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Draft Guidance: Economic (Benefit-Cost) model to calculate water loss standards

Benefit-Cost Analysis Model Overview

The economic model conducts a benefit-cost analysis for each urban retail water supplier. The model assumes 2022 through 2027 to be the implementation period for water loss control, based on the regulatory timeline for adoption of the standards.

The model consists of the following individual sheets:

<u>Inputs</u>: This sheet is where the individual leak characteristics, unit costs of leak detection and repair, the efficiency of leak detection and value of water are entered into the model, based on inputs or default values as described in the following sections of the guidance. The real discount rate, average annual rise in price of water and effective lifecycle timeline have been determined by The State Water Board. These inputs are described in later sections of the guidance.

<u>Calculations</u>: All model inputs entered in the Inputs tab are used to calculate reported, unreported and background leakage as described in the report. The calculated unreported leakage is used as the initial leakage that can potentially be reduced by the supplier depending on the average leak detection frequency. Reducing background leakage either specifically requires asset management or pressure management, while reducing reported leakage requires reducing response time to repairs. Assuming reasonable specifics for an achievable response time to repairs or asset or pressure management programs involves a high amount of uncertainty. Hence, the model assumes that only unreported leakage can be potentially reduced, as any standard industry approach including pressure and asset management and reducing response time for repairs can be used to reduce unreported leakage. The model uses active leak detection and repair as a standard approach to reduce leakage to conduct the benefit-cost analysis based on data collected from industry vendors and water suppliers. However, water suppliers are not required to solely use active leak detection and repair to meet their water loss standards. Suppliers may use any water loss control actions they deem feasible and effective.

The model assumes that all leaks found within a month would be repaired within that month. On an annual average, the total number of leaks repaired would be the same if the leaks were repaired beyond the month in which they were detected.

The average leak detection frequency is used to divide the entire distribution into parts of the water distribution systems that can be surveyed each month. The model calculates the impact of surveying the water distribution system at the average leak detection frequency on real loss during each month (described in later sections of the guidance). The model calculates the total cost of leak detection, by multiplying the unit cost of leak detection for each mile surveyed with the average number of miles surveyed per month. The model calculates the number of unreported leaks to be repaired and the cost of leak repair per month by multiplying the unit cost of repair for each leak with the number of unreported leaks and dividing by the leak detection efficiency to account for false positives. These costs constitute the total associated costs and are calculated for each month. The real monthly discount rate is applied to the costs to calculate the present value of costs in 2020.

The water saved from water loss control is calculated as the difference between the real loss after implementing active leak detection and repair and the baseline average real loss, which is the supplier's current real loss assuming they would maintain the real loss without water loss intervention. This water saved contributes to the benefits. The standards would require all suppliers to at least maintain their real loss if they are not required to reduce real loss based on the benefit-cost analysis.

The model applies the annual real rise in price of water to calculate the price of water at the beginning of 2022, after which a monthly rise is applied to the price of water. The price of water is multiplied by the water saved from water loss control. This constitutes the benefits. The monthly discount rate is applied to each month of benefits after 2022 to calculate the present value in 2020.

The present values of both benefits and costs are calculated over a period of 30 years from 2022 through 2051. The net benefit is calculated as the difference between the present value of benefits and the present value of costs associated with active leak detection and repair.

Output: This sheet calculates the standard. If the net benefit over 30 years is positive, the model calculates the unreported real loss over the year 2027, by summing the unreported leakage occurring over the 12 months of 2027. The standard is calculated by adding the average annual reported and background leakage to the unreported real loss over 2027, as the model assumes that only unreported leakage can be reduced by all standard industry approaches. If the net benefit over this time period is zero or negative, the standard is set equal to the current average baseline real loss.

Technical background on water loss control

Distribution system characteristics and the nature of real loss influence the suitability of intervention strategies to reduce real loss. Real loss can occur in several forms described as follows (Sturm, Gasner, Wilson, Preston, & Dickinson, 2014; American Water Works Association, 2016):

- Reported leakage that occurs in the form of visible failures over the ground.
- Unreported leakage that is not visible above ground but detectable by surveying the distribution system through specialized leak detection equipment.
- Background leakage that is too small to be detected with leak detection equipment but can be reduced by replacing or rehabilitating infrastructure or managing operational pressure.

Real loss reduction has four key approaches as per industry practices that are suited for each form of leakage:

- Active leak detection and repair involves surveying the distribution system for leaks with specialized equipment and repairing those leaks. This method is used to reduce unreported leakage. Water distribution system infrastructure (i.e. pipes, valves, hydrants) is surveyed using specialized leak detection equipment to detect and locate leaks, and then repair them. Leak detection equipment are available commercially and are typically use acoustic signals, imaging, or pressure differentials.
- Reducing time between locating and repairing a leak minimizes the amount of water lost through visible or detectable leaks.
- Pressure management to reduce excessively high water pressure or spikes in water pressure (water hammer effect) that strain distribution system infrastructure and increase leakage through existing infrastructure defects.
- Systematic asset management by prioritizing replacement of pipes and other appurtenances, which are leakiest and have most failures, especially located in areas of high consequence, for example, hospitals and dense commercial centers.

Pressure and asset management are the only approaches that can be used to reduce background leakage that is too small to be detected through leak detection equipment (American Water Works Association, 2016, pp. 220,259; Fanner, Thornton, Liemberger, & Sturm, 2007, p. 15). Additionally, reducing repair time with pressure and asset management reduce the occurrence and loss of water through reported leaks. The feasibility of implementing pressure management and asset management and the estimated volume of leakage reduction depends on operational characteristics for each distribution system. Estimating the amount of leakage that is recoverable through pressure management and asset management for urban retail water suppliers is influenced by the operating pressure, and thus hydraulic design of the distribution system; and the amount of water leaking through pipes needing replacement.

On the other hand, due to availability of data, associated costs and benefits of implementing active leak detection and repair for each supplier can be determined to a much greater degree of accuracy. The amount of leakage that is recoverable can be determined from data on length of pipeline, number of service connections and operational water pressure, as reported by suppliers. Hence pressure and asset management are excluded from the scope of the model while determining the amount of leakage that suppliers can reduce with a positive net benefit.

Input parameters

There are twenty-five input parameters to the model. There are default values provided for all of these, while supplier-specific values may be provided for all but three parameters. A supplier may request an adjustment to these supplier-specific parameters, and thus its water loss standard, no later than July 1, 2023. If the supplier requests an adjustment, it must provide supporting documentation to adjust a particular input. It must also assess the impacts from the adjustment. General guidance for an adjustment request and its supporting documentation, if the supplier opts to input its supplier-specific values, is provided for each input parameter. The input parameters are described below.

