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State Water Resources Control Board

December 28, 2020

James Nachbaur, Director
California State Water Resources Control Board
Office of Research, Planning, and Performance
1001 I Street
Sacramento, California 95814

SUBJECT: INTERIM RESPONSE NUMBER 2 TO REQUEST FOR AN EXTERNAL PEER REVIEW OF THE SCIENTIFIC BASIS OF ECONOMIC MODEL FOR THE DEVELOPMENT OF WATER LOSS PERFOMANCE STANDARDS

[MY FIRST RESPONSE WAS SENT DECEMBER 18, 2020 AND INCLUDED REVIEW BY PROFESSOR OSTFELD. THIS SECOND INTERIM RESPONSE INCLUDES HIS REVIEW NOW ADJUSTED TO MEED ADA REQUIREMENTS, AND REVIEWS FROM THE ADDITIONAL THREE REVIEWERS. MY FINAL RESPONSE WILL BE SENT AFTER ALL NEEDS FOR CLARIFICATION, OR ADDDITIONAL INFORMATION, IF ANY, HAVE BEEN SATISFIED.]

Dear Dr. Nachbaur,

This letter responds to the attached October 27, 2020 request for external scientific peer review for the subject noted above. The review process is described below. All steps were conducted in confidence. Reviewers' identities were not disclosed.

To begin the process for selecting reviewers, I contacted the University of California, Berkeley (University) and requested recommendations for candidates considered qualified to perform the assignment. This service is supported through an Interagency Agreement co-signed by CalEPA and the University. The University was provided with the request letter and attachments. No additional material was asked for, nor provided. The University interviews each promising candidate.

Each candidate who was both qualified and available for the review period was asked to complete a Conflict of Interest (COI) Disclosure form and send it to me for review, with Curriculum Vitae. The cover letter for the COI form describes the context for COI concerns that must be taken into consideration when completing the form. "As noted, staff will use this information to evaluate whether a reasonable member of the public would have a serious concern about [the candidate's] ability to provide a neutral and objective review of the work product."

For each candidate judged to be free of conflict, I approved that person as reviewer, affirmed by an approval letter. Reference was made to specific parts of the completed COI form and CV. The approval letter also asked the approved candidate which of the conclusions that person would be able to address "with confidence, based on expertise and experience".

Later, I sent letters to reviewers to initiate the review. These letters provided access instructions to a secure FTP site where all material to be reviewed was placed. Confirmation was requested that the reviewer could access the site and all documents that had been uploaded to it. Each reviewer was asked to address each conclusion for which he or she had previously agreed, and these were identified in the letter. Thirty days were provided for the review, unless a reviewer requested additional time. I also asked reviewers to direct enquiring third parties to me after they have submitted their reviews.

Following my signature on the initiating letter, guidance was provided a) to ensure confidentiality through the review process; and b) for format presentation to meet "accessibility" requirements.

Reviewers' names, affiliations, curriculum vitae, initiating letters and reviews are being sent to you now with this letter. This information can be accessed easily through the bookmarks listed on the left of the screen, or by scrolling down.

Approved reviewers:

1. Joseph H. Cook, Ph.D., Associate Professor
   School of Economic Sciences
   Washington State University
   Pullman, WA 99164

2. William K. Jaeger, Ph.D., Professor
   Department of Applied Economics
   College of Agricultural Sciences
   Oregon State University
   213 Ballard Extension Hall
   Corvallis, OR 97331

3. Professor Avi Ostfeld, P.E., D.WRE
   Professor ATS Staff Academic Chair
   Deputy Vice President for Academic Affairs
   Civil and Environmental Engineering
   Technion – Israel Institute of Technology
   Rabin Building, Room 610
   Haifa, 32000, Israel

4. Jordyn M. Wolfand, Ph.D., P.E., Assistant Professor
   Department of Civil Engineering
   Donald P. Shiley School of Engineering
   University of Portland
   5000 N. Willamette Blvd.
   Portland, OR 97203

If you have any questions, or require clarification from the reviewers, please contact me directly.

