# Four Energy Metrics for Public Water Systems

Robert B. Sowby, Ph.D., P.E., ENV SP

Hansen, Allen & Luce, Inc.

American Public Works Association, Utah Chapter, 2018 Fall Conference

## INTRODUCTION

Modern public water systems require energy to extract, treat, and deliver reliable, high-quality water to their customers. Energy is a significant cost, accounting for up to 40% of a water utility's operating budget, or even more for small systems; this proportion is expected to increase with scarcer water supplies and stricter water quality standards (USEPA 2017). While many aspects of water utilities are well managed, energy has historically received relatively little attention. Fortunately, considerable guidance has emerged in recent years (AWWA 2016; Chelius & McDonald 2016; Jones & Sowby 2014; UDDW 2014; Martin & Ries 2014; Liu et al. 2012; USEPA 2008; Barry 2007).

In seeking to effectively manage a public water system's energy use, several practical questions arise. How much energy are we using? Are we paying too much for it? Is our equipment performing as expected, or is it time to replace it? Is this pump more efficient than that one? How does water loss affect our energy use? To answer such questions, one needs the right information. Fortunately, much of this information is already being collected and ready to be put to use.

The following four energy metrics, each suited to particular applications, can inform energy management decisions, operation and maintenance, capital projects, and other actions in a public water system. Three metrics address energy use at equipment, facility, and system levels, and a fourth metric addresses energy cost (Figure 1). (While energy use here is primarily electricity, natural gas and other fuels may also be evaluated by similar metrics.)

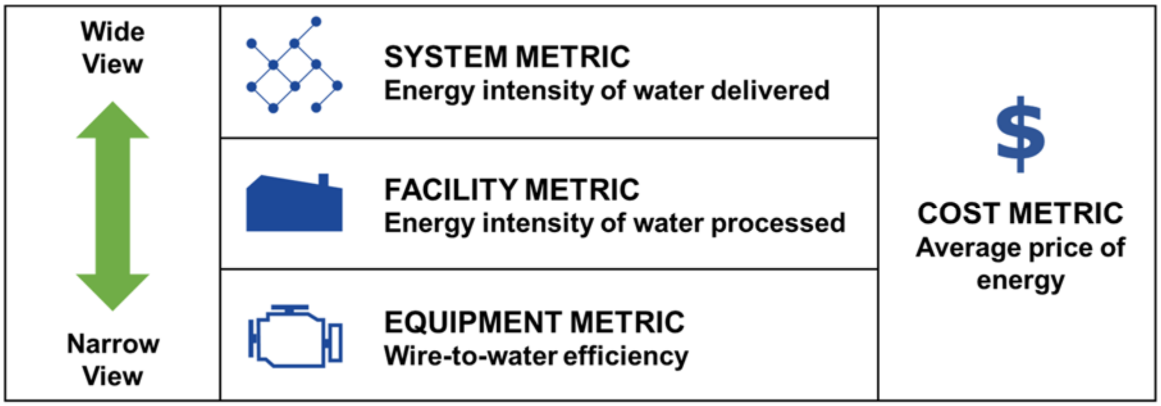

***Figure 1.*** *Four energy metrics for public water systems.*

## EQUIPMENT METRIC: WIRE-TO-WATER EFFICIENCY

The most familiar energy metric in the water industry is *wire-to-water efficiency*, the ratio of energy output to energy input in pumping equipment, often expressed as a percentage. Variable-frequency drives, motors, and pumps are devices that convert electricity into a combination of flow and head, but not all of the electricity can be converted; a portion is lost to heat. Wire-to-water efficiency describes how efficiently the equipment converts electricity ("wire") into work applied to the fluid ("water"). It answers the question, "How much of the energy input is useful?" A high value is desirable.

In design, wire-to-water efficiency is determined from expected hydraulic conditions, pump curves, and manufacturers' specifications. In reality, the value may differ from design depending on the actual conditions, especially over a number of years. For example, a decline in water table, an increase in pipe roughness, and normal wear and tear will increase the total dynamic head (TDH) and draw the pump away from its design point. Eventually the energy performance will deteriorate until the equipment must be maintained or replaced. For this reason, it is wise to periodically compute actual wire-to-water efficiency.