1. **Input parameters from water loss audit reports submitted by urban retail water suppliers per Water Code 10608.34 to the California Department of Water Resources**
   Data on system characteristics will be used by calculating the average of values reported from 2017 through 2020 through water loss audits for each of the following parameters as shown below. Currently the model uses data reported from 2017 through 2019, but suppliers may use data from 2017 through 2020.
   - **Average baseline real loss**: Average of current annual real loss reported from 2017 through 2020. Currently the model uses data reported from 2017 through 2019, but suppliers will use data from 2017 through 2020. They may choose to exclude one outlier year to improve data quality if the outlier year is either a negative value or varies by more than 10 gallons per connection per day or 740 gallons per mile per day, depending on the metric that the suppliers use to report, from each value reported in the other three years.
     Adjustment: The data in the water loss audit leading to the adjustment and its supporting evidence for the change in underlying data should be identified.
   - **Average length of mains**: Average of length of mains
   - **Average number of service connections**: Average of number of active and inactive service connections
     Adjustments: For adjusting the average length of mains or number of service connections, supporting evidence for the cause for this change should be included in the adjustment request.
   - **Average variable production cost of water**: Average of variable production cost
     Adjustment: The request should include the calculation of the new variable production cost, with the cause for change from previously reported value identified.
   - **Average operating pressure**: Average of the annually reported average operating pressure
     Adjustment: The request should include the calculation of the new average operating pressure, with the cause for change from the previously reported value identified. It should also include a summary of the extent and frequency of pressure monitoring in the supplier's water distribution system.

2. **(a) Leakage profile of urban retail water supplier:**
   The model uses default values per the AWWA M36 manual, such as, Reported,

Unreported, and Background leakage and underlying leakage characteristics. The American Water Works Association M36 manual provides equations for estimating volumes of different types of leakage that exist in a distribution system (American Water Works Association, Fourth edition, 2016, pp. 199-201). The model uses these equations to calculate background leakage and reported leakage that a supplier would have in their distribution system. The model then calculates unreported leakage by deducting the minimum background and reported leakage from the supplier's total leakage as reported in the water loss audits.

- **Rate of rise of leakage**: Default value is 4 gallons per connection per day per year. Default value: The model uses default rise of 4 gallons per connection per day per year, adapted from the EU Reference document: Good Practices on Leakage Management (Main Report) is used. As per the EU Report, this value is very low as compared to water systems in the U.K. and is selected as a representative rate for California systems, based on field experience of technical experts. The low rate of rise of leakage means that the model results are impacted more by the backlog of leakage (represented by the real loss reported by suppliers) than the default value for rate of rise in leakage.
  Adjustment: The supplier should provide a measurement of rising leakage in a representative portion of their water distribution system. The rising leakage can be measured using leak detection and repair surveys conducted across time, by measuring the rise in leakage between surveys divided by the time between surveys and number of connections.

Background leakage

- **Infrastructure Condition Factor (ICF)**: Default value is 1.0
  The model uses a default value of 1.0 to calculate the minimum amount of background leakage occurring in the water distribution system, to then estimate the potential unreported leakage that can be reduced.
  Adjustment: The supplier should provide a calculation of the weighted average age of their system using pipe inventory on age of pipe. The weighted average can be used to develop an initial estimate of the ICF.
  Assuming that the total pipeline length for your distribution system is 'L', if your system has pipeline length 'L1' of age 'A1'; length 'L2' of age 'A2' and so on, the average age for that distribution system will be:

$$\frac{A1 \times L1 + A2 \times L2 + \cdots}{L}$$

  Additionally, the supplier should calculate the ICF for two scenarios:
  A. No background leakage i.e. ICF = 1.0
  B. ICF when the total water loss is equal to Background leakage.
     Calculate ICF for which

Three-year average real loss = ICF × Unavoidable background leakage, where unavoidable background leakage is calculated as:

$$(0.2 \times Total\ length\ of\ mains + 0.008 \times Number\ of\ service\ connections) \times \left(\frac{Average\ operating\ pressure}{70}\right)^{1.5}$$

The new proposed ICF can be calculated as the median of the ICF calculated from scenario 1 and 2.

- **Annual background leakage**: No default input, calculated value
  The model uses equation 7-5 from the AWWA M36 manual (American Water Works Association, 2016, p. 201) for the Unavoidable background leakage which is calculated as follows:

$$(0.2 \times Total\ length\ of\ mains + 0.008 \times Number\ of\ service\ connections) \times \left(\frac{Average\ operating\ pressure}{70}\right)^{1.5}$$

$$\text{Total Background leakage} = \text{UBL} \times \text{ICF}$$

Adjustment: If this value is known to the supplier, and the supplier opts to input this total volume instead of only the ICF, the supplier should provide documentation on the calculation of this parameter per equation 7-5 from the AWWA M36 manual, including the determination of the ICF (per the adjustment documentation specified for the ICF) and the average operating pressure (per the adjustment documentation specified for the average operating pressure).

Reported leaks on mains

The AWWA M36 manual provides estimates for leak characteristics for reported leakage for a system operating at an average pressure of 70 psi in Table 3-22 (American Water Works Association, 2016, p. 102). All suppliers reported through water loss audits that all customer meters are located at the curb stop of properties. Hence, the model includes the leakage up to the curb stop point in the service area for reported and background leakage (rows 1 and 2 of Table 1).

Table 1 Leakage volumes and numbers for reported and unreported leakage for an average operating pressure of 70 psi

Infrastructure Component	Background leakage	Reported leakage	Unreported leakage
Mains	8.5 gallons per mile per hour	0.2 leaks per mile per years at 50 gallons per minute of flowrate for 3 days' duration	0.01 leaks per mile per year at 25 gallons per minute for 50 days' duration

Service connections, main to curb stop	0.33 gallons per service connection per hour	2.25 leaks per 1000 service connections at 7 gallons per minute of flowrate for 8 days' duration	0.75 leaks per 1000 service connections at 7 gallons per minute of flowrate for 100 days' duration
Service connections curb stop to meter or property line	0.13 gallons per service connection per hour	1.5 leaks per 1000 connections at 7 gallons per minute of flowrate for 9 days' duration	0.5 leaks per 1000 service connections at 7 gallons per minute of flowrate for 101 days' duration

- **Average duration between reporting of and repair of reported leaks on mains:**

  Default value: 3 days based on Table 1
  Adjustment: If the system-specific value for this parameter for the years 2017 through 2020 is different from the default value, the supplier should provide logs of the average time taken to repair leaks over 2017 through 2020. If data is unavailable throughout 2017 through 2020, data should be provided for the most recent years within 2017 through 2020.

- **Number of reported leaks per year on mains:**

  Default value: 0.2 leaks per mile per year based on Table 1
  Adjustment: If the system-specific average value for this parameter for the years 2017 through 2020 is different from the default value, the supplier should provide logs of the average annual number of annual reported leaks for the years 2017 through 2020 or the most recent years that data was collected within these years.

- **Average flow rate of reported leaks on mains:**

  Default value: 50 gallons per minute per leak based on Table 1
  Adjustment: If the system-specific average value for this parameter for the years 2017 through 2020 is different from the default value, the supplier should provide logs of annual reported leaks and estimated flow rates, based on size of leak and average operating pressure as calculated in the American Water Works Association M36 Manual, fourth edition, Table 7.3 and equation 7-24. The leak flow rate should also be calculated using in-field methods for measurement and the method used and calculations should be described.

- **Average duration between reporting of and repair of reported leaks on laterals and service lines:**
  Default value: 8 days based on Table 1

Adjustment: If the system-specific value for this parameter for the years 2017 through 2020 is different from the default value, the supplier should provide logs of the average time taken to repair leaks over 2017 through 2020. If data is unavailable throughout 2017 through 2020, data should be provided for the most recent years within 2017 through 2020.

