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Could Fixing Leaky Pipes Help Solve California's Water Problems?

Amanda Rupiper, Joakim Weill, Ellen Bruno, Katrina Jessoe, and Frank Loge

Water utilities in the United States lose approximately 17% of their delivered water to leaks each year. California's Senate Bill 555 aims to reduce these water leaks through the imposition of utility-specific water standards. For the average utility, we find it is cost-effective to reduce water losses by 34.7%. While this reduction only translates to about 100 acre-feet per year for the average utility, it is low-hanging fruit.

For the average utility, leak management is the most cost-effective water management strategy.

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Drought and population growth are increasing water scarcity worldwide. In the United States, almost half of the watersheds may soon lack sufficient water supplies to meet monthly demand. Urban water suppliers are faced with the difficult task of satisfying water demand under growing supply uncertainty.

Historically, water utilities have met projected deficits in supplies with new water sources, such as drawing from previously unused surface water or groundwater aquifers. However, supply augmentation is not always feasible. Therefore, utilities have also turned to demand-side strategies, with the implementation of conservation tools to achieve end-user water savings (for instance through information campaigns, mandates, and rebate programs). Absent from this water-management portfolio, however, are water savings that could occur through improved management of the water distribution system. The concept of "leak management" has only recently entered the water management discussion.

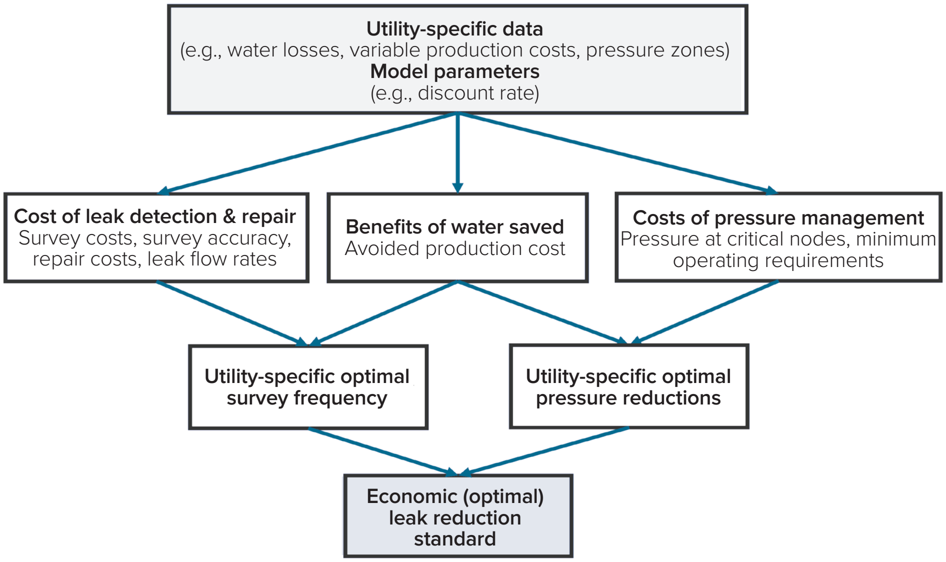
How Leaky Are the Pipes?

More than 90% of California residents are served by an urban water retailer, which is defined as a utility that reaches at least 3,000 homes or businesses. These urban water retailers source water, treat it, and then deliver it to households through a local distribution network of underground pipes. Between the treatment plant and the household faucet, about 8% of the water is lost due to leaks in the system in California. Nationally, this number is even higher: 17% of water is lost each year due to leaks in the distribution system.

While large pipe failures are the most visible examples, water lost in the distribution system is usually imperceptible from the surface, occurring as background or unreported leakage. This makes it challenging to identify and repair leaks.

So far, leak reduction as a water-saving strategy has been largely ignored. Water losses in distribution systems in the United States are not systematically tracked or regulated. Only seven states require standardized water loss audits, and no state regulates the level

Figure 1. Determining Utility-Specific Optimal Leak Reduction Targets



Note: The figure diagrams the model for optimal water loss. The model combines utility-specific data with other parameters to maximize the net benefits of leak reduction by considering both pressure management and leak detection and repair activities.

of water losses. However, the regulations governing water losses are rapidly evolving, and are currently under debate and design in several states, including California.

