Energy-Saving Potential of Water Service Line Leak Reduction in Michigan

Rick Bunch and Daniela Tapia
Michigan Municipal Association for Utility Issues

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Introduction

Water service lines burst into the Michigan public consciousness in recent years, when it was discovered that water customers in the City of Flint were being exposed to high levels of lead in drinking water originating in their service lines (SLs). Until then, most people thought about water service lines only on the rare occasion when a nearby homeowner had to excavate their front lawn because a service line leak turned it to mud or flooded their basement.

In the wake of the Flint water crisis, the State of Michigan enacted the Revised Lead and Copper Rule. It requires that water utilities in Michigan within 20 years identify and replace all service lines that are lead or galvanized previously connected to lead (GPCL). While compelling from a public health standpoint, this requirement departs from historical practice by making the water utility responsible for replacement of the service line. Normally, the property owner is responsible for installing and maintaining the service line beyond the curb stop.

Identifying and replacing all service lines covered by the Revised Lead and Copper Rule imposes an enormous contingent financial burden on local water utilities. Many utilities are already burdened by the need to replace aging pumps, treatment equipment and mains, or to improve quality of water and wastewater treatment. Further, lead and galvanized lines generally serve older homes, disproportionately located in core cities like Detroit and Flint that already face financial difficulties. Water utilities serving these cities have severely constrained ability to raise rates to pay for lead service line (LSL) replacements.

However, service lines are financially problematic not only when they need to be replaced for public health reasons. “The majority of both leakage events and leakage volume losses occur on customer service connection piping.”[1] Many service lines leak, and many service line leaks go undiscovered at length. Because service lines are “upstream” of the customer’s meter, these leaks represent non-revenue water for the utility – a cost that must be passed on to all customers, rather than billed to the customer whose line has broken.

Leaks impose various costs on a water utility and its ratepayers. First, leaks mean that the utility must install and operate expensive sourcing, transmission, treatment, and distribution capacity for more water than its customers need, since some of that water will never reach a customer. Second, locating and fixing leaks can be very costly. Third, leaks may cause damage to public or private property. Fourth – and our concern here – leaks represent waste of all the energy used to produce and supply the water up to the point of the leak.

Costs imposed on water utilities by leaks are not only largely avoidable but can be significant as well. Most local governments use more energy to treat and supply water than for any other purpose. An increasing number of local governments are looking for ways to spend less money on energy, and many are adopting climate change policies and goals that motivate them to use less energy.

The question arises, then, whether there is a case to be made that fixing leaks in service lines can reduce energy waste significantly and measurably enough to justify more aggressive practices for managing and detecting leaks and replacing lines. Certainly, no homeowner wants to wait 20 years to have their LSL replaced with safer material. A utility that finds it can save money by replacing LSLs faster than the law

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[1] AWWA. 2016. Manual M36 *Water Audits and Loss Control Programs*. Denver, Colo.: AWWA, 175.

requires will not only reduce costs and possibly avoid rate increases, but also will satisfy its public health obligations more quickly.

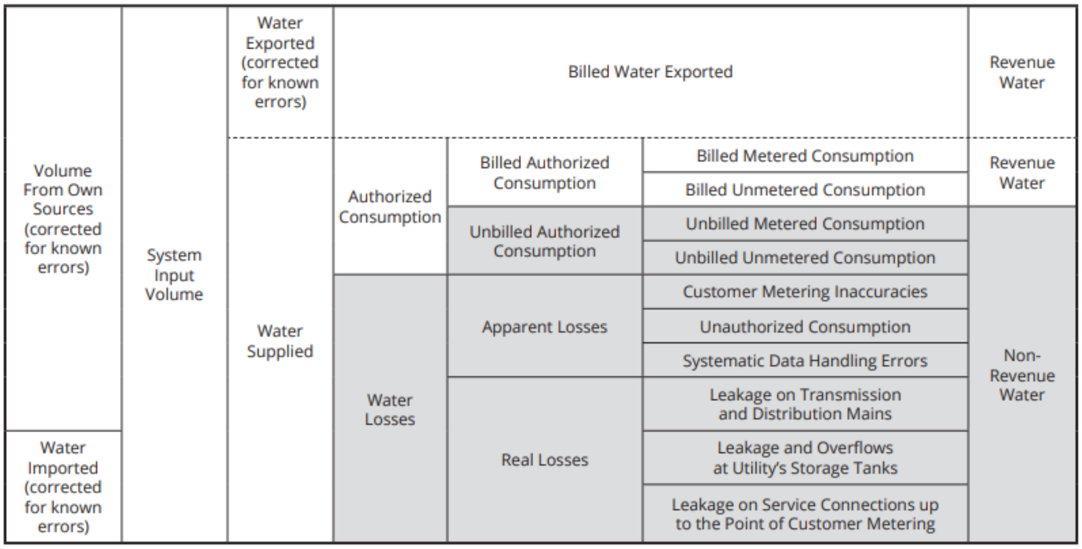
The purpose of this study is to assess how much energy is wasted in the production of water that leaks from water service lines in Michigan and to determine where energy could be saved if SL leaks were reduced. Demonstrating previously unrecognized, or unquantified, may inform water utilities' plans for financing and implementing SL monitoring, management, and replacement programs. Accordingly, our research addressed three questions:

1. How much energy is wasted by leaks from lead service lines in Michigan?
2. How much energy is wasted by leaks from other water service lines in Michigan?
3. Where could water utilities reduce energy use by fixing leaking service lines?

Water Loss

The International Water Association (IWA) and the American Water Works Association (AWWA) have developed standard terminology and methods to assist water systems in tracking water losses and in performing water audits as shown in Figure 1.

Figure 1: Water Balance illustrating different types of losses[2]



Volume From Own Sources (corrected for known errors)	System Input Volume	Water Exported (corrected for known errors)	Billed Water Exported			Revenue Water
		Water Supplied	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption	Revenue Water
					Billed Unmetered Consumption	
				Unbilled Authorized Consumption	Unbilled Metered Consumption	Non-Revenue Water
					Unbilled Unmetered Consumption	
			Water Losses	Apparent Losses	Customer Metering Inaccuracies	
					Unauthorized Consumption	
					Systematic Data Handling Errors	
				Real Losses	Leakage on Transmission and Distribution Mains	
Water Imported (corrected for known errors)					Leakage and Overflows at Utility's Storage Tanks	
					Leakage on Service Connections up to the Point of Customer Metering	

- ***Real Losses**, also referred to as physical losses, are actual losses of water from the system and consist of leakage from transmission and distribution mains, leakage and overflows from the water system's storage tanks and leakage from service connections up to and including the meter...*
- ***Non-Revenue Water** (NRW) is water that is not billed and no payment is received. It can be either authorized, or result from apparent and real losses. Unbilled Authorized Consumption is a component of NRW and consists of unbilled metered consumption and unbilled un-metered consumption (e.g., line flushing, firefighting, and street cleaning).*

Average overall real water loss in systems is estimated at 16%, with up to 75% of that being recoverable.[3] In most well-run systems, the greatest annual volume of real losses occurs from long-running, small-to-medium-sized leaks on customer service connections.[4] "Although their leakage rates are low, the annual volume of hidden leakage losses is usually a significant proportion of the total leakage volume and far exceeds the water lost in catastrophic, visible main break events."[5]

Many of these hidden leaks may be addressed by aggressive monitoring and replacement of service lines. In addition, many detectable leaks may be prevented by replacing service lines before they break. This is

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[2] AWWA *Manual M36*, 38.

[3] Thornton, J., Sturm, R., and Kunkel, G. *Water Loss Control Manual* (2nd Edition), McGraw-Hill, 2008.

[4] Brown, T.G., D. Huntington, and A. Lambert. Water loss management in North America–Just how good is it? In Proceedings, Technical Session on Progressive Developments in Leakage and Water Loss Management, Distribution System Symposium. Denver, Colo.: American Water Works Association. 2000.

[5] AWWA, *Manual M36*, 172.

a plausible outcome because research has shown a direct relationship between the ages of various service lines, their material composition, and their propensity to develop leaks. Thus, a proactive program of monitoring, managing, and replacing service lines may significantly reduce both hidden and detectable leaks, preventing water waste and the waste of the energy embodied in it.

Energy Use in Drinking Water Production and Supply

Energy is used to extract water at its source, transmit it to treatment works, treat it to satisfy safe drinking water standards, pump it through the distribution system to end users, and pump and treat wastewater. Water that is lost to leaks before it reaches a meter represents waste of the energy used upstream of that point. Because service lines are the endpoint of the distribution system, service line leaks represent a waste of all energy used to source, transmit, treat, and pump the water to that point.

The amount of energy used to supply water varies significantly among utilities. Broadly speaking," …wastewater plants and drinking water systems can account for up to one-third of a municipality's total energy bill. A 10 percent reduction in U.S. drinking water and wastewater systems costs would collectively save approximately $400 million and 5 billion KWh annually".[6]

A study of Wisconsin water utilities done by Focus on Energy found the two most important variables determining energy use were the size of the utility and the water source.[7]

> Utilities in Wisconsin serving more than 4,000 customers used an average of 1.81 KWh/1,000 gallons of water supplied. Utilities serving fewer than 1,000 customers used an average of 2.41 KWh/1,000 gallons.
>
> Utilities sourced from surface water used an average of 2.16 KWh/1,000 gallons and those sourced from groundwater used 2.01 KWh/1,000 gallons.

Other variables that can affect energy use in drinking water systems include transmission and distribution distances, topography, quality of source water and age, condition and control systems of pumps and treatment systems. The Wisconsin study found that "More than 90% of energy consumed in producing and delivering drinking water is used for pumping."[8]

The Wisconsin figures are available because the state's Public Service Commission regulates water utilities and requires them to file annual reports that include energy consumption. Water utilities in Michigan are not required to file similar reports and thus comparable, comprehensive data are not available for Michigan.

Wisconsin's water systems appear to be reasonably comparable to Michigan's, in terms of water sources, climate, and topography. We found, however, that energy use by major water utilities to supply drinking water in Michigan is generally higher than that reported for Wisconsin:

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[6] U.S. EPA. ENERGY STAR for Wastewater Plants and Drinking Water Systems. Available: http:// www.energystar.gov/index.cfm?c=water.wastewater_ drinking_water.

[7] "Water & Wastewater Industry Energy Best Practices Guidebook", 4.

[8] "Water and Wastewater Industry Energy Best Practices Guide", 4.

Table 1: Energy Intensity in water supply for some utilities in Michigan

Water Utility	Source Water	KWh/1,000 Gallons
City of Ann Arbor	Surface (~85%) Ground (~15%	2.66[9]
City of Grand Rapids	Surface	2.38[10]
Lansing Board of Water and Light	Ground	2.71[11]
City of Mount Pleasant	Ground	2.22[12]
Kalamazoo Lake, Sewer, and Water Authority	Ground	2.01[13]

According to the Michigan Department of Environmental Quality (now EGLE), 45 percent of the Michigan population is served by groundwater, while 55 percent is served by surface water or water from the Great Lakes.[14]

Table 2: Weighted average energy intensity in Michigan's water supply (KWh/1,000 gallons)

Source	Average	% of state	Weighted Total
Groundwater	2.31	45%	1.04
Surface water	2.52	55%	1.39
Weighted average			**2.43**

We arrive at an estimated statewide weighted-average energy intensity of 2.43 KWh/1,000 gallons of drinking water supplied by municipal systems. Table 2.