- **Number of reported leaks per year on laterals and service lines:**

  Default value: 2.3 leaks per 1000 connections per year based on Table 1
  Adjustment: If the system-specific average value for this parameter for the years 2017 through 2020 is different from the default value, the supplier should provide logs of the average annual number of annual reported leaks for the years 2017 through 2020 or the most recent years that data was collected within these years.

- **Average flow rate of reported leaks on laterals and service lines:**

  Default value: 7 gallons per minute per leak based on Table 1
  Adjustment: If the system-specific average value for this parameter for the years 2017 through 2020 is different from the default value, the supplier should provide logs of annual reported leaks and estimated flow rates, based on size of leak and average operating pressure as calculated in the American Water Works Association M36 Manual, fourth edition, Table 7.3 and equation 7-24. The leak flow rate should also be calculated using in-field methods for measurement and the method used and calculations should be described.

- **Annual reported leakage if known:** No default input, calculated value

  The number of reported leakage is calculated based on average number of reported leaks over 2017 through 2020 and estimated average flow rate of reported leaks using the following equation:

$$\begin{aligned}&\mathit{Number\ of\ reported\ leaks\ per\ length\ of\ main} \times \mathit{Total\ length\ of\ mains}\\&\quad \times \mathit{Estimated\ average\ flow\ rate\ for\ reported\ leaks\ on\ mains}\\&\quad \times \left(\frac{\mathit{Average\ operating\ pressure}}{70}\right)\\&\quad \times \mathit{Average\ time\ between\ reporting\ of\ and\ repair\ of\ leaks}\end{aligned}$$

$$\begin{aligned}&+\mathit{Number\ of\ reported\ leaks\ per\ 1000\ service\ connections}\\&\quad \times \frac{\mathit{Total\ number\ of\ service\ connections}}{1000}\\&\quad \times \mathit{Estimated\ average\ flow\ rate\ for\ reported\ leaks\ on\ service\ connections}\\&\quad \times \left(\frac{\mathit{Average\ operating\ pressure}}{70}\right)\\&\quad \times \mathit{Average\ time\ between\ reporting\ of\ and\ repair\ of\ leaks}\end{aligned}$$

  Adjustment: If this value is known to the supplier, and the supplier opts to input this total volume instead of individual number of reported leaks and corresponding flow rates, the supplier should provide documentation on average number of reported leaks as specified for adjustments for number of reported leaks, duration of leaks and corresponding flow rates, and a document showing the calculation of the total volume.

Annual Unreported leakage

- **Unreported leakage if known:** No default input, calculated value

  This value is calculated using the following equation:

  Annual Unreported leakage
  = Average baseline real loss – Annual Background leakage – Annual Reported leakage

  Adjustment: If this value is known to the supplier, the supplier should provide documentation on average number of unreported leaks from 2017 through 2020 as specified for adjustments for number of unreported leaks and corresponding flow rates, and a document showing the calculation of this parameter, in addition to results from leak detection survey results for representative portions of the supplier-owned water distribution system. The sum of the annual unreported leakage, annual reported leakage and annual background leakage should be equal to the average baseline real loss.

- **Number of unreported leaks per year on mains:** No default input, calculated value

- **Number of unreported leaks per year on service lines or laterals:** No default input, calculated value

  The number of unreported leaks per year are based on the first two rows of Table 1 (for unreported leakage) for each of these parameters.
  Adjustment: If the average value for these parameters are known to the supplier, the supplier should provide documentation on how these values were calculated, in addition to results from leak detection survey results for representative portions of the supplier-owned water distribution system.

2. **(b) Associated unit costs and marginal avoided cost of water**

- **Average leak detection survey frequency:**

  The State Water Board obtained estimates of from suppliers, leak detection consulting firms and vendors to inform the model. The leak detection survey mileage ranges from 2 to 5 miles per day. Additionally, suppliers that are proactive and advanced in leak detection informed The State Water Board that they can survey their distribution systems once in two to three years.

  The model assumes different leak detection survey frequencies according to water system sizes. Based on these estimates, the model assumes that a range of two to three years for different system sizes (Table 2).

Table 2 Average leak detection frequency in economic model

Total pipe length (miles)	Time taken to survey entire system once
Less than 500	2 years
500 to 1000	2.5 years
Above 1000	3 years
Above 7000	4.75 years

Adjustment: If active leak detection and repair is the only method that would be used to meet the standard, supporting documentation should include leak detection surveys previously conducted, efficiency achieved and identification of the portions of the water distribution system on which active leak detection and survey cannot be conducted with the cause identified. Based on this supporting evidence, the supplier may request to adjust the average leak detection survey frequency that is feasible for the supplier, including all types of proactive leak detection, such as visual surveying.

- **Unit average cost of leak detection surveying per mile:** The default value used for this parameter is $595 per mile. The State Water Board obtained data on leak detection and repair costs from consultants and water suppliers (Table 3). The State Water Board used the higher end of the cost range for leak detection to ensure that suppliers have the flexibility to select from a variety of vendors and technologies and pipe material, i.e. $595 per mile including surveying (detection of leak) and pinpointing (precise location of leak), cost of labor, material, equipment and other auxiliary costs. Non-metallic pipes may warrant additional equipment due to relatively low conduction of sound, as most of this equipment are acoustic. The cost estimates include costs for both metallic and non-metallic pipes.

  Adjustment: The supplier should provide documentation to adjust this value if it opts for the adjustment, if based on field implementation of active leak detection and repair, the unit average cost of leak detection surveying per mile for the supplier is different from the default value. The supplier should provide competitive estimates from vendors for leak detection for which the supplier plans to opt.

Table 3 Unit costs obtained from various vendors and water suppliers

Source	Unit cost (dollars)	Additional information
Kunkel Water Efficiency Consulting, 2019	177 to 395 per mile	Based on location, pipe material, includes surveying (Detection) and pinpointing (precise location of leak)
Water Systems Optimization, Inc., 2019	250 to 400 per mile	Includes surveying and pinpointing
M.E. Simpson, 2019	295 to **595** per mile	Includes surveying and pinpointing
Municipal District of Orange County (a regional water authority comprising of 28 water suppliers), 2019	278 to 350 per mile	Surveying
Municipal District of Orange County	347 per leak	Pinpointing
Los Angeles Department of Water and Power (Water Loss Action Plan, 2015)	255 per mile	Lifecycle costs

- **Efficiency of leak detection equipment:** The default value used for this parameter to account for false positives is 70%.

  This represents the average percentage of actual leaks found, on excavation, as a percentage of the total detected leaks including false positives expected to be pinpointed by leak detection equipment. Per vendor and water supplier knowledge based on field implementation, this efficiency increases with higher training and experience. This parameter adds the cost of additional excavation associated with locating leaks pinpointed by false positives, without the benefits of water loss reduction, to the overall costs of leak detection and repair.

  The model incorporates the extraneous cost incurred when leak detection equipment has false positives, but there are no actual leaks to yield benefits in water loss. The estimated false positive percentage is 70%, based on data collected from vendors and water suppliers that provided leak detection unit costs to the State Water Board, resulting in a range of 98 to 99 percent for surveying and 50 to 92 percent for pinpointing. The State Water Board calculated the overall efficiency for leak detection including surveying and pinpointing by multiplying the average efficiency for surveying (97%) by the average efficiency for pinpointing (71%), which resulted in an overall efficiency of 70%.

