitation schedule. The data necessary for specific energy based well or pump rehabilitation analysis was not available at any of the sites interviewed and was not estimated. A rough estimation would be an additional 1-2% increase in energy reduction on top of the 7-8% seen in set scheduling. This implies that a site without a maintenance plan could save 8-10% if implementing a specific energy based maintenance plan.

Pump Efficiency Optimization

Pump efficiency optimization involves finding the combination of pumps that provides the greatest efficiency possible for the system's configuration. Basically, this is identifying the most efficient pumps and concentrating their use. The specific energy (kWh/MG) is used as a surrogate for pump efficiency and depends on:

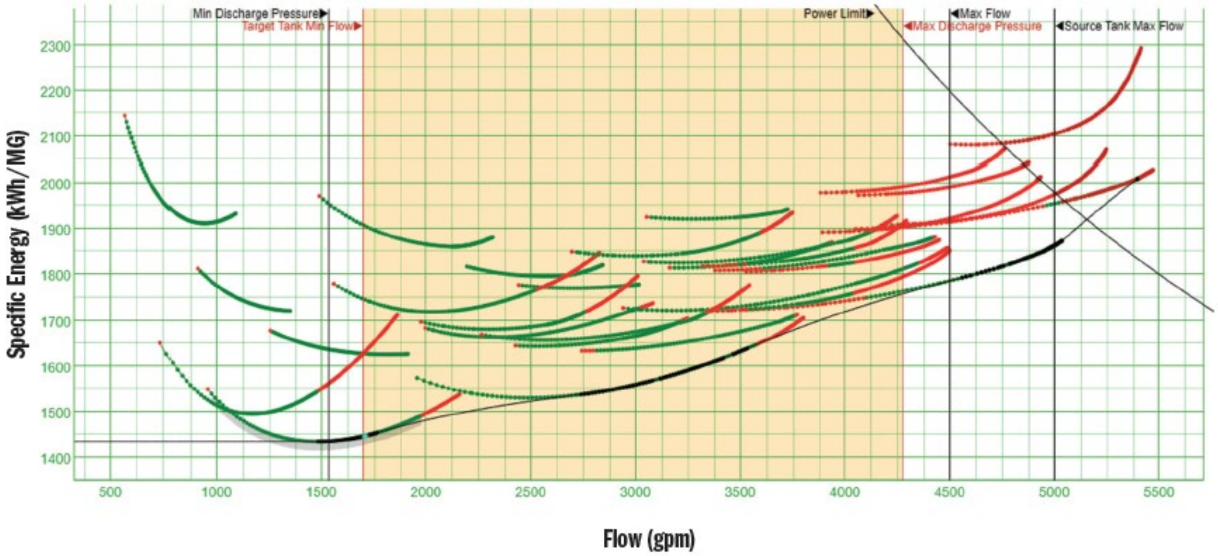
- pump design;
- operating pressure or water lift height the pump works against;
- operating point on pump curve; and
- pump operating condition or degree of wear.

The simplest way to take advantage of variations in pump efficiency is to measure it for all pumps and then choose to use the most efficient pumps that accomplish the water production needed. The most direct way to determine pump efficiency is to measure the power draw and flow in real time and calculate the pump's specific energy (kWh/MG), ideally within the SCADA system. Amps/MG or other energy efficiency measures can be substituted depending on data availability. Four examples of energy savings were developed in this study by analyzing data from four separate water utilities. Two different modes of analysis were completed: determining actual savings from historic data and projected savings. In these cases best to worst well pump efficiencies varied from 38 to 54% within the four utilities, and savings from selecting more efficient pumps for operation ranged from 2.9% to 7.8% of total system energy. System energy reduction ranged from 46-180 kWh/MG and averaged 120 kWh/MG.

For very large systems of pumps there are automation packages that allow the identification of the optimal set of pumps to run for any operating condition that occurs, as illustrated in **Figure 1**, with programming that automatically changes operation to that optimal set (Peterson & Pierce, 2019).

Optimizing acquisition pumps is often complicated by differing quality of water sources, in which more efficient pumps may collect from water sources that require more intensive treatment or is best balanced with water from less efficient wells. It is further complicated by pump first cost considerations in the case of wells.

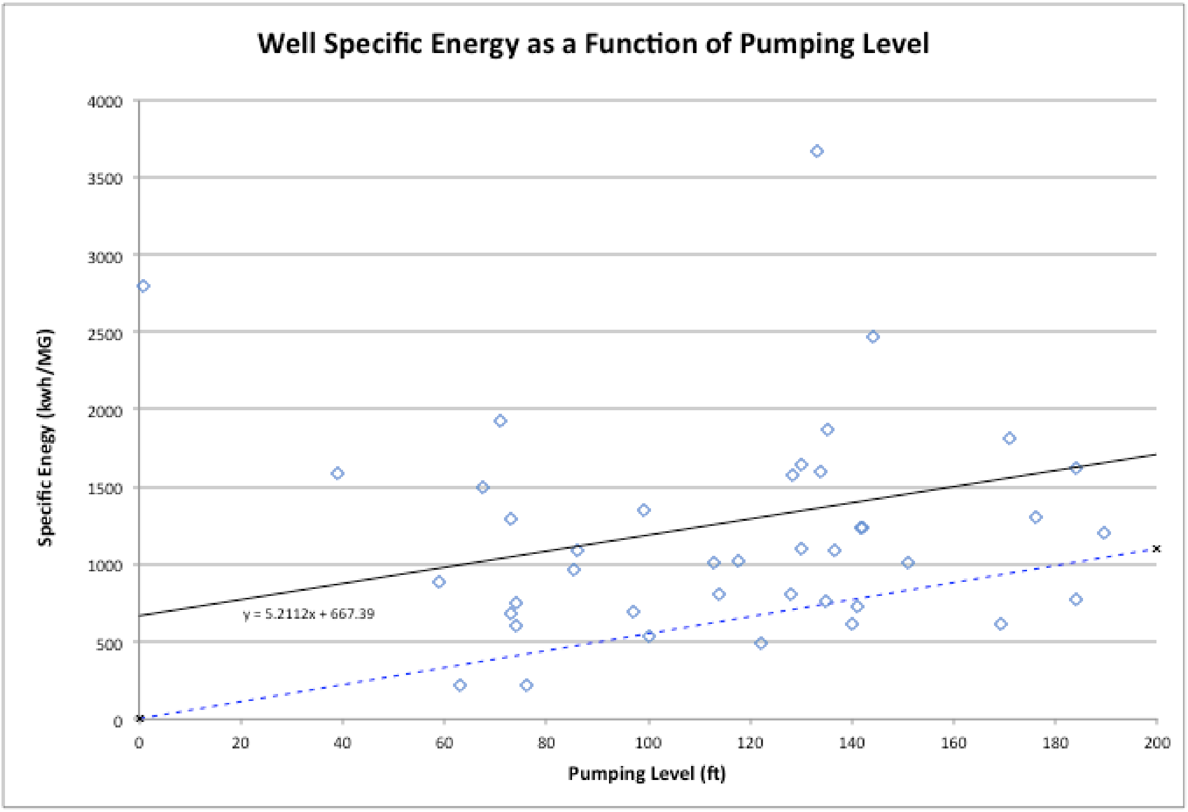
Figure 1 Specific Energy Optimization for Large Pump Systems



Saving energy can also be achieved by addressing the two major causes of reduced efficiency. First, within the realm of pump design the two broad categories of well pumps used in municipal service are vertical turbine pumps (VTPs) and submersible pumps. Vertical turbine pumps typically have about a 10% efficiency advantage over submersible pumps. Submersible well pumps have a lower first cost because they do not require a well house but are more difficult to repair so they tend to be replaced rather than repaired. Distribution pumps tend to be vertical turbine pumps.

Second, within pump classes there are significant differences in energy efficiency among pump models and manufacturers. Selecting pumps and motors with higher energy efficiency at the time of pump purchase is another way to improve system efficiency. This study did not go into how to identify the highest efficiency pump in detail but **Figure 2** shows the specific energy or operating efficiency for 41 pumps encountered, as a function of the pumping level. The solid line in **Figure 2** is the best fit for this data set while the dashed line is an estimate of what might be the best practical pumping efficiency – the level that could reasonably be reached. For pumping levels below 60 ft there is not enough data to make an estimate, but above 60 ft, savings look like they should be 670 kWh/MG in going from an average pump to a "best" pump. The dashed line in **Figure 2** can be used to determine a benchmark for a "best" pump at any pumping level for use as a discussion point and perhaps a "specification" for pump purchase negotiations.

Figure 2: Specific energy as a function of pumping level for each well from the 15 interview sites. The solid line represents the average specific energy, and the dashed line is the best reasonable specific energy.



Optimal pump selection is not widely practiced. Of the 15 utilities interviewed in this study, three were using this technique for their well pumps and one of those had been encouraged to look into the savings potential in the year before this study started by the authors. Two of 15 water utilities have tried this technique on their distribution pumps which leads to an estimate that this opportunity is available to 87% of the sector.

The sector savings potential is 14,300,000 kWh/yr for well optimization and 2,150,000 kWh/yr for distribution pumps, with 76% of the savings coming from large plants for well optimization, and 78% coming from large plants for distribution pump optimization. These estimates are based on optimal pump selection, but do not include possible savings from addressing root causes of low pump efficiency.

There are difficulties and barriers to implementing this opportunity. While making selection decisions is low cost, creating the basis for monitoring pump efficiencies has costs. Flow meters are common on well pumps, but kWh meters on pumps are uncommon. There are some water utilities that have ammeters on their pumps and many VFD’s have ammeter read-out although it is rare if these are connected to the SCADA system and are therefore not monitored. Individual distribution pumps generally do not have flow meters on their operation. The end result is that measurement infrastructure is generally needed before pump efficiency can be measured on more than a spot-check basis. Most CIP programs do not provide incentives or support for measurement activities, so this is a hurdle for greater implementation. In addition, there can be limitations on well pump selection based on water quality balancing considerations.

VFD Installation and Optimization

VFD's provide several benefits, some of which improve energy performance, and some do other desirable things:

- Energy performance benefits
    - Eliminating restricted flow (throttled valve)
    - Allowing pump to operate at its best operating point
    - Reducing friction losses
- Other non-energy benefits
    - Vary pump speed to match demand
    - Reduce wear on internal components
    - Reduce stress on aquifer and geologic formation
    - Provide soft start for motor

The water utilities we spoke to and assessed had installed VFDs on most, and in some cases all, of their large pumps (76 of 105 well pumps, and 19 of 37 high service pumps). Three WTPs were using VFD's to achieve direct energy reductions. One small WTP (WT2) had eliminated an "altitude valve" in a water tower, which restricted flow and introduced significant additional head, resulting in a 30% reduction in their electric consumption. A second WTP (WT11) monitors pump efficiency through their SCADA system and uses their VFD's to identify their best operating point. The magnitude of energy savings from this second effort was not quantified due to data acquisition barriers. A couple other WTPs claimed their implementation of VFD's reduced their energy bills, but it was concluded that these saving were more likely to have been demand charge reductions than energy savings. Most WTPs seemed to get much greater benefit from the non-energy benefits of VFDs. WTPs almost universally used VFDs at a single speed, usually 90-95% of the design pump speed. In most cases there was not a clear rationale for the speed chosen. Where there was a rationale, it ranged from achieving an arbitrary flow rate, to minimizing the effect on aquifer level. Using the VFD as a soft-start was mentioned by more than one as a benefit.

The largest energy conservation opportunity that a VFD can accomplish is eliminating pumps throttling. In the population studied, 1 of 15 WTPs, had identified a throttled pump and they had eliminated it a few years prior to this study, achieving a 30% energy reduction. While this is the largest potential opportunity implementing VFDs can achieve, it is not clear how many WTPs still have throttled flow as an opportunity. This opportunity should be looked for in all energy assessments, but we claim no potential savings for this sector.

The opportunity for capturing energy reduction from reducing friction loss in pumping systems with VFDs, is highly dependent on system design, but the system curves for water utilities tend to have a very large proportional static head component, so in general the potential savings from reducing friction is likely small. If friction losses are 10% of total head, and 10% of the losses can be captured, savings would be 1% of the pump energy. Very few WTPs (none that were encountered in this study) are looking at friction loss, so this opportunity has probably not been exhausted, but for savings to be significant the length of horizontal piping should be very large compared to the height water is raised. Horizontal piping should be perhaps 100 times the lift height.

VFDs can also be used to adjust the pump to its best operating point (BOP) – the speed where it runs most efficiently – and adjust the BOP as it moves due to wear. While three quarters of our sample of wells were fitted with VFDs, and half the high service pumps have VFDs, only 1 out of 15 WTPs indicated they were using the VFDs to operate at the most efficient speed. In addition, the reasons for operating at the chosen speed at the remaining WTPs had nothing to do with energy use, and generally little to do with important operating constraints, so there appears to be lots of room to move toward BOPs. Based on pump curves, the likely energy reduction will likely be in the 1-3% of energy consumed by that pump, although in extreme cases the reduction can be larger. Everything depends on where the pump operates compared to its best operating point. The largest improvements will likely be for pumps running at slow speeds (30-50% of full speed) assuming the pump was sized correctly in the first place.