Three pieces of information are needed to compute wire-to-water efficiency: power input, flow rate, and total dynamic head. The electricity input (kW) into the pumping equipment should be measured directly with a portable fluke meter (or SCADA connection, if applicable) in order to avoided including other electric loads like HVAC and lighting that would be counted with the facility's electric meter. Average flow rate (gpm) may be measured on site. Average total dynamic head (ft) may be computed from the difference in discharge and suction head when the pump is operating. With these three variables, wire-to-water efficiency can be calculated from a variation of the pump equation:

$$\eta = \frac{Qh}{5280P}$$

where $\eta$ is wire-to-water efficiency expressed as decimal, $Q$ is the average flow rate (gpm), $h$ is the total dynamic head (ft), 5280 is a constant for unit conversions and fluid properties, and $P$ is the power input (kW).

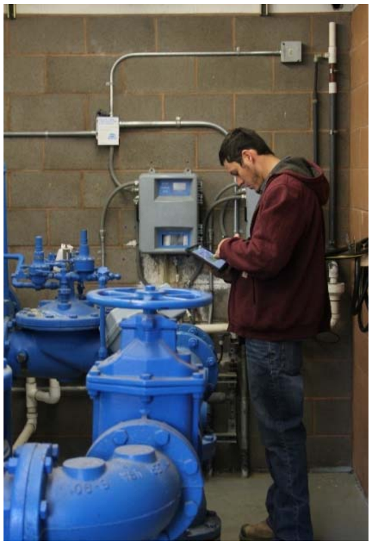

***Figure 2.*** *On-site measurements of flow, head, and power enable calculations of wire-to-water efficiency.*

For example, consider a pumping system designed for 79% wire-to-water efficiency (84% pump efficiency and 94% motor efficiency). Eight years after construction, on-site measurements indicate that the equipment draws 75 kW while pumping 1,000 gpm at 210 ft total dynamic head, yielding an average wire-to-water efficiency of 0.53, or 53%. The equipment is underperforming relative to its design, prompting further exploration of causes and solutions.

By itself, wire-to-water efficiency only indicates how efficiently the pumping equipment converts electricity into flow and head. It cannot be used to compare facilities and does not indicate the necessity of the energy use. While a high wire-to-water efficiency value is desirable, it does not necessarily mean it is the best choice. The following metrics help address those questions.

## FACILITY METRIC: ENERGY INTENSITY OF WATER PROCESSED

While wire-to-water efficiency focuses on pumping equipment, *energy intensity of water processed* is a more useful metric for facilities. Energy intensity, an energy footprint expressed as a ratio of energy use to water volume like kilowatt-hours per million gallons (kWh/MG), describes how much energy is needed to process a unit of water. It is an appropriate metric for any facility that produces water (e.g., well or diversion), treats water (e.g., treatment plant), or lifts or pressurizes water (e.g., booster station). Normalizing by water volume eliminates all effects of water production or demand and allows comparison solely in terms of energy. Energy intensity answers the question, “How much energy does it take to process a unit of water at this facility?” A low value is desirable.

Unlike wire-to-water efficiency, energy intensity at the facility level allows comparison and prioritization among several facilities. All else being equal (e.g., water quality, rights, and capacity), water utilities should prioritize facilities with the lowest energy intensity. Such opportunities are not apparent with wire-to-water efficiency, which does not directly correspond with energy intensity. If the objective is to save energy, the facility with lower energy intensity should always be favored, regardless of its wire-to-water efficiency; if its wire-to-water efficiency can be improved, the situation is even better.