Sincerely,

Gerald W. Bowes, Ph.D.
Manager, CalEPA External Scientific Peer Review Program
Office of Research, Planning, and Performance
State Water Resources Control Board
1001 “I” Street, 13thFloor Sacramento, California 95814
Gerald.Bowes@waterboards.ca.gov

Attachments:
(1) October 27, 2020 Request by James Nachbaur, for Scientific Peer Review
(2) Letters to Reviewers Initiating the Review
    (1) Joseph H. Cook, Ph.D.
    (2) William K. Jaeger, Ph.D.
    (3) Avi Ostfeld, P.E., D.WRE
    (4) Jordyn M. Wolfand, Ph.D.
(3) Curriculum Vitae
    (1) Joseph H. Cook, Ph.D.
    (2) William K. Jaeger, Ph.D.
    (3) Avi Ostfeld, P.E., D.WRE
    (4) Jordyn M. Wolfand, Ph.D.
(4) Reviews
    (1) Joseph H. Cook, Ph.D.
    (2) William K. Jaeger, Ph.D.
    (3) Avi Ostfeld, P.E., D.WRE
    (4) Jordyn M. Wolfand, Ph.D.

cc: Kartiki Naik
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State Water Resources Control Board

TO: Gerald Bowes, PhD
Manager, CalEPA Scientific Peer Review Program
Office of Research, Planning, and Performance
California State Water Resources Control Board

FROM: James Nachbaur
Director
OFFICE OF RESEARCH, PLANNING, AND PERFORMANCE

James Nachbaur

CC: Kartiki Naik, Max Gomberg, Eric Oppenheimer

DATE: October 27, 2020

SUBJECT: Request for external scientific peer review of the scientific basis of economic model for the development of water loss performance standards

Model for Review

This request is regarding the development of water loss performance standards per Water Code 10608.34. State Water Resources Control Board (State Water Board) staff requests that you initiate the process to identify external scientific peer reviewers for the economic model for developing water loss performance standards. A detailed description of the economic model is provided in the Technical Report (Attachment 5).

Purpose of Review

Per Water code 10608.34, the State Water Board is required to adopt performance standards for water loss from leaks in water distribution systems for urban retail water suppliers this year. Staff have been developing a proposal for the standards informed by stakeholder input. Staff developed an economic model to calculate these standards by assessing benefits and costs associated with actions anticipated to be taken by suppliers to reduce water loss. Stakeholders have recommended a third-party peer review of this model. State Water Board staff acknowledges that this review request exceeds the scope legally required and typically conducted per California Health and Safety Code section 57004.

E. JOAQUIN ESQUIVEL, CHAIR | EILEEN SOBECK, EXECUTIVE DIRECTOR

1001 I Street, Sacramento, CA 95814 | Mailing Address: P.O. Box 100, Sacramento, CA 95812-0100 | www.waterboards.ca.gov

When References will be Available at the FTP Site

Tentatively, November 15, 2020.

Requested Review Period

We request that scientific peer review be accomplished within 30 days.

Necessary Areas of Expertise for Reviewers

We request at least 2 reviewers.

For Items 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12 (a) and (d): Research faculty or staff, scientist, engineer, **or** university faculty affiliated with Civil, Environmental or Water resources engineering, **with expertise in water leakage loss, water supply engineering, and modeling.**

For Items 5, 6, 9 and 12 (all sub-items): Research faculty or staff, economist, **or** university faculty **with expertise in economics, benefit-cost analysis water supply infrastructure and water supply resiliency.**

Refer to Attachment 2 for more details.

Contact Information

Kartiki Naik (staff lead), kartiki.naik@waterboards.ca.gov, 916-319-9468.

Please copy Max Gomberg (program manager), max.gomberg@waterboards.ca.gov, 916-322-3052, on all communication from the CalEPA Scientific Peer Review Program.

Attachments

Attached please find:

1. Attachment 1: Plain English Summary.
2. Attachment 2: Scientific Assumptions, Findings, and Conclusions to Review.
3. Attachment 3: Individuals who Participated in the Development of the Economic (Benefit-Cost) Model.
4. Attachment 4: References Cited.
5. Attachment 5: Technical Report describing the Economic (Benefit-Cost) Model for Peer Review.

Attachments to the letter

Attachment 1: Plain English Summary

Regulatory background

California Water Code section 10608.34 (Senate Bill 555, 2015) sets statutory requirements for monitoring and reducing water losses through leaks in certain distribution systems. The State Water Resources Control Board (State Water Board) is required to develop performance standards for water loss by 2020 for urban retail water suppliers (URWS). Per statute, the State Water Board is required to evaluate in the development of the performance standards is a life cycle cost accounting[1]. An average water supplier in California loses about 34 gallons per service connection per day through leakage, which translates to water losses of about 326,000 acre-feet on an annual basis, as per data reported by urban retail water suppliers from 2017 to 2019[2]. With the advent of the multi-year drought in 2011, several Governor-issued Executive Orders (B-37-16 and B-40-17)[3] directed state agencies to conserve water, reduce waste of water through leakage, and direct actions to reduce large leaks that waste large amounts of water.