Is Every Drop Worth Saving?

It may seem counterintuitive, but the optimal amount of water loss is not zero. At some point, the cost of conserving an additional drop of water exceeds the benefits of saving that drop. But the optimal amount to save is not obvious. The question becomes, how much should utilities invest in leak management?

To answer this question, we first need to understand what is in a utility's toolkit for reducing leaks. There are two primary management options available to utilities: 1) pressure reduction and 2) leak detection and repair. Pressure reduction in a distribution system can lower leak flow rates and reduce the frequency of pipe failures. Leak detection surveys help utilities locate small leaks that have yet to come to the surface.

Small, undetected leaks in the water distribution system may occur from corrosion, poor installation practices, soil movement, and high pressure. While leaks can be small, they often go unnoticed for long periods, leaving total water losses to accumulate. As more leaks form, and existing leaks endure, water losses grow. These small leaks collectively account for the majority of a utility's water losses. Once subsurface leaks are detected and located, a utility can develop a repair or replacement strategy to eliminate the leaks and reduce water losses.

In our study, we assessed utility-level urban water losses using the most comprehensive collection of water loss audit data available from almost 900 water utilities in California, Georgia, Tennessee, and Texas. We built an economic model that quantifies all the costs and benefits accrued by a utility when undertaking a water-loss-reduction activity. We then used this model to find the amount of loss reduction that maximizes the net benefits of repairs.

As diagrammed in Figure 1, this model solves for both the optimal leak reduction due to pressure management and the optimal leak reduction due to periodic leak detection and repair. This latter part embeds a calculation of the optimal frequency with which a utility should survey for leaks, a decision characterized by fixed search costs and benefits and repair costs that accrue over time as leaks grow. The economic benefits of leak reduction derive primarily from the value of water saved, which we approximate using variable production costs ($341 per acre-foot for the median California retailer).

Our model departs from typical past approaches to this problem in two key ways. First, previous engineering approaches tend to simply calculate a break-even point, that is, the point where the total benefits of water loss control equal the total costs. Our model improves upon this by maximizing the net benefits of water loss control, as we explain in detail later. A second departure stems from explicitly calculating the optimal frequency with which a utility should survey for leaks. Previous approaches typically assume a fixed survey frequency, e.g., every two years. These simplifying assumptions may lead to estimates of water loss recovery that are suboptimal.

Optimal Water Loss

Given that water utilities vary in a number of characteristics that influence distributional losses, leak management strategies are not a one-size-fits-all tool. Distribution systems differ in the pipe age, pipe materials, system size, and elevation, all of which influence the costs of leak management. The benefits of saving water are also location specific. For instance, drought-prone regions place a higher value on incremental water compared to relatively water-rich areas. These differences imply that the optimal amount of leak reduction will vary between utilities.

Applying our economic model to utility-specific data, we find that it is almost always economically efficient to reduce water losses in distribution systems, but that there is large variation among utilities in the efficient levels of distributional losses. We find that the average optimal leak reduction by state ranges between 30.1% and 39.6% of current water losses. For the median utility, this amounts to a reduction in real losses of 34.7% and an increase in the available water supply of 105.3 acre-feet (AF) annually.

As shown in Figure 2, higher levels of initial water losses, measured in gallons per connection per day (GPCD), are systematically associated with higher optimal reductions. Figure 2 graphs optimal leak reduction for each utility as a percentage of their total distributional volume in box-and-whisker plots. We separately plot optimal reductions for three different levels of initial water losses: greater than 60 GPCD in losses, between 20–60 GPCD, and less than 20 GPCD. Box-and-whisker plots split the data into quartiles to illustrate the spread. The length of the box shows the interquartile range of the data, ranging from the 25th percentile to the 75th percentile, with the median shown as the horizontal line through the box. In other words, half of the utilities in each subsample fit in the 25–75% range shown by the box. The first and fourth quarters of the data are displayed as lines extending off the box.