Two pieces of information are needed to compute a facility’s energy intensity: total energy use and total water volume. The expression is

$$Y_F = \frac{E_F}{V_F}$$

where, over a given time period, $Y_F$ is the energy intensity of the facility (kWh/MG), $E_F$ is the total energy used at the facility (kWh), and $V_F$ is the volume of water passing through the facility (MG). Energy use is usually reported on monthly power bills; water volume should be measured on site. In general, annual totals of energy and water are sufficient for this calculation, but seasonal variations may be of interest as well, especially if the facility has only one power meter and the energy intensity captures building energy uses like HVAC and lighting.

For example, consider two wells, A and B, of equal capacity pumping to the same elevated tank. In one year, Well A consumed 500,000 kWh and produced 200 MG, while Well B consumed 300,000 kWh and produced 150 MG. Their energy intensities are 2,500 kWh/MG and 2,000 kWh/MG, respectively. Well B, therefore, is the better facility in terms of its energy intensity; producing the same amount of water from Well A would require 25% more energy. This may be because the water table at Well B is higher, Well B has better equipment, or the path from Well B to the tank has more capacity and therefore less head loss. Further analysis may uncover the exact reason for Well B’s lower energy intensity and options to favor it and/or improve both wells may be considered.

A collection of several facilities’ energy intensities constitutes an *energy map* (Figure 3). Jordan Valley Water Conservancy District, which serves the Salt Lake City area, created an energy map during an energy management program with its power provider. Until examining the data, the District did not know which wells were the least energy-intensive, or how much more energy-intensive they were than surface water. The District then used the energy map, along with existing constraints like water rights and water quality, to decide which water facilities to operate and when to operate them. Over a two-year period, the district reduced its energy use by 19% (Sowby et al. 2017).

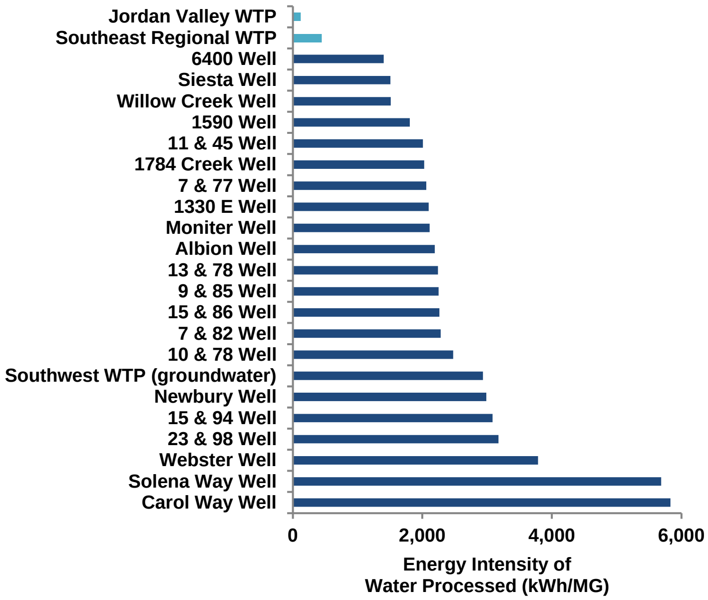

***Figure 3.*** *Jordan Valley Water cut its energy use by 19% after computing each water source's energy intensity and prioritizing the lowest ones.*

## SYSTEM METRIC: ENERGY INTENSITY OF WATER DELIVERED

Like energy intensity of water processed, *energy intensity of water delivered* is a type of energy footprint. In this case, it is a system-wide metric that characterizes the energy associated with end-use deliveries, i.e., water that actually makes it to the customer. Energy intensity of water delivered answers the question, "How much energy does our system take, on average, to deliver one unit of water to the end-user?" A low value is desirable.

Delivery, rather than production, is counted because the water lost between production and delivery contains wasted energy that does not benefit any intended user. (Consider two systems that produce the same amount of water and consume the same amount of energy, but one has 10% water loss and the other has 50% water loss. The one with greater water loss should have the larger energy footprint.) By putting delivery in the denominator, the metric then accounts for this loss and can measure energy performance improvements as a result of water loss control.