Best operating points can be found on published pump curves after the current operating point has been found, with the help of a head pressure measurement at the pump outlet, and a system curve has been plotted. However, small, medium and many large systems will find it simpler to determine the BOP by trial. This involves measuring the pump power and flow at a range of speeds and calculating the specific energy for each speed (kWh/MG), and then choosing to operate at the best efficiency point – the lowest kWh/MG – unless there are system constraints such as high water demand that require a different setting. This technique would also include any friction loss potential that can be captured, which is not the case with the pump curve method unless additional calculations are included in the analysis. Power can be measured with the amp draw, as a substitute for kWh, as long as supplied voltage does not vary significantly at the WTP.

If 40% of the cities can improve pump operating efficiency by 1% through identifying the speed that give the best operation point, and if 20% of the remaining cities can improve pump energy by 2%, the energy saving potential for this technique is 1,900,000 kWh/yr.

Customer Conservation

Water conservation by water customers reduces the volume of water the utility needs to pump, treat, and distribute, which reduces the energy needed for those functions proportional to the amount of water saved, and defined by the specific energy metric of the utility (kWh/MG). Customer conservation includes:

- Leak reduction / repair at the customer.
- Upgraded appliances such as low flow toilets and showerheads, washer for laundry, dishwasher, and other household appliances that use less water than what was previously installed.
- Improved irrigation practices including rain or moisture sensors, and smart irrigation controls.

This customer conservation energy impacts will be larger in systems that have higher water use per capita and in water utilities that have a high specific energy.

Customer water conservation programs exist within some water utilities and also within some energy utilities. The two types of programs are rarely coordinated, and the populations served are rarely identical except for municipal utilities that have water and energy components. Energy utility water conservation programs are almost exclusively focused on hot water and are based on the heat energy that can be saved – imbedded energy for producing and distributing this water is not included. Generally, energy utilities rebate efficient hot water heaters, dishwashers and laundry washers. Some energy utilities offer free efficient shower heads and faucet aerators. The Demand Reduction Law (Minnesota Statues, section 103G.291 subd. 3 and 4) requires water utilities serving more than 1,000 people to adopt water demand reduction measures. Demand reduction measures are measures that reduce water demand, water losses, peak water demands, and nonessential water uses. The Minnesota DNR regulates state water resources and provides an annual reporting system to help cities track conservation impacts. All analysis of water utility conservation programs was based on DNR ESPWater survey data acquired from the DNR. Formal water utility conservation programs include promotional flyers in bills and rebates or incentives for automatic faucets, dishwashers, food steamers, spray rinse valves, toilets, irrigation controllers, clothes washers, showerheads, efficient irrigation nozzles, water softeners, and sink aerators, as well as facility audits, laundromat retrofits, large landscape projects, and rainwater harvesting. We were also told of informal programs where if a large upward trend in a customer's metered volume is identified, staff will call the customer, notify them of the excursion and suggest they look into possible leak repair.

Utility Size Observations

For the three years 2017-2019, the DNR ESPWater survey reported 85 cities made formal efforts promoting water conservation among their customers. This is 13% of the municipalities in the survey shown in **Table 15**, along with the size classes based on the annual water production, the number in each size class, the number with conservation efforts during this period, and the volume of conservation achieved. No conservation was reported for the largest size class (Minneapolis & St Paul) and none was reported for the smallest category. These are the size classes not included in this study.

Table 15: Water Conservation by size of the water utility.

Size Class	Pumping Class (MGY)	Number of Cities in Size Class	Cities with Water Conservation projects	3-yr Total Gallons Saved	% of Total Gallons Saved
Not included	>10,000	2	0	0	0%
Large	3,000-5,000	2	1	18,628,551	10.8%
Large	1,000-3,000	28	13	93,410,746	54.3%
Medium	500-1,000	37	16	16,670,610	9.7%
Medium	100-500	114	33	11,561,245	6.7%
Small	50-100	70	10	2,355,431	1.4%
Small	10-50	224	12	29,409,041	17.1%
Not included	<10	168	0	0	0%
	totals	645	85	172,035,624	

It is notable that within each size class, three cities together account for well over half the conservation for that class, and 9 cities contributing large shares to their class, account for 71% of all reported conservation. These cities appeared to have very strong water conservation programs. Water reduction at these 9 cities ranged from 0.5% to 7% per year with one city having a very strong program emphasizing irrigation improvements had an average 7% per year reduction over the three years of data. These facts – the number of cities with no conservation program and the small number of strong programs - suggest a lot of the state's water conservation potential remains. **Table 16** provides an estimate of the electrical savings that resulted from these very strong conservation programs for these 9 cities as representatives of their utility size as classified by this study. Again, the estimated percent reduction ranges from 0.5 to 7%, and kWh reductions ranged from 650 kWh/yr for small utilities to 21,500 kWh/yr for large utilities.

Table 16: Electric savings from strong water conservation programs.

Size Class	# of Cities with Strong Programs	Specific Energy (kWh/MG)	Average Water Conservation (MGY)	Average Water Conservation E2 (kWh/yr)	Average % Total Pumping
Large	3	2,150	10.0	21,566	3.2%
Medium	3	1,620	0.6	1,008	0.8%
Small	3	2,270	0.27	649	1.3%

Water Conservation Initiatives

Table 17 presents conservation efforts conducted by water utilities with their customers in Minnesota over a three-year period. The DNR identified 25 types of conservation efforts divided between three types of water customers: SF = single family residential; MF = multi-family residential; CII = commercial, industrial & institutional. The five most impactful efforts (irrigation, showerheads, toilets, washers and other) along with the ten related efforts account for 84% of water reductions. Irrigation efforts feature prominently, accounting for 42% of total water reduction, and providing the largest impact per rebate, ranging from 12,000 to 428,000 gallons per individual project. Ultimately the electrical benefit per rebate is very small. The rebates referred to in **Table 17** are rebates that the water utility provides to its customers. These rebates are not offered by the DNR; they are only reported to the DNR.

Looking at the conservation efforts by customer type, the greatest effort and impact has been with single family unit which account for 74% of the impact, followed by multifamily units at 23%, and commercial industrial accounting for less than 4% of savings.

If 50% of the medium and large cities are able to develop strong water conservation programs that achieve a 0.5% reduction every year and sustain that level for five years, the drinking water utility sector can achieve a water reduction of 1,366 MG over that 5 year period. Based on a typical specific energy metric of 2,000 kWh/MG, this translates to 2,700,000 kWh reduction over that period. While there is room for significant water reduction at drinking water utilities by promoting water conservation at end-of-pipe customers, the ability for electric utilities to provide meaningful incentives through the water utilities seems small. The strongest water utility conservation programs produced less than 40,000 kWh/yr in savings, and the individual types of conservation efforts have produced less than this.

Table 17: Water Conservation efforts conducted between 2017-2019. SF = single family residential; MF = multi-family residential; CII = commercial, industrial & institutional.

Type of Water Conservation	Number of Rebates Awarded	Total Gallons Saved	% of Total Saved	Savings per Rebate (gal)	Savings per Rebate (kWh)
Irrigation Controllers SF	3,485	44,142,100	25.7%	12,666	25.3
Irrigation Controllers MF	7	3,000,280	1.7%	428,611	857.2
Efficient Irrigation Nozzles SF	49	137,150	0.1%	2,799	5.6
Shower and Aerator Kits SF	6,454	32,386,172	18.8%	5,018	10.0
Showerhead and Aerator Kits MF	118	592,124	0.3%	5,018	10.0
Large Landscape Projects MF	66	24,911,000	14.5%	377,439	754.9
Toilet Retrofits SF	3,075	24,727,493	14.4%	8,041	16.1
Clothes Washer Rebates SF	4,574	14,915,404	8.7%	3,261	6.5
Clothes Washer Rebates MF	157	1,719,150	1.0%	10,950	21.9
Coin Operated Clothes Washer Rebates MF	5	43,800	0.0%	8,760	17.5
Toilet Retrofits MF	1,125	10,778,625	6.3%	9,581	19.2
Toilet Retrofits CII	43	256,230	0.1%	9,490	19.0
LF Showerheads SF	3,478	7,171,636	4.2%	2,062	4.1
LF Showerheads MF	990	1,879,020	1.1%	1,898	3.8
Other	24	2,094,556	1.2%	87,273	174.5
Dishwashers CII	20	1,155,140	0.7%	57,757	115.5
Rain Barrels SF	737	843,311	0.5%	1,144	2.3
Spray Rinse Valves CII	67	469,000	0.3%	7,000	14.0
Rainwater Harvesting MF	3	225,240	0.1%	75,080	150.2
Rainwater Harvesting Rebates SF	27	212,868	0.1%	7,884	15.8
Food Steamers CII	2	163,000	0.1%	81,500	163.0
Facility Audits CII	813	90,800	0.1%	112	0.2
Laundromats CII	3	90,000	0.1%	30,000	60.0
HE Water Softeners SF	11	31,200	0.0%	2,836	5.7
Automatic Faucets CII	13	325	0.0%	25	0.1
Grand Total	**25,330**	**172,035,624**			

Water Loss Reduction

Water loss reduction provides energy savings through water conservation accomplished by the water utility staff by improving their system infrastructure. These efforts are also referred to as occurring 'Before the Meter' (in contrast to 'After the Meter' water conservation efforts by utility customers), or as the reduction of non-revenue water. The Minnesota DNR began their own efforts to promote before the meter conservation by requiring reporting on efforts by water utilities withdrawing state water resources in 2017 (Nelson & Steidel, 2019). These efforts are focused on water that is produced but the utility is not able to bill for. This includes both true water conservation efforts and efforts to account for and accurately charge unbilled water consumption to the appropriate customer. The focus of this analysis is on efforts that reduce the volume of water produced. We use the 2019 DNR report and its underlying 2018 data, along with information collected from this project's interviews and assessments, to quantify this opportunity.

The DNR water conservation effort has seven objectives:

- Reduce unaccounted water loss to less than 10%.
- Achieve less than 75 residential gallons per capita per day (GPCD).
- Achieve at least 1.5% annual reduction in non-residential per capita water use.
- Achieve a decreasing trend in total per capita per day.
- Reduce ratio of maximum day to average day demand to less than 2.6.
- Implement demand reduction measures.
- Strategies to reduce water use and support wellhead protection planning.

Before the meter conservation measures fall under the first objective. There are 757 city water utilities, but the DNR water conservation survey focused on the 348 "large" cities that serve more than 1,000 people, and of this group they concluded they had reasonable data from 230. The DNR found the average loss rate in 2018 was 8.8%. If the 8.8% loss rate for large cites is representative of the sector, 15,000 MGY are lost, and of this 6,100 MGY (approximately 12,000,000 kWh) might be recoverable if all loss rates could be reduced to the 10% objective.

Among the interviewed systems for this project, the average water loss rate reported in this study was 11%, compared to the state of Minnesota average of 8.8%. Of the fifteen sites interviewed, ten had loss rates below 10%, with three less than 5%. Only three reported having loss rates above 10%, ranging from 15.6% to an extraordinarily high loss rate of 65% of all water produced.

Figure 3 shows the distribution of the loss rate – 55% have losses less than the state objective of 10% and 27% have loss rates less than 5%. On the other hand, 45% have loss rates higher than the state objective, 22% have loss rates above 15% & 7% of large cities have losses greater than 30%. Cities with loss rates above the state objective are candidates for loss reduction, and the fact that 27% have losses below 5%, there may be even more room for loss reduction.

Water losses can be found throughout the water treatment system, but the majority is lost during treatment and distribution processes. The losses during water treatment are significantly less than losses during distribution but tend to be unavoidable due to health and safety requirements. Systems with filtration systems typically run a backwash through the filter for cleaning and cannot significantly reduce the amount of water needed for this. These systems could consider reclaiming filter backwash to treat and distribute, but this in typically cost prohibitive. WTP6 sees approximately 5,000 gallons of water lost to post-service flush when turning off a reverse osmosis (RO) skid, resulting in a reduction of treatment losses only being possible by increasing RO skid runtimes. This leaves the majority of the opportunity for water loss reduction in the distribution system.

In the DNR survey, there were 379 loss reduction projects conducted by 126 cities. **Table 18** lists the type of non-revenue water loss projects, dividing them into projects that reduce water, and thus the energy needed to produce that water, and projects that are aimed at moving volumes of "lost" water to billable categories.

Figure 3: Water loss distribution from DNR 2019 report (Nelson & Steidel, 2019).