Adjustment: If the supplier has found that this efficiency is different during field implementation of active leak detection and repair from the default value and requests an adjustment, the supplier should provide results of active leak detection and repair of a representative portion of the supplier-owned water distribution system, specifically outlining the number of leaks detected and located using pinpointing leading to excavation for repair, and the number of actual leaks found on excavation.

- **Average unit leak repair costs for mains and Average unit cost of leak repair costs for laterals and service lines**

  Default input values are as follows:

  - Leak repair costs for mains: $5,946 per leak
  - Leak repair costs for service lines: $2,330 per leak

  The State Water Board calculated repair costs by collating unit costs for repairs from consultants and water suppliers. Unit repair costs depend on the type and extent of leak and pipe material and size. The State Water Board assumed that all types of leaks have an equal probability of occurrence. Thus, The State Water Board averaged all estimates collected on repair costs to develop unit repair costs for the model for main leaks and service line leaks. The average cost from the leak detection programs described in the Pacific Gas and Electric Report were $4,466 (Pacific Gas and Electric, 2015). Additionally, The State Water Board collected data from Irvine Ranch Water District. The average unit cost based on these sources was $5,946 per leak.

  Repair costs for service connections and laterals was obtained from Kunkel Water Efficiency Consulting and Water Systems Optimization, Inc.

  Adjustments: To request an adjustment for these parameters, the supplier should provide a summary of the historical unit repair costs over the years 2017 through 2022, for unit repair costs for mains and service or lateral lines respectively.

- **Marginal avoided cost of water: The default value is $1093 per acre-foot of water loss reduced**
  The State Water Board used the higher of variable production cost and avoided cost of water based on available alternative sources to value water saved. The avoided cost of water was calculated by averaging cost of alternative water supply from Pacific Institute's report (Pacific Institute, 2016), supported by Natural Resource Defense Council's Issue Brief (Natural Resources Defense Council, 2016), and is equal to $1093 per acre-foot of water.

Typically, in the water loss industry, water lost through leakage is valued at either the Variable Production Cost (marginal cost to produce water that flows into the distribution system) or the Customer Retail Unit Cost (marginal cost of water that customers pay for water service). The water loss audits submitted annually by suppliers provides the variable production cost. Typically, water loss is valued at the Variable Production Cost (American Water Works Association, 2016). Variable Production Costs would value the real loss on a short-term basis. The Customer Retail Unit Cost is applied to real losses for water suppliers with limited water resources and potential water stresses in the future. Yet, per feedback from water suppliers, the Customer Retail Unit Cost could over- or underestimate the actual value of lost water depending on the rate structure. The proposed regulation is intended to capture the long-term effects of water loss control, while incorporating the need for water resilience and sustainability.

The State Water Board calculated the avoided cost of water for suppliers in the future owing to water loss control by averaging the anticipated average cost of water for alternative sources such as imported water, recycled water, stormwater reuse and brackish water desalination, based on the Pacific Institute's report on the Cost of Alternative Water Supply and Efficiency Options (Pacific Institute, 2016). The Issue Brief by the Natural Resources Defense Council supported the estimated value of these alternative supplies (Natural Resources Defense Council, 2016). The average value was calculated from the estimated values for alternative supplies adjusted for inflation in Table 4.

Table 4 Value of alternative supplies used in benefit-cost model

Alternative water supplies	Cost (2015 dollars)	Costs (2019 dollars)	Cost (2020 dollars)
Stormwater	590	567.38	567.43
Indirect potable reuse	1800	1731.00	1731.13
Brackish water desalination	1100	1057.84	1057.91
Imported water	1015	1015	1015.07

Some suppliers may have expanded their water portfolio with alternative water sources in their variable production cost; while suppliers relying on local water resources (e.g. only groundwater or local snowmelt) may not have not incorporated long-term avoided costs in their variable production costs. The State Water Board propose to value water lost through leakage at the higher of the Variable Production Cost, and the avoided cost of water. The present value of the avoided cost has been calculated for 2020.

Adjustment: The supplier should provide an estimate of the marginal avoided cost of water which considers future water resilience and costs that would be avoided in the future due to water loss savings and improved monitoring and maintenance of the supplier-owned water distribution system. Such resilience and avoided costs may include avoided costs in obtaining new water supply, environmental impacts due to additional surface or groundwater extractions, rise in costs due to additional volumes of imported water purchased, prevented unexpected water distribution infrastructure failures, water treatment to address PFOA and PFAS, and sustainable groundwater management.

3. **State determined inputs to the model (Not subject to adjustments):**

- **Real discount rate:** The value is estimated to be 3.5%.

  The associated costs and benefits would be discounted annually at the rate of 3.5% per stakeholder recommendation. This is also in line with the Guidelines for Preparing Economic Analysis (2014) from the US EPA, which suggests that the real discount rate should be in the range of 3%-7%, depending on whether costs and benefits are incurred contingent on the time horizon. In general, lower discount rates are adopted if the impact is anticipated to last longer, especially with consideration of intergenerational equality. The proposed regulation is intended to conserve water and it would have permanent impacts on water resources and environment, with a time horizon of 30 years for economic analysis. Therefore, a discount rate of 3.5% is adopted.

- **Average annual rise in price of water**: The estimated value is 5.9%

  California is progressing towards increased water conservation, sustainable groundwater management to mitigate impacts of climate change on water resources. Additionally, the water suppliers would be required to monitor and treat source water for contaminants such as PFAS and PFOA. Thus, majority of water suppliers, including suppliers relying on local groundwater are anticipated to experience an increase in price of water to meet these new requirements. The State Water Board proposes to incorporate these factors into the regulation with a view to consider the long-term benefits of improving water loss reduction in the face of stressed water resources.

  Predicting the rise in in price of water due to these factors has a significant amount of uncertainty associated with it. Water suppliers use the treated water rates set by the Metropolitan Water District of California, the largest supplier of treated water that supplies half the population in California, as a representative of the increase in price of water for urban retailer water suppliers, while accounting for increased production costs due to the implementation of the Sustainable Groundwater Management Act, and higher water quality requirements addressing emerging contaminants such as PFOA and PFAS. The real increase in price of water sold by the Metropolitan Water District, over the past decade was 5.9%. Table 4, shows the projection of the consumer price index for 2020. Table 5, shows the calculation of the real annual rise in price of water.

Table 3 History of treated water prices from the Metropolitan Water District (Metropolitan Water District of Southern California, 2020)

Year	Price (Tier 1, treated	Consumer price indices (Commodities)	Real price as 2019 dollars	Annual percent increase
2008	508	173.193	549.8	--
2009	579	168.093	645.7	17.4%
2010	701	172.129	763.4	18.2%
2011	744	180.192	773.9	1.4%
2012	794	183.705	810.2	4.7%
2013	847	183.443	865.5	6.8%
2014	890	183.920	907.1	4.8%
2015	923	180.260	959.8	5.8%
2016	942	178.010	991.9	3.3%
2017	979	180.509	1016.6	2.5%
2018	1015	184.966	1028.6	1.2%
2019	1050	187.445	1050.0	2.1%
2020	1078	187.431	1078.1	2.7%

Effective timeline for lifecycle benefit-cost analysis: The estimated lifecycle period is 30 years.

