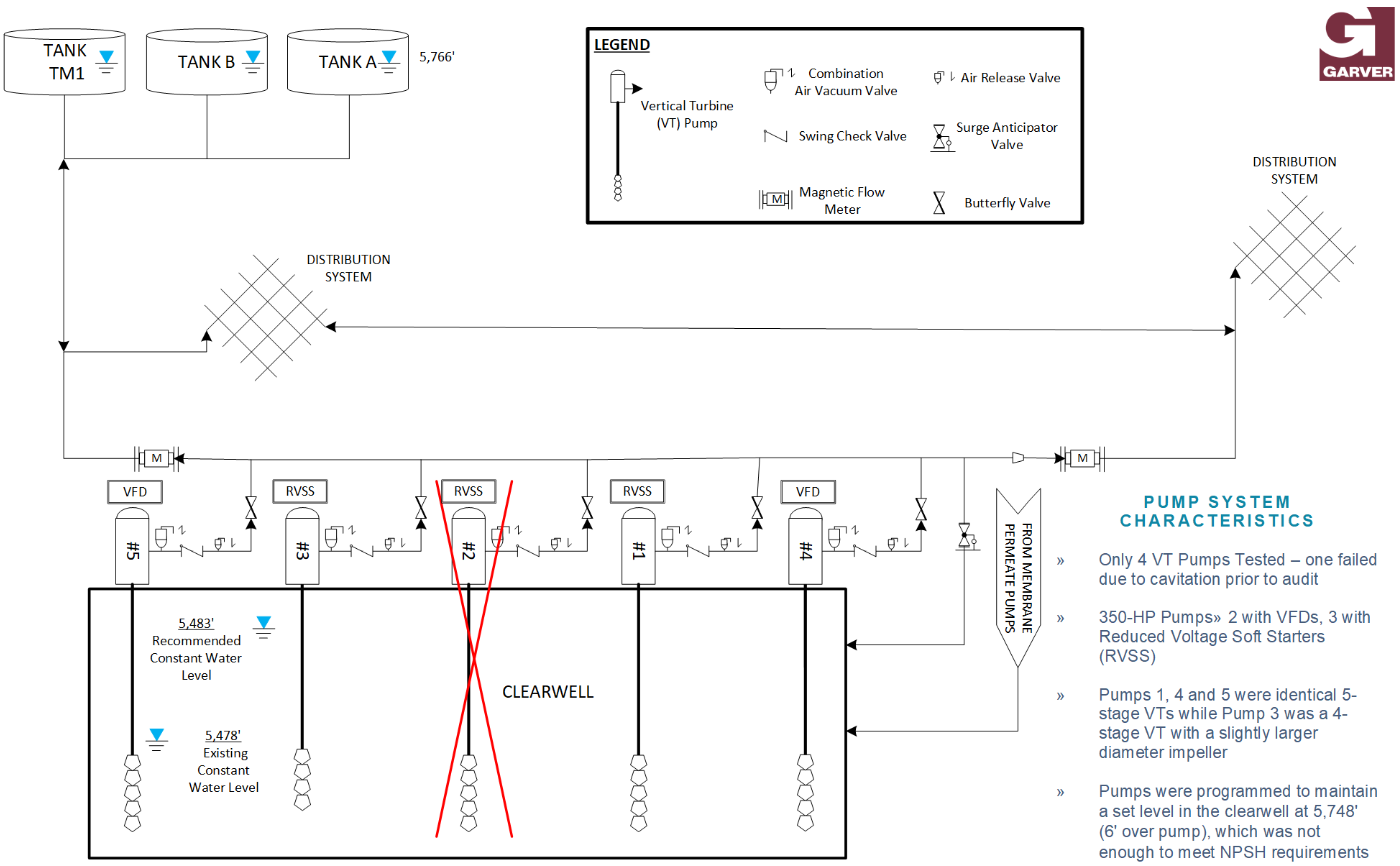
PUMP SYSTEM TRAINING AND CERTIFICATION DRIVE SAVINGS

Garver, a multi-disciplined engineering, planning, architectural, and environmental services firm, was called to audit the pumping system of a facility with four large (350-horse power) vertical turbine pumps. The audit focused on ensuring efficient operation and minimizing wear that could cause increased electrical costs, maintenance costs and potentially reduce the pumps' lifespan. This investment grade energy audit was partially funded by Xcel Energy as a part of their demand side management (DSM) rebate program, contributing $24,025 of the $32,066 engineering fee. The four pumps evaluated in this study deliver treated water from a 16-million gallon-per-day ultra-filtration membrane treatment plant clearwell to the local distribution system's elevated storage tanks, as described in Figure 1. After having one pump fail previously due to cavitation, the site did not want to risk another pump failure.