Two pieces of information are needed to compute this energy intensity: total system-wide energy use and total water deliveries. The expression is

$$Y_S = \frac{E_S}{V_D}$$

where, over a given time period, $Y_S$ is the energy intensity of the system (kWh/MG), $E_S$ is the total energy used by all facilities in the system (kWh), and $V_D$ is the volume of water delivered to customers (MG). The energy intensity of water delivered varies considerably depending on system size, water sources, climate setting, and other factors, so comparisons among systems should be made with caution (Sowby & Burian

2018). Research suggests a range of 250 to 12,000 kWh/MG, with an average around 2,500 kWh/MG (Sowby & Burian 2017; Chini & Stillwell 2018).

Water loss control, optimal conveyance routes, pressure management, source selection by energy map, equipment upgrades, and many other energy management strategies can reduce the energy intensity of water delivered, even if water demand increases.

In 2015, the Parker Water & Sanitation District of Parker, Colorado, completed its first surface water source. The District had previously relied entirely on very deep groundwater in the Denver Basin aquifer system and recognized a need to diversify and include more renewable water sources. The project also provided an energy benefit: even while water demand increased, the District's energy intensity of water delivered declined from 15,600 kWh/MG in 2015, to 12,900 kWh/MG in 2016, to 11,000 kWh/MG in 2017 (Figure 4). The consistent decrease is largely attributed to the increasing proportion of surface water, which is much less energy intensive than the District's wells.

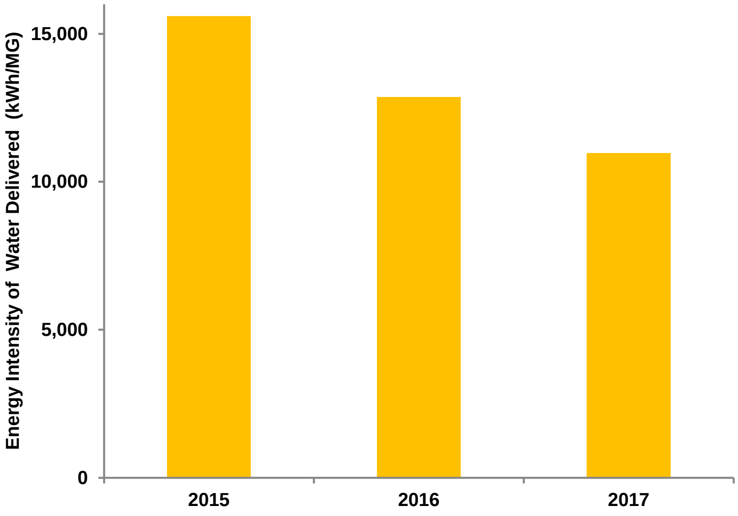

***Figure 4.*** *After adding surface water in 2015 to complement its deep wells, Parker Water & Sanitation District observed a consistent decline in energy intensity of water delivered.*

## COST METRIC: AVERAGE PRICE OF ENERGY

The final metric concerns the cost of energy. Industrial power customers, including water utilities, are subject to a variety of electric rate schedules. Each rate schedule, in turn, has several fee components depending on how, when, and how much power is used. As a cost metric, the *average price of energy* is the average price paid for every kilowatt-hour—the simple ratio of the total bill to the total amount of energy used. It answers the question, "How much does every unit of energy cost after including all the other fees?" A low value is desirable.

Fortunately, most components of the electric power bill are at least partially within the water system's control: demand charges, time-of-use (on-peak/off-peak) rates, and load factors, just to name a few. Operating off peak, for example, will reduce the overall cost, even if using the same amount of energy. A relatively low average price of energy indicates an ability to favorably manage such charges.

Calculating average price of energy involves dividing the total electricity cost by the total number of kilowatt-hours consumed:

$$A = \frac{Total\ Cost\ (\$)}{Total\ Energy\ (\text{kWh})}$$

For example, consider a water treatment plant that consumed 390,000 kWh and was billed $31,200 in a given month. The average price of energy was therefore $0.08/kWh. After switching one treatment train to off-peak operation and reducing the number of simultaneously running finished water pumps, the following month's bill was for 485,000 kWh and $34,000. Water production was greater that month, but the average price of energy dropped to $0.07/kWh, meaning the plant was using cheaper electricity.