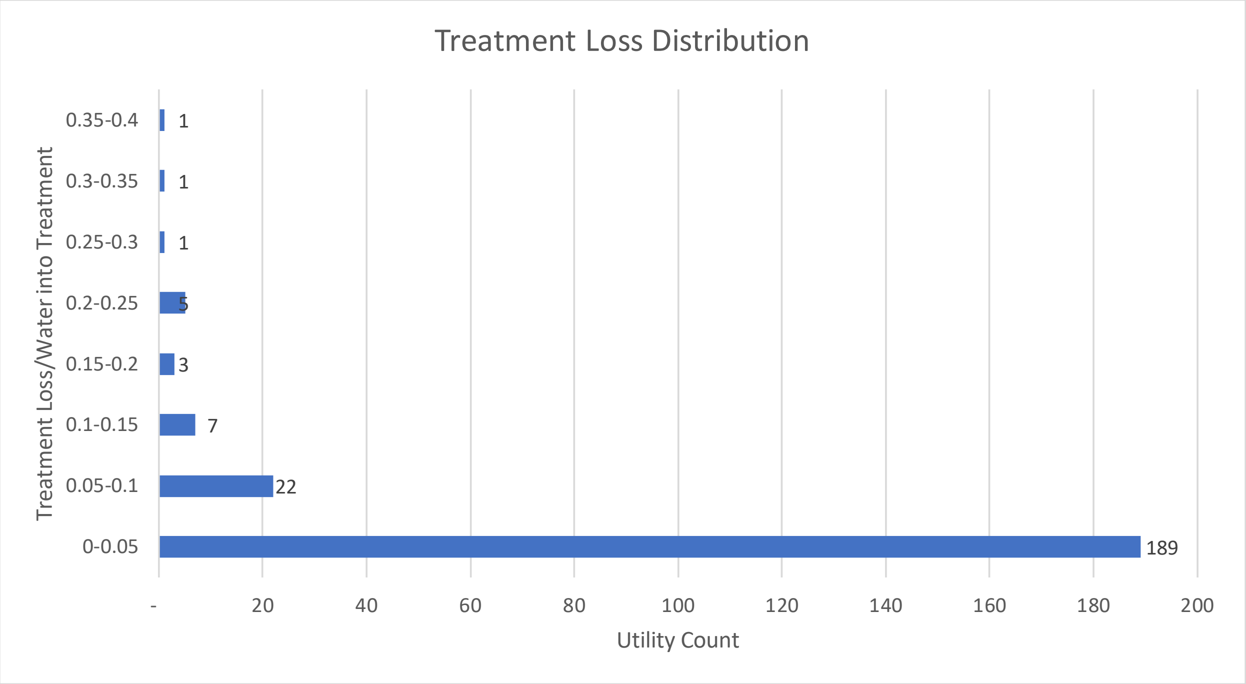


Table 18: Loss reduction project types.

Reduction Project Classes	Revenue Related Project Classes
System Leak Fixing BTM	Add Irrigation Meters
Hydrant Repair	Add Non-Irrigation Meters
Pressure Control	Meter Repair Replace
Storage Mixing	Meter Testing
Increase Treatment Efficiency	Reduce Unauthorized Water Use

Water losses during distribution typically involve water main breaks and leaks in pipes and fire hydrants. Losses also occur from hydrant flushing/use purges from treatment systems such as filter backwash or reverse osmosis system reject water, purges of stagnant water from storage reservoirs. The procedures used for purges or flushing such as un-monitored or excessively long flushing can result in wasteful losses. Older systems tend to have higher rates of water main breaks due to aging pipes. Five sites reported that the type of pipe that had the highest break rate in their system was cast iron piping. Water main breaks can be avoided by identifying and replacing aging pipes, however only one site reported actively replacing old pipes without a main break based on known areas of corrosive soil where water main leaks and failure were more prevalent. Two sites also reported wrapping repaired sections of pipe in polyethylene in order to increase their resistance to corrosion. To reduce water losses due to leaks in the system, leak detection can be performed. Four sites reported performing routine leak detection on a set schedule in order to identify and repair leaks in the system.

Pressure control is another factor. Sufficient pressure needs to be maintained in distribution systems so customers at the furthest locations in the system and at the highest elevations have sufficient pressure to provide flow. This results in pressure variations in the system, and if either the minimum system pressure is higher than needed or some areas have excessively high pressures due to low elevation, high pressures can cause equipment wear and result in higher leak rates. If the minimum system pressure is higher than needed, distribution pumps will have a higher than necessary pressure they need to work against, resulting in higher than needed energy consumption.

Table 19 shows the 2018 claimed impacts of loss reduction projects in the state. Almost 90% of the claimed reduction is the result of true water conservation; 86% from leak repair and 4% from the remaining four types of water conservation projects. 10% of the impact involved improved metering and being able to charge for lost or unbilled volumes. We assume the 90:10 ratio is the likely proportion for water conservation vs. improved billing potential remaining in the sector.

Table 20 shows the number of cities conducting non-revenue/water reduction projects in 2018, by both the size of the utility and the project type. It also shows the number of cities not reporting any projects. The number of cities conducting leak reduction, other conservation, and revenue related projects is evenly distributed by project type. The fraction of cities conducting projects is very high for the large cities but declines as cities get smaller, so that projects are rare among small cities. We also classified a few cities as having strong reduction programs. These 21 cities accomplished reduction that accounted for 60 to 100% of the reduction for their size class. This suggests reduction potential is likely significant with the possible exception of perhaps cities in the 3,000-5,000MGY size class, although these cities are still reporting significant losses.

Table 19: Reduction impact by reduction project.

Project type	Projects Count	Water to Distribution (gallons)	Average distribution loss	Project reduction (gallons)	% of impact	% reduction
System Leak Fix	89	43,382,404,080	10.7%	1,524,642,983	85.7%	3.5%
Hydrant Repair	67	40,692,252,093	10.9%	56,024,967	3.1%	0.1%
Pressure Control	3	1,854,268,120	4.1%	5,877,320	0.3%	0.3%
Storage Mixing	2	363,477,713	9.2%	10,001	0.0%	0.0%
Treatment Eff.	8	4,539,537,536	7.9%	11,634,500	0.7%	0.3%
Revenue	97	37,394,323,647	10.2%	181,560,841	10.2%	0.5%
Grand Total	**266**	**128,226,263,189**	**10.4%**	**1,779,750,612**		

Table 20: Cities with before the meter reduction projects.

Size Category	Leak Reduction Projects	Other Reduction Projects	Revenue Projects	Cities with No Projects	Total Cities	% Of Cities with Projects	% Of Cities with Strong Projects
>10000	1	2	2	0	2	100%	0%
3000-5000	2	0	0	1	3	100%	66.7%
1000-3000	18	27	31	7	28	75.0%	17.9%
500-1000	25	29	34	9	37	75.7%	8.1%
100-500	57	68	96	44	113	61.1%	4.4%
50-100	24	27	40	36	70	48.6%	4.3%
10-50	34	24	49	181	225	19.6%	1.3%
5-10	4	3	3	75	81	7.4%	0%
<5	0	0	1	87	88	1.1%	0%
Grand Total	165	180	256	440	647	N/A	N/A

The magnitude of the reported non-revenue water loss rate is a good starting indicator for reduction potential. Anything above 10% has some potential, with the larger the loss, the greater the potential. Loss rates above 15-20% suggest strong potential. Aging water systems, systems with high leak rates, and systems that have a high specific energy will see the largest energy savings from water loss reduction and prevention. The energy savings are proportional to the amount of water saved, using the specific energy as a conversion factor.

The main barrier for water loss reduction is funding. While large water main breaks will usually always be fixed, leak detection for smaller leaks and preventative measures are more dependent on funds as well as administrative permission. The site with the largest water loss rate, WTP8, was unable to identify leaks because they were denied permission from the city administration to have leak detection performed, despite the comparatively low cost.

Water audits are the first step in controlling water loss. Metering and better water accounting are key to improving the city's water loss percentage. Approximately 75 cities have gone through Water Loss and Water Audit training sponsored by AWWA however, only a few Minnesota cities have completed comprehensive water audits.

Leak reduction programs achieved 2.5-31% reduction in their distribution losses. We estimate strong leak repair programs could reduce sector electrical consumption by 190,000-2,380,000 kWh. Incentives for system leak reduction could be structured like compressed air audit programs where part of the audit cost is reimbursed if a predetermined fraction of leaks are repaired (for example 75%).

Hydrant repair is mostly a subset of system leak repair and could be handled similarly. We deal with it as a separate opportunity, because the DNR does and because water loss can also be reduced through improved hydrant flushing procedures such as predetermined flush time so no more than the sufficient volume is used for the flush. Strong programs achieved 0.4-2.3% reduction in their distribution losses. We estimate strong leak repair programs could reduce sector electrical consumption by 28,000-176,000 kWh.

Treatment water efficiency can be improved by reducing process wastewater such as reducing or reusing filter backwash and improving reverse osmosis yields. Not all water utilities treat water in a way that increases water use, with perhaps 90% of large systems, 60% of medium sized systems, and 10-20% of small systems producing some amount of treatment related losses. Seven of 120 systems appeared to have strong treatment efficiency programs. Strong programs achieved 2.3-43% reduction in their treatment losses. If their reductions could be extended to 50% of the remaining systems electrical consumption could be reduced by 48,000-890,000 kWh.

Pressure control involves controlling the distribution system pressure so excessively high pressures are avoided. High pressure requires greater pumping energy to create the pressure, increase the likelihood of leak creation and makes leak rates higher. The minimum working pressure in the most remote or highest elevation portion of the system should be at least 35psi, and the highest working pressure should be 60-80psi (Nelson & Steidel, 2019). If actual working pressure exceeds these standards in a significant portion of the system, there may be an opportunity for better pressure control. Small pressure adjustments can be made through adjustments in reservoir level, and back pressure valves can limit pressures in geographic areas with low elevations. 3 of 230 large cities had strong pressure control programs and this opportunity applies to only perhaps 10-20% of the water utilities in the state. These strong programs achieved 1.4% reduction in their distribution losses. We estimate strong pressure control programs could reduce sector electrical consumption by 31,000 kWh.

Storage mixing improvements are probably the smallest opportunity and depends on the design of the storage reservoirs. The indicator of an opportunity is that water is purged from storage to prevent stagnation of the water supply. The ideal solution is a reservoir design that minimized stagnation and to have flow through the reservoir came closer to a first in, first out flow pattern. New reservoirs are very expensive so a much more likely interim solution would be to add mixing to storage so there are no pockets of water volumes that stay in the reservoir for long periods of time. In 2017 there were only 2 storage mixing projects at relatively small water utilities, but we have no information that this is a widespread issue. 2 of 230 large cities had strong leak programs and this opportunity applies to only perhaps 10-20%. These strong programs achieved 0.6% reduction in their distribution losses. We estimate strong storage mixing programs could reduce sector electrical consumption by 2,000 kWh.

Miscellaneous Energy Efficiency Measures

In the process of conducting this project, assistance has been requested from Minnesota Rural Water Association (MRWA) for help with energy reduction in one small water treatment facility. The major recommendation for this site was to lower the set point of the heating system for the treatment plant as the water contained in the piping and clear well offer a large thermal mass to buffer outside temperatures. By reducing the thermostat set point to 60°F a savings of 15% were identified. This primarily applies to facilities pumping less than 10 MGY, but thermostat set point adjustment is applicable to all sites with heated buildings.

Conclusion

WTP Sector Energy Conservation Potential

Statewide electricity use was estimated using the specific energy (the energy required to pump one million gallons of water) calculated during the interview and assessment phases, along with pumping totals from the DNR MPARS database. These values are presented in **Table 21.** The total energy was calculated using the average specific energy of the size class using data from the 15 sites interviewed.

Table 21: Total energy electricity calculated using the specific energy calculated for each size class.

Size Category	Total Number of Plants	Total Million Gallons Pumped (MG/yr)	Specific Energy (kWh/MG)	Total Energy (kWh/yr)
Small (5 – 50 MGY)	307	5,900	2,300	13,400,000
Medium (50 – 500 MGY)	187	32,000	1,600	52,500,000
Large (>500 MGY)	67	100,000	2,300	227,200,000
Total	561	138,000	N/A	293,000,000

Data in **Table 21** shows that even though small and medium sized plants greatly outnumber large plants, they only account for 27% of the yearly water pumped. This is also represented in the estimated total energy used, as small and medium plants only make up 22% of the total energy. This indicates that the large size class (plants pumping more than 500 million gallons per year) is the largest opportunity for energy savings, using 78% of the sectors estimated energy.

Replication Potential

Rough estimates for each opportunity were made using data gathered during the interview and assessment process and are presented in **Table 22**. The estimates for water conservation and water loss reduction were made with a preliminary analysis of the DNR Water Conservation Report System database. The estimates for the other opportunities were completed using adoption rates of each opportunity gathered from the 15 water utility interviews and initial data provided by assessment sites.

Once the assessments were complete, an in-depth analysis of each opportunity was completed. The data from these analyses are presented in **Table 23**.

Table 22: Overall opportunity potential from preliminary interview and assessment estimates.

Opportunity	Percent of State Water Utilities Available	Estimated Savings	Estimated Sector Energy Saving (kWh/yr)
Water Loss Reduction	88%	15%	38,000,000
Customer Conservation	81%	14%	33,000,000
Pump Efficiency Optimization	80%	6%	14,000,000
Well/Pump Rehabilitation	53%	6%	9,300,000
VFD Optimization	80%	3%	7,000,000
VFD Installation	20%	15%	8,800,000
Statewide Total	**N/A**	**N/A**	**98,000,000**

Table 23: Overall opportunity potential from in-depth assessment analyses.

Opportunity	Percent of State Water Utilities Available	Estimated Savings	Estimated Sector Energy Saving (kWh/yr)
Pump Efficiency Optimization (PEO):	**N/A**	**N/A**	**25,000,000**
PEO: Well Pump Selection	87%	5%	14,000,000
PEO: Distribution Pump Selection	87%	0.7%	2,200,000
PEO: Pump Redesign	10%	600 kWh/MG	8,300,000
Well/Pump Rehabilitation	**53%**	**6%**	**9,300,000**
Water Loss Reduction (WLR):	**N/A**	**N/A**	**3,500,000**
WLR: Distribution Leak Repair	95%	2.5-31% of losses	2,400,000
WLR: Hydrant Repair	96%	0.4-2.3% of losses	180,000
WLR: Treatment Losses	87%	2.3-43% of losses	890,000
WLR: Pressure Control	15%	1.4% of losses	31,000
WLR: Storage Mixing	15%	0.6% of losses	2,000
Customer Conservation (CC):	**N/A**	**N/A**	**2,700,000**
CC: Irrigation	94%	N/A	1,200,000
CC: Residential Appliances	94%	N/A	1,500,000
CC: Other	94%	N/A	85,000
VFD Optimization	**60%**	**1.5%**	**1,900,000**
Statewide Total	**N/A**	**N/A**	**42,000,000**

Electric Utility Support of Conservation Initiatives

The major conclusions for electric utility support for each of the opportunity are grouped into two main categories: identification and the possible incentive structures. The statewide potential is the third major part of this, and is discussed in the previous section, **Replication Potential**. For a summary of the information presented below, refer to **Appendix E: Opportunity Summary Table**.