Service Line Leaks May Increase Energy Used in Wastewater Treatment

This paper is not directly concerned with energy used to pump and treat wastewater. It is relevant to acknowledge here, though, that "(S)ignificant volumes of leakage drain into community waste or stormwater collection systems and are treated by the wastewater treatment plant—thereby experiencing two rounds of expensive treatment without providing beneficial use."[15] We found no data or methodology to quantify how much leakage drains into wastewater treatment systems, however, and consequently could not quantify marginal energy use in treating that water.

We note, however, that large water utilities in Wisconsin require between 2.3 and 7.3 KWh/1,000 gallons of water treated.[16] This range is up to 3x the energy required to produce and supply drinking water, which we derive below. Thus, if we suppose that one-third of water leaked from service lines drains into and is

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[10] Brian Steglitz, Manager of Water Treatment Systems for the City of Ann Arbor, email to author Tapia, May 20, 2021.

[10] Chad Reenders, Water Plant Supervisor at Grand Rapids, email to author Tapia, May 27, 2021.

[11] AWWA Utility Benchmarking Program, 2020.

[12] Jason Moore, Mt Pleasant DPW director, email to author Bunch dated August 2, 2021.

[13] Joseph Bonhomme, Water Resources Division Manager for the City of Kalamazoo, to author Tapia, August 5, 2021.

[14] Michigan Department of Environmental Quality. *DEQ Fact Sheet – Groundwater Statistics.*, January 2018.

[15] AWWA, *Manual M36*, 185.

[16] Wisconsin Focus on Energy. "Water & Wastewater Industry Energy Best Practices Guidebook", 2020, 6.

treated by wastewater systems, and further suppose that treating that water requires 3x the energy required to produce it, then total energy wasted in treating water leaked from service lines is comparable to the energy wasted in producing it.

Reducing energy wasted by treating leaked water is not only a case of reducing those leaks, but also of treatment-works efficiency. In the Wisconsin study, facilities that have the same treatment methods and comparable biochemical oxygen demand vary substantially in energy intensity, suggesting that systems with better equipment or management methods can realize significant energy savings.

However, because we have no method for measuring or estimating what volume of leaked water drains to wastewater collection systems, we can only speculate how much energy is used to treat it. This topic may be worthy of deeper examination, but we do not consider it further in this analysis.

Energy Efficiency Measures Linked to Water Conservation

Michigan's regulated utilities operate energy waste reduction (EWR) programs that, among other things, provide financial incentives to customers to invest in energy efficiency measures. Rebates are tied to the amount of energy the measure is projected to save over its lifetime.

Utilities currently offer rebates for two kinds of water-related efficiency measures. First, they support replacement of water treatment equipment and pumps operated by water utilities with more-efficient equipment. Second, they support measures on the customer side of the meter that reduce energy used to heat water. For example, rebates support installation of low-flow showerheads, which by reducing the total amount of water flowing from the showerhead also reduce the amount of energy used to heat that water.

The showerhead example relates to an exclusion in the EWR rebates scheme: they do not support measures that reduce energy used by a water utility by reducing household leaks and waste of cold water. The showerhead rebates could expand to include energy saved by allowing the water utility to supply less water to the house, in addition to the heating energy saved. No standard measures have been developed in Michigan assigning "deemed savings" to cold-water efficiency investments, either in front of or behind the meter. Energy utilities, or their customers, could propose their own "custom measures" with energy rebates specifically figured for a particular customer, water utility and water-efficiency project. Although Consumers Energy has studied the feasibility of custom measures for cold-water conservation[17], we are not aware that any utility or customer in Michigan has adopted such measures.

Additionally, energy utilities in Michigan currently provide no rebates for water utility programs that reduce water loss on the utility side of the meter, including service lines, for two reasons:

1. **Lack of additionality**: EWR rebates can support only projects that would not happen absent the rebate, or that would be significantly delayed. Repairs to water utility main breaks happen as soon as they are discovered – it is not necessary to offer a rebate to make them happen.
2. **Measurement challenges**: it can be hard to know how much water, and therefore how much energy, is wasted by a leak. It is also problematic to guess how long that leak would continue, which makes estimating lifetime savings difficult.

In the case of lead service lines, the additionality requirement poses an especially high hurdle because projects required by law are not eligible for rebates: they are going to happen anyways and offering the rebate will make no difference. Under the existing statutory provisions, it appears the strongest potential case for including leak-reduction investments in EWR rebate schemes would be to demonstrate that the potential for energy savings motivates the water utility – or their customers – to act sooner than they otherwise would. Conceivably, for example, energy savings from SL leak reduction might motivate a water utility to replace LSLs faster than required under the Revised Lead and Copper Rule.

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[17] Cadmus Group (David Molner, Amy Ellsworth, Emily Miller, Shannon Donohue), "Energy Savings from Water Associated Efficiency Measures", memo prepared for Consumers Energy dated February 4, 2020. Attached as Appendix G.

Reducing Water Leaks May Not Reduce the Energy Used to Supply It

Even when it is possible to measure how much water is saved by a given measure – whether behind the meter, or SL or mains replacement– it is not safe to assume that implementing it will save energy “upstream”. Supplying less water will allow a utility to use less energy only if it can turn down, or shut down, its equipment. As noted above, about 90% of energy consumed by water utilities in Wisconsin is used in pumping. A pump can use less energy, in proportion to leak remediation efforts, only if it is equipped with a variable frequency drive. This is not the case at Great Lakes Water Authority (GLWA) which, cannot change its pump speeds.[18] If distribution utilities were to reduce how much water they buy from GLWA, the only way GLWA could reduce the amount of water it supplies for distribution would be to partially close valves to reduce outflow from the pumps. The pumps would continue to run at full speed, using just as much energy as ever and possibly more, owing to the inefficiency of forcing the pumps to strain against partially closed valves.

The GLWA example is akin to installing a dimmable lightbulb without also installing a dimmer switch: there is no way to realize the energy efficiency benefits of the dimmable bulb without also installing the necessary controls. Customers of GLWA have straightforward incentives to reduce water waste, allowing them to buy less water from GLWA, and reducing pumping and storage costs in their distribution systems. These efficiencies, however, may not reduce impact of GLWA operations because GLWA cannot set their pumps to run slower.

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[18] Eric Griffin, GLWA Energy Program Manager, interview with author Bunch, May 10, 2021.

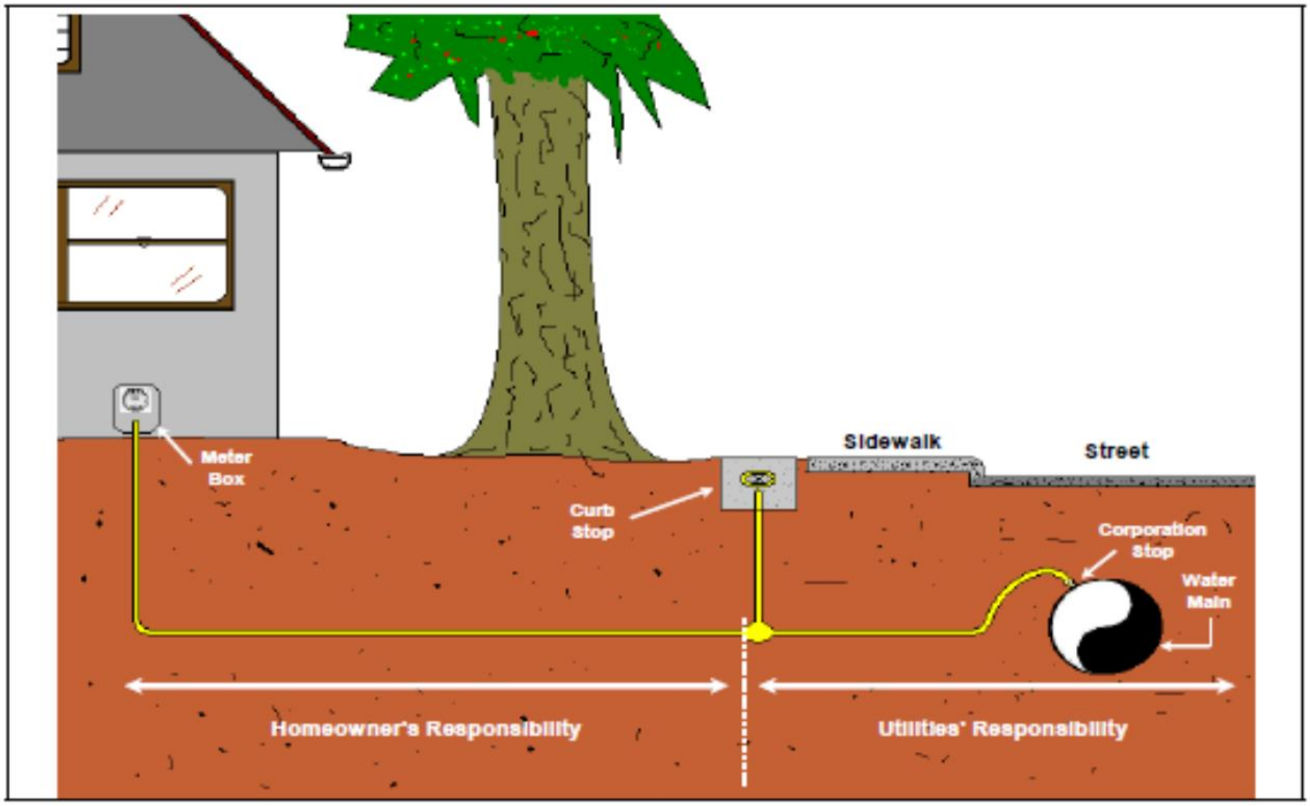
What are water service lines?

Water service lines, or SLs, serve customer premises by spanning the distance from the utility main to just inside the premises. SLs have a public side, spanning from the corporation stop attached to the main to the curb stop at the edge of the customer's property. The private side of the SL crosses the customer's property, from the curb stop to just inside the building. In most cases in Michigan, the SL ends just inside the building at the meter.

The private side of the SL tends to be more problematic for management of leaks or proscribed materials than the public side. A leaking service line normally imposes financial cost on the water utility, in the form of non-revenue water. The property owner has no reason to care about an SL leak unless they notice puddles in the front yard above the SL, or if the water leaks through their building foundation into the basement.

In comparison, the public side of the SL is more likely to be monitored by the water utility, which has both incentive and access to fix leaks or replace lead or galvanized components. Many water utilities also replace or upgrade water lines concurrent with water main or road improvement projects.