Leak detection equipment and pipe repair material have lifecycle periods that extend beyond the compliance date (by 2028), and correspondingly the model accommodates for the useful life of repair in the time horizon. Water distribution infrastructure maintenance is conducted to prolong its useful life, and reduce water loss, and damages and outages from main breaks. Water suppliers would also be required to continue maintaining leakage at their standard after 2028 on a three-year average basis. The State Water Board therefore anticipate that where water loss reduction is cost-effective, suppliers would continue to achieve these benefits beyond compliance. The State Water Board request reviewers to provide insights on this policy proposal.

Calculation of impact of intervention on real loss

Unreported or hidden leakage can be reduced by either of the standard approaches, in contrast to background or reported leakage. The intent of this regulation is to provide the supplier the flexibility to choose any approach best suited for their system and budget to reduce the leakage to the volumetric standard. The economic model developed by the State Water Board to calculate the individual volumetric standards focuses on unreported, hidden leakage to ensure flexibility in choice of approach.

The State Water Board developed a model to calculate volumetric standards for urban retail water suppliers by analyzing the costs and benefits associated with leakage reduction. If the leakage reduction results in a net positive benefit, the suppliers would reduce the amount of leakage feasible during the compliance period, based on the distribution system characteristics. The suppliers would be required to maintain their current leakage if the net benefit for any leakage reduction is not positive.

Calculating reduction in leakage with regular surveying per the assumed survey frequencies.
The model uses the following methodology to calculate the reduction in leakage due to regular active leak detection.

The model relies on simplifying assumptions:

- All detected leaks are repaired by the supplier within the same month as detected.
- The model is applied to various system sizes and allows for partial leak detection surveys. The model divides the water distribution system for each supplier into parts that can be surveyed in a month and calculates the associated benefits and costs across the time horizon of 30 years. It is assumed, for simplicity, that at any point in time, a part of the system is being surveyed. The rate of surveying is an average rate for the entire system.

The model calculates the reduced water loss that occurs as a result of active leak detection and repair as an intervention, and compares it to the water loss that would occur if the supplier maintained their water loss at the baseline or current level. The model calculates additional costs that would be incurred to reduce water loss through leak detection and repair. If the net benefit is positive, the supplier is required to reduce the water loss to the standard calculated per the leak survey frequency, type of leakage, rate of rise of leakage and system size. The 2028 standard is equivalent to the water loss occurring during the year prior to compliance in 2028, since water loss is reported annually.

The model estimates the impact of active leak detection and repair on the water loss level by calculating the effect on the backlog of leakage and rising leakage separately. The model employs the following simplifying procedure to estimate the impact of intervention:

(a) Variables used

Column (1) on 'Calculations tab:

N = Number of parts into which the distribution system is divided (equivalent to n which is equivalent to the Number of months taken to survey entire system) (cell B60)

ΔT = duration of time step in model (equivalent to one month or one twelfth of a year)

L_o = Annual unreported leakage

l_o = Unreported leakage per part of the system (cell B61), calculated as follows:

$$\frac{Lo}{N}$$

R = Natural rise in leakage for the entire system

r = Rate of natural rise of leakage per part of the system occurring (cell B62), calculated as follows:

$$\frac{R}{N}$$

The model divides the water lost during regular leak detection and surveying into three elements for ease of calculation:

- Water lost due to backlog of unreported leakage
- Water lost due to natural rise in leakage for the never surveyed parts of the system (for parts being surveyed for the first time)
- Water lost due to natural rise in leakage for rest of the parts of the system not being surveyed in current time step (parts that have been surveyed before).

The State Water Board developed equations to represent water loss occurring in each part, and summed up the water loss for all parts of the system. 'i' represents the current month of implementation, so that we can develop a general formula for each of these categories. For each of the three leakage components, The State Water Board have schematically shown the unreported leakage per month for each part of the system on the y-axis and the month of implementation on the x-axis in figures 1 through 4. The volume of unreported leakage occurring in each month of implementation is equivalent the water lost at a certain leakage level during the month. Thus, the volume of leakage occurring during each month is equivalent to the area under the curve for each component of leakage.

(b) Water loss due to backlog of leakage from parts not surveyed in each month, Column (2):

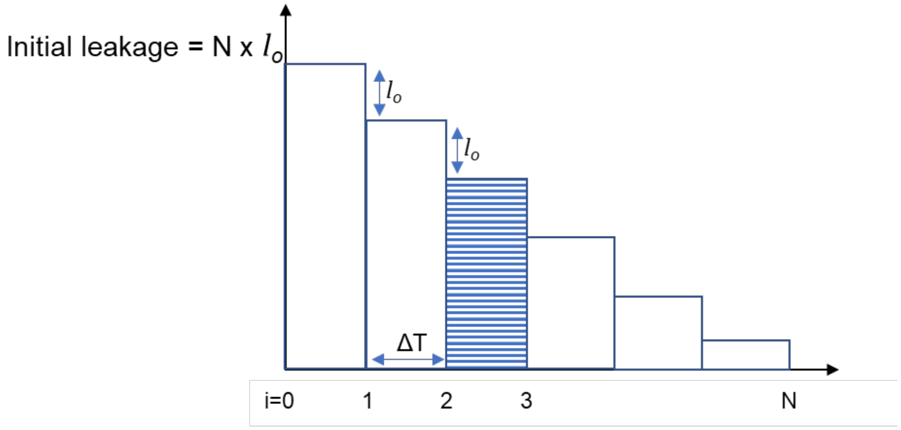

Figure 1 shows how the backlog unreported leakage for the entire system is impacted after each part of the system is surveyed. Note that the backlog element considered here does not include any rise in leakage, as elements including rising leakage are calculated separately.

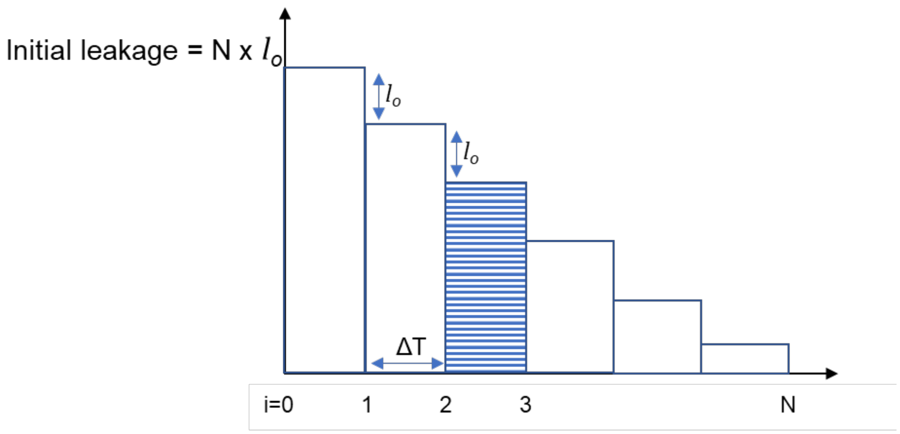

Figure 1 Decrease in backlog unreported leakage as each part of the distribution system is surveyed

As parts of the system are surveyed serially, the overall backlog of unreported leakage drops by l_o in each time step (the backlog unreported leakage per part of the system).