Well/Pump Rehabilitation and Pump Efficiency Optimization

Two major distinctions should be considered when identifying potential opportunity with pump rehabilitation: 1) whether the water utility has a schedule for pump/well rehabilitation, and 2) whether energy and water volume measurement is available on pertinent pumps. Sites without a set schedule for rehabilitation should consider well rehabilitation (including pump inspection) on a 7-10 year cycle. This will reduce energy use and reduce risk of pump failure. If a site is on a set schedule of well rehabilitation, but does not have measurement infrastructure, energy and water volume measurement systems would be the next step for added efficiency. This would allow for real-time calculation of the specific energy of each well pump which would allow the operator to schedule well rehabilitation when the specific energy begins to increase. Monitoring specific energy can also help predict pump wear which reduces the risk of pump failure. This also represents a major barrier identified in each electric utility interview: monitoring is not typically incentivized. The electric utilities surveyed are focused on verifiable electricity savings and monitoring does not guarantee savings. To ensure energy savings, this could be structured as a standard compressed air audit, where incentives are given once maintenance activities are completed. In this case, monitoring would be installed, and the electric utility would provide financial incentive for that installation once well or pump rehabilitation was completed. At a minimum, water utilities should have a schedule for pump and well maintenance and this does not necessarily need financial incentive.

Pump efficiency optimization is more applicable to systems with several pumps that serve the same purpose such as a central treatment plant where all water is pumped or distribution pumps servicing the same storage system, more importantly, for drinking water utilities that have a large number of wells to choose from. Five wells might be where this opportunity starts, while systems with more than 10 wells are very good candidates. But even small systems with just two wells – a primary well and a backup - can take advantage of this opportunity. Small systems are generally operated to equalize operating hours on the pumps to delay major maintenance, but they could run primarily on the most efficient pump until maintenance is needed, and then switch to the less efficient during repairs. This type of operation should increase the frequency of repair on the primary pump but should not increase repairs overall. Of the 634 groundwater systems in Minnesota, 108 have five or more wells, and these would be the larger systems with greater potential for savings through pump selection optimization.

Energy conservation incentives for measurement infrastructure, including SCADA programming, would also be beneficial for pump efficiency optimization, if those costs can be tied directly to making pump selections that save energy. For very large systems, automation costs can be significant, and this would be an obvious place for incentives.

Customer Conservation and Water Loss Reduction

Only 6% of cities had a robust customer conservation program and 5% of cities had a strong program for leak reduction. This indicates that most water treatment plants in the state have the opportunity to implement one or both. The water use per capita and the specific energy could be used as a way to identify higher opportunity as higher per capita use would indicate more opportunity for customer conservation and a higher specific energy would indicate a larger incentive to reduce water use.

One area where incentives might work would be for electric utilities to provide direct incentives to their own electric customers with large irrigation needs to reduce irrigation water. The best application would be for customers using greater than 1-2 million gallons per year for irrigation who have old systems with rudimentary control. Smart irrigation timers and moisture sensors can reduce water demand by 15-40% depending on site conditions and current system operation. A possible additional reason to provide this type of incentive is that peak irrigation demands can occur at the same time as peak air conditioning demand for electric utilities. This would be peak shaving rather than energy savings since preventing irrigation during peak energy consumption periods would likely shift irrigation to a different time. One problem with irrigation incentives is the electrical customer who would find irrigation incentives useful, might not buy water from a water utility served by the electrical utilities, or there may be remote pumps or facilities that are not in the service territory. This should be handled on a per case basis. An alternative approach to incentivizing irrigation reduction might be to pay the water utility to ban or shut off lawn watering, generally, or by specific large customers, at times of peak electrical demand. Many energy companies already do this with agricultural irrigators and some cities have lawn irrigation ordinances that permit watering only on certain days or at certain times of day, but installing additional energy/water shutoff systems may be necessary to ensure energy savings.

Another area where CIP could help with water conservation is in education, outreach, and advertising. As long as energy companies have to promote energy conservation, they could tie in water conservation at the same time using the idea that all water savings lead to energy savings for the drinking water treatment facility. Most water utilities struggle to do education and outreach.

Leak reduction opportunities can be identified based on the reported system loss rate and more importantly the loss rate for the distribution system. If the distribution is higher than 10% of the volume produced the system is a reasonable candidate for reduction; the higher the distribution loss, the larger the likely opportunity. A likely first estimate of leak volume is 90% of the distribution loss. Leak repair is a continuous effort because new leaks develop, but only 12 of 230 large cities had strong leak programs (they account for 40-100% of their size category’s leak impact). These strong programs achieved 2.5-31% reduction in their distribution losses. Incentives for system leak reduction could be structured like compressed air audit programs where part of the audit cost is reimbursed if a predetermined fraction of leaks are repaired (for example 75%).

VFD Installation and Optimization

A majority of the sites interviewed had VFDs installed on all or most of their wells (12 of 15), and most had VFDs installed on distribution pumps. Therefore, the statewide potential for VFD installation is currently small, but if identified, could have a major positive impact. Another further optimization technique for VFD operated pumps is to find the pump speed that maximizes the efficiency of the pump and motor, effectively finding the best operating point of the pump by modulating the speed of the motor.

If a throttled flow situation is identified, current prescriptive rebates would mostly likely handle it. For best operating points, operator time is required to run speed tests and calculate pump specific energy, but this time is relatively small unless the number of pumps gets large, and there is no cost to actually choosing the operating point, so there are no significant costs that can be off-set with incentives to encourage manual pump testing and BOP selection. However, manual BOP optimization would likely be a one-off effort unless the WTP is very committed.

Currently most, but not all, wells have real-time flow measurements, and those are generally connected to centralized SCADA systems. Some wells also have power measurements available, but the most frequent form is an amp measurement within the VFD controller that is not connected to the SCADA system. Individual flow and power measurements are less common for high service pumps serving the distribution side of WTPs. Ideally, measurement improvements would be made so that both flow and power measurements would be available in real-time on the SCADA system for each pump, and the SCADA system would be programmed to calculate specific energy. The availability of real-time specific energy on each pump would allow WTP staff to set best operating points (including friction loss impacts); select the most efficient pumps for maximum use; and identify BOP trends that signal the need for pump or well rehab. Costs for measurement infrastructure would be the largest cost associated with implementing energy conservation other than the more direct costs of pump and well rehab.

Two electric utilities indicated CIP rules do not allow them to provide incentive for measurement infrastructure because, while it can be a precursor and aid to energy conservation, it does not directly result in energy reduction. Perhaps incentives for measurement infrastructure costs could be made if a behavioral change made off of that energy information, such as a shift in pump use, was maintained over a 6 or 12 month period with the energy reduction associated with that change quantified. In other cases a process similar to compressed air leak rebates could be offered (see the section titled **Well/Pump Rehabilitation and Pump Efficiency Optimization**, above).

Miscellaneous Energy Efficiency Measures

Although this opportunity only represents a small fraction of the total energy saving potential, it is worthwhile to keep in mind as an easy no-cost change. Many times the only necessary change is a lower the temperature set point in the main treatment building. This showed a 15% decrease in energy for the one facility analyzed.

Electric Utility Interview Findings

Interviews with electric utilities were conducted throughout the duration of the project to answer three main questions:

- How could the electric utility help the drinking water utility implement each conservation opportunity?
- What information do the electric utilities need to identify and properly incentivize each conservation opportunity?
- How does each conservation opportunity fit into existing incentive programs?

Incentivizing Energy Conservation

Conservation incentive at each of the electric utilities interviewed was governed by one overarching principle: incentives are only given to projects that reduce the use of electricity (kWh). In most cases, this implies that sub-metering for identification of energy reduction opportunities is not incentivized. This makes incentivizing pump efficiency optimization and pump/well rehabilitation difficult without pre-existing metering infrastructure. These two opportunities rely on energy use monitoring (pump/well rehabilitation does not require monitoring, but it is encouraged) as they both require calculation of specific energy. Pump and well rehabilitation is discussed further in a subsequent section titled, **Long-Term Maintenance**.

Demand charges incentivize customers to keep their power draw as low as possible which helps the electric utilities manage their overall power production. For the average industrial customer, this works well because all of their load is on one or two meters and can be manipulated by any electrical equipment in the facility. Most water utilities have more than one well and some have 20 – 30 wells each on their own electric meter. This means that if a well runs during a given billing period, its operational power will be charged as demand. If all of the water utility's operation were lumped into one bill and treated as one meter, the utility could shut down less efficient wells and power on more efficient wells without fear of being charged for demand on all of the wells. This structure is being implemented in smaller cities where the electric utility and water utility are sister utilities (more discussion on this in the next section, **Water/Electric Utility Partnership**). For a more in-depth discussion on this topic, see the appendix section **Appendix D: Demand Charge E2 Disincentive Discussion**.

VFD installation is the one opportunity that is a straightforward incentive by the electric utility and should continue to be offered to sites that have a need for a VFD. This is also something that has been offered by many electric utilities as a rebate for several years and is easy to identify as an opportunity. Although this opportunity is easy to rebate, it is fairly common in the drinking water treatment sector as previous efforts have been successful to push adoption of VFD technology.

Water/Electric Utility Partnership

Many of the electric utilities that are members of larger electric cooperatives are also sister utilities with the water utility. This is typical if a town or region that operates both the local water utility and electric utility, and can be advantageous. With a closer partnership, special billing is possible, such as system wide demand sharing (see previous section), or blended rates (per kWh rates that combine the usage and demand cost into one rate). This partnership is also beneficial for energy efficiency opportunities such as customer water conservation and water loss reduction. With a closer tie between the electric and water utilities, these two opportunities are easier to coordinate and easier to share costs and benefits which allows for greater buy-in from both parties.

Feedback from electric utilities indicated that customer water conservation and water loss reduction are both opportunities that would work better with a partnership between the electric and water utility. This is based on the nature of the opportunity, as neither are true rebates that the electric utility can offer the water utility and cooperation is necessary to realize energy savings. To further complicate this, a small subset of water utilities receive electricity from multiple electric utilities which increases the need for cooperation between the water and electric utilities.

Long-Term Maintenance

Both pump and well rehabilitation are currently performed by many water utilities on a set schedule (typically every 7-10 years). The potential opportunity is to convert this scheduled maintenance plan to an energy efficiency-based plan by metering pumps to identify when the specific energy is increasing signaling the time for maintenance. Although this practice of monitoring the specific energy of pumps was not observed at any of the 15 sites interviewed, the cycle of maintenance will likely fall to every 4-7 years. This is still a relatively long timeframe for electric utility rebates and will need to be addressed thoughtfully. Two possible incentive scenarios were identified with input from the electric utilities interviewed: 1) providing rebates for metering technology to identify the proper timing of maintenance and 2) providing rebates for maintenance activities aimed at increasing the efficiency of pumps.

To provide a rebate for metering technology, two of the three electric utilities interviewed required automation to be installed alongside the metering to ensure energy savings. The third utility was not asked directly but would likely echo these concerns. One alternative option to automation is to structure this type of rebate in a similar fashion as compressed air audits. In this scenario, an estimate of the potential savings would be identified and when the water utility perform maintenance based on the metering technology, the electric utility would rebate the metering technology.

Providing a rebate for maintenance activities may be an easier approach than trying to offer metering technology rebates. This type of rebate would be offered for maintenance activities based on either metering data or historical data indicating previous energy efficiency baselines and current energy efficiency values. The major barrier with this type of incentive is the length of time necessary to verify energy savings.

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Appendix A: Literature Review

Energy Use at Drinking Water Utilities

The Minnesota DNR regulates the use of water in the state by permitting withdrawal from both surface waters like lakes and rivers, and from groundwater in volumes larger than one million gallons per year (Water Use Permits, 2019). The DNR publishes a spreadsheet with withdrawal volumes annually (Hunt, 2018). For 2017, spreadsheet analysis showed there are 666 cities in Minnesota with DNR permits for municipal water use; 638 cities used 119 trillion gallons per year (GPY) of ground water; while 28 permitted cities used 64 trillion GPY of surface water. Minneapolis and St. Paul account for nearly 70% of municipal surface water use. Municipal ground water is withdrawn from 59 aquifers, with 86% of the volume removed from depths of 100 to 700 feet; only 6% comes from depths less than 100ft, and 8% from depths of 700 to 1200 ft.

A 2011 GAO report (Mittal & Gaffigan, 2011, p. 10) concluded limited data is available nationally on energy use in the urban water lifecycle, which includes drinking water production. This report also indicated the task of quantifying this energy use is made difficult by the location specific variables that greatly affect energy use, such as the water source and quality of that source (surface water, shallow wells, deep wells); the distance and topography water is conveyed over; and the types of treatment needed and used. The GAO report stated the two most cited national studies were conducted by EPRI in 1996 and 2002 but concluded these studies are dated. We found a more recent EPRI study dated 2013 (Pabi, 2013) which will be discussed below.