Garver's Water Technology team leveraged their experience and expertise performing wire-to-water efficiency tests to initially baseline the existing energy intensity and later optimize pumping operation through the development of Energy Efficiency Measures (EEMs). "No cost" to "low cost" EEM's were recommended as actions that would increase efficiency, reduce energy consumption, increase reliability, and lower the total cost of operation. The assessment and optimization concepts incorporated in this project are outlined in Hydraulic Institute's Pump System Assessment Professional (PSAP) Certification, and Preparatory Course offered by Pump Systems Matter.

Eric Dole, PE, PSAP, Garver's Water and Energy Practice Lead completed the audit. Eric is one of the country's first water engineers to obtain the Hydraulic Institute's PSAP Certification, which he gained in 2018. He has performed over 165 wire-to-water efficiency tests and hydraulic optimization projects over his 21-year career, while also serving on the Water Research Foundation's Energy Advisory Committee. To qualify for PSAP certification, applicants must have at least three years of pumping assessment experience and demonstrate knowledge on pump system assessment and optimization during an examination held by the Hydraulic Institute's Certification Section. Their educational foundation Pump Systems Matter (PSM) also offers a two-day Pump Systems Assessment Professional course that provides attendees with a thorough training on pump system physics and engineering, and system assessment and optimization techniques, plus a half day of focused preparation for the challenging certification exam.

Figure 1 – Distribution System Pump Process Flow Schematic



SYSTEM UPGRADES

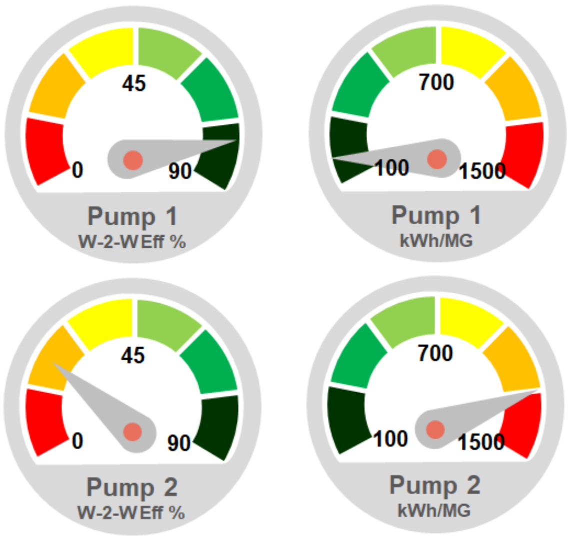
Figure 2 – Picture of Pumps that Received Wire-to-Water Testing

Over the course of the project, wire-to-water efficiency tests were conducted to baseline the system's energy intensity, establish field-verified pump and system curves, and determine "no cost" to "low cost" EEMs to improve efficiency and reliability. Not only does an investment grade audit provide valuable information on the existing pump system operation, it also establishes a field-verified system curve. This eliminates the guesswork involved in characterizing the buried pipe configuration, as well as major and minor friction losses. For each flow and total head data point collected, a corresponding input power was recorded simultaneously. This information was used to calculate the wire-to-water efficiency, true horsepower (hp) and pump curve for each pump at multiple throttle points. Wire-to-water efficiency is an excellent way to determine the "fitness" of the pump. Wire-to-water efficiency is simply the pump

Throttling a pump discharge valve for a pump at full speed is used to build a pump curve when coupled with the pump upstream boundary condition control point (i.e.; pressure or level) to determine head vs. flow. Collecting pressures immediately downstream of the throttled valve is used to build the system curve. Varying the speed of a pump can also be used to build a field system curve.

efficiency multiplied by the motor efficiency and the VFD efficiency (if applicable) at the pump operating point. As part of this project, a Key Performance Indicator (KPI) dashboard tool was implemented that tracks the real-time wire-to-water efficiency and energy intensity. This KPI tool was used by the electric utility to perform measurement verification to ensure the design upgrades resulted in the predicted savings so they could rebate the EEMs at $400/kW. Figure 3 shows an example of the efficiency and energy intensity measures provided by the dashboard.