Urban water retailers have been required to submit water loss audits since October 2017 pursuant to Water Code section 10608.34, subdivision (b) and regulations developed by Department of Water Resources. The water loss audits are required to be conducted per the M36 manual by the American Water Works Association (AWWA) and calculate the amount of leakage or real loss, based on the reported volumes of water that flow into the distribution system, and are supplied. Assembly Bill 1668 and Senate Bill 606, passed in 2018, require URWSs to calculate their own individual urban water use objective beginning in 2024, which include efficient indoor; outdoor and an allowable water loss volume based on the standards.

Water loss standards and Economic model

The goal of the economic model is to establish individual standards for each supplier based built on industry-established concepts and economic analysis of the benefits and costs associated with reducing leakage. State Water Board staff have developed a model (referred to as economic model in the technical report and other attachments) to calculate these standards based on benefit-cost analysis and water distribution system characteristics. The underlying assumptions and conclusions to be reviewed are provided in the Technical Report. The spreadsheet encompassing these assumptions and conclusions is provided on the FTP site for additional context. The model is proposed to be used as follows:

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[1] The lifecycle cost accounting considers costs, and benefits, projected to accrue while implementing interventions over their lifetime, including planning, installation, implementation, and operation of interventions that may be used to meet the performance standards.

[2] These figures are based on data from water loss auditing in California over 2016-17 and 2017-18.

[3] https://www.waterboards.ca.gov/water_issues/programs/conservation_portal/executive_orders.html.

- Urban water retailers would be required to comply with individual numeric volumetric standard for water loss by 2028. These standards would be calculated using a model developed by the State Water Board that assesses the additional benefits and costs associated with reducing the leakage to the volumetric standard determined based on water system characteristics. The standard would involve leakage reduction only if the net benefit is positive for the supplier given the system and water resource conditions.
- The economic model will be used to set standards with the following provisions for urban water retailers:
    - Adjustments: The supplier can provide individual data for the model with supporting evidence to the State Water Board as they improve their data accuracy and begin field implementation of water loss control approaches, to then adjust their standard. These adjustments can be requested by 2023.
    - Variances: In case of natural disasters or adverse circumstances, suppliers can request for variances, which would provide suppliers with temporary or permanent relief from compliance as seen fit by the State Water Board.

Urban retail water suppliers will be required to meet volumetric standards based on the economic model. State Water Board staff request a peer review of the underlying engineering and economic assumptions and derived conclusions used in the economic model to develop the volumetric standards. The formal rulemaking process to adopt the standards is expected to begin in October 2020. The peer review and comment periods from the formal rulemaking process in the model will inform any revisions required to be made to the model.

Attachment 2: Scientific Assumptions, Findings, and Conclusions to Review

Scientific assumptions, findings, and conclusions for review
The specific assumptions or findings for which State Water Board staff request a review are presented as numbered items in Attachment 2. These numbered items are preceded by brief technical background and context. **The technical report provides detailed technical explanation for each of these items. Some of the technical text has been repeated in these items to provide a summary for the reviewers.**

Input parameters
There are twenty-five input parameters to the model, for information on:

- System characteristics from water loss audits, such as water distribution system size, service connection density, and operating pressure.
- System leakage profile with default values per the AWWA M36 manual, such as, Reported, Unreported, and Background leakage and underlying leakage characteristics.
- Associated costs and benefits, such as Cost of water and intervention (unit costs for leak detection, repair), Variable production cost of water, Avoided cost of water, Discount rate, and Average annual rise in price of water.

Reviewers should keep in mind that, while the State Water Board has determined default values for these parameters, suppliers will be able to provide system-specific values for all but three parameters through the rulemaking process or adjustments. This is why staff requests review of the model structure, in addition to the parameter values below.

Note: Items for review are presented in a numbered format, and categorized as an assumption, finding or conclusion below.

1. Assumption: The assumed default infrastructure condition factor value.
The State Water Board staff request a review of the value used for the Infrastructure Condition Factor in the model. The model uses a default value of 1.0. This is used to calculate the minimum amount of background leakage in a system.