Figure 2 Diagram of Typical Water Service Line



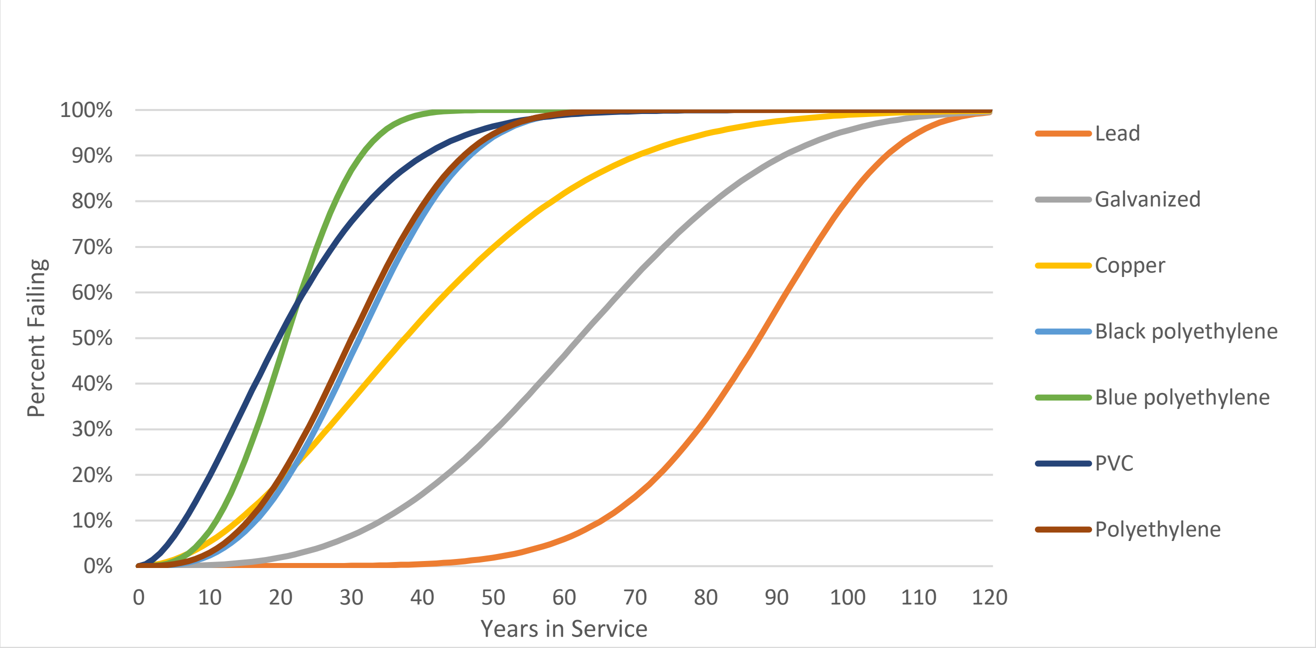
Source: *Installation, Condition Assessment and Reliability of Service Lines*, AWWA Research Foundation, 2007. Figure 4.1

Service Line Leaks

Because property owners are not financially responsible for SL leaks on their property, and often suffer no property damage or other consequences from them, they have reduced incentive to choose durable materials, install them properly and monitor them over time. Common service line materials include copper, PVC, various kinds of polyethylene, and historically lead and galvanized steel.[19] These materials vary in their durability, and in the volume of water they leak once they fail. Ironically, lead was the material of choice for service lines for decades because its flexibility made it more durable than other choices, and less likely to suffer large leaks.

Service lines can develop leaks for a variety of reasons, including freezing, human interference, shifting ground, tree roots and faulty installation. Service lines are more likely to develop leaks as they age. The probability of failure is also related to material composition. Survival analysis of service lines shows, for example, that lead service lines reach 50% failure rate at about 88 years, whereas 50% of PVC lines fail within 20 years of installation.[20] Figure 3 depicts cumulative probability of failure over time for various service line materials.

Figure 3: Cumulative Failure Rates of Various Service Line Materials



Source: Lee and Meehan, 2017. See detailed data in Appendix A.

Service Line Materials and Failure Rates

Complete, rigorously verified data on prevalence of service line materials in Michigan will become available in 2025 when water systems are due to submit their Complete Distribution System Materials Inventories (CDSMIs) to the state, per the Revised Lead and Copper Rule. Water systems submitted Preliminary Distribution System Materials Inventories (PDSMIs) to the State in 2020, with detail only on

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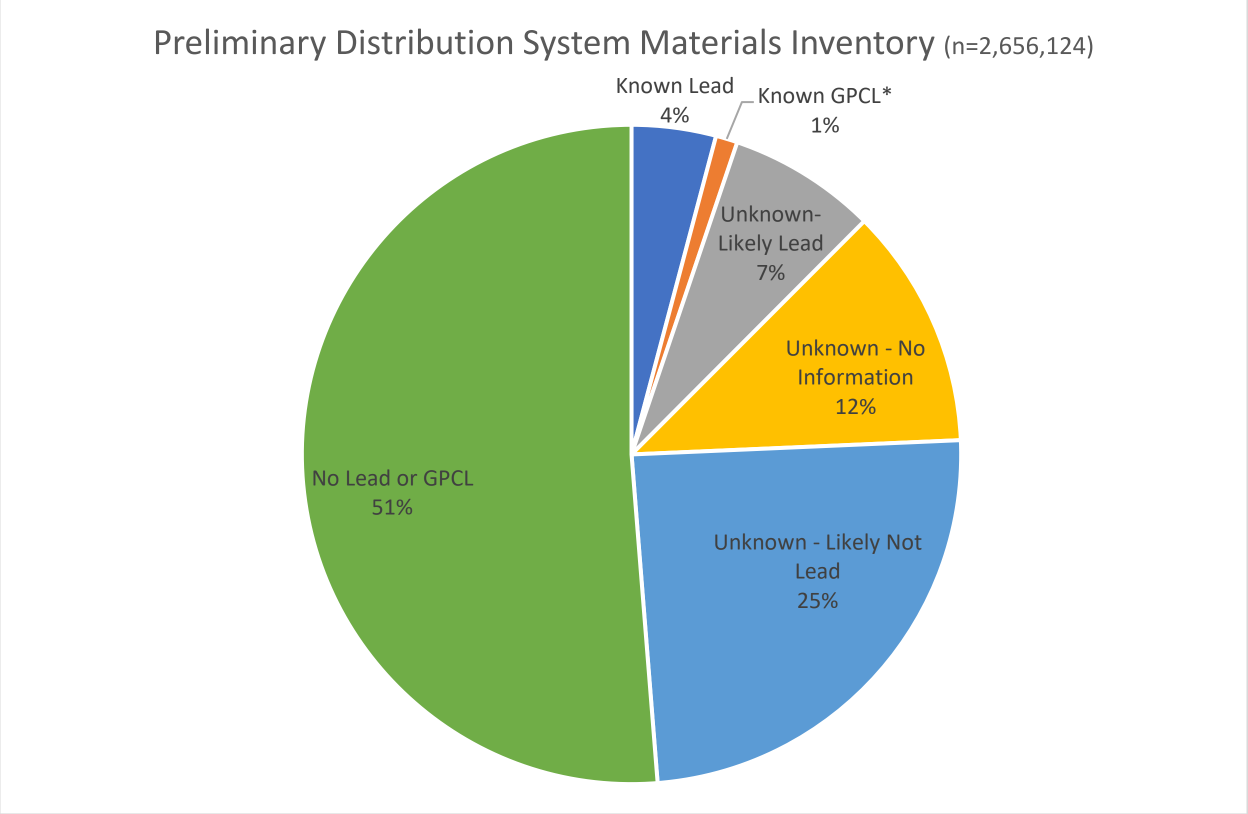
[19] AWWA Research Foundation. *Installation, Condition Assessment and Reliability of Service Line*s, 2007.

[20] Lee, J. and Meehan, M., "Survival Analysis of Water Service Lines Utilizing a Nationwide Failure Dataset," *AWWA* 109, no. 9 (2017): 13-21. Cumulative failure rates are reproduced in Appendix A.

materials targeted by the Revised Lead and Copper Rule as shown in Figure 4. The PDSMI methodology does not require reporting utilities to distinguish between the public and private sides of service lines, which may be different since the former is installed and managed by the water utility and the latter is installed by the home builder and managed thereafter by the property owner.

Figure 4. Michigan PDSMI breakdown



Source: Michigan EGLE, 2020.

Additionally, the PDSMI reporting standards specify that a service line having any single lead component should be reported as an LSL. For example, the original lead pipes themselves may have been replaced, leaving only an original lead gooseneck connection to the main. Under the PDSMI standards, however, this entire SL assembly counts as an LSL. The mixed-material/date SL will have a different age and composition, and thus different probability of failure, than the complete original lead SL. The PDSMI reports do not distinguish SLs having components of mixed materials and ages. This data limitation may inflate our estimates of failure rates. More comprehensive data may be available when water utilities submit their CDSMIs in 2025.

Although lead service lines appear to be highly durable, remaining LSLs are old. Congress banned lead service lines in 1986 but they had been largely phased out by the 1960s, making most of them over 50 years old. Survival analysis predicts that 50% of LSLs will develop leaks within 88 years of installation (Figure 3 and Appendix A). While we do not have data establishing the age distribution of remaining lead service lines in Michigan, it appears very likely that many of them are very old, leaking at undetected levels and likely to develop detectable leaks soon.

Galvanized service lines were commonly used until the 1960s.[21] The state's Revised Lead and Copper Rule requires replacement of galvanized lines that were previously attached to lead ("GPCL"). Same as with lead lines, therefore, assessing potential energy savings that result from replacing leaking galvanized pipes is of interest. Survival analysis shows that galvanized lines are second in durability only to lead lines, with half of them developing leaks 62 years after installation (Figure 3 and Appendix A). Although reliable data are not available on age distribution of galvanized lines in Michigan, they entered use more than 100 years ago. It is likely that many of them have developed leaks.

PVC and polyethylene have also been used in service lines. Survival analysis shows these materials are the least durable of commonly used service line materials.[22] Half of all PVC and blue polyethylene pipes leak within 20 years. Polyethylene and black polyethylene have 50% failure rates at about 30 years after installation. (Figure 3 and Appendix A).

Based on conversations with water utility staff, the most used materials for new service lines in Michigan are copper and PEX.[22] PEX is a fairly new material, and we did not find survival analysis data for it. Copper has proven to be relatively durable, though less so than lead and galvanized, with 50% failure rate reached at about 37 years. (Figure 3 and Appendix A)

Cumulative and marginal failure rates for different SL materials are drawn from a nationwide academic study of 47,454 service line failures using data from a national home-repair services firm, HomeServe.[22] The authors found that service line leakage occurs owing to various factors, including temperature and soil corrosivity, that vary across the country. National survival data may not fully represent conditions in Michigan.

Complete data on distribution of service line materials in Michigan will not be available until 2025, with submission of CDSMIs by the water utilities. The age of service lines generally relates to when the building was connected to the water supply main, which varies significantly across the state. It also appears that the choice of service line materials has varied from place to place and over time. Furthermore, from our limited sample it is clear that the amount of energy used to produce and supply water varies significantly around the state. These factors make estimation of statewide SL leakage difficult and imprecise.

To test our methodology and the plausibility of results it generates, therefore, we first develop estimates for water and energy waste attributable to service line leaks in the City of Detroit. Detroit is a good test case for two reasons. It is the largest water utility in the state, and its PDSMI reports the most likely LSLs. In addition, all service lines in Detroit are metallic, making it necessary to develop estimates for fewer SL materials.[23] After presenting our estimates for Detroit, we go on to develop collective estimates for all water systems in Michigan.

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[21] https://535plumbing.com/2018/08/25/4-signs-its-time-to-replace-your-galvanized-pipes/. Also, https://americanvintagehome.com/advice-for-older-homes/need-swap-galvanized-pipes/#:~:text=What%20are%20galvanized%20pipes%3F,pipe%20for%20water%20supply%20lines.

[22] Lee and Meehan, 2017.

[23] Bryan Peckinpaugh, Public Affairs Deputy Director at the Detroit Water and Sewerage Department, email to author Tapia, July 26, 2021.