At month of implementation 'i', the survey would begin for the ith part of the system. Thus, during each month, leakage would occur from the parts that have not been surveyed yet, that is, (N - i), and one additionally part to be surveyed by the end of the current time step.

Number of parts of the system not surveyed yet = (N – i) + 1

Each part of the system will leak at l_o during the duration of the current month ΔT as shown in the dashed part of the schematic. The water loss occurring in month of implementation 'i' from all parts in the system due to only backlog leakage is represented as:

Equation 5: ΔT x l_o x (N – i + 1)

(c) Water loss due to natural rise in leakage in never surveyed parts in each month, Column (3)

Figure 2 shows how the rising unreported leakage for the entire system is impacted after each part of the system is surveyed for the first time. Leakage level for each part of the system increases as the rate of rise of leakage, till that part of the system is surveyed. Thus, all the parts of the system which have not been surveyed before are at the same leakage level by a particular month of implementation.

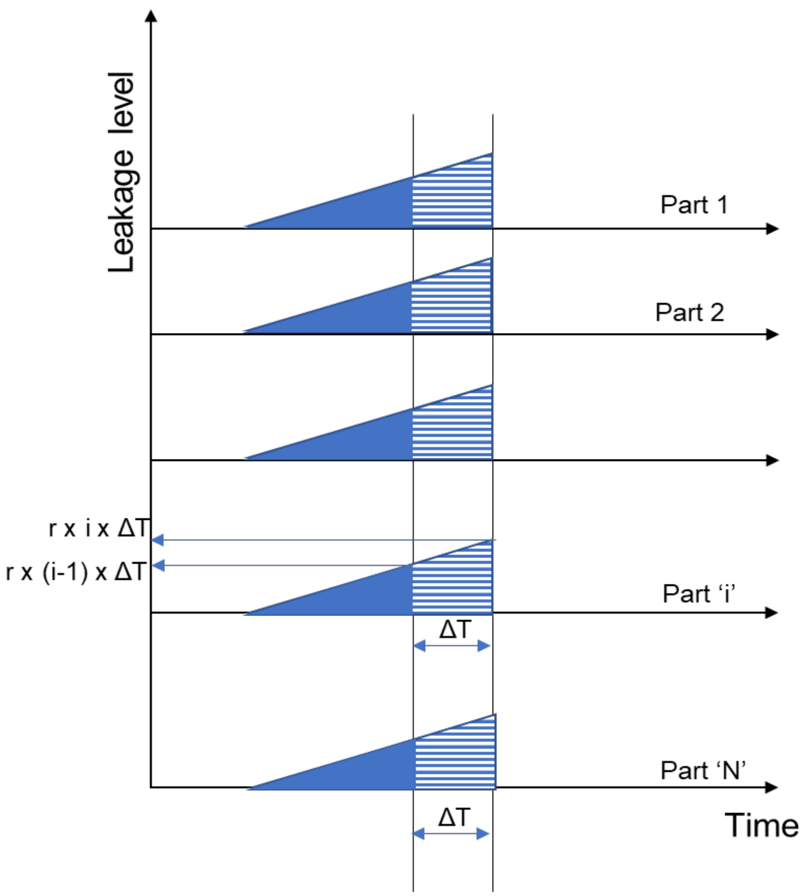

Figure 2 Rise in leakage in parts of the system never surveyed before.

The leakage occurring in each time step is the area under the curve traced by the leakage level and time. The area under the leakage curve for each duration of a month, marked by the dashed area in the schematic.

$$\frac{1}{2} \times (r \times (i-1) \times \Delta T) \times \Delta T = \big(r \times \Delta T \times (i-0.5)\big) \times \Delta T = r \times \Delta T^2 \times (i-0.5)$$

During the first survey, while the ‘i’th part is being surveyed, (i-1) parts would have been surveyed. Hence, out of ‘N’ parts, (N - i +1) parts would remain to be surveyed and would have been leaking due to the naturally rising leakage. The total leakage due to this component is as follows.

Equation 6:

$$(N-i+1) \times \big(r \times \Delta T^2 \times (i-0.5)\big)$$

After the entire system is surveyed once, this component becomes zero.

(d) <u>Water loss due to natural rise in leakage in previously surveyed parts in each month, Column (4)</u>

Figure 3 shows how the rising unreported leakage for the entire system is impacted after each part of the system that has been surveyed at least once before. Each part of the system starts leaking after a survey as the leakage rises naturally in the distribution system after being surveyed. The leakage occurring in each month of implementation is the rise in leakage that occurs over that time step for all parts in the system. Since this component of leakage occurs in previously surveyed parts, all parts are surveyed at different times.

Figure 3 shows how leakage occurs in different parts of the system that have been surveyed before, in a time step, due to this component.

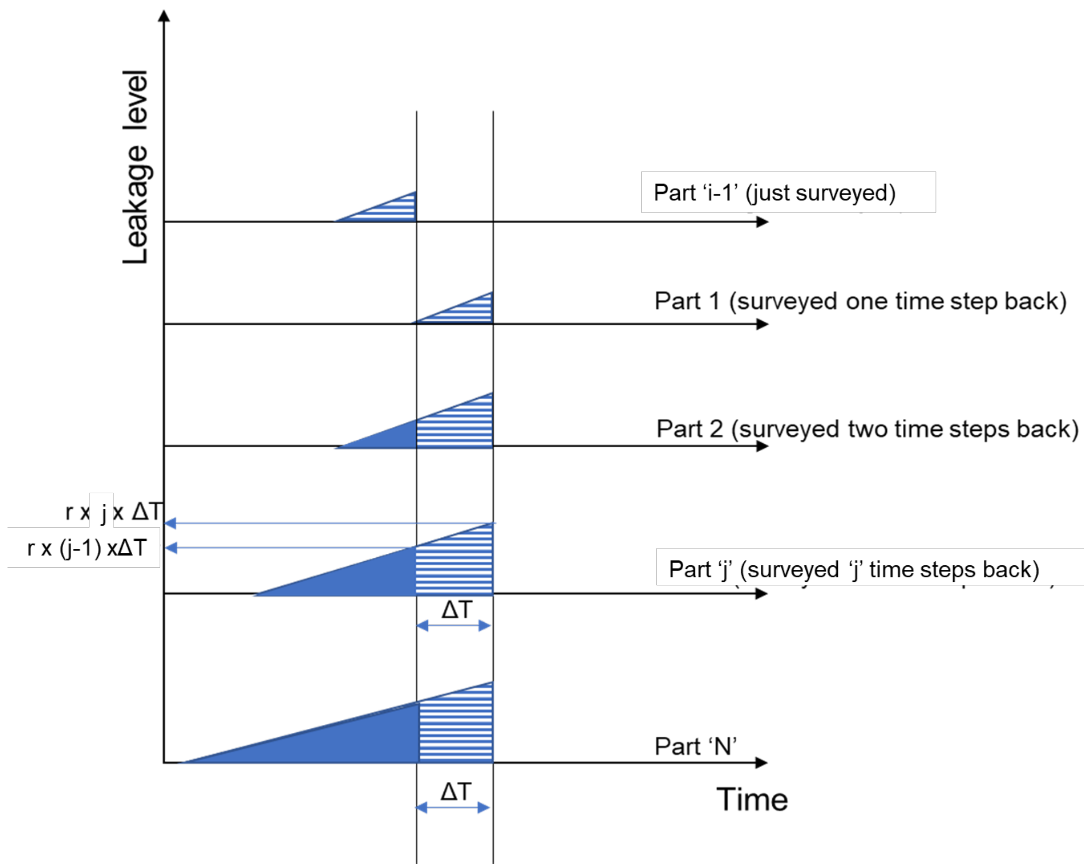

Figure 3 Rise in leakage in parts of the system that have been surveyed before.