AWWA Research Foundation report (Carlson & Walberger, 2007, p. 2) also describes the limited availability of information on water utilities and the wide variation of parameters that affect energy use. This study is based on a survey of drinking water utilities where the survey was mailed to all 1723 utilities serving populations of greater than 10,000 (Carlson & Walberger, 2007, p. 11). They received 251 responses (13%). Disinfection was the leading treatment objective. Treatment for turbidity, taste and odor, and organic carbon were significant objectives in the response but much smaller than disinfection. Pumping is by far the most energy intensive operation at drinking water utilities while a relatively few plants had other high energy operation like UV disinfection or membranes (Carlson & Walberger, 2007, p. 13). 93% of utilities reported that electrical energy use was greater than 90% of total energy consumption (Carlson & Walberger, 2007, p. 21).

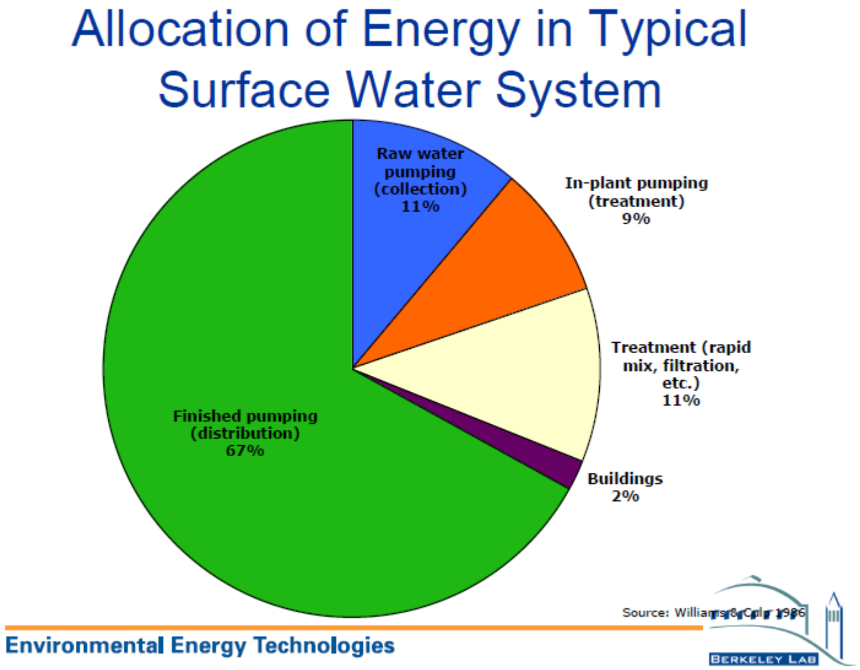
Water utilities have 3 main operations: water production, treatment, and distribution with the relative footprint depending on the water source as shown in **Table 24** (Carlson & Walberger, 2007, p. 123). MnTAP conducted an assessment at a single water utility plant (Vanyo & DeWahl, 2018, p. 3) using a groundwater source and found treatment energy was only 2.5% of the total while well pump energy was 45% & distribution energy was 2.5%.

Table 24: Relative energy use of groundwater versus surface water treatment facilities.

Water source	Groundwater (1800 kWh/MG)	Surface Water (1400 kWh/MG)	MnTAP assessment (2200 kWh/MG)
Well or raw water pumping	33%	9%	45%
Treatment	1%	5%	2.4%
Distribution pumping	66%	86%	52.5%

A Lawrence Berkeley study (R. Brown, 2005, p. 6) found the energy footprint of a surface water plant (see **Figure 4**) is 11% raw water acquisition, 20% treatment and 67% distribution.

Figure 4. Energy Footprint of a Surface Water Plant



Source: Williams & Culp 1986

AWWA also looked at the variables affecting energy used by the 3 main operations finding the variables listed in **Table 25** have the largest impact on utility energy use (Carlson & Walberger, 2007, pp. 31, 46, 49, 52).

EPRI has done 3 reports on Water and Wastewater utility energy use, the latest from 2013 stated that energy use at drinking water utilities increased faster that the population during the period 1950-1985, but slowed to the rate of population growth from 1985-2005 (Pabi, 2013, pp. 2-4) and the rate of energy growth is expected to remain at 5% per year into the near future.

Table 25: Operational variables with significant effect on energy use at drinking water plants: total plant energy; production energy, treatment energy; and distribution energy.

Total plant energy	Production energy	Treatment energy	Distribution energy
total flow	total flow	total flow	total flow
purchased water flow	purchased water flow	purchased water flow	
total horsepower	raw water pump hp	raw water pump hp	distribution pump hp
water loss		The presence of 5 treatment processes	The presence of 3 treatment processes
system change in elevation			system change in elevation
length of distribution mains			

The EPRI study also estimated energy intensities for seven water production levels and 21 plant operations (Pabi, 2013, pp. 4-6) based on key assumptions including a well lift of 150ft, a distribution pumping pressure of 65psig and a pumping efficiency of 65%. They also estimated pumping energy intensity at 3 efficiency levels as shown in **Figure 5** (Pabi, 2013, pp. 4-7). These estimates could be used to get an initial sense of a plants energy efficiency during an informational interview or assessment. EPRI reviewed 8 studies on drinking water energy intensity and concluded 1900kWh/MG is a reasonable estimate of national drinking water plant energy intensity (Pabi, 2013, pp. 4-15).

Figure 5. Screenshot of Table 4-3 from Pabi, 2013

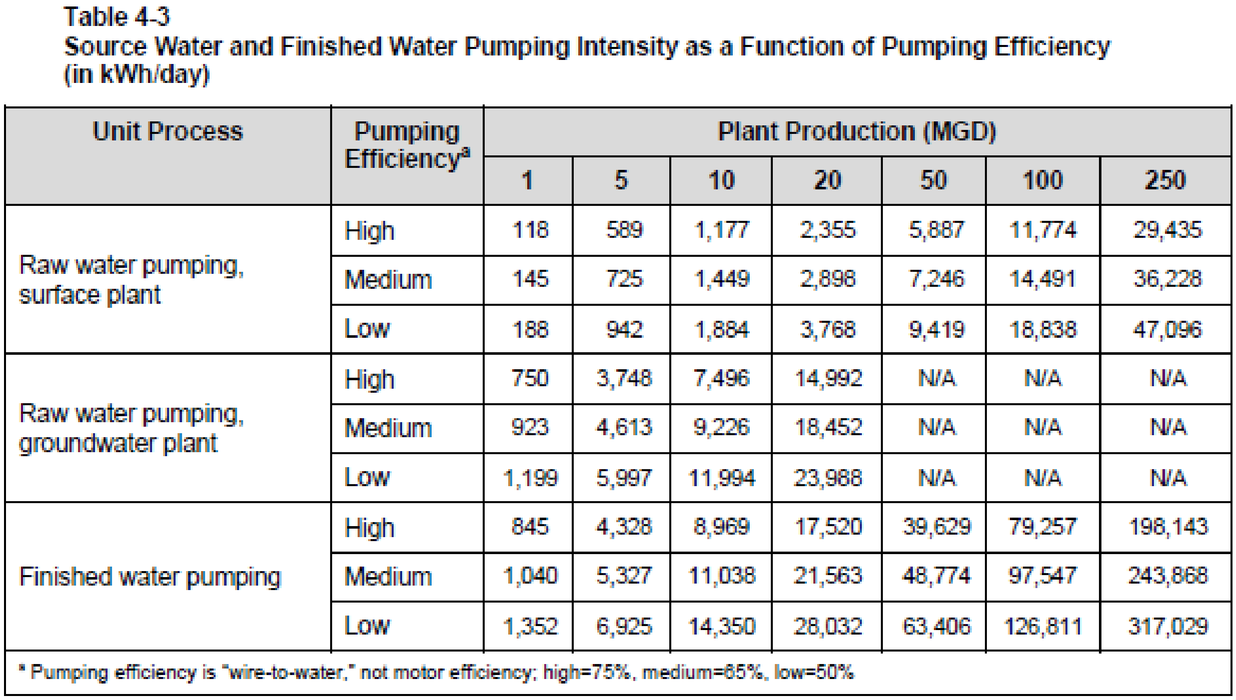


Table 4-3
Source Water and Finished Water Pumping Intensity as a Function of Pumping Efficiency (in kWh/day)

Unit Process	Pumping Efficiency[a]	Plant Production (MGD)						
		1	5	10	20	50	100	250
Raw water pumping, surface plant	High	118	589	1,177	2,355	5,887	11,774	29,435
	Medium	145	725	1,449	2,898	7,246	14,491	36,228
	Low	188	942	1,884	3,768	9,419	18,838	47,096
Raw water pumping, groundwater plant	High	750	3,748	7,496	14,992	N/A	N/A	N/A
	Medium	923	4,613	9,226	18,452	N/A	N/A	N/A
	Low	1,199	5,997	11,994	23,988	N/A	N/A	N/A
Finished water pumping	High	845	4,328	8,969	17,520	39,629	79,257	198,143
	Medium	1,040	5,327	11,038	21,563	48,774	97,547	243,868
	Low	1,352	6,925	14,350	28,032	63,406	126,811	317,029

[a] Pumping efficiency is "wire-to-water," not motor efficiency; high=75%, medium=65%, low=50%

Wisconsin surveyed their plants in 2016 (Water and Wastewater Energy Best Practice Guidebook, 2016, p. 6) and 2006 (Cantwell, 2006, p. 10). **Table 26** summarizes the energy use – kWh/MG (or per million gallons). Between the surveys, energy increased by nearly 20% for the largest plants, and by nearly 30% for the smallest plants. Energy use was stable for the medium size group. Energy intensity also increased. A comparison of the two reports also shows an increase in energy intensity for both plants drawing in groundwater as well as drawing from surface water, although the basis of comparison is different between the reports – Wisconsin only plants in 2016 compared to U.S. averages in 2006.

Table 26: Energy use rates at Wisconsin drinking water utilities.

Type	Size	2006 kWh/MG	2016 kWh/MG	% Increase
Class AB	(>4000 customers)	1510	1810	19.9%
Class C	(1000-4000 customers)	1850	1940	4.9%
Class D	(<1000 customers)	1890	2410	27.5%
-	Surface water	1400	2160	54.3%
-	Groundwater source	1800	2100	16.7%

If the Wisconsin averages are representative of Minnesota drinking water supply infrastructure, the state could be using as much as 240 million kWh for groundwater procurement and 139 million kWh for surface water supply based on 2017 use rates.

A recent series of articles in the American Water Works Association journal Opflow stated pumping is responsible for at least two thirds of a utility's energy consumption with part 1 giving an excellent overview of the factors affecting pup system efficiency and performance and suggesting specific energy (power in KW divided by flow in MG/hr) as an important pump benchmarking tool (Steger & Pierce, Specific Energy: Comprehensive Measure of Pump Station Performance, 2018, p. 12)

Energy conservation potential within utility operations

Notable best practices from several sources are shown in **Table 27** and discussed below. Costs of implementation for many of the best practices were not mentioned, as most sources focused on potential savings instead. As a result, payback period info is vague for some best practices. Larger, complete WTP best practice guides are available from the Wisconsin Focus on Energy (WI FoE) (WI FoE, 2016, pp. 35-36) and WRF NYSERDA (Leiby & Burke, 2011, p. 18), but the most impactful best practices are listed in Table 27. The specifics and potential savings regarding the minimization of water losses are discussed in Section 3 of this report.

The WI FoE recommends that a utility install a real-time energy monitoring system to allow for the collection and analysis of energy data for each treatment process, pump system, and building function. This may help a WTP identify opportunities for energy savings, which may range from 5-20% at WTPs where E2 is an ongoing function (WI FoE, 2016, p. 49). Monitoring may also support load management, maintenance, and the identification of failing equipment. Installing enhanced Supervisory Control and Data Acquisition (SCADA) systems to a WTP to monitor and control energy use in addition to more standard process variables such as, flow rate, chemical use, etc., would improve the ability to understand an optimize energy use. One particular use of a SCADA system may be to calculate pump efficiency in real time by monitoring flow rate, suction and discharge pressures, and required power.

WTPs are encouraged to benchmark their operations and to compare their results with other WTPs to understand their relative efficiencies. Doing this may help to identify potential savings in various areas of a WTP. In general, more advanced instrumentation and automation provide further detail and control and eventually end up paying for themselves by uncovering otherwise unknown savings opportunities.

Table 27: List of best practices.