Determining Leak Volumes

To determine overall water loss from service lines, we need to know how many are leaking, how much they are leaking and for how long. Survival analysis, along with information about the age of service lines, can yield an estimate of the number of pipes that are leaking.

The volume of water leaked from SLs is more difficult to determine. We have no direct way to measure water loss from service lines, and not enough data to estimate it using AWWA's water loss component analysis approach. Instead, we rely on AWWA's M36 Water Loss Manual for general guidance on leak estimation. AWWA describes methods for estimating loss from reported leaks, unreported leaks, and unavoidable background leaks (UBL). AWWA attributes the majority of UBL and unreported leak volumes to service lines, and because LSL replacements will reduce both kinds of leaks, we estimate both here. Similarly, AWWA provides only very general guidance on leak duration because it is very difficult to know how long before discovery an SL break occurred.

Unavoidable Background Leaks

AWWA provides a methodology for estimating UBL based on length of mains, number of service connections, length of service connections and average system pressure, with adjustment for overall infrastructure conditions.[24] Because we are not concerned here with leaks from mains, we simply omit the mains term from AWWA's formula, leaving terms for the public and private side of SLs. Thus:

$UBL\ (1{,}000\ gal/d) = [(0.20 * Lm) + (0.008 * Nc) + (0.34 * Lc)] \times (Pav/70) \times ICF^{1.5}$ becomes

$UBL\ (1{,}000\ gal/d) = [(0.008 * Nc) + (0.34 * Lc)] \times (Pav/70) \times ICF^{1.5}$

Where Lm = Length of mains
Nc = number of service connections (known)
Lc = length of service connections (use national average)
Pav = average system pressure (use 70 psi = middle of 60-80 psi recommended range)
ICF = Infrastructure Condition Factor

For the City of Detroit, using AWWA's methodology, we estimate total UBL from service lines to be 2,329,448,148 gallons/year (See **Appendix B** for calculations). This estimate represents an average of 21 gallons per day per service connection – almost one gallon per hour.

To determine the amount of energy embodied in this leaked water, we use the Grand Rapids municipal water system as a proxy. We are unable to calculate total energy consumption for Detroit water because DWSD is a distribution utility only – Great Lakes Water Authority sources, transmits, treats, and delivers the water and its energy costs are rolled into the price it charges DWSD for water. Grand Rapids is a vertically integrated utility and is a good proxy for Detroit water because it is the second biggest water system in the state and, like Detroit, uses only surface water for sourcing. Thus, we use the Grand Rapids embodied energy figure of 2.38 KWh/1,000 gallons.

At 2.38 KWh/gallon, Detroit's estimated UBL embodies 5,544,087 KWh of electricity per year.

Our estimate is adjusted using an Infrastructure Condition Factor (ICF), per AWWA's methodology. A system in optimal condition will have an ICF of 1. ICF multipliers as high as 4 are not unusual and may be

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[24] AWWA, *Manual M36*, 199.

appropriate given that more than half of Detroit's mains have been assessed in poor condition[25]. To be conservative but reasonable, we apply an ICF of 2.

In the context of an LSL replacement program, the term "Unavoidable" may be misleading. It describes leaks that cannot be detected by direct observation or sensing technologies, and that may cost more to find and fix than the water that would be saved. If hidden SL leaks account for 85% of UBL, and almost 80,000 LSLs are going to be replaced over the coming decades, then the costs of finding and fixing those leaks become irrelevant. Therefore, we can expect a substantial reduction in UBL resulting from SL replacements, even if we cannot reliably estimate how much.

Detectable Leaks

AWWA states that the average reported service line leak is 6.9 gallons per minute at 70 pounds of pressure per square inch (psi).[26] 60-80 psi is the target range for most water utilities to provide adequate water pressure to their customers[27].

This assumed psi may be conservative because many water systems operate at higher average pressure. AWWA's survey of North American water systems found that 39% reported average system pressures above 80 psi.[28] Because these are system averages, some segments of these systems are likely to be even higher. "…(W)ater distribution systems operating with pressure levels notably higher than 80 psi may encounter a greater opportunity for high leakage and rates of failure on water distribution piping."[29] However, we did not find average system pressure data for Michigan, and we use 70 psi in our calculations, representing the middle of the recommended range.

Further, we assume that SL leaks average 30 days until repair. This assumption is consistent with AWWA's finding that "unreported leaks on customer service connections may also have variable awareness times [depending on whether proactive or reactive leakage management is employed] … the property owners may not notice a leak for some time after it occurs and may not be motivated to act promptly since they can also have variable repair times depending on the utility's policies... Water utilities that conduct repairs on customer service connections or have programs to handle repairs can keep average repair times at a reasonable level, perhaps on the order of several days. For those systems that rely on customer-arranged repairs, the repair time can extend for weeks or months."[30]

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[25] "DETROIT DOUBLES DOWN ON ASSESSMENT OF WATER INFRASTRUCTURE WITH EPULSE", Water & Wastes Digest, July 13, 2021. Accessed at https://www.wwdmag.com/channel/casestudies/detroit-doubles-down-assessment-water-infrastructure-epulse

[26] AWWA, *Manual M36*, 249.

[27] Water Supply Committee of the Great Lakes‑Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers, *Recommended Standards for Water Works*, 2007.

[28] AWWA, *Manual M36*, 178

[29] AWWA, *Manual M36*, 177.

[30] AWWA, *Manual M36*, 185.

Lead Service Lines in Detroit

We focus our analysis of water- and energy waste from leaking SLs on Detroit because it has reported the highest estimated count of LSLs in the State according to the PDSMI. Detroit estimates it has 77,198 service lines that are either lead, unknown-likely lead or galvanized previously connected to lead (GPCL)[31]. The Revised Lead and Copper Rule requires the city to replace lines that fall in these three categories.

Another reason we focus on Detroit is because the State of Michigan has approved the City to replace LSLs on a 40-year timeline rather than the standard 20 years set by the Revised Lead and Copper Rule. With the longer timeline, the city can replace LSLs as it replaces adjacent water mains as part of its Capital Improvement Plan,[32] significantly reducing the unit cost. At the same time, however, the longer timeline extends how long old LSLs remain in the ground, allowing more to develop leaks and increasing cumulative water and energy waste.

Finally, Detroit represents a potentially compelling case in point because it stopped installing LSLs in 1945.33 Widespread phaseout of LSLs occurred nationally about 20 years later, in the 1960s. While Detroit made a good decision to stop using LSLs, the 1945 cutoff also means all of Detroit's LSLs are 76 years or older and have a much higher predicted failure rate than communities with newer LSLs. A 76-year-old LSL is 24.4% likely to have failed, whereas a 50-year-old LSL has a predicted failure rate of only 1.9% (Appendix A). Detroit's surviving LSLs likely cluster in an age range that has the highest projected marginal annual failure rate according to survival analysis, meaning they are more likely to start leaking over the next several decades than cities with average-younger service lines.

Average Loss per Leaking SL in Detroit

SL materials have varying performance characteristics and it is unlikely they all have the same vulnerability to leak or average leak volume. We were unable to locate data on the severity of breaks in relation to service line materials, however, and we use the AWWA figure of 6.9 gallons per minute in our estimate of losses from service lines of all compositions.

First, we must estimate how many leaking service lines are in Detroit. For that, we must estimate how many lines of each material are installed in Detroit, and how old they are.

Ages of Lead Service Lines in Detroit

Installation of LSLs in Detroit ended in 1945.[34] Thus, we assume that their age distribution follows the age distribution of houses built in Detroit before 1945.

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[31] Michigan EGLE, Detroit PDSMI, January 2020.

[32] Smalley, S.A. and Peckinpaugh, B., "Detroit's Robust Full Lead Service Line Replacement Program," Journal AWWA, October 2020, p.43.

[33] Detroit Water and Sewage Department. 2020 Water Quality Report. Detroit's PDSMI report, submitted to EGLE in 2020, estimates 2,240 known lead lines and 77,197 unknown-likely lead. We use the number from the Annual Report because it is more recent and may reflect that some lines have been replaced since the PDSMI was submitted.

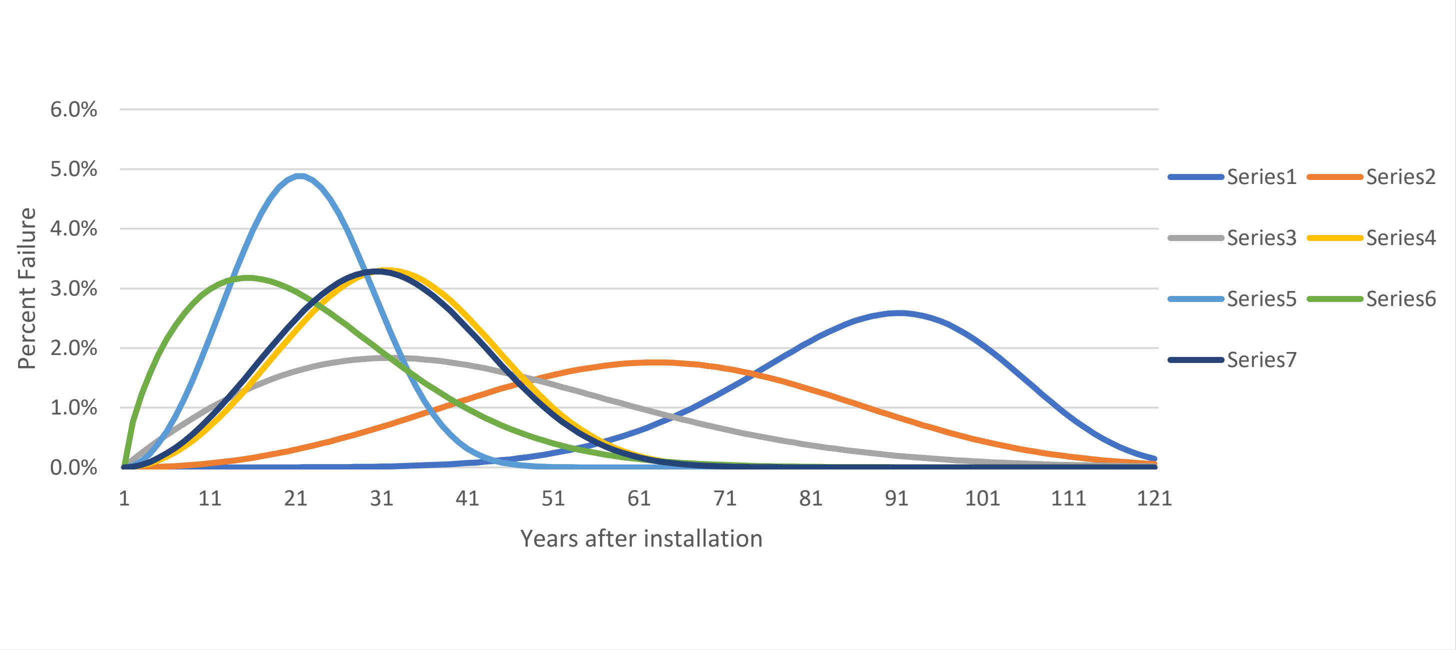
[34] The Detroit LSL ban starting in 1945 may have applied only to the public side of the SL. Homebuilders may have been able to continue using their preferred materials, including lead, for the private side of the SL after that date. CDSMIs, due in 2025, may provide more complete and accurate information.