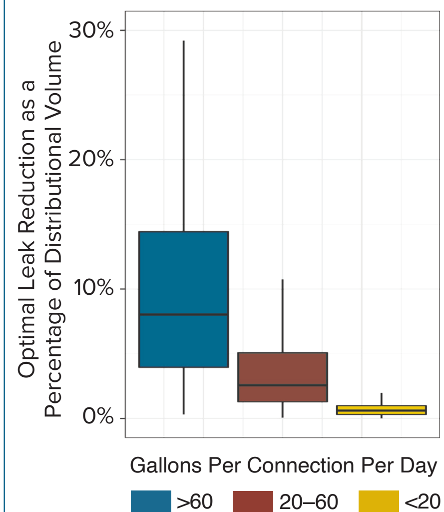
We see that the utilities with initial leak rates exceeding 60 GPCD have a median optimal target for reduction that represents 8% of their distributional volume, whereas those with leak rates of less than 20 GPCD have an optimal target that is just 0.7% of their distributional volume.

Comparing Leak Reduction to Other Strategies

For the majority of utilities in our sample, leak reduction is the least-cost option to obtain additional water supplies. Figure 3 illustrates the normalized median cost per recovered acre-foot of water for leak detection and pressure reduction compared to four commonly used water supply management tools: desalination, recycling, traditional source, and conservation. Traditional source refers to the costs of developing additional groundwater or surface water sources, and conservation includes a range of water activities that reduce consumption, such as the installation of water-efficient devices, changes to water rates, and water-reduction mandates.

The median cost of water savings from leak management (which includes leak detection and pressure reduction) is $277 per acre-foot, which falls well below the cost of other typical water management tools. The most expensive source for the median utility is desalination. This is followed by recycling, either at a centralized facility or at the user level. Where feasible, pressure reduction is the least-cost strategy, irrespective of baseline leakage levels, utility size, or location.

Figure 2. Optimal Leak Reductions by Initial Water Loss Levels (in GPCD)

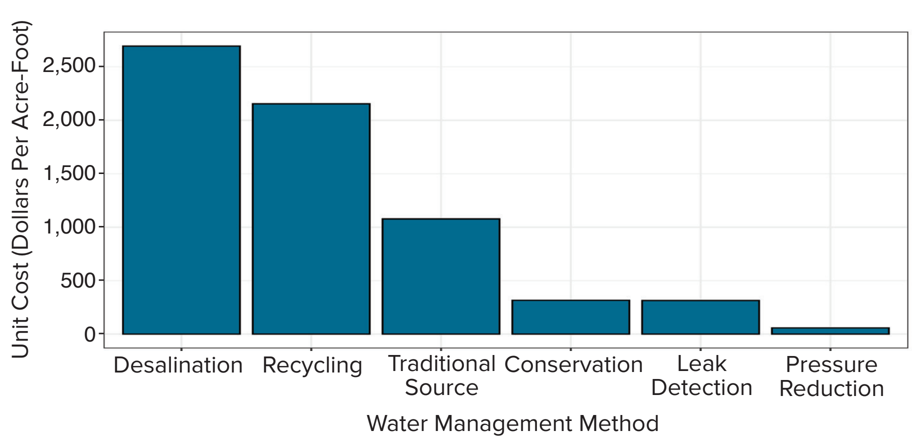


Note: The figure graphs the optimal leak reduction as a percentage of a utility's total water distributional volume displayed by gallons per connection per day (GPCD) leakage levels. The plotted boxes capture the 25–75 percentile interquartile range. The figure combines optimal reductions from pressure management with optimal reductions from leak detection and repair.