Figure 3 – KPI Energy Dashboard Developed for this Project

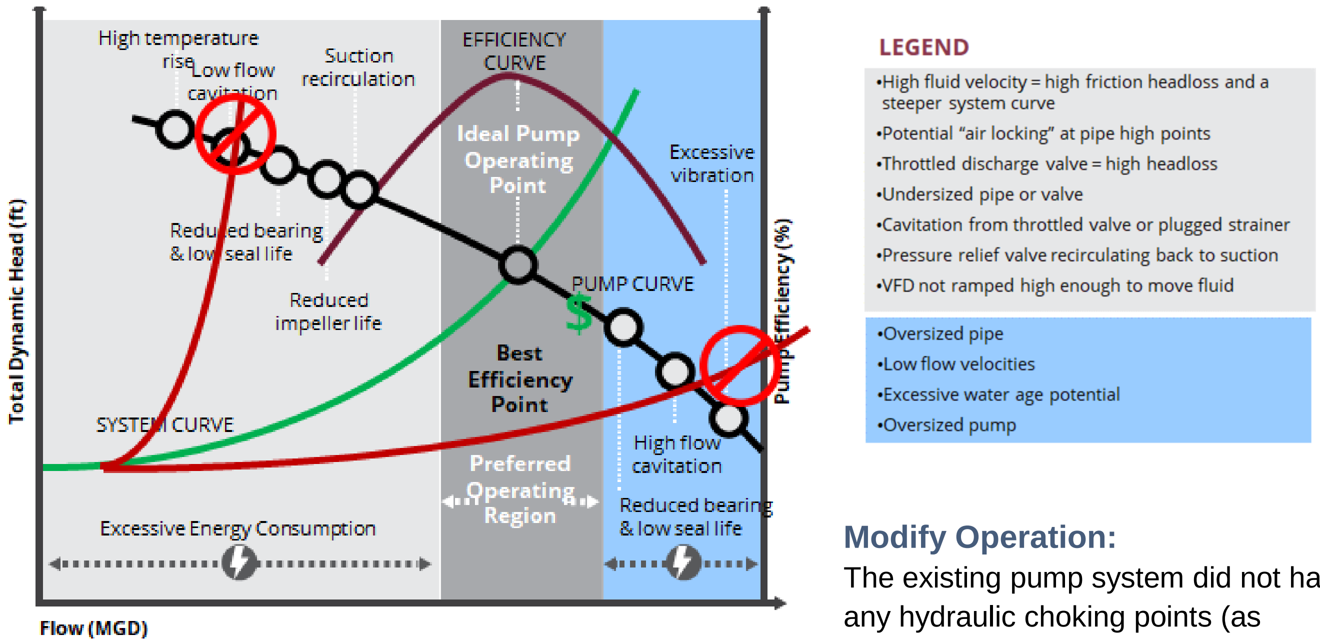


Three categories of system improvements highlighted in the PSAP Course for system energy improvements are: flatten the system curve by eliminating hydraulic choking points, modify operation, or replace equipment.

Flatten System Curve:

System pressure takes two forms: static head (the pressure in liquid level a pump must overcome to start fluid flow) and dynamic head (the pressure in liquid level created by friction caused by fluid velocity in the system). Dynamic head, is a function of the flowrate through the system and head loss associated with major losses through pipe and minor losses through fittings and valves. Because a pump's operating point occurs where the system curve intersects the pumps curve, understanding this relationship is essential to properly designing, assessing, and optimizing pump systems to ensure efficient, reliable operation. Figure 4 describes the pump-system curve relationship, and what happens to a pump when it is operated outside of the preferred operating region (POR). For systems with steep system curves, there may be opportunities to improve pump performance by flattening the system curve to reduce total head requirements, which also reduces power requirements to maintain the same flow.