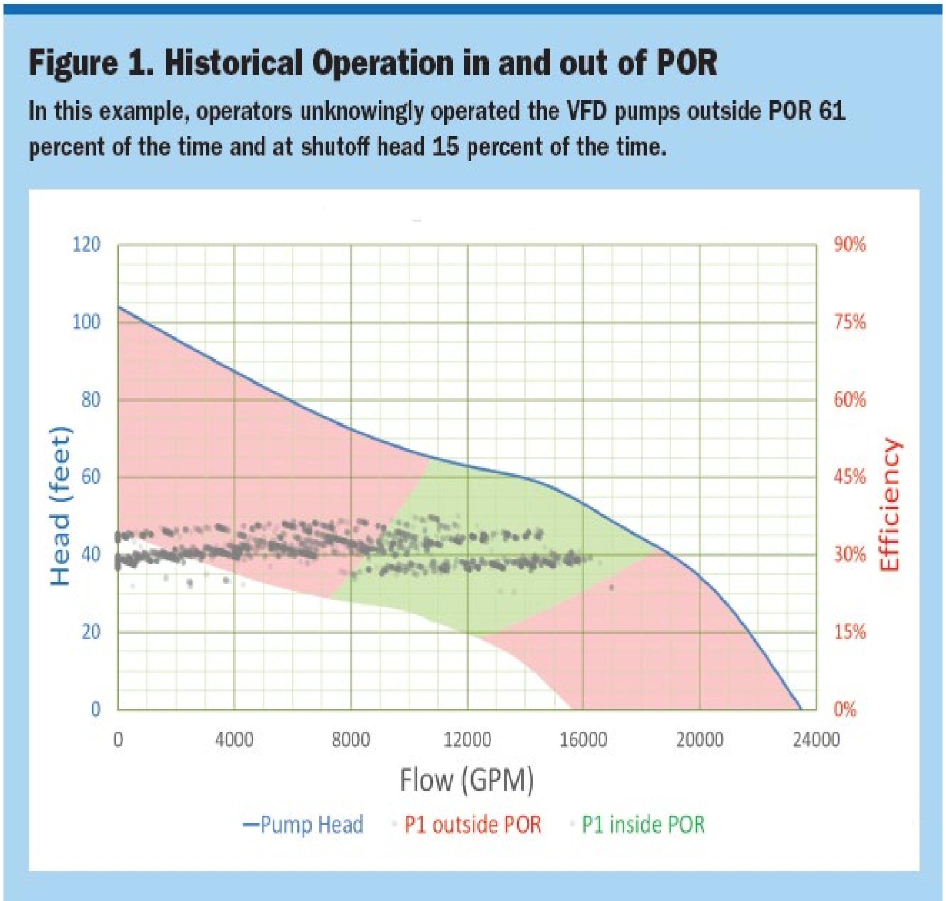
Best Practice	Capital Investment	Potential Savings	Payback Period
Minimize Water Losses	Variable	Proportional to water loss rate	Variable, depends on severity
Install Premium-Efficiency Motors	$3,100-175,000	5-10% of pumping energy, $2,800-44,300	0.5+ years
Rehabilitate Old Pumps	Variable depending on size	Variable	2-3 years *
Apply Internal Coatings to Pumps	Low	5-10% of pumping energy	Short, < 1 year
Use Smaller Pumps in Parallel	Variable	10-50% of pumping energy	Variable
Install VFDs	$3-126.5k	$1,620-51,600	Several months to years
Replace or Trim Impellers	Low	Depends on extent of throttling	Short or immediate
Prioritize Most Efficient Well and Distribution Pumps	None	10-20% of pumping energy *	Immediate
Manage Peak Energy Demand	None	Variable	Immediate
Minimize Pipe Head Losses	Variable	5-20% of pumping energy *	Variable
Rapid-Gravity Filtration versus Pressure Filtration		50%	
Install High-Efficiency Lighting and HVAC Systems	$7-154k	20-40% of associated energy	Variable

Installing new and premium-efficiency motors should be considered to replace old electric motors for both water acquisition and distribution pumps, especially on those with the highest operating hours. WI FoE states that payback periods are usually less than two years and that typical savings may be 5-10% of the energy used by the motor being replaced, but these figures may vary depending on the initial motor efficiency, size, and its operating hours (WI FoE, 2016, p. 58).

Rehabilitating old pumps to regain lost efficiency may be a viable option as well. In 2017, the City of St. Cloud WTP rehabilitated a 500 hp pump installed in 1992 for a cost of $75k. As a result, energy demand dropped from 1.95 kWh/1000 gal to 1.77 kWh/1000 gal, effectively saving $81 per day for a payback period of about 31 months (St. Cloud, 2018, p. 24). Part 2 of the AWWA OpFlow series states that operating pumps wear and slowly change their operating efficiency and that operating outside of the pump’s Perferred Operating Range (POR) results in increased wear and decreased energy performance

(Steger & Pierce, Centrifugal Pumps and variable-frequency drives: a match made in heaven?, 2018, p. 12). They also state that without adequate controls and education, the application of VFD drive to pumps results in significant time of operation outside the POR as shown in **Figure 6**. Specific energy is a tool that can identify the degree of wear, or more precisely the departure of pump performance from factory specifications. Part 3 of the series gave an example where the pump preferred by operators, out of a set of 5 pumps in parallel, operated at 68% of its factory peak efficiency, while 2 other pumps were still within 4% of factory peak efficiency (Steger & Pierce, Optimal Pump Station Operation is Important, But it isn't Easy, 2019, p. 16)

Figure 6. Historical Operation in and out of POR



Belzona Corporation recommends applying their proprietary coating, Belzona 1341 Supermetalglide, to the interior components of pumps and other fluid handling equipment to result in efficiency increases of up to 8% and 20% on new and refurbished equipment respectively (Belzona, 2018, p. 4). The hydrophobic coating increases fluid flow efficiency, protects equipment from corrosion and erosion, and is safe to use for potable water systems. Using a different ceramic-filled epoxy coating following pump refurbishment, Monroe County Water Authority improved their pump efficiencies by 8%, resulting in savings of $17k per year on a single pump (Leiby & Burke, 2011, p. 53). Payback periods for these actions are dependent on hours of operation, but a complete payback for all pumps was estimated to be less than a year.

WTPs typically invest in oversized equipment such as pumps to handle peak loads and prepare for future growth (NEEP, 2018, p. 12). While this is effective for offsetting the urgency to expand a WTP's capacity, it results in suboptimal performance of equipment and wastes pumping energy due to throttling in order to regulate water pressure. If a WTP utilizes throttling/control valves to limit flows, pumping equipment is likely oversized and may be altered to achieve savings. WI FoE recommends water utilities use the DOE's free software, PSAT and MotorMaster+, to identify inefficient and oversized pumps and motors, determine potential savings, and select new options for pump and motor installation (WI FoE, 2016, p. 57). As shown in Table 24, pumping energy is a major constituent of water utility energy use, making this opportunity one of the highest potential savers, even for mildly oversized systems. An alternative to using oversized pumps is to use several smaller pumps that work in parallel. Doing so allows an automated system to gradually ramp up or down the delivered flow to meet demands without incurring the unnecessary costs of running an oversized pump at all times. Using multiple small pumps allows the system to be more precise in choosing a flow rate. Furthermore, each pump may be operated at its best efficiency point to secure more energy savings. Potential energy savings for this option usually range from 10% to even 50% of pumping energy for highly oversized pumps (Leiby & Burke, 2011, p. 52). As a result, expected payback periods depend on the extent of oversizing and the total cost of new equipment.

Alternatively, installing variable-frequency drives (VFD), to motors allows for an automated system to control the speed of an existing pump to save energy rather than using throttling valves. Energy and money savings from installing VFDs typically range from 15-35% for a single pump (WI FoE, 2016, p. 60). A pool complex in Connecticut installed VFDs on four pumps, two 30 hp, one 20 hp, and one 10 hp in 2015. The VFDs created total savings of $7,215 per year, which equated to a payback period of only 2 years. For a small pumping system, these savings are substantial and proportional savings are expected for larger pump systems at WTPs. The costs of purchasing and installing VFDs may range from $3k up to $126.5k depending on the size and complexity of the order (Horne, Turgeon, & Byous, 2016, p. 49), resulting in payback periods of a few months to a few years (Leiby & Burke, 2011, p. 55). VFDs on large drives operating for long hours with high load variability yield the highest savings. Part 2 of the AWWA series cautions that VFD can cause pump wear and high energy costs in situation where speed change takes the pump outside it POR (Steger & Pierce, Centrifugal Pumps and variable-frequency drives: a match made in heaven?, 2018, p. 12) and part 3 gives an example where their analysis showed the average specific energy performance (kWh/MG) of a 5-pump system was 50% higher than at the optimal combination of pumps and speeds (Steger & Pierce, Optimal Pump Station Operation is Important, But it isn't Easy, 2019, p. 15)

A lower cost alternative to installing a VFD on a centrifugal pump is to install a smaller impeller or to trim an existing one to a smaller size. Doing this effectively lowers the delivered head and flow rate of a pump with the benefit of decreasing energy consumption. The Philadelphia Water Department trimmed the impellers of two large, oversized pumps that were always running and realized $9,400 per month in energy savings as a result of no capital investment. The DOE recommends that a WTP calculate potential savings from trimming or replacing an impeller by using the affinity laws (US DOE, 2006, pp. 1-2). Expected savings will vary depending on the extent of throttling.

NEEP states that adhering to Strategic Energy Management (SEM) practices through equipment upgrades, staff behavioral changes, and operations and maintenance (O&M) optimization may yield considerable energy savings (NEEP, 2018, pp. 2-3). NEEP recommends that water utilities cooperate with each other and share best practice experiences, as competition between municipal sectors does not exist unlike in industrial settings. SEM programs and related programs are hosted by several organizations including Cascade Energy, NYSERDA, Efficiency Vermont, and the DOE with their Superior Energy Performance program (NEEP, 2018, pp. 14-16). In a program hosted by Cascade Energy in 2013, a group of 11 facilities from Idaho ranging from 1.6-16M kWh per year was on track to save an average of 7.8% of utility budgets from only non-capital O&M procedure opportunities over 2 years (NEEP, 2018, p. 14). These types of changes typically require very little to no capital investments and thus have very short or immediate payback periods. Thus, it is important for water utilities to identify potential opportunities for non-capital opportunities to begin saving. Pursuing an SEM or similar program is a great way for utilities to share best practices and for staff to learn about opportunities for immediate energy savings.

O&M procedure changes can be as simple as turning off equipment when not needed or establishing pump priorities for the highest efficiency well or distribution pumps in a WTP. MnTAP found that prioritizing the most electrically efficient well pumps could save the Apple Valley WTP $22k (17% reduction for well pumps) and 380,000 kWh (30% reduction) per year (Vanyo & DeWahl, 2018, p. 6). It was also found that managing peak power draws could save the WTP $6,400 in demand charges per year by keeping power consumption rates as flat as possible if on-peak electrical rates do not exist (Vanyo & DeWahl, 2018, p. 10). Rather than allowing reservoirs to drop to critical levels, thus warranting several pumps to turn on, flow should be gradually adjusted to meet demand in order to minimize monthly peak power draws.

The inner diameter (ID) and roughness of distribution pipes are important factors in the head loss of a distribution system. Wall thicknesses of different pipe materials vary due to differing material strengths, such as a ductile iron (DI) pipe having a smaller wall thickness than a polyvinyl chloride (PVC) pipe due to its greater strength. Therefore, for the same nominal pipe diameter, a PVC pipe will have a smaller ID than a DI pipe. However, PVC was noted to have a C-Factor of 150 versus a C-Factor of 140 for DI, meaning that PVC is smoother (St. Cloud, 2014, p. 1). It has also been observed that the C-Factors of DI pipes decrease over time due to tuberculation and internal corrosion (Khurana, 2017, pp. 22-23). Through calculations, the City of Saint Cloud found that using only PVC and PCCP pipes for 6-16 in and 18+ in pipes, respectively, would require $330,789 more in pumping costs (19.4% more) per year to operate the WTP than if only DI pipes were used (St. Cloud, 2014, p. 2). Therefore, the change in ID caused a more profound change in energy requirements than the change in C-Factor. Water utilities are encouraged to perform their own analysis to determine the economics behind each pipe material to guide decisions regarding pipe network expansion and maintenance. Pipe materials are discussed further with regard to water losses in Section 3 of this paper.

Energy savings regarding water treatment operations are not nearly as significant as those regarding pumping as seen in **Table 24**. Furthermore, water utilities are typically hesitant to alter operations regarding treatment due to regulatory compliance (NEEP, 2018, p. 12). Therefore, water treatment processes should not be a priority for E2 projects. Most academic papers found regarding treatment processes described new experimental treatment operations or computational methods for optimizing new systems rather than energy efficiency opportunities, but some information has been gathered regarding potential options. An academic study by Molinos-Senante and Sala-Garrido found that rapid-gravity filtration was significantly more efficient than pressure filtration, with average energy intensities regarding filtration being 2 to 3 times less while achieving the same water quality (Molinos-Senante & Sala-Garrido, 2018, p. 1098). Regarding filters that require backwashing, the WI FoE recommends that WTPs sequence the backwashing of multiple filters rather than performing the backwashes all at once and to backwash during off-peak times in order to reduce peak power demand (WI FoE, 2016, p. 53). Expected savings are low, yet this O&M procedure has no cost so payback periods should be immediate.

Building energy also represents a small portion of total water utility energy, but savings with moderate payback periods may still be achieved. WRF found in 2011 that replacing lights with higher efficiency options such as advanced (T8s, T5s) and compact fluorescent lamps (CFL) or LEDs may result in payback periods of 2-3 years or less if rebates are available (Leiby & Burke, 2011, p. 26). WRF recommended that a lighting maintenance program be established to clean lights, as dirt and buildup can decrease light output by up to 30%. Lighting energy use was estimated to be 35-45% of the total building energy use. However, American Water, a water utility in New Jersey, experienced payback periods of less than 2 years after replacing T-12 fluorescent light bulbs with T-8 alternatives (Leiby & Burke, 2011, p. 91). WRF also found that installing new high-efficiency HVAC systems can reduce HVAC energy use by 20-40% compared to systems from 1990-2000s (Leiby & Burke, 2011, p. 27). Installing control systems to account for weather and building use patterns and automatically controlling operations may reduce energy consumption by up to 20% as well. Replacing a single, older, large air conditioning or heating unit with several smaller ones may reduce energy use by up to 40% as the parallel units may be operated as needed to match demand (Leiby & Burke, 2011, p. 27). Xcel Energy recommends performing energy audits to uncover further opportunities to save energy, such as adding occupancy sensors or refining a compressed air system as was done in Eden Prairie in 2017 (Xcel Energy, 2017, p. 1).