Policy Implications

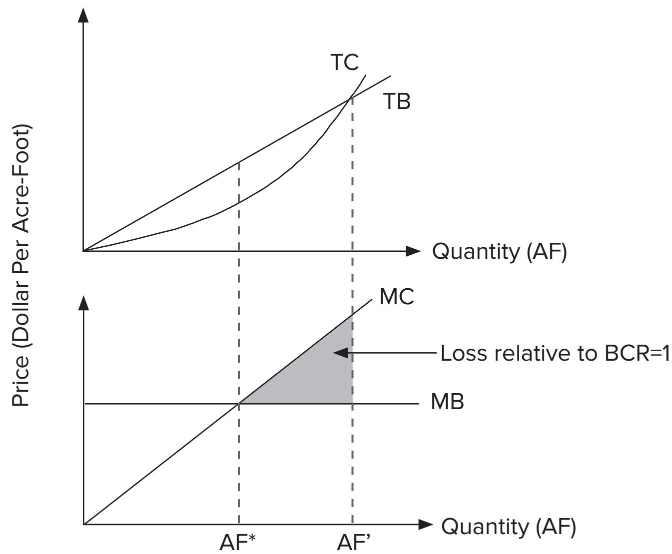
The few countries or states that have set goals for water loss reductions currently do so through a uniform approach, whereby all utilities are required to bring their annual water losses below some percentage level of their total supply. However, utilities face different costs to achieve the same reduction in water losses. Because of the substantial variation in the optimal amount of leak reductions at the utility level, a uniform standard is not a desirable policy for achieving these savings: it will likely be too stringent, and therefore too costly, in some cases, while too lenient in others.

Figure 3. Comparison of Per-Unit Costs of Water Management Methods



Note: The figure shows normalized cost per acre-foot (AF) of additional water supply via traditional (i.e., surface or groundwater) and alternative water supply management methods. Leak detection and pressure reduction costs per acre-foot were calculated under the economic model for the 882 utility dataset.

Figure 4. Economic Loss from a Break-Even Point (BCR=1)



Note: The figure illustrates the welfare loss of a water loss standard determined by a break-even point (where total costs, TC, equal total benefits, TB, or a benefit-cost ratio equal to 1 (BCR=1)) relative to a standard determined by the maximization of net benefits.

Alternative regulatory proposals tend to adhere to the engineering standards-of-practice, which consist of a break-even point and a fixed survey frequency for leak detection. Under a break-even point, water loss standards will be set such that the economic benefits from the standard are equal to the costs of the standard, which is equivalent to a benefit-to-cost ratio (BCR) equal to 1. This approach has the desirable property of allowing for heterogeneity across utilities, but it is not optimal since, by definition, such standards do not seek to maximize the net benefits of loss reduction.

Figure 4 demonstrates the efficiency loss associated with using a break-even point rather than the maximization of net benefits for calculating the optimal water loss standard. Given total cost (TC) and total benefit (TB) curves like those shown in the top half of Figure 4, maximizing net benefits would yield an optimal standard denoted by AF* where the marginal benefit (MB) and marginal cost (MC) curves intersect. The shaded triangle shows the welfare loss relative to the standard that would be set if using the break-even point (AF').

If we were to instead assume a BCR of 1 and a fixed survey frequency, the model would estimate that the median utility should reduce water losses by 51.3% at a cost of $374 per acre-foot. This implies greater reductions at a higher cost relative to what would be economically efficient according to our preferred model.

In California, Senate Bill 555 aims to reduce water leaks through the imposition of utility-specific water standards. Informing these standards with a model that optimizes survey frequency and requires an amount of leak reduction such that net benefits are maximized, could yield cost-effective water savings for Californians. Failing to do so would impose an undue burden on utilities.

Concluding Remarks

Reducing distributional leaks could generate water savings at low cost. The amount of savings is not huge and won't solve California's water problems, but these water savings are cheap in comparison to alternative options and, in most cases, should be undertaken. California's policy is the first attempt at regulating water losses in the United States and it is being closely monitored by utility managers and decision makers alike. Setting the "correct" water loss standard for each utility is crucial to achieving and maximizing net benefits.

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For additional information, the authors recommend:

Rupiper, Amanda M., Joakim Weill, Ellen Bruno, Katrina Jessoe, and Frank Loge. 2022. "Untapped Potential: Leak Reduction is the Most Cost-Effective Urban Water Management Tool." *Environmental Research Letters* 17(3). Available at: https://bit.ly/3xegMm7.

Rupiper, Amanda M., MacKenzie S. Guilliams, Micaela M. Bush, Katrina K. Jessoe, and Frank J. Loge. 2021. "Assessing Data Adequacy for Determining Utility-Specific Water Loss Reduction Standards." *Journal of Water Resources Planning and Management* 147(8). Available at: https://bit.ly/3LU0tPN.