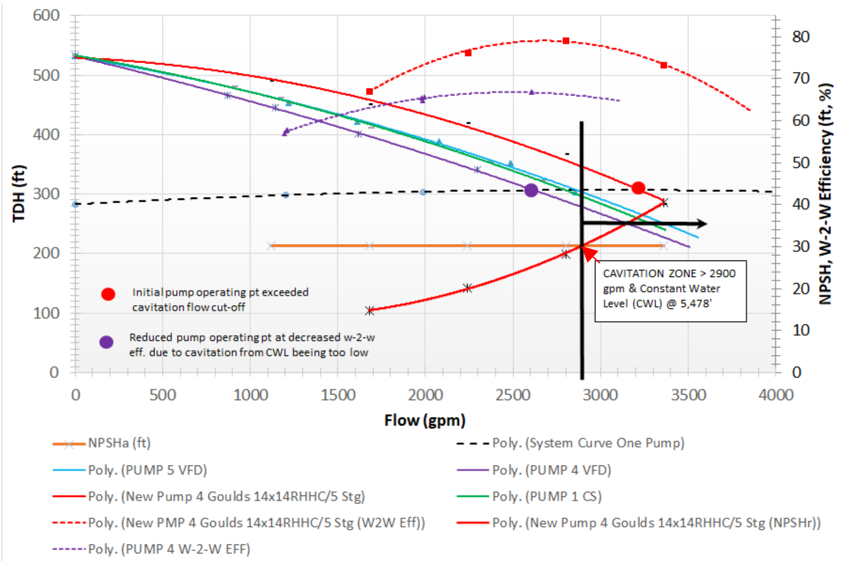
Figure 4 – Pump / System Curve Relationship & Symptoms of Inefficient Pump Operation



Modify Operation:

The existing pump system did not have any hydraulic choking points (as indicated by the flat field system curve shown in Figure 5), nor was it oversized for the system to operate outside the POR of the pumps. In fact, the pump was designed to intersect the system curve in the POR of the pump. However, what Pumps 1, 2, 4 and 5 did have was an excessive Net Positive Suction Head Required (NPSHR) for the operating point where they ran 60% of the time as can be seen in Figure 5. Additionally, testing revealed the performance for all three pumps was well below the original manufacturer's pump curve (red solid curve). Pump 4 was the least efficient (purple dashed curve) when compared to the original pump efficiency, adjusted for motor efficiency (red dashed curve).

Figure 5 – Pump 1, 4 and 5 Wire-to-Water Testing Results and Field System Curve



The pump station is located at 5,478 feet above sea level, meaning there is less barometric head to work with when determining Net Positive Suction Head Available (NPSHA). This critical fact was not considered when determining the constant water level setting in the pump station control logic. This can be seen by the original Pump 4 curve intersection with the system curve being significantly to the right of where the NPSHA curve intersects the NPSHR curve (red dot), which resulted in cavitation. The force of water vapor bubbles imploding at the surface of the impeller where the can cause local pressure waves up to 100,000 psi, which can erode the pump impeller. See Figure 6 for a picture of the damaged Pump 2 impeller. Based on the results of the testing, Pumps 1, 5 and 4 are likely to experience the same cavitation issues, with Pump 4 having the highest likelihood of cavitation. A "no cost" solution was to: 1) increase the minimum pumping water level by five feet so NPSHA is 10% greater than NPSHR per ANSI/HI 9.6.1; *and* 2) stage the pump sequencing so the most efficient pump runs the most, followed by less efficient pumps as flow increases (i.e. Pump 3 (1^{st}) Pump 5 (2^{nd}) Pump 1 (3^{rd}) Pump 4 (4^{th})). By incorporating these two measures, the pumps would no longer cavitate, and average savings of 23.5 kW demand (68,560 kWh) during the summer months, and 21.7 kW average power demand over the course of a year, and a 133,070 kWh/yr power consumption savings are realized. This resulted in approximately $4,790 in annual electrical savings without any capital expenditure.