The Unavoidable Background Leakage (UBL) is the minimum amount of background leakage that a distribution system has, based on the number of connections and length of pipe. The Total Background Leakage for a distribution system is calculated by multiplying the UBL by the Infrastructure Condition Factor (ICF). The ICF symbolizes the actual condition of the distribution system.
Equation 2 in the technical report describes the Total Background Leakage as follows:

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

The model uses a default value of 1.0. This is used to calculate the minimum amount of background leakage in a system. Note: Suppliers can use a value other than this default.

There are several methods to calculate the ICF. The most reliable methods are water distribution system condition assessments and assessments of the change in leakage as factors such as operational pressure change.

2. ***Assumption*: Calculation of minimum amount of reported and unreported leakage.**

State Water Board staff requests a review of the estimation of the minimum reported and background leakage. The model uses the AWWA M36 manual to estimate the minimum amount of reported and background leakage that could occur in a system. This is subject to supplier inputs as they get improved data.

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:
Equation 3 in the technical report describes the unavoidable background leakage.

The AWWA M36 manual provides minimum 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).

The following equation shows the equation used to estimate the reported leakage in the model, adjusted to the suppliers' average operating pressure of the distribution system. Equation 4 in the technical report describes the minimum reported leakage.

3. ***Assumption*: Average leak detection survey frequency.**

State Water Board staff request a review of the leak detection survey frequency used. The model assumes that a range of two to three years per different system sizes.

State Water Board staff obtained estimates of from suppliers and leak detection consulting firms 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 State Water Board staff that they can survey their distribution systems once in two to three years (Conversation with Joseph Berg, Municipal Water District of Orange County).

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 per different system sizes (from Table 2 in technical report).

- Less than 500 miles of total system pipe length: 2 years

- Between 500 and 1000 miles of total system pipe length: 2.5 years
- Over 1000 miles of total system pipe length: 3 years

4. <u>Assumption:</u> Annual rate of natural rise of leakage.
State Water Board staff request a review of the assumptions behind including the annual rate of natural rise of leakage in the model. State Water Board staff assumed a default value of 4 gallons per connection per day in the model, which can be updated by urban retail water suppliers.

The natural rise in leakage is specific to each distribution system. There are limited references that specify ranges for rate of rise of leakage. To estimate or assume a natural rise in leakage suitable for water systems in California, State Water Board staff communicated with several technical experts on water loss (communication with Reinhard Sturm, Alan Wyatt, and Gary Trachtman). These technical experts pointed State Water Board staff to the typical ranges in the EU Reference document: Good Practices on Leakage Management for different levels of rising leakage (European Union, 2015). Additionally, from their experience, the rate of rise of leakage in California water systems is typically very low to low. The report specifies a rate of rise of leakage with an upper limit of 20 liters per connection per day for the very low range. Estimates from the Water Research Foundation Report 4372a (Sturm, Gasner, Wilson, Preston, & Dickinson, 2014) for a California and Tennessee water systems were calculated to be in the same range (3.9 and 3 gallons per connection per day).

Based on these estimates, State Water Board staff assumed a value of 4 gallons per connection per day. This ensures that the leakage backlog reported by suppliers through the audits have a more significant influence on the calculation of benefits, than the default value of rate of rise of leakage assumed by the State Water Board. Per sensitivity analysis conducted by State Water Board staff, a higher rate of rise of leakage results in higher benefits, but simultaneously results in a higher water loss standard. Suppliers can provide their system-specific value for rise in leakage through adjustments or the rulemaking process.

5. <u>Assumption:</u> Avoided costs and Variable production costs.
State Water Board staff requests a review of the default value of water saved through water loss control, which is estimated to be higher of the avoided cost and variable production cost. The calculation and sources are described as follows.

Staff 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.

6. <u>Assumption:</u> Rise in price of water.

State Water Board staff request a review of the assumed value for rise in price of water. State Water Board staff estimated an annual real rise in price of water of 5.9 percent.

State Water Board staff proposes 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. State Water Board staff 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 <u>real</u> increase in price of water sold by the, over the past decade was 5.9%. Time horizon.

7. <u>Assumption:</u> Assumed life cycle time horizon.

State Water Board staff request a review of the assumed time horizon over which any benefits and costs associated with water loss control actions and the useful life of repair as a result of active leak detection.