The US Census Bureau provides housing data going back to 1940 in decadal bundles[35], and cumulative before then. Based on this data we assume that:

- Two-thirds of the 79,736 houses built in Detroit in the 1940s were built in the second half of the decade, during the post-World-War II economic expansion. We assume the other 1/3 were built steadily between 1940 and 1944 (after which LSLs were no longer used).
- 80% of the 117,572 homes built before 1940 were distributed evenly across the 40 years starting in 1900, and the remaining 20% were built before 1900.

We estimate that 120,636 houses were built in Detroit from 1900 to 1944 – greater than the 77,198 LSLs Detroit estimated in its PDSMI. Presumably some of the houses built in Detroit during that era no longer exist, and some have already replaced their original LSLs. We therefore apply an adjustment factor of 0.640 to normalize our calculations to the number of LSLs Detroit currently reports (figured as reported LSLs divided by total homes built). (see Appendix C)

Figure 5. Marginal Annual Failure Rates of Various Service Line Materials



Source: Lee and Meehan, 2017.

For each year, we use the survival analysis probability density function to determine the marginal failure rate of LSLs of that age (Figure 5). These curves show, for example, that blue polyethylene has peak marginal failure rate of 4.9% at 20 and 21 years after installation, whereas LSLs have peak marginal annual failure rate of 2.6% from 88 to 92 years after installation. The summation of marginal failure rates determines the cumulative failure rates shown in Figure 3.

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[35] U.S. Census Bureau (2020). *Year Structure Built*. American Community Survey 2019 1-year estimates. https://data.census.gov/cedsci/table?t=Year%20Structure%20Built&g=0400000US26&tid=ACSDT1Y2019.B25034&hidePreview=.

We multiply the marginal failure rate times the number of houses built in that year to determine the total number of LSLs installed in that year that will fail in 2021. We multiply that figure by 6.9 gallons per minute, annualize the result and apply the adjustment factor to find total LSL leakage for 2021.

For 2021, this approach yields estimated leakage from LSLs breaks in Detroit of 390,642,388 gallons (Table 3). This amount does not include Unavoidable Background Leaks.

Table 3. Estimated LSL Leaks and Waste Energy in Detroit, 2021.

LSL leaks (count)	1,311
Leak volume (gallons)	390,642,388
Embodied energy waste (KWh)	929,729

Again using energy intensity of the Grand Rapids water system as a proxy, we estimate energy waste from LSL water leaks of 929,729 KWh. This is about the same amount of electricity as that used by 4,099 54-watt LED streetlights for an entire year. See also Appendix C.

Other Leaking Service Lines in Detroit

In its PDSMI, Detroit reports 231,383 service lines of materials not covered by the Revised Lead and Copper Rule: Unknown-No Information, Unknown-Likely Not Lead and No Lead or GPCL.

Detroit builders, per city code, began using copper pipes for lead service lines after 1945. Furthermore, Detroit has service lines made only of metallic material.[36] Thus, Detroit presents a relatively simple scenario of installing lead SLs before 1945 and copper thereafter. However, we cannot assume that the age distribution of copper service lines will simply follow the age distribution of homes built in Detroit from 1945 onwards. Our allocation of Census Bureau housing data estimates that 215,472 homes have been built in Detroit since 1945 – fewer than the 231,383 copper service lines (CuSLs) we estimate above. Some of the copper service lines may be serving homes built before 1945 that originally had LSLs, or they are serving non-residential customers. To stay conservative with our projections, we assume those replacement SLs are as young as possible. Specifically, we assume they were installed as recently as 2020 and replaced LSLs originally installed 100 years earlier. We allocate these replacement copper SLs working back in time from 2020 until we have at least as many new and replacement copper SLs as the 231,383 non-lead SLs reported by Detroit. This is not a realistic temporal allocation for replacement copper SLs, but it employs conservative assumptions and will thus yield a conservative estimate of leaks and water loss.

For data and calculations, please see Appendix D. We estimate that 1,927 copper service lines in Detroit will develop leaks in 2021. We again assume average leak rate of 6.9 gallons per minute and leak duration of 30 days. These assumptions yield estimated water loss from leaking copper service lines in 2021 of 574,514,784 gallons.

At 2.38 KWh/1,000 gallons of water, this amount of leakage will waste 1,367,345 KWh in 2021.

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[36] Bryan Peckinpaugh, Detroit DWSD Communications Deputy Director, email to author Tapia, July 26, 2021

Summary - Detroit

Adding projected LSL and other SL line breaks plus Unavoidable Background Leaks from SLs in 2021, we estimate total leakage of 3,294,605,320 gallons representing 7,841,161 KWh of embodied energy. (Table 4)

Table 4: 2021 Projected SL Leaks in Detroit

	LSL	CuSL	UBL	Total
Number	1,311	1,927	n/a	3,238
Gallons	390,642,388	574,514,784	2,329,448,148	3,294,605,320
KWh	929,729	1,367,345	5,544,087	7,841,161

These estimates may be relevant in assessment of Detroit's plans to replace service lines over a 40-year period, rather than the 20-year standard replacement period under the Revised Lead and Copper Rule. The City currently plans to replace about 2,000 LSLs/year in conjunction with mains replacements as part of its Capital Improvement Plan, at an average cost of $1,600/LSL.[37] The City estimates that replacing LSLs independent of mains replacement would cost $6,000/LSL. To replace all LSLs within 20 years, the City would have to replace about 2,000 more per year than it currently plans, for a total marginal cost of about $12,000,000 (= 2,000 LSLs x $6,000/LSL).

However, the $6,000/LSL cost may assume that the lines would be fully excavated and removed, because current replacements are done in conjunction with excavation and replacement of mains. Many cities plan, instead, to leave LSLs in place and either insert new lines inside the LSLs or horizontal-bore new lines parallel to the LSLs. We understand these techniques are cheaper to implement than excavation[38] and therefore might be preferable if an LSL were replaced as a standalone project, not in conjunction with excavation of adjoining mains.

DWSD does not directly pay all costs of electricity associated with water production. GLWA embeds electricity costs of sourcing, transmitting, treating, and supplying water in the rates it charges DWSD. Furthermore, GLWA cannot currently pump less water if a customer, such as DWSD, uses less water because GLWA's pumps are not variable frequency drives (VFD). If it cannot turn down its pumps in response to reduced demand from customers, then GLWA's energy consumption will not respond to customer demand either. Therefore, we cannot predict how much water-supply cost DWSD would save by reducing service line leaks, nor how much energy would be saved in the GLWA-DWSD system. Our estimate is, therefore, illustrative but by no means definitive.

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[37], "Detroit's Robust Full Lead Service Line Replacement Program,".43.

[38] Boyd, G.R. et al, "Lead pipe rehabilitation and replacement techniques for drinking water service—survey of utilities," Tunneling and Underground Space Technology, 2001.

Statewide estimates

To estimate statewide annual water and energy loss from SL leaks, we first estimate how many homes were built in Michigan every year from 1900 onwards. We use US Census housing data, which is generally provided in decadal bundles. We assume the number of houses built in any given year is 10% of the decade total. This assumption does not recognize various recessions and booms that occurred within decades, but we assume those fluctuations even out over time and will not materially affect overall totals for the last 120 years.

Next, we estimate how many service lines of each common material are currently in service. Except for LSLs (known, likely and GPCLs), we do not yet have material distribution data for Michigan. Instead, we start with a nationwide SL material distribution survey conducted by AWWA in 2002.[39] However, the AWWA data must be adjusted to reflect what we do know about SL material prevalence in Michigan. From the PDSMI reports, we know that Michigan has more known and likely lead (11.4%) than in the national sample (lead = 3.6%), so we redistribute the other SL materials across the other 88.6% according to their prevalence in the national sample. See Table 5.

Table 5. Estimated Distribution of Service Line Materials in Michigan.

SL material	**% of national total***	**% of non-lead total**	**Estimated % in Michigan**	**Estimated Michigan count**
Copper	60.5%	63.0%	55.8%	1,464,983
Polyethylene	12.4%	12.9%	11.4%	300,261
Galv. Steel (inc. GPCL)	8.6%	9.0%	8.0%	208,246
PVC	6.3%	6.6%	5.8%	152,552
Known & Likely Lead	3.6%	n/a	11.4%	331,523
Polybutylene	2.6%	2.7%	2.4%	62,958
Steel	1.7%	1.8%	1.6%	41,165
Cast Iron	1.3%	1.4%	1.2%	31,479
Asbestos Cement	0.4%	0.4%	0.4%	9,686
Other	2.2%	2.3%	2.0%	53,272

NB: AWWA national survey totals do not sum to 100%

**Source: Installation, Condition Assessment and Reliability of Services Lines, AWWA 2007, Table 2.1.*

The AWWA survey did not provide separate totals for polyethylene, blue and black polyethylene per the Lee/Meehan survival analysis, so we assume the AWWA's estimate for polyethylene comprises all three types. Further, the Lee/Meehan survival analysis research does not cover some of the lesser-used materials included in the AWWA survey, including polybutylene, cast iron, steel and asbestos cement.

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[39] AWWA Research Foundation, 2007, *Installation, Condition Assessment and Reliability of Service Lines*, Table 2.1.

Because these materials comprise only about 6% of the national sample, they are unlikely to significantly alter our findings and we exclude them from further analysis (Table 5).

The number of SLs reported by water systems in Michigan for the PDSMI totals 2,656,124, a smaller number than the 4,629,605 homes we estimate were built in Michigan since 1900. Some of the homes built since 1900 no longer exist. Also, 27% of Michigan homes are served by wells or other private water facilities rather than municipal water systems.[40] However, we simply assume that the age distribution of homes with service lines connected to municipal water systems follows the age distribution of all homes in Michigan since 1900. We estimate there are 2,457,564 total lead, copper, galvanized, polyethylene and PVC lines in the state. This is less than the total reported in the PDSMI because of our exclusion of lesser-used materials for which we have no survival analysis data.

Next, we estimate the period over which each common SL material has been in use. Again, very limited data is available regarding history of use in Michigan for these materials. We know that lead was not used in Detroit starting in 1945 but was used elsewhere into the 1960s. Similarly, Detroit began using copper SLs before most other places. Statewide, then, we simply use 1955 as the average phase-out date for LSLs and the initial use date of copper. For history of other materials, we refer to dates when AWWA passed technical specifications, as well as various Internet references.[41] In short, our estimates of periods of use of various materials are not authoritative.

Based on rough periods of use of each material, and total SLs of that material, we can estimate the number of SLs of that material installed in Michigan in each calendar year. Using the survival analysis probability density functions, we can then project how many of those lines will start to leak in 2021. See Appendix E.

To estimate statewide UBL, we use a similar approach as for UBL in Detroit. Statewide, however, we apply an Infrastructure Condition Factor of 1, representing excellent infrastructure condition. This assumption is likely to be very conservative, but we are aware of no overall statewide infrastructure assessment, and conditions likely vary greatly among water systems. Even employing the most conservative ICF, UBL nearly equals projected losses from service line breaks. See Appendix F.

We estimate total losses from all SL breaks and UBL statewide in 2021 will be 21,550,571,040 gallons of water, representing 52,367,888 KWh of embodied energy. Table 6 shows how LSL breaks, other SL breaks and UBL contribute to this total.

Table 6. 2021 Water and Energy Waste Projections from SL Leaks in Michigan.