The rise in leakage to the beginning of the time step is represented by:

Rate of rise of leakage x months of implementation passed prior to current time step

If j' months have passed, time passed after months = $j \times \Delta T$

The leakage level only due to natural rise in leakage, at the beginning of the 'j'th month, or at the end of the (j-1)th month is = $r \times (j-1) \times \Delta T$

The leakage level at the end of the 'j'th month is = $r \times j \times \Delta T$.

The leakage volume lost during this time step is represented by the transition from the lower leakage level to the higher leakage level across duration of a month ΔT, which is the area under the curve, which is a trapezoid, summed for all the parts of the system. Each part of the system will contribute to the overall leakage in this component as follows:

$Part\ 1: \frac{1}{2} \times (\mathbf{0} + r \times \mathbf{1} \times \Delta T); Part\ 2: \frac{1}{2} \times (r \times \mathbf{1} \times \Delta T + r \times \mathbf{2} \times \Delta T) \times \Delta T; Part\ 3: \frac{1}{2} \times (r \times \mathbf{2} \times \Delta T + r \times \mathbf{3} \times \Delta T) ...; Part\ i: \frac{1}{2} \times (r \times (\boldsymbol{j} - \mathbf{1}) \times \Delta T + r \times \boldsymbol{j} \times \Delta T)$

Simplifying the leakage volume lost during the 'j'th month for a single part of the system as follows:

$$= \frac{1}{2} \times (r \times (\boldsymbol{j} - \mathbf{1}) \times \Delta T + r \times \boldsymbol{j} \times \Delta T)$$

$$= \frac{1}{2} \times (r \times j \times \Delta T - r \times \Delta T + r \times j \times \Delta T)$$

$$= \frac{1}{2} \times (2 \times r \times j \times \Delta T - r \times \Delta T) \times \Delta T$$

$$= \left(r \times j \times \Delta T - \frac{1}{2} \times r \times \Delta T\right) \times \Delta T$$

$$= r \times \Delta T^2 \times \left(j - \frac{1}{2}\right)$$

If the distribution system is being surveyed for the first time, only '(j-1)' parts have been surveyed when the 'j'th month begins, and will contribute to this element of leakage:

$$= r \times \Delta T^2 \times \sum_{j=1}^{i-1} \left(j - \frac{1}{2}\right)$$

The summation of consecutive integers is represented by:

$$\sum_{x=1}^{n} x = \frac{n \times (n + 1)}{2}$$

The summation of a constant is represented by:

$$\sum_{x=1}^{n} constant = n \times constant$$

Thus,

$$= \sum_{j=1}^{i-1} \frac{1}{2} \times r \times \Delta T^2 \times \left(j - \frac{1}{2}\right)$$

$$= \frac{1}{2} \times r \times \Delta T^2 \times \left(\frac{(\boldsymbol{i-1}) \times \left((\boldsymbol{i-1}) + 1\right)}{2} - \frac{(\boldsymbol{i-1})}{2}\right)$$

$$= \frac{1}{2} \times r \times \Delta T^2 \times \left(\frac{(\boldsymbol{i-1}) \times (i)}{2} - \frac{(\boldsymbol{i-1})}{2}\right)$$

$$= \frac{1}{2} \times r \times \Delta T^2 \times \left(\frac{i^2 - 2 \times i + 1}{2}\right)$$

The loss due to only rising leakage for previously surveyed parts of the system is:

Equation 7:

$$\frac{1}{2} \times r \times \Delta T^2 \times \left(\frac{(i-1)^2}{2}\right)$$

If the system has undergone a complete survey and this is the next round of surveying, ‘N’ parts of the system have been surveyed before, and all of these parts of the system will contribute to this element of leakage. After one survey, and the backlog of leakage is reduced, this element of leakage is the only one that constitutes the overall leakage for the distribution system is as follows.

Equation 8:

$$= \frac{1}{2} \times r \times \Delta T^2 \times N^2$$

(e) ***Water loss occurring without intervention in each month (equal to that prior to first survey), Column (7)***

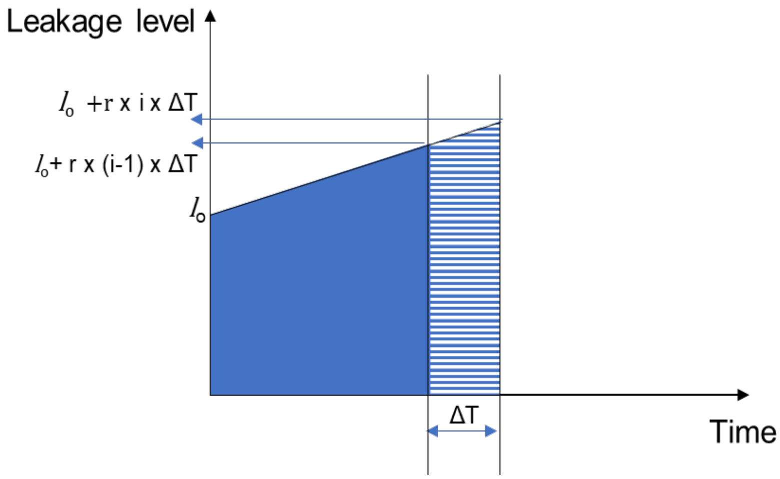

Figure 5. Increase in the first month of surveying with rising leakage, to estimate the leakage befire beginning any surveying

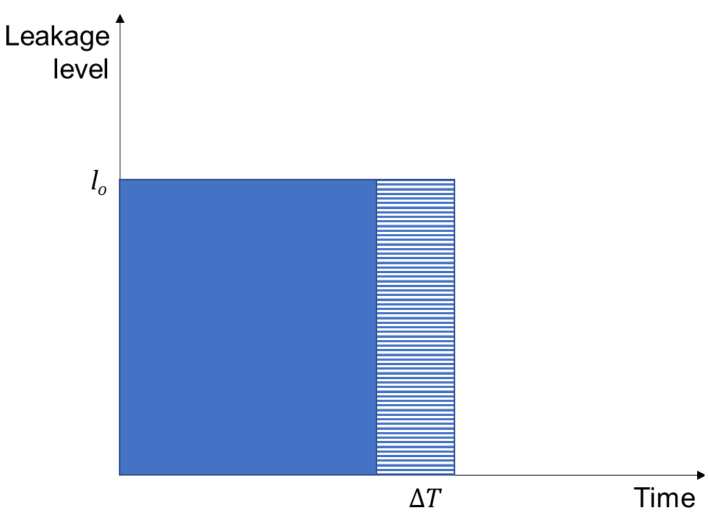

Figure 6. The leakage is assumed to be maintained constant without intervention

Figure 4 Rise in leakage if regular intervention is not conducted is equivalent to the leakage in the first month of surveying prior to conducting the first survey, after which it is assumed to stay constant.