NEEP stated that barriers to implementation for many best practices include lack of capital, little incentive for employees to adhere to E2 principles, intentionally oversizing equipment, and regulatory compliance making utilities neglect E2 opportunities (NEEP, 2018, pp. 12-13). Water utilities typically hesitate to try new methods or equipment that could potentially affect water quality due to a lack of understanding and an unwillingness to change old habits. Additionally, employees are not incentivized to improve energy performance and often do not see a plant’s energy bills. Oversizing singular pieces of equipment is done in preparation for future expansion and to meet design flows which may be significantly higher than real flow demands. As a result, much of the energy used for pumping is wasted due to necessary throttling to regulate water pressure. An alternative discussed earlier was using several small pumps in parallel that can meet the same demands as a singular large pump while being able to fine-tune the delivered flow at any given time. In the case where there is a lack of capital for E2 projects, targeting O&M and staff behavior for potential savings is possible for a lesser cost. NEEP recommends countering these barriers through SEM training programs to develop a WTP’s understanding of E2 opportunities, both regarding potential equipment and O&M options (NEEP, 2018, p. 21). Regarding this issue, the WI FoE recommends appointing an energy manager to lead work on energy efficiency projects at a WTP (WI FoE, 2016, p. 37).

Water losses / leakage rates among WTPs

A 2018 comprehensive study at USU of water mains in the US and Canada found the average water loss rate to be 10% with a standard deviation of 7.7% from a sample of 200 water utilities (Folkman, 2018, p. 38). The worst leakage rates reported were between 20-50%. The US EPA reported that the average leakage rate was 16%, of which 75% is recoverable (EPA, 2013, p. 1). CNT estimated the average water leakage rate in the Great Lakes region to be 14-18% (CNT, 2013, p. 3). Furthermore, between 1996 and 2010, the cost of water services in the US rose by nearly 90% partly due to increased water losses over time (CNT, 2013, p. 2). It was found that the average and median water loss rates for 302 utilities in Minnesota were 15.2% and 11.3% respectively in 2018 (ESPWater 2018 Muni Water Accounting Spreadsheet, 2018) although 17 utilities reported gains rather than losses. These losses are characterized by real and apparent losses. Real losses are due to physical losses of water from leaks or pipe breaks whereas apparent losses are due to water theft, metering inaccuracy, and data handling errors in the billing process (EPA, 2013, pp. 1-2). As a result of water losses, drinking water production is more expensive by a rate proportional to the water loss rate. Minimizing water losses is a direct way to decrease the required load on all operations of the drinking water production process, particularly well and distribution pumping and water treatment.

Table 28: Total length and break rates by pipe material.

Pipe Material	Description	Percent of Total Length	2012 Break Rate [breaks/(100 mi-yr)]	2018 Break Rate [breaks/(100 mi-yr)]	Change
AC	Asbestos Cement	13%	7.1	10.4	46%
CI	Cast Iron	28%	24.4	34.8	43%
CSC	Concrete Steel Cylinder	3%	5.4	3.1	-43%
DI	Ductile Iron	28%	4.9	5.5	13%
PVC	Polyvinyl Chloride	22%	2.6	2.3	-10%
Steel	Steel	3%	13.5	7.6	-44%
Other	HDPE, PVCO, etc.	3%	21	12.4	-41%
Total		**100%**	**11**	**14**	**27%**

The USU study found the average failure rate of water mains to be 1 break per 7.17 miles per year or 14.0 breaks per 100 miles per year, as shown in **Table 28** (Folkman, 2018, pp. 17, 24-25). Total break rates have increased between 2012 and 2018, mainly due to aging cast iron (CI) and asbestos cement (AC) pipes, indicating their need for replacement. The current average replacement schedule of water mains is 125 years whereas the average age of failing water mains is 50 years, indicating a growing backlog of needed pipe replacement (Folkman, 2018, p. 39). Polyvinyl chloride (PVC) was found to have the lowest failure rate of all pipe materials. Furthermore, the USU study cited that through LCCA and LCA, PVC pipes have both a lower cost of ownership and total carbon footprint than ductile iron (DI) pipes (Folkman, 2018, p. 44). However, this contradicts the findings by the City of Saint Cloud discussed in Section 2 regarding increased pumping costs due to a change in ID when using PVC pipes of the same nominal diameter. The study cited by Folkman did not elaborate on if nominal or inner diameter was equalized when calculating head losses for PVC and DI pipes, but their LCCA and LCA methodology is described in detail (Khurana, 2017, pp. 67-77). For expansion and replacement of water mains, it is recommended that water utilities evaluate their options for pipe materials depending on cost of ownership, stress requirements, and estimated head losses.

The USU study stated that the most common failure mode is a circumferential crack, often caused by corrosion due to soil, especially in CI and AC pipes (Folkman, 2018, p. 28). They found that for CI pipes, break rates were 20 times as large in high corrosivity soil versus low corrosivity soil (Folkman, 2018, pp. 35-36). For DI pipes, break rates were 10 times as large. CI pipes with leadite joints have higher break rates than those with lead joints (Folkman, 2018, p. 31). Leadite and cast iron have different coefficients of thermal expansion, causing internal stresses that can lead to longitudinal splits in the pipe bell. Additionally, the sulfur in the leadite can cause pitting corrosion, leading to circumferential breaks near the joint at the spigot end. The USU study found that construction related failures are most relevant in DI and PVC pipes, indicating that construction methods regarding underground construction and maintenance should be improved (Folkman, 2018, p. 37).

Performing water audits can help to discover problems leading to water loss such as leakage from supply pipes. Leaks and water theft may then be located through system flow monitoring, visual inspection, or leak detection equipment. The results of water audits and water loss location can lead to intervention in order to fix the discovered problems. Following this, the effectiveness of the actions should be evaluated and the water audit cycle may be iterated upon. Performing audits should be a regular task at a WTP to ensure that water loss is handled effectively.

Table 29: Descriptions, costs, and savings of several water auditing case studies (NRDC, 2015, pp. 3-4).

Case Study	Description	Total Cost	Savings	Payback Period
Tennessee, 1988	Water auditing and corrective actions were done to reduce water loss in a total of 278 water utilities.	$2.7M	$24.4M per year	38 days
California Utility	A 37k customer water utility identified leaks and apparent losses over a period of two years through water auditing and interventions.	$200k	$300k+ per year	8 months
Philadelphia Water Department	The active leak detection program regularly checks for leaks and performs corrective actions to minimize water losses year-round.	$800k per year	$2.5M per year	4 months

The NRDC states that typical methods of intervention following a water audit include fixing water main leaks through repair or replacement and fixing or replacing customer water meters (NRDC, 2015, p. 1). The costs and results of these actions vary greatly yet are typically expected to have short payback periods in most cases. In a Georgia case study, it was found that testing and repairing commercial water meters for customers with more than $10k in annual water bills would yield on average $924 or more of recovered revenue per account per year, equating to a payback period of about 1 year for a service cost of nearly $1,000 (NRDC, 2015, pp. 6-7). The NRDC also states that Philadelphia saved $23 million in total from 2000-2013 by controlling leakage and apparent losses (NRDC, 2015, p. 4). The results of the city's active leak detection program are shown in **Table 29** along with two other relevant water auditing case studies.

To perform water audits, the AWWA Free Water Audit Software incorporates the M36 manual methodology into a computer program. For many WTPs, this is the preferred method of performing water audits. However, CNT reports that many WTPs still do not use this best practice tool (CNT, 2013, p. 7). For WTPs that want to try out a simpler method of water auditing first, the EFCN Water Audit Handbook for Small Drinking Water Systems is a useful option (EFCN, 2013, p. 30). After trying this simple method, a water utility can decide on pursuing more advanced options for further detail regarding their water losses.

User water intensity among WTPs

The AWWA survey (Carlson & Walberger, 2007, p. 19) found water use per capita served ranges from 50 gallons per day per capita to greater than 1000 gpd, with the most frequent use ranging from100-250gpd peaking at 150 gpd. Consumption above 250 gpd likely indicate significant industrial use. A 2016 WRF study found a median residential water consumption of 83,000GPY per household (DeOrea, Mayer, & et.al., 2016, p. 4) (or 86gpd per capita). The WRF study also found indoor water use averaged 52gpcd, with the largest uses toilets (24%), showers (20%), faucets (19%), clothes washers (17%) and leaks (12%) (DeOrea, Mayer, & et.al., 2016, p. 5). The change in water use since a 1999 WRF study, with a different population, was a 15 decrease per capita (DeOrea, Mayer, & et.al., 2016, p. 8).Looking at outdoor water use, the WRF study found 13% of households irrigated at very high levels (140-more than 300% of theoretical plant needs) (DeOrea, Mayer, & et.al., 2016, p. 6). A USGS spreadsheet estimated Minnesota public water use by county ranges from 22-97 gpcd (Dieter & et.al., 2018) with an average of 55gpcd (Dieter & et.al., Estimated Use of Water in the United States in 2015, 2018, p. 23). A MN DNR spreadsheet covering 301 municipalities shows median residential water use is 50gpd per person but ranges from 20-233gpd, with nine municipalities having average residential consumption greater than 100gpd per capita (ESPWater 2018 Muni Water Accounting Spreadsheet, 2018).

Water Use intensity information may allow us to evaluate the potential for water conservation programs as an approach to energy conservation at water utilities. A disincentive to water conservation initiatives is "If less water is sold, then revenues drop. Because many of a utility's costs are fixed (e.g., the capital costs of existing infrastructure), conservation can drop revenue (income) faster than costs" (Kenney, 2014, p. 37). Conservation can result in "demand hardening" where in cases of drought or water supply pressure, it becomes difficult for the system to quickly lower volume if needed (Kenney, 2014, p. 39\). Declining rate structures, that is the cost of water becomes smaller as the volume of use becomes larger, are now out of favor because they tend to encourage excessive use and they cannot be fiscally justified unless the cost of providing water declines with increasing volume (Kenney, 2014, p. 40), which generally occurs only in bill preparation.

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Appendix B: Interviews

Interview Form

1. Description of the utility's operation:
   # & types of Customer; key customers
   Water source(s)
   # of wells, capacities, pump parameters (power, voltage, phase, curves), and depths
   Treatment description – disinfection, softening, FE, other; elevations
   Distribution description - # towers/reservoirs; elevation; customer pressure
   Operational Issues or problems that constrain options
   Are you a member of a Trade associations?:
      MN Rural Water Association – MRWA
      Mn Wastewater Operators Association - MWOA
      Water Environment Federation (WEF)
      Water Research Foundation (WRF)
      American Water Works Association (AWWA)
      Other…
      Do they provide useful Energy or water conservation resources or assistance?
   Have your worked with energy utilities to identify, or implement energy conservation?
   Who do you work with to?:
      procure key equipment e.g. pump suppliers?
      for key equipment maintenance, e.g. pump overhauls?
      for plant design / engineering?
    Is energy efficiency part of the procurement discussion? How?

2. Current energy use at WTPs – average & range
      # of electric bills & what they cover
      Energy for water acquisition (kWh/MG)
      Energy for water treatment (kWh/MG)
      Energy for water distribution (kWh/MG)
      Other
      'Energy cost of water' benchmarks used

3. Energy conservation accomplished
    What has been tried; how were opportunities identified?
    Do you Benchmark energy? How? (kWh/MG)
    How was conservation done?
    What were the results and how much energy was saved?
    How did you pay for E2 changes? Are there barriers to funding E2?
    Conservation approaches that apply
      Operations energy – pumps, drives etc.
      Operations Controls

Building energy – lights, ventilation
Leak / non-revenue water reduction
    Current loss rate
Customer conservation

4. Energy conservation potential within utility operations
    What types of energy efficiency (E2) options exist for?:
    1. well pumps.
    2. water distribution systems (pumps, etc.)
    3. other treatment operations (filtration, separation etc.) [determine relative significance if possible – is this important?]
    4. control systems, automation, improved maintenance [determine relative significance if possible – is this important?]
    5. lighting, HVAC & building uses [determine relative significance if possible – is this important?]

    What types of best management practices have been established for these E2 opportunities?
    What energy savings are possible, and likely for each opportunity – average and range?
    What is the cost of implementation for E2 opportunities?
    Barriers to implementation

5. Water losses / leakage rates among WTPs
    What are system Leak rates – average and range?
    What are common causes or sources of leaks? & which are most important?
    Leak reduction methods, costs, and reduction by type
    Are there other resources than the M36 manual (AWWA water audit manual) that cover distribution water loss?

6. Customer use intensity & conservation potential/barriers
    Gallons per household
    Gallons per business – by type
    Gallons per acre for irrigation
    Are there conservation opportunities at end-users / customers that would reduce water extraction and resulting energy use (also delay system expansion)?
    Do you have a customer water conservation program? Structure? Impact?
    What are the barriers or disincentives to customer conservation programs?

Appendix C: Assessment Summaries

WT4

An informational interview was completed on October 29, 2019 between MnTAP and WT4 staff. An assessment was completed throughout the following year. Two major analyses were completed, 1) verifying the energy savings associated with well rehabilitation and 2) simulating increased well efficiency prioritization. We were unable to sufficiently differentiate between well pump replacement and well rehabilitation, so this analysis was primarily focused on well rehabilitation. This analysis indicated an energy savings of **120,000 kWh/yr** that the city is already realizing by rehabilitating each well on a seven year cycle. This corresponds to a cost savings of **$9,600 per year** and constitutes 2% of the total energy used by the utility. The simulation of further well efficiency prioritization indicated a possible savings of **465,000 kWh/yr** which corresponds to a **$37,000** annual savings and would be an 8% reduction in total energy use. The analysis on efficiency prioritization shifted the hours that pumps were run to pumps that had a lower specific energy on a rolling 12-month average. This is subject to change depending on specific well water quality and other parameters affect actual well utilization. The savings values are displayed in **Table 30**.