	Known & Likely Lead SLs	Other SLs	UBL	Total	Units
# of SL Leaks	5,656	33,270	n/a	38,926	count
Volume of SL Leaks	1,686,015,297	9,917,123,056	9,947,432,687	21,550,571,040	gallons/year
Embodied Energy waste	4,097,017	24,098,609	24,172,261	52,367,888	KWh

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[40] Cadmus Group, 2.

[41] See prior references. Also, AWWA approved standard for HDPE pipe for water tubes up to 75 mm (3 in.) in diameter in 1978. In 1975, AWWA approved the first edition of AWWA C900, "AWWA Standard for Polyvinyl Chloride (PVC) Pressure Pipe.

We do not attempt to estimate marginal energy use from wastewater treatment of leaked SL water that flows into treatment systems. As discussed above, we have no way to estimate this volume, but it is plausible to suppose it rivals the amount of energy embodied in leaks from SLs.

Recommendations

The American Water Works Association (AWWA) and several water loss experts we spoke with over the course of our research maintain that leaking service lines and their associated curb and corporation stops account for most real water loss at most US water utilities. By applying survival analysis to the estimated ages of service lines in Michigan, we show there are likely significant energy costs associated with service line leaks. Water utility managers will have to assess how these and other costs as well as public health outcomes trade off against replacing LSLs faster than planned or mandated. They must also consider whether the energy costs of leaks from SLs justify implementation of various monitoring and maintenance practices suggested by AWWA.

Utilities now have a valuable opportunity to directly assess the state of service lines and make better-informed decisions about monitoring, maintenance, and replacement. 2021 marks the first year of the 20-year timeline for replacement of LSLs required by Michigan's Revised Lead and Copper Rule. We recommend that LSL replacement contractors be required to note when they encounter wet soil, or other signs of leaks. Leaking LSLs will be most evident for projects that involve excavation and complete line removal. However, replacement by insertion or horizontal bore requires partial underground access to the curb stop and the building foundation, where wet soil may also be noted. We also recommend that utilities, especially those with district meters, carefully track changes in non-revenue water as LSL replacements proceed, to discern any systematic changes. Empirical data of this nature can inform utilities' strategy for LSL replacement going forward, as well as for management of SLs made from other materials.

Given strong indications that leaking SLs are costly to water utilities and their ratepayers, but lacking direct empirical evidence from Michigan, we recommend that both water utilities and regulatory agencies work toward a clearer understanding of water and energy loss attributable to service lines. Specifically, we suggest:

1. Water utilities should:
    a. test a statistically representative sample of service lines to estimate leak frequencies and volumes;
    b. employ AWWA's Water Loss Component Analysis to identify and address sources of real water loss;
    c. investigate subsidized insurance options for service lines, which could both reduce customer out-of-pocket repair costs and losses from unbilled water to the utility.[42]
    d. Replace old pumps with Variable Frequency Drive Pumps to allow them to reduce energy use in response to water efficiency gains. Investments in energy-efficient pumps are eligible for Energy Waste Reduction rebates from regulated utilities.
2. The State of Michigan should:
    a. Gather more accurate data on the amount of lead in reportable LSLs. The PDSMI reporting methodology treats an SL with any single lead component as an LSL. However, if most original lead components have been replaced with other materials, and only a minor lead component remains, the failure rate of that line will be very different than for the full, original LSL.

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[42] For examples, see *Installation, Condition, Assessment, and Reliability of Service Lines*, 51-52.

b. Require applicants to the Drinking Water Revolving Fund to estimate real water losses.
c. Require applicants to the Drinking Water Revolving Fund to document their pressure management methods and average system pressure.
d. Request the MPSC to support development of custom measures methodology for EWR rebates for non-lead service line replacements and projects that reduce UBL. Our findings suggest that non-LSL leaks and UBL cause energy waste for water utilities. EWR rebates might motivate utilities to more quickly discover and fix leaks in service lines. While potential energy savings are large, measurement and verification challenges require expert attention.

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Appendix A: Cumulative Failure Rates of Various Service Line Materials

Year	Lead	Galvanized	Copper	Black polyethylene	Blue polyethylene	PVC	Polyethylene
10	0.0%	0.2%	5.3%	2.4%	7.7%	19.8%	3.0%
20	0.0%	1.9%	18.7%	17.0%	46.0%	50.8%	19.5%
30	0.1%	6.7%	36.3%	46.2%	86.8%	75.5%	49.8%
40	0.5%	15.8%	54.2%	76.7%	99.1%	89.8%	79.0%
50	1.9%	29.4%	69.8%	94.1%	100.0%	96.4%	94.8%
60	5.9%	46.2%	81.7%	99.2%	100.0%	98.9%	99.3%
70	15.2%	63.5%	89.8%	100.0%	100.0%	99.7%	100.0%
80	32.2%	78.4%	94.8%	100.0%	100.0%	99.9%	100.0%
90	56.4%	89.2%	97.5%	100.0%	100.0%	100.0%	100.0%
100	80.5%	95.5%	98.9%	100.0%	100.0%	100.0%	100.0%
110	95.1%	98.5%	99.6%	100.0%	100.0%	100.0%	100.0%
120	99.5%	99.6%	99.8%	100.0%	100.0%	100.0%	100.0%

Source: Lee and Meehan, 2017.

Appendix B: Unavoidable Background Leaks from SLs in Detroit, 2021

$$UBL = ICF^* \, [((0.008 \, {}^*N_c) + (0.34{}^*L_c)) \, (P_{av}/70)^{1.5}] \text{ x } ICF$$

Abbreviation	Descriptor	Units
UBL	Unavoidable background leakage	1,000 gallons/day
N_c	Number of service connections	
L_c	Total length of private connections	miles
P_{av}	Average system pressure	psi
ICF	Infrastructure condition factor	

Detroit's UBL estimate

Input	Value	Source
Lm	2,700	DWSD website
Nc	311,000	(Detroit PDSMI, EGLE, 2020)
Lc	0.0066288	35 feet/private SL. Lee & Meehan, 2017
Pav	70	PSI. assumed.
Energy intensity (KWh/1,000 gal)	2.38	Grand Rapids proxy
Infrastructure Condition Factor (ICF)	2	AWWA M36 manual

Summary Results

Unavoidable Background Leakage (w/mains)	2,723,907,348	gallons/year
UBL (service lines only)	2,329,448,148	gallons/year
UBL Gallons/SL/day	21	
Energy waste from SL UBL	5,544,087	KWh

Appendix C: Projected 2021 LSL failures in Detroit

Year built	# Built	Projected LSL leaks	
1944	5316	100	
1943	5316	104	
1942	5316	109	
1941	5316	113	
1940	5316	117	
1939	2351	53	
1938	2351	55	
1937	2351	56	
1936	2351	58	
1935	2351	59	
1934	2351	60	
1933	2351	60	
1932	2351	61	
1931	2351	61	
1930	2351	61	
1929	2351	60	
1928	2351	60	
1927	2351	59	
1926	2351	58	
1925	2351	56	
1924	2351	55	
1923	2351	53	
1922	2351	51	
1921	2351	48	
1920	2351	46	
1919	2351	43	
1918	2351	40	
1917	2351	37	
1916	2351	34	
1915	2351	31	
1914	2351	29	
1913	2351	26	
1912	2351	23	
1911	2351	20	
1910	2351	18	
1909	2351	15	
1908	2351	13	
1907	2351	11	
1906	2351	10	
1905	2351	8	
1904	2351	7	
1903	2351	5	
1902	2351	4	
1901	2351	3	
1900	2351	3	
Total homes	120,636		count
Unadjusted 2021 leaks est.		**2,048**	scale to reported # LSLs
House-survival factor		**0.640**	reported LSLs/Total homes built
Adjusted 2021 leaks total		**1,311**	count
2021 Leak volume		**390,642,388**	gallons
Energy waste		**929,729**	KWh
Streetlight benchmark			
Average watts/light		*54*	
Hours lit/year		*4200*	
KWh/year/light		*226.8*	
Energy wasted in street light-years		*4099*	

Appendix D: Projected CuSL leaks in Detroit in 2021

Decade built	**New CUSLs**	**replacement CUSLs**	**Total CUSLs**	**CUSL marginal failure count**
1945-1949	53,157	0	53,157	276
1950-1959	80,932	0	80,932	612
1960-1969	27,216	0	27,216	308
1970-1979	18,473	0	18,473	279
1980-1989	10,923	0	10,923	194
1990-1999	10,259	0	10,259	183
2000-2009	1,755	0	1,755	25
2010-2020	3,775	8,982	12,757	51
Total	206,490	8,982	215,472	1,927

Leak volume	574,514,784	gallons/year
Energy	1,367,345.19	KWh/year

Appendix E: 2021 Michigan Statewide SL Failures Projections

		Lead		Galvanized		Copper		PVC		Polyethylene	
Build years	Est. # houses built	# SLs installed	projected 2021 failures	# SLs installed	projected 2021 failures	# SLs installed	projected 2021 failures	# SLs installed	projected 2021 failures	# SLs installed	projected 2021 failures
2010-2020	172,765	-	-	-	-	77,294	469	13,009	281	28,614	108
2000-2009	447,095	-	-	-	-	200,029	2,850	33,664	1,037	74,050	1,410
1990-1999	603,050	-	-	-	-	269,802	4,815	45,407	1,050	99,880	3,123
1980-1989	447,907	-	-	-	-	200,392	3,560	33,726	436	74,184	2,052
1970-1979	710,427	-	-	-	-	317,843	4,801	26,746	189	23,533	457
1960-1969	553,159	-	-	-	-	247,481	2,797	-	-	-	-
1950-1959	680,118	-	-	90,845	1,557	152,141	1,281	-	-	-	-
1940-1949	334,358	77,869	1,587	44,661	644	-	-	-	-	-	-
1930-1939	136,145	63,414	1,571	18,185	183	-	-	-	-	-	-
1920-1929	136,145	63,414	1,470	18,185	104	-	-	-	-	-	-
1910-1919	136,145	63,414	813	18,185	47	-	-	-	-	-	-
1900-1909	136,145	63,414	215	18,185	17	-	-	-	-	-	-
Total	4,629,605	331,523	**5,656**	208,246	**2,553**	1,464,983	**20,575**	152,552	**2,993**	300,261	**7,150**
Leak Volume (gal/yr)			**1,686,015,297**					**Galvanized+Copper+PVC+Polyethylene**			**9,917,123,056**
Energy waste (KWh/yr)			**4,097,017**								**24,098,609**

Appendix F: Unavoidable Background Loss from Service Lines, Michigan, 2021

SL UBL (thous gal/d) = (0.008 * Nc) + (0.34 * Lc)] × (Pav/70)1.5 x ICF

source: AWWA M36 Water Loss manual, equation 7-2

Input	Value	Source/comment
Lm	n/a	UBL from mains not estimated for state
Nc	2,656,124	(Detroit PDSMI, EGLE, 2020)
Lc	0.0066288	35 feet/private SL. Lee & Meehan, 2017
Pav	70	PSI. assumed.
Energy intensity (KWh/1,000 gal)	2.43	Statewide average (Table 2)
Infrastructure Condition Factor (ICF)	1	Assume excellent condition

Summary

UBL (service lines only)	9,947,432,687	gallons/year
UBL Gallons/SL/day	10	
Energy waste from SL UBL	24,172,261	kwh

Appendix G: 2020 Cadmus Group Memo on Energy Savings from Water-Associated Efficiency Measures

To: Joe Forcillo, Matt Rife, Jenny Sample, Consumers Energy
From: David Molner, Amy Ellsworth, Emily Miller, Shannon Donohue, Cadmus
Subject: Energy Savings from Water Associated Efficiency Measures
Date: February 4, 2020

This memo outlines proposed savings potential and a calculation methodology to attribute energy savings to water-related measures in the Michigan Energy Measure Database (MEMD) for reduced electric consumption at water supply facilities, wastewater treatment plants, and residential well usage.