Leak detection equipment and pipe repair material have lifecycle periods that are longer than the compliance date (by 2028), due to which, 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. State Water Board staff therefore anticipate that where water loss reduction is cost-effective, suppliers would continue to achieve these benefits beyond compliance. State Water Board staff request reviewers to provide insights on this policy proposal.

8. <u>Assumption:</u> Leak detection and repair costs.

State Water Board staff request a review of the default values of leak detection costs and efficiency and leak repair costs used in the model.

State Water Board staff used the following:

- Leak detection costs: $595 per mile
- Leak repair costs for mains: $5,946 per leak
- Leak repair costs for service lines: $2,330 per leak
- Efficiency of leak detection to account for false positives: 70%

State Water Board staff obtained data on leak detection and repair costs from consultants and water suppliers (Table 6 in technical report). State Water Board staff 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).

State Water Board staff calculated repair costs by collating unit costs for repairs from consultants and water suppliers. Unit repair costs depend heavily on the type and extent of leak and pipe material and size. State Water Board staff assumed that all types of leaks have an equal probability of occurrence. Thus, State Water Board staff 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, State Water Board staff also collected data from Irvine Ranch Water District. The average unit cost based on these sources was $5,946.

The model also 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.

9. *Conclusion: Projection of benefits and costs across 30-year time horizon using a real discount rate and real rise in price of water.*

State Water Board staff request a review on the projection of benefits and costs across the 30-year time horizon. State Water Board staff has applied an annual discount rate of 3.5% to both costs and benefits associated with water loss control.

The model estimates the real rise in cost of water as showed in Item 6, based on Metropolitan Water District's history of rise in price of treated water. Since the model uses the real projection for price of water, it also uses the real costs associated with leak detection and repair, that is, with the inflation excluded from both benefits and costs. Additionally, both benefits and costs are discounted at 3.5%. State Water Board staff request reviewers to evaluate whether the costs and benefits are being projected accurately in the model.

10. *Finding: Correlation of leakage reduction with unreported leakage.*

State Water Board staff request for reviewers' insights on the sensitivity of the required water loss reduction to unreported leakage.

State Water Board staff 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. The calculation of unreported leakage is shown in Equation 1 of the technical report.

11. ***Findings/Conclusions*: Calculating reduction in leakage with regular surveying per the assumed survey frequencies.**

State Water Board staff request a review of the methodology for calculating reduction in leakage with regular active leak detection and repair per the assumed survey frequencies. The detailed equations are provided in the technical report for review.

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 leaks 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 only for a positive net benefit. The 2028 standard is equivalent to the water loss occurring during the year prior to compliance in 2028, since water loss is reported annually. Please refer to the technical report for the detailed equations of the model.

12. ***Findings/Conclusions*: Benefit-cost analysis for water loss control actions.**

The State Water Board staff request a review of the methodology used to assess the benefits and costs. Items 12 (a), (b), (c) and (d) describe the methodology used to calculate costs and benefits associated with water loss control actions.

a. Water saved due to water loss control actions.

The water lost is calculated by adding all three components together (Item 11 in technical report) over the 30-year time horizon. This sum is subtracted from the water lost without any water loss control actions to calculate the water saved due to water loss control actions (active leak detection and repair).

b. Benefit associated with water loss control actions

The benefit is calculated by multiplying the higher of the avoided cost of water and variable production cost (refer to Item 5), by the water saved due to water loss control action per Item 12(a). The real annual rise in price of water (refer to Item 6) is applied to this product, while applying a discount rate of 3.5% (refer to 9) to calculate the present value of benefits over the time horizon (refer to Item 7 for the justification).

c. Number of unreported leaks and efficiency of leak detection equipment
The number of unreported leaks is calculated per the AWWA M36 manual (Table 1 in technical report) 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.

d. Cost associated with water loss control actions
The cost of leak detection per mile is multiplied by the number of miles surveyed over the time horizon of 30 years (Item 7). The cost of repairing each unreported leak is multiplied by the number of unreported leaks detected per Item 12(c). The sum of cost of leak detection and repair is calculated over the time horizon while applying a discount rate of 3.5% (refer to Item 9).

e. Water loss over the year 2027
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 (Item 7), the standard of the suppliers is equivalent to the water lost per section 11(f), that is the sum of water lost per Item 11 for the year 2027. The standard is to be met by 2028 through reporting their water loss