Table 30: Savings potential from past and future energy savings opportunities.

Opportunity	Annual Energy Savings (kWh)	Annual Cost Savings
Well Rehabilitation	120,000	$9,600
Well Pump Efficiency Prioritization	465,000	$37,000

Customer conservation was also analyzed to determine the impact of rebate programs on water pumped, and ultimately on energy consumption. The analysis conducted showed a reduction in the gallons per capita for WT4 of approximately 3 gallons per capita per day every year between 2014 and 2019. This reduction did not show a corresponding reduction in energy use by the utility which is still under investigation.

WT10

An informational interview was completed on December 3, 2019 between MnTAP and WT10 staff. An assessment of the drinking water treatment system was completed throughout the following year. The primary analysis completed was verifying the energy savings associated with well pump replacement and well pump efficiency prioritization. These two analyses indicated an energy savings of **380,000 kWh/yr and 210,000 kWh/yr,** respectively that the city is already realizing. These two energy savings together correspond to a $47,000 per year savings in electricity consumption and constitute 6% and 3% of total energy use, respectively.

Two other opportunities were identified that could potentially save energy in the future: prioritizing booster pumps based on efficiency and tuning each well pump's variable frequency drive (VFD) to match the best operating point for each pump. These two opportunities need more analysis but have the potential to save **15,000 kWh/yr and 64,000 kWh/yr**, respectively. The savings from these analyses and opportunities are listed in **Table 31**.

Table 31: Savings potential from past and future energy savings opportunities.

Opportunity	Annual Energy Savings (kWh)	Annual Cost Savings
Well Pump Replacement	380,000	$30,000
Well Pump Efficiency Prioritization	210,000	$17,000
Booster Pump Prioritization*	15,000	$1,200
VFD Optimization*	64,000	$5,100

*Opportunities need more analysis before implementation.

Customer conservation was also analyzed to determine the impact of rebate programs on water pumped, and ultimately on energy consumption. The analysis conducted showed a reduction in the gallons per capita for WT10 of approximately 3 gallons per capita per day every year between 2012 and 2019. This led to a 2019 pumping total that was 87 MG less than the 8-yr average and a 2019 energy total 110,000 kWh less than the 8-yr average.

WT8

An informational interview was completed on November 21, 2019 between MnTAP and WT8 staff. An assessment was completed throughout the following year to identify energy savings opportunities. The primary opportunity identified was to reduce water losses by performing leak detection and identifying significant sources of water losses. Repairing these water losses will result in an estimated energy savings of **53,100 kWh per year, $5,700 in annual energy cost savings**, and $12,900 in annual overall cost savings when combined with chemical costs for treatment. This represents a 30% reduction in energy usage which is larger than other sites due to an unusually large leak rate at WT8.

WT14

An informational interview was completed on January 14, 2020 between MnTAP and WT8 staff. An assessment was completed in the following year to identify low or no-cost energy savings opportunities for WT14. The purpose was to find strategies for adjusting operations to reduce energy consumption and operating costs. The primary analysis completed was verifying the energy savings associated with well pump efficiency prioritization and optimizing distribution pump utilization based on pumping efficiency is on-going (**Table 32**). This involved simulating 2018 water production with 2019 utilization as well prioritization was initiated in 2019. By compared 2018 and 2019 relative well pumping and energy usage a savings of **43,000 kWh and $1,500 per year** was identified. A similar opportunity was identified for distribution pumps, but an in-depth analysis was not completed due to insufficient data. An estimated **21,000 kWh and $730 per year** could be saved with this process change.

Table 32: Summary of analyses and opportunities for energy reduction.

Opportunity	Annual Energy Savings (kWh)	Annual Cost Savings
Well Pump Efficiency Prioritization	43,000	$1,500
Distribution Pump Prioritization*	21,000	$730

*Opportunities need more analysis before implementation.

WT2

An informational interview was completed on October 15, 2019 between MnTAP and the City of WT2 Water Treatment Plant. An assessment was completed throughout the following year to identify energy saving opportunities for the WT2 Water Treatment System. The primary opportunity identified for WT2 was the installation of VFDs to eliminate well throttling. The primary analysis completed was verifying the energy savings associated with eliminating well throttling and altitude valves by installing VFDs. It is estimated that VFD installation saved **46,000 kWh and $9,000** annually. These findings are summarized in **Table 33**.

Table 33: Realized savings from VFD installation on well pumps.

Opportunity	Annual Energy Savings (kWh)	Annual Cost Savings ($)
VFD Installation	46,000	$9,000

Appendix D: Demand Charge E2 Disincentive Discussion

Demand charges are a tool electrical utilities use to assure they have system capacity to supply the maximum electrical usage of their customers individually and as an aggregate. Demand charges are typically structured based on continuous measurements of kW and charging demand on the highest average kW for a predetermined interval (usually 15-20 min) for that month. Demand charges for most manufacturing or large institutional customers provide an incentive to avoid peak usage, and encourages energy efficiency.

For industrial and institutional customers the demand charge rate structure works well and accurately reflects their usage – if production goes up, more equipment goes online, and electrical consumption increases. These large customers typically have one location with relatively few electric meters, and metered consumption is proportional to production. For most large customers with more than one electric meter, while loads fed by one meter may affect loads fed by a second meter, the loads are generally used for different purposes - parallel loads are not on different electric meters – if production goes up, loads on all of the meters are needed to meet that increased production. In this case the demand charge reflects the electrical use, and especially the peak use by that customer.

Water utilities are different – their operations are geographically spread out, with multiple electric meters for pumps (especially wells) that operate in parallel and are used interchangeably. Water utilities, on a seasonal basis, can act like traditional customers, with water production increasing in the summer with more pumps brought on line and aggregate electrical consumption rising with water production. But for large parts of the year, they are rotating and exercising their pumps to keep run hours relatively equal. In addition, the DNR requires many water utilities to run monthly drawdown tests for each well on sensitive aquifers. These tests require the water utility to run each well for 30-60 minutes every month regardless of what the current water production needs are. In this situation, the high demand intervals on each meter bear no relation to system water production or to total electrical consumption for the whole system.

A few more sophisticated WTPs will select pumps for operation based on their efficiency. However, for many WTPs, demand charges create incentives to run less efficient equipment more than is needed. A WTP exercising an inefficient well pump will pay the same demand charge to run it for 4 hours to verify its operability and get the bearing lubricated, as they would to run the pump for a month (720 hours). In this situation it makes sense to run the pump longer to spread the demand charge over more gallons pumped.

Water utilities general operate with multiple electric meters, each with its own billing structure. Of the 15 water utilities interview, 9 had sufficient data to determine whether demand charges were applied. These 9 systems had 58 meters, and 44 of the meters had a rate structure that included demand charges. As an example: Water system WT14 has 12 electric meters, six meter reading patterns, and 2 rate structures (eleven electric meters using a demand charge and one using a blended electrical usage rate). WT14 has four wells on their own electric meter; there are four pairs of wells on a meter – one of these pairings is also combined with the main filtration plant; one well is paired with a second filtration plant; and three other meters for booster stations or reservoirs with a boost pump.

The meter reading patterns were mostly similar with readings generally occurring during the first week of the month, but in any given month, the reading date on one meter could be up to four days different from the reading date for another meter. Although, each bill from Xcel Energy has the next meter read date, it is still difficult to manage demand because:

1. For some Cities, plant staff do not see the electric bills – another City department deals with the bills.
2. There is still the question of the time of day the meters are read.
3. Even with all the information needed, the effort to optimize for demand is significant – staff cannot plan, for example that the first and second days of the month are when pump exercising should be done.

For WT14, the $2,600 annual savings for well optimization (see **WT14**) at 2019 production levels is erased if the demand on any one well is not adequately controlled for a bit over two months.

Possible solutions:

1. Ideally the electric utility would treat drinking water utilities as the systems they are and charge demand on the high kW draw for the system rather than on each electric meter individually. A barrier to this approach is it would require coding to monitor and combine readings from groups of meters.
2. Electric utilities could make it easier for water utilities to manage their demand by:
    a. Standardizing the meter reading dates so all readings for billing purposes are identical for all meters in the system
    b. Making the reading date and ideally a time window for readings transparent and known to water utility staff. Ideally, that time window would be at a low water demand time, such as midnight to 6am.
3. Charge a blended electrical rate that does not have a separate demand charge.
4. Water utilities could minimize demand charges by any of the following.
    a. Exercising low-use pumps at the lowest speed that provides productive flow and increase speeds to test desired flow rates for a timed interval that is less than the demand charge interval.
    b. Except during the highest water production months, where two wells are on the same meter, one pump should be shut off before starting the second pump.
    c. Run DNR required draw-down tests at the beginning and end of a billing period so two tests are run in a single billing period, while zero are run in the next billing period – if DNR rules allow this).
    d. Run pumps as long as possible – run small pumps continuously as a base load.

Appendix E: Opportunity Summary Table

Table 34: Opportunity summary table.

Opportunity	ID	Savings Potential	Sector Potential	Cost Range	Incentive
Pump/well Rehabilitation: Period maintenance on pumps and wells based on schedule or specific energy	• Target groundwater sites (95% of sites)	• 8% of acquisition energy • Additional 1-2% if measuring specific energy • 70 – 110 kWh/MG	• 14,100,000 kWh/yr	• Measurement – low cost • Rehabilitation – medium	• Incentivize # of gallons a more efficient pump produces for 2 years going forward compared to baseline pump use • Incentivize rehabilitation activities
Pump Optimization: Optimal pump selection, including use of shallower wells	• Screen specific energy: amp & flow snapshots • Use pumping level chart to estimate potential	• 46-180 kWh/MG average 120 kWh/MG • shallow wells: 500kwh/MG-100ft	• Wells: 14,300,000 kWh/yr • Distribution: 2,150,000 kWh/yr	• Measurement – low cost • SCADA measurement – significant • Lrg system control software - significant	• Incentivize # of gallons a more efficient pump produces for 2 years going forward compared to baseline pump use
Pump Optimization: Pump design at replacement	• VTP vs submersible • Evaluation of pump curves	• VTP have 10% eff advantage • 670 kWh/MG average	• 8,280,000 kWh/yr	• Well house – significant • Cost premium unknown	• Incentivize equipment purchase

Opportunity	ID	Savings Potential	Sector Potential	Cost Range	Incentive
VFD Installation and Optimization: Eliminate throttling	• Presence of a throttling valve with at least some restriction • A pump with significantly greater flow capacity than it produces	• 30% seen; no further claimed	• N/A	• VFD Installation – medium	• Standard VFD incentive • Better – compare specific energy before & after and apply to the gallons produced
VFD Installation and Optimization: BOP	• Use pumping level chart to estimate potential	• 1-3% of pump energy	• 1,900,000 kWh/yr	• Measurement– low cost • SCADA measurement– significant • Change – low cost	• Incentivize # of gallons a more efficient pump produces for 2 years going forward compared to baseline pump use
VFD Installation and Optimization: Friction loss reduction	• Evaluate if system has horizontal pipe lengths at least 100 times the lift height • Compare the pump head with the lift height	• 1% of pump energy where friction is significant	• N/A	• Engineering analysis to verify the amount of friction loss and the potential for reduction	• Incentivize engineering study

Opportunity	ID	Savings Potential	Sector Potential	Cost Range	Incentive
Customer Conservation: Irrigation	• System peaking factor	• 750-860 kWh/rebate (DNR/MnTAP)	• 1,150,000 kWh/yr	• Medium	• Rebate for purchase • Pay WTP to prohibit / penalize irrigation during peak energy events (load shift) • Pay large irrigators to interrupt irrigation during peak events
Customer Conservation: Shower heads, aerators, toilet, washers, dishwashers	• Gallons per capita • Age of housing stock	• 5-20 kWh/rebate (DNR/MnTAP)	• 1,500,000 kWh/yr	• Low to medium	• Rebate for purchase
Customer Conservation: Other – commercial, rainwater, audits	NA	• 1-170 kWh/rebate (DNR/MnTAP)	• 85,000 kWh/yr	• Medium	• Rebate for purchase
System Loss Reduction: Leaks	• DNR reported lost rate >10%	• 2.5-31% reduction of distribution losses	• 190,000-2,380,000 kWh	• Small leak monitoring: medium • Repair: medium – large	• Incentivize on number of leaks repaired
System Loss Reduction: Hydrant repair	• Hydrant leaks are identified • Flushing occurs without a procedure	• 0.4-2.3% reduction of distribution losses	• 28,000-176,000 kWh	• Medium	• Incentivize number of leaks repaired • No incentive needed for procedure improvement

Opportunity	ID	Savings Potential	Sector Potential	Cost Range	Incentive
System Loss Reduction: Treatment efficiency	• Treatment loss volume	• 2.3-43% reduction of treatment losses	• 48,000-890,000 kWh	• Medium	• Depends on solution – possibly incentivize equipment purchase
System Loss Reduction: Pressure control	• Max pressure 80 psi • Minimum pressure 35 psi	• 1.4% reduction of distribution losses	• 100,000 kWh	• Medium	• Incentives are unlikely