Executive Summary

In 2019, Consumers Energy inquired about capturing energy savings benefits that accrue to commercial water supply and wastewater treatment plants and residential well pumps as a result of water-savings measures installed in residences. Water supply facilities pump and distribute clean water to homes and businesses while wastewater treatment plants collect and treat water. Water savings measures such as faucet aerators and low-flow showerheads produce energy savings at the residence by reducing the amount of energy used by water heaters when those measures are in use. Installation of these measures means water supply and wastewater treatment facilities must transport, treat, and process less water, thereby reducing electric energy consumption within those facilities. Additional electric savings can also be found for residential customers with well pumps who install water saving measures. Table 7 shows measures in the Michigan Energy Measure Database (MEMD) currently used in Consumers Energy's residential energy waste reduction (EWR) portfolio that provide energy savings by reducing water consumption. The table also includes the associated calculated gallons per minute (GPM) savings.

Table 7. Water-Saving Measures and GPM Savings used in the Residential EWR Portfolio

Measure Name	GPM Savings
Low Flow Showerheads	1.50 - 1.75
Low Flow Bathroom Aerators	1.00 – 1.50
Low Flow Kitchen Aerators	1.50
Thermostatic Showerheads	1.50
ENERGY STAR Clothes Washer	4.00

Consumers Energy calculated that they conserved over 293 million gallons of water in 2018 through rebating and installing energy-efficiency measures that also conserve water, with lifetime water savings of over 2.9 billion gallons.

Total energy use by both water supply and wastewater facilities can be quantified based on the amount of energy used to treat 1,000 gallons of water and the percentage of Michigan households whose water is provided and treated by municipal infrastructure and wells. In Michigan, electric savings can be calculated using the following inputs:

Municipal Water Facilities (Commercial & Industrial)

- KWh required to supply 1,000 gallons of municipal water: 2.10
- KWh required to treat 1,000 gallons of municipal wastewater: 1.65
- Percentage of customers that use municipal water facilities: 72.9%[43]

Private Water Facilities (Residential)

- KWh required to supply 1,000 gallons of private(well) water: 1.56[44]
- KWh required to treat 1,000 gallons of private water:0[45]
- Percentage of customers that use private water facilities: 27.1%

Figure 6 shows the process which derives the additional electric savings from reducing residential water usage.

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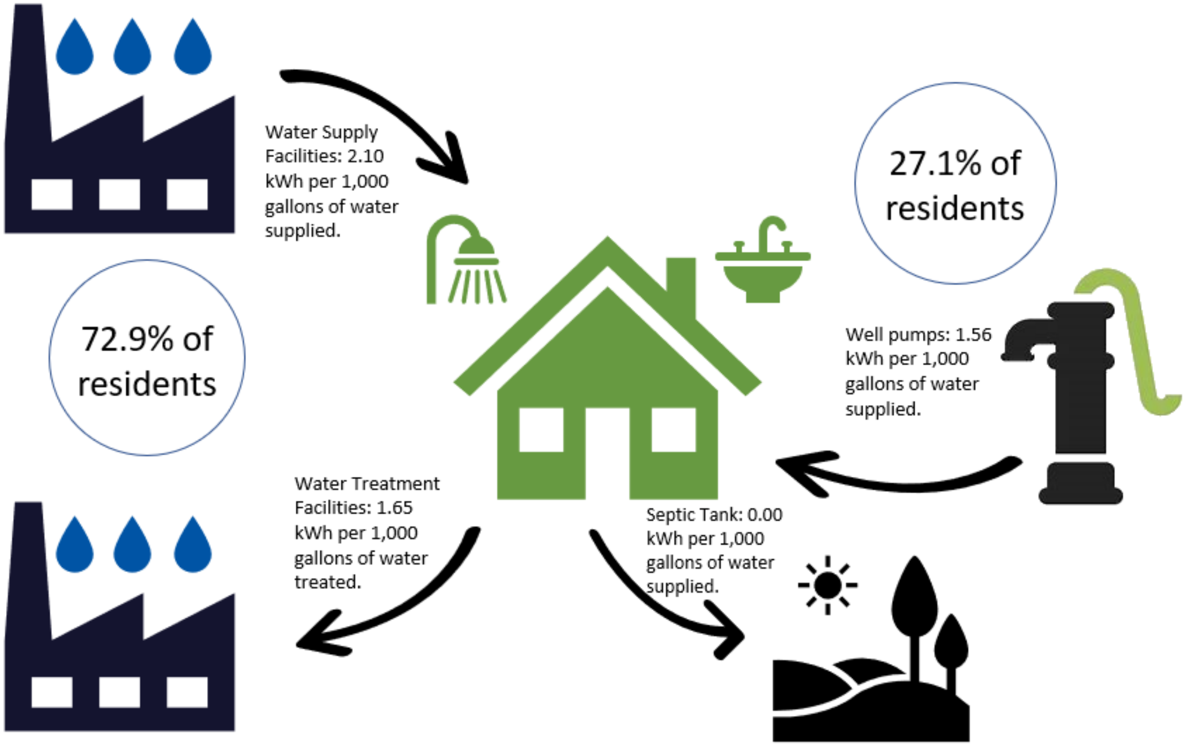
[43] The other 27.1 percent or 1.25 million Michigan households use well water and would not be included in the reduction to municipal water usage.

[44] Calculated from the average well depth in Michigan from the Department of Environmental Quality and assuming 43% total pumping efficiency and 39PSI supply water pressure.

[45] Homes on private wells use septic systems for treatment, septic is typical gravity powered and requires little or no quantifiable electricity.

Figure 6. Cycle of Electric Savings for Residential Water Usage



Energy savings attributable to 1,000 gallons of water saved at water supply and treatment facilities through the installation of residential water saving measures can be calculated as:

$$(2.1 + 1.65) \times 72.9\% + (1.56) \times 27.1\% = \frac{3.16kWh}{1000\ gallons}$$

The Cadmus team's research indicated that there is the potential for Consumers Energy to claim 3.16 KWh per 1,000 gallons of water saved as energy savings at treatment and supply facilities. For the 2018 program year, this is equivalent to an additional 928,039 net KWh energy saved per year. Due to the higher percentage of municipal water customers and the facilities' higher energy consumption, 86% of water-saving equipment are realized at commercial water supply and wastewater treatment facilities; these savings must be claimed through Consumers Energy's commercial reconciliation process[46]. Table 8 shows the breakout of KWh savings per equipment type and the savings by residential and commercial.

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[46] Per 1000 gallons. 2.73KWh is attributable to commercial municipal facilities while 0.42KWh is attributable to the residential customer 2.73/(2.73+0.42)=86%

Table 8. KWh Savings Per Residential Energy-Saving Equipment

Dwelling	Equipment Type	GPM	Annual Gallons of Water Saved	KWh savings per year		
				Residential	Commercial	Total
Single Family	Low Flow Showerheads	1.50	2,881	**1.27**	**7.83**	**9.10**
	Low Flow Bathroom Aerators	1.00	869	**0.38**	**2.36**	**2.75**
	Low Flow Kitchen Aerators	1.50	2,909	**1.29**	**7.91**	**9.19**
	Thermostatic Showerheads	1.50	479	**0.21**	**1.30**	**1.51**
	ENERGY STAR Clothes Washer	4.00	1,518	**0.67**	**4.12**	**4.80**
Multifamily	Low Flow Showerheads	1.50	2,816	**1.25**	**7.65**	**8.90**
		1.75	2,112	**0.93**	**5.74**	**6.67**
	Low Flow Bathroom Aerators	1.00	896	**0.40**	**2.44**	**2.83**
		1.50	523	**0.23**	**1.42**	**1.65**
	Low Flow Kitchen Aerators	1.50	2,104	**0.93**	**5.72**	**6.65**
School Education Kit	Low Flow Showerheads	1.50	4,236	**1.87**	**11.51**	**13.39**
	Low Flow Bathroom Aerators	1.00	1,390	**0.62**	**3.78**	**4.39**
		1.50	811	**0.36**	**2.20**	**2.56**
	Low Flow Kitchen Aerators	1.50	2,909	**1.29**	**7.91**	**9.19**

This memo addresses the following research objectives:

- Assess the potential electric energy savings attributable to water supply facilities and treatment plants from energy-saving equipment in the MEMD that reduce water usage in residential homes.

To assess the potential for additional energy savings at the water treatment and supply level, the Cadmus team reviewed existing data that quantified water supply and treatment facility savings and conducted secondary research for Michigan-specific information. These data are intended to help inform Consumers Energy about the potential to capture commercial electric savings from residential water conservation measures in the MEMD that already produce residential energy savings.

We organized this memo as follows:

- Summary of key findings, conclusions, and recommendations
- Detailed findings from the water facility savings research

Summary of Key Findings, Conclusions, and Recommendations

This section presents the Cadmus team's key findings, conclusions, and recommendations associated with the research objectives for the evaluation activity. The Detailed Findings section of this memo provides further explanation of these findings and the context for our conclusions and recommendations.

Research Objective: Assess the potential electric energy savings attributable to water supply facilities and treatment plants from energy-saving equipment in the MEMD that reduces water usage in residential homes.

Conclusion 1: Energy savings occurs at water supply and water treatment facilities when residential water conservation measures are installed in residential homes that rely on municipal water services.
Cadmus analyzed Michigan-specific energy savings at water supply and treatment facilities and adapted the calculation methodology used in Wisconsin to calculate additional commercial electric savings from the installation of residential water saving measures. Additional commercial savings from residential water-saving equipment comes from the 72.9 percent of Michigan residents that use and rely on municipal water facilities for their supply and collection of water usage.

Cadmus calculated that 2.10 KWh and 1.65 KWh is saved per 1,000 gallons of water reduced in transfer from water supply and wastewater facilities, respectively.

Conclusion 2: Residential water conservation measures produce secondary energy savings in homes that use well water by reducing the demand on well pumps.
Cadmus calculated energy savings for the 27.1 percent of Michigan residents that use a well instead of municipal water supply and commercial treatment facilities. Well users generate electric savings through reducing the need for pumping with reduced demand for well water.

Cadmus calculated 1.56 KWh is saved per 1,000 gallons of water reduced in transfer from a residential well pump to home usage.

Recommendation:

- ***High Priority:*** Cadmus recommends developing a white paper based on the findings outlined in this memo to add water treatment facility savings to the MEMD as additional savings derived from water-saving equipment.

Detailed Findings

This section highlights the secondary research conducted by the Cadmus team for water supply and wastewater treatment plants energy usage based on the capacity output of water supplied or treated. The Cadmus team reviewed national, regional, and local sources to identify best practices in calculating water-savings from supply and treatment facilities.

Water supply and wastewater facility sizes range across municipalities. Different classifications are used to categorize the types of water facilities. Water facilities can be categorized based on three primary metrics.