Average price of energy can be combined with the previous two metrics to produce corresponding cost metrics (e.g., dollars per million gallons by facility or system).

Mountain Regional Water District of Park City, Utah, has tracked its average price of energy since 2009 (Figure 5). Recognizing energy as a significant operating cost, the District examined its electricity rate schedules and began deliberately managing its operations to pump water during off-peak times and to pump "long and low" with VFDs and jockey pumps to avoid demand charges. The result was a considerable decrease in energy costs in the following years.

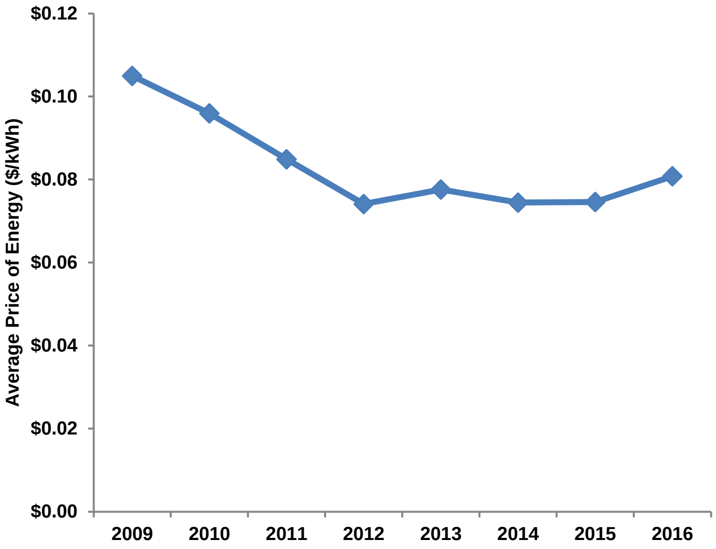

***Figure 5.*** *Mountain Regional Water District tracked its average price of energy and observed a downward trend as a result of off-peak pumping and demand reduction.*

## CONCLUSION

This suite of energy metrics enables characterization of energy use at various levels within a public water system. The metrics alone, however, will not change performance. To be most valuable, the metrics need regular analysis and discussion that lead to actions for improvement. Such a process may be integrated with existing team meetings, planning efforts, policies, or reporting activities specific to each organization (Sowby 2018). When embraced and acted upon, the metrics will ultimately lead to more efficient and sustainable operations.

**Summary Table: Energy Metrics for Public Water Systems**

| | Wire-to-water efficiency | Energy intensity of water processed | Energy intensity of water delivered | Average price of energy |
|---|---|---|---|---|
| Scope | Equipment | Facility | System | Cost (facility or system) |
| Purpose | Quantifies actual ratio of energy output to energy input | Quantifies energy needed to process a unit of water | Quantifies system-wide energy footprint based on energy inputs and water deliveries | Indicates ability to manage demand charges, time-of-use, and other rate components |
| Units | Percent | kWh/MG | kWh/MG | $/kWh |
| Desired Value | High | Low | Low | Low |
| Applications | Compare actual value to design value (pump curve); monitor changes to schedule maintenance | Watch seasonal variations to identify efficient periods; identify other loads; compare to similar facilities | Monitor performance monthly or annually; compare to peers | Monitor effect of deliberate action to reduce average price |
| Example | Pumps and motors | Water treatment plant | Whole system | Facility or whole system |
| Method | For pump, measure electricity use, flow rate, and head; solve for efficiency term in pump equation | Divide facility total energy use by volume of water processed | Divide system total energy use by volume of water delivered | Divide total electricity expenses by number of kilowatt-hours consumed |

## ACKNOWLEDGMENT

The author thanks Jamie Langer, former project engineer at Parker Water & Sanitation District, and Doug Evans, energy and water manager at Mountain Regional Water District, for sharing data and examples.

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