Without any intervention, it is assumed that suppliers would maintain the 2022 real loss for the system (three-year average of real loss reported by supplier). The 2022 real loss is calculated by adding the rise in leakage from 2020 through 2022. This is also equivalent to the unreported leakage in the first month of surveying.

The water loss occurring in a time step without any intervention is represented by the transition from the lower leakage level to the higher leakage level across time step ΔT, which is the area under the curve summed for all the parts of the system. To determine the leakage occurring in time step ‘i’:
The leakage level rises to l_o + r x (i-1) x ΔT by the beginning of the ‘i’th step.
The leakage level then rises to l_o + r x (i) x ΔT by the end of the ‘i’th step.
The water loss occurring during the time step is:

$$\frac{1}{2} \times (l_o + r \times (i-1) \times \Delta T + l_o + r \times i \times \Delta T) \times \Delta T$$

$$= \frac{1}{2} \times (2l_o + 2r \times (i) \times \Delta T - r \times \Delta T) \times \Delta T$$

$$= (l_o + r \times (i) \times \Delta T - 0.5 \times r \times \Delta T) \times \Delta T$$

$$= \left(l_o + r \times \Delta T \times (i - 0.5)\right) \times \Delta T$$

Leakage without intervention for each part from 2022 and beyond would be as follows. The month of implementation would be 1 to calculate the unreported leakage for the first month of surveying, after which the unreported leakage is assumed to remain constant.
Equation 9:

$$\text{Months taken to survey whole system} \times \Delta T \times \begin{pmatrix} \textit{Unreported leakage per month} + \textit{Rate of rise of leakage per month} \times \\ (\textit{month of implementation} - 0.5) \times \Delta T \end{pmatrix}$$

Benefit-cost analysis for water loss control actions.

(a) Water saved due to water loss control in each month with intervention actions (Column 9)
The water lost is calculated by adding all three components together (Column 5): Water lost due to backlog of unreported leakage, water loss in parts of the system never surveyed and water lost only due to natural rise in leakage in parts of the system surveyed previously over the 30-year time horizon. This sum is subtracted from the water lost without any water loss control actions (Column 7) to calculate the water saved due to water loss control actions (active leak detection and repair) (Column 9).

(b) Unreported leakage level for parts surveyed each month; Leaks found per part of the system with intervention; and efficiency of leak detection equipment (Columns 11 and 12)
The initial unreported leakage occurring in a month is used to determine the number of leaks that would need to be repaired in that month. It is calculated as the sum of the backlog of leakage occurring every month and the rise in leakage

occurring per month times the number of months since the last survey. Once the backlog is removed, the leakage per part of the system reduces to the rise in leakage per month times the number of months since the last survey. The number of leaks to be repaired are calculated for that month are the total number of leaks occurring annually multiplied by the proportion of leakage occurring in that month. The number of unreported leaks is calculated per the AWWA M36 manual (Table 1 of this text) by summing the unreported leaks on mains and unreported leaks on service lines or laterals. The number of unreported leaks is divided by the leak detection efficiency to account for false positives.

(c) Cost associated with water loss control actions (Columns 10, 13, 14, 15)
The cost of leak detection per mile is multiplied by the number of miles surveyed over the time horizon of 30 years. The cost of repairing each unreported leak is multiplied by the number of unreported leaks detected. The sum of cost of leak detection and repair is calculated over the time horizon. The present value of costs is also calculated for reference using a discount rate of 3.5%.

(d) Benefit associated with water loss control actions (Columns 16, 17, 18)
The benefit is calculated by multiplying the higher of the avoided cost of water and variable production cost by the water saved due to water loss control in each month with intervention actions calculated as described in (a). The real annual rise in price of water is applied to this product. The present value of benefits is also calculated for reference using a discount rate of 3.5%.

(e) Water loss over the year 2027 (Columns 19 and 20)
Note: In the model the net benefit is calculated by deducting the total cost for each month from the value of water lost for each month, without applying the discount rate. The discount rate is then applied to the net benefit to calculate its present value. This present value of the net benefit over 30 years is used to assess the benefit cost.

If the benefit associated with water loss control actions is higher than the cost associated with water loss control actions over the time horizon of 30 years, the standard of the suppliers is equivalent to the water lost per (a) for the year 2027. The standard is to be met by 2028 based on reported water loss for 2027.

Correlation of leakage reduction with unreported leakage.

The State Water Board have observed a strong correlation of the water loss reduction per the model results using default values for reported and background leakage to the unreported leakage.

The model calculates a performance standard based on water system and leakage characteristics. The calculated percent reduction per the standard shows a high correlation with unreported leakage. The benefits associated with water loss reduction for suppliers with a high unreported leakage is high, whereas those for suppliers with low unreported leakage is low (Figure 1).

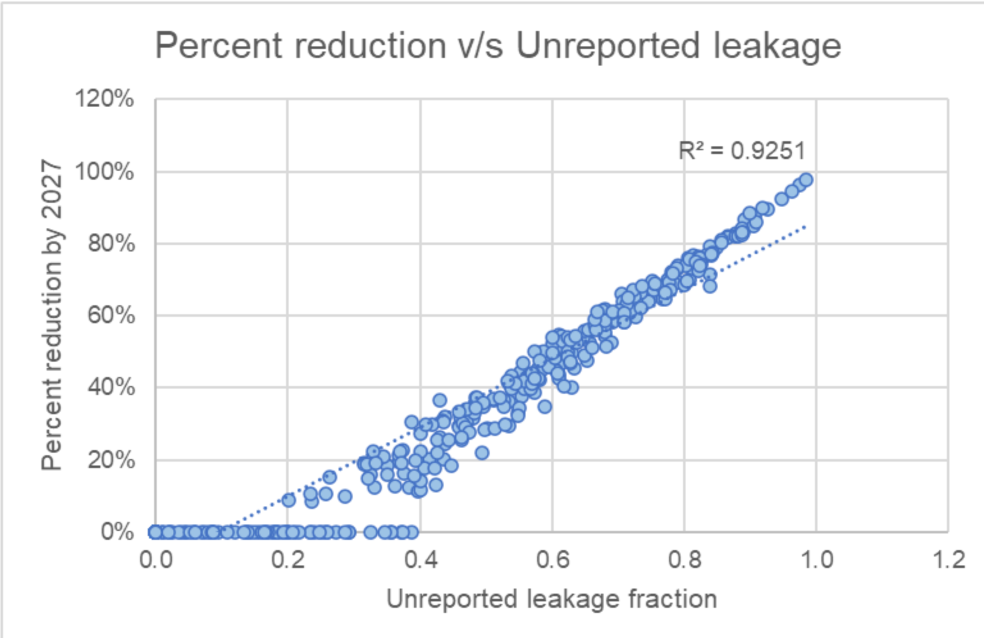

Figure 5 The correlation of percent reduction of water loss with the fraction of unreported leakage

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