1. The average daily flow rate (typically defined as millions of gallons of water processed on an average day (MGD)),
2. The population served daily by the facility,
3. Type of water process (e.g. groundwater vs. surface water).

Wastewater facilities typically measure energy savings in MGD while water supply facilities measure in population served or type of water processed.

Water Supply Facilities

Water supply facilities play an important role in the processing and distribution of clean water to municipal residents. Customers that use less water daily due to energy-efficient equipment create secondary energy savings at water supply facilities because they pump and distribute less water.

National studies conducted by the Electric Power Research Institute (EPRI) and American Council for an Energy-Efficient Economy (ACEEE) have demonstrated the potential for reducing energy usage in water facilities. The EPRI study compiled secondary data from a variety of public and private sources and calculated energy usage and water output for nearly all the water facilities in the country based on the facility's daily water output (measured as millions of gallons of water per day or "MGD")[47]. The ACEEE study used a primary survey research method: requesting water facilities self-report data about their energy usage and based their findings on facilities usage of surface water or groundwater as a water source[48]. Table 9 shows the energy use (KWh used to process 1,000 gallons of water) results from the two national studies. EPRI data was not able to be broken out by type of water facilities since it included non-municipal water facilities that purchase water from outside sources.

Table 9. Water Supply Energy Usage, National Averages

Water Supply Facilities by Source and Daily Flow Rate	KWh/1,000 Gallons of Water
ACEEE[49]	
Surface water source	1.80
Groundwater source	2.40
EPRI[50]	
Less than 3 MGD	2.00
3 to 5 MGD	1.40
5 to 20 MGD	1.60
20 to 600 MGD	1.50

The two national studies, while informative, did not produce a pertinent savings value for the state of Michigan. However, two state-wide studies have been conducted by NYSERDA for New York state and Focus on Energy for Wisconsin; both have been instrumental in establishing best practices for analyzing energy usage at water facilities and serve as a more applicable approach for Michigan. Both studies used a survey approach, reaching out to water facility representatives and asking about their energy usage and number of customers served by the facility. Table 10 shows energy use per 1,000 gallons of water processed based on the studies conducted by Focus on Energy and NYSERDA. Results from both studies are broken out by number of customers served per facility and Focus on Energy results are additionally broken out by water source.

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[47] *Electricity Use and Management in the Municipal Water Supply and Wastewater Industries*. Electric Power Research Institute, November 2013.

[48] *A Survey of Energy Use in Water Companies.* American Council for an Energy-Efficient Economy, June 2015.

[49] *Ibid*

[50] *Electricity Use and Management in the Municipal Water Supply and Wastewater Industries*. Electric Power Research Institute, November 2013.

Table 10. Water Supply Energy Usage, Statewide Averages

Water Supply Facilities by Customer Population and Source	KWh/1,000 Gallons of Water
Focus on Energy[51]	
Less than 4,000 customers	1.81
1,000 – 4,000 customers	1.94
Greater than 1,000 customers	2.41
Surface water source	2.16
Groundwater source	2.01
NYSERDA[52]	
Less than 3,300 customers	1.08
3,330 – 50,000	0.98
50,000 – 100,000	0.81
Greater than 100,000	0.25

The Focus on Energy survey in Wisconsin[53] is a good proxy for Michigan due to its similar population characteristics, topography, and use of the Great Lakes as a major source of water supply. The NYSERDA study included water supply facilities that serve large, concentrated populations in New York State that are less comparable to Michigan water facilities, especially those in Consumers Energy's service territory.

According to the Michigan Department of Environmental Quality, 45 percent of the Michigan population is served by groundwater, while 55 percent is served by surface water or water from the Great Lakes[54]. Table 11 shows the weighted average energy use for Michigan's population based on the equivalent energy use per water source as analyzed in the Wisconsin study. Cadmus calculated the weighted average for water supply energy usage in Michigan as 2.10 KWh/1,000 gallons.

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[51] *Energy Best Practice Guide: Water & Wastewater Industry.* Focus on Energy, 2016.

[52] *Importance of Energy Efficiency to the Water and Wastewater Sector.* Matthew Yonkin, Katherine Clubine and Kathleen O'Connor, New York Water Environmental Association. Spring, 2008.

[53] Michigan and Wisconsin have similar mean elevations 900ft and 1,050ft respectively and population 10 million and 5.8 million respectively and withdrew 268 and 311MGal/day of water from Lake Michigan for public water.

[54] *DEQ Fact Sheet – Groundwater Statistics.* Michigan Department of Environmental Quality, January 2018.

Table 11. Water Supply Energy Usage in Michigan, Weighted Average

Water Supply Facilities by Source	KWh/1,000 Gallons of Water	MI Percent of Population Supplied	Weighted KWh/1,000 Average
Surface water source	2.16	55%	1.19
Groundwater source	2.01	45%	0.91
Total			**2.10**

Wastewater Treatment Plants

Wastewater treatments plants account for over one-fourth of energy used by local governments, and that share of energy usage has continued to grow each year for over a decade[55].

Studies conducted by EPRI, NYSERDA, and Focus on Energy have had varied results for wastewater treatment facilities. Additionally, a study conducted in 2017 by the Michigan Water Environmental Association (MWEA) on behalf of the Michigan Department of Environmental Quality looked at energy use by wastewater treatment plants in Michigan using methods like the studies completed by NYSERDA and Focus on Energy[56]. These studies all provided energy use broken out based on facility size in terms of million gallons treated per day (MGD). Finally, An ACEEE report noted that the data available from wastewater treatment facilities was limited and therefore ACEEE did not publish the results, instead opting to highlight other studies completed in 2012 or earlier, including an EPRI study conducted in 2002[57].

Table 12 shows energy usage per 1,000 gallons of water treated from the national EPRI study, broken out by facility processing size in MGD. The nationwide EPRI study used dissimilar binning compared to the NYSERDA, Focus on Energy, and Michigan Water Environmental Association (MWEA) studies but still offers insights on the national average energy consumption in comparison to statewide averages.

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[55] *Electricity Use and Management in the Municipal Water Supply and Wastewater Industries*. Electric Power Research Institute, November 2013.

[56] *Michigan's Wastewater Treatment Plants Energy Survey and Estimate of Energy Baseline*. Michigan Water Environment Association, April 15, 2017.

[57] *A Survey of Energy Use in Water Companies.* American Council for an Energy-Efficient Economy, June 2015.

Table 12. Wastewater Treatment Energy Usage, National Averages

Wastewater Treatment Facilities by Daily Flow Range	KWh/1,000 Gallons of Water
EPRI[58]	
Less than 2 MGD	3.30
2 to 4 MGD	3.00
4 to 7 MGD	2.40
7 to 16 MGD	2.00
16-100 MGD	1.70
101-303 MGD	1.60

Table 13 shows the energy usage in KWh per 1,000 gallons treated at wastewater facilities from the NYSERDA, Focus on Energy, and Michigan Water Environmental Association (MWEA) studies, broken out based on similar facility size categories.

Table 13. Wastewater Treatment Energy Usage, Statewide Averages

Wastewater Treatment Facilities by Daily Flow Rate	NYSERDA[59]	Focus on Energy[60]	MWEA[61]
	KWh/1,000 Gallons of Water		
Less than 1 MGD	4.62	5.44	N/A
1 to 5 MGD	1.58	2.50	2.50
5 to 20 MGD	1.74	2.29	2.36
20 to 75 MGD	1.70	2.29	1.80
Greater than 75 MGD	1.10	2.29	1.40

As shown in Table 13, wastewater facilities capture measurable economies of scale: energy use declines significantly in facilities that produce more than one million gallons of water per day compared to facilities that treat less than one million gallons of water. A facility's energy use per 1,000 gallons continues to trend downwards as the daily flow rate increases.

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[58] *Electricity Use and Management in the Municipal Water Supply and Wastewater Industries*. Electric Power Research Institute, November 2013.

[59] *Importance of Energy Efficiency to the Water and Wastewater Sector.* Matthew Yonkin, Katherine Clubine and Kathleen O'Connor, New York Water Environmental Association. Spring, 2008.

[60] *Energy Best Practice Guide: Water & Wastewater Industry.* Focus on Energy, 2016.

[61] *Michigan's Wastewater Treatment Plants Energy Survey and Estimate of Energy Baseline*. Michigan Water Environment Association, April 15, 2017.

MWEA used an energy intensity model originally developed by the Environmental Protection Agency (EPA) to calculate a statewide mean energy use value of 1.65 KWh per 1,000 gallons of wastewater treated in Michigan[62]. This value likely reflects the most accurate estimate of energy savings impacts at water treatment plants resulting from reduced water usage associated with water conservation measures.

Private Water Wells and Septic Systems

Consumers Energy customers that use a well and receive water-savings equipment from a Consumers Energy program cannot claim savings for water supply and treatment at these commercial facilities but can claim pumping energy savings associated with reduced demand for well water. The Michigan Department of Environmental Quality estimates that there are about 1.25 million households in Michigan with a private well[63], based on available census and well drilling data. Additionally, the U.S. Census estimates that there are 4.61 million households in Michigan as of 2018[64]. Homes with private well are typically dispose of wastewater using a septic system with a leech field. These systems are gravity powered and do not consume energy.

A private well uses energy to lift, filter and pressurize a ground water source for a home. The primary energy consumption comes from the pump. Energy required by the pump can be expressed as a function of the total dynamic head from the water source to where it is used and the efficiency of the pump using the follow equation:

$$P_{kWh/1000gal} = \frac{h_{ft} \times 0.746\left(\frac{kW}{hp}\right) \times 1000gallons}{3960(\frac{GPM * ft}{hp}) \times \eta \times 60(\frac{min}{hr})}$$

Where:

h_{ft} = total dynamic head in feet (included static and dynamic head)

0.746 = kilowatts per horsepower conversion

η = efficiency of the pump and motor

3960 = hydraulic horsepower unit conversion

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[62] *Ibid.*

[63] *DEQ Fact Sheet – Groundwater Statistics.* Michigan Department of Environmental Quality, January 2018.

[64] *Quick Facts Michigan.* U.S. Census Bureau (2018). https://www.census.gov/quickfacts/fact/table/MI/HSG010218#HSG010218.

The Michigan Department of Environmental Quality keeps records on well details throughout the state. The average well depth in Michigan is 114 ft[65] with the deepest wells located around Clinton, MI. We calculated the total dynamic head for an average Michigan home with a well to be 209ft.[66]

Household well pump efficiency is not typically published by manufacturers or government agencies. Research by Kenny/Jenks consultants show pump efficiencies of municipal scale pumps of 65-81%[67] and efficiency increases with the size of the pump. An article published in MDPI[68] estimated the global average efficiency of all submersible pumps to be 48%. We estimate typical residential well pumps in Michigan to have a pump efficiency of 60% with a motor efficiency of 70% for a total efficiency of 42%. Using the energy equation outlined above, 1.56 KWh of energy is consumed per 1000 gallons of water pumped by a residential well pump on average.

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[65] Found as the average well depth from 636,102 well records where well depth was reported. From: http://gis-michigan.opendata.arcgis.com/search?q=Wellogic

[66] Assuming a home with 2 bathrooms and a total piping length from the well to the home of 173 ft and a household water pressure of 39 PSI.

[67] http://www.energy.wsu.edu/LinkClick.aspx?fileticket=t3ubiA8D8A4%3D&tabid=692&mid=1345

[68] https://www.mdpi.com/2073-4441/10/10/1310/pdf