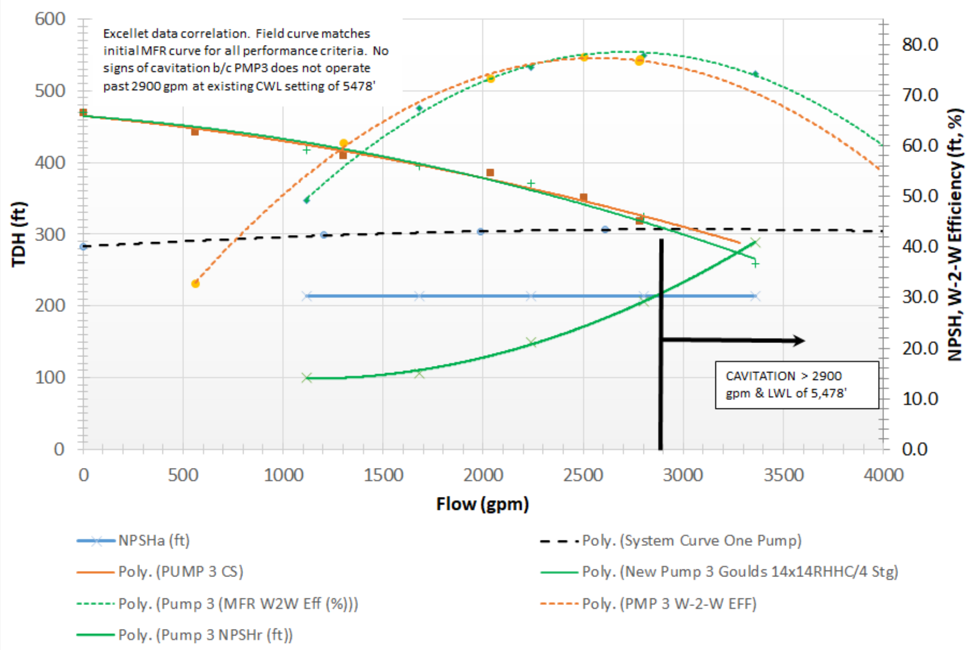
Figure 6 – Picture of Cavitated Pump 2 from Repair Shop

Pump 3's field curve matched the initial manufacturer data for all performance criteria, indicating excellent field correlation and design, as can be seen in Figure 7. Despite Pump 3 having a slightly higher NPSHR value at 2,800 gallons per minute (gpm) of 29.3 feet versus 28.3 feet for the other 5-stage pumps, it did not have cavitation damage. This was because the 4-stage pump (Pump 3) resulted in 2,900 gpm versus 3,250 gpm with the 5-stage pumps (Pumps 1, 2, 4, and 5). The lower flow from Pump 3 fell within the NPSHA, whereas Pump 1, 2, 4, and 5 intersected the system curve at a flow that required 37 feet of NPSHR when there was only 31.1 feet NPSHA.

Replace Equipment:

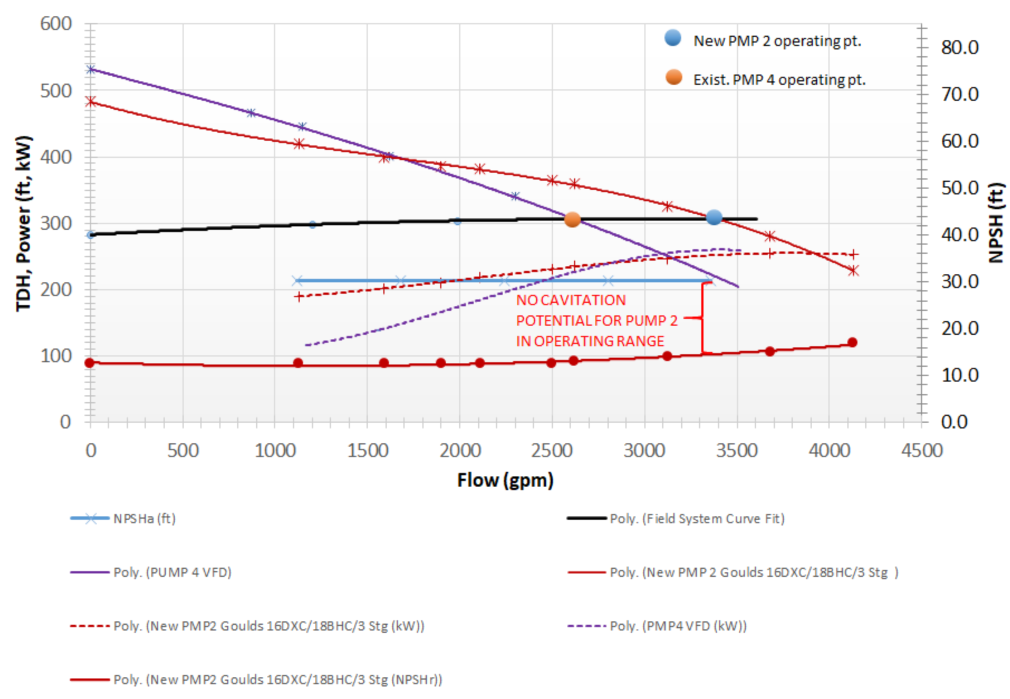
Since these distribution pumps deliver treated water to elevated storage tanks that "float" the distribution system below, there was no need to add a Variable Frequency Drive (VFD) to Pump 2 or replace Pump 4 that was driven by a VFD, as it would just decrease the wire-to-water efficiency. VFDs are well suited for closed loop distribution system pumping that requires change in system pressures as demand changes, whereas an elevated tank simply raises and lowers water level in response to changing demands. VFD's are also well suited for systems with steep system curves to maintain high efficiencies over a wide range of total head conditions.

Figure 7 – Pump 3 Wire-to-Water Testing Results and Field System Curve



A "low cost" solution was to incorporate all the "no cost" EEMs previously stated, but also replace Pump 2 with a more efficient, lower NPSHR pump. Pump 2 was already scheduled to be equipped with a new 350 hp 3-stage pump with lower NSPHR, that would increase the flow by 800 gpm at 10% less kW than Pump 4 experienced in the field, with no concern of cavitation at the existing water levels. Refer to Figure 8 for Pump 2's anticipated performance curves as compared to the performance of Pump 4's wire-to-water efficiency test results. Equipping Pump 2 with the previously mentioned 3-stage pump ultimately resulted in a decrease in demand of 33.7 kW (434,575 kWh) during the summer months, 26.8 kW average power demand saving over the course of the year, and 725,624 kWh/yr energy consumption savings. The potential rebate and electrical cost savings resulted in less than 1.77 years Return on Investment.

Figure 8 – Replacement Pump 2 Performance Curve



TURNING THEORY INTO RESULTS

From the investment grade energy audit, two paths to achieving energy savings were recommended:

- "No cost" EEM: Maintaining the current equipment but increase the clearwell level by 5 feet and optimizing pump staging. This results in the following savings with no expenditure:
  - **Avg. summer demand reduction of 23.5 kW**
  - **Potential rebate at $400/kW of $9,400**
  - **Energy Savings = $4,790/yr**

- "Low cost" EEM: incorporate "no cost" EEM, but additionally replace Pump 2 (which was out of commission at the time of audit) with a more efficient pump that delivers 30.8% more flow than Pump 4 at 10% lower kW. Operate Pump 2 as the primary pump in the pump sequencing followed by Pump 3, Pump 5, Pump 1 and lastly Pump 4. This results in the following savings with low expenditure:
  - **Assumes new Pump 2 will operate 30.8% less than existing Pump 4 while delivering equivalent total flow since Pump 2 delivers 30.8% more flow than Pump 4**
  - **10% less kW for new Pump 2 is excluded from cost savings to be conservative**
  - **Average summer demand reduction of 33.7 kW**
  - **Annual kWh reduction of 725,624 at $0.036/kWh = $26,122/yr energy savings**
  - **Potential rebate at $400/kW (avg. summer demand savings) of $13,460**
  - **$49,926 for new constant speed Pump 2 on existing 350 HP motor**
  - **ROI = 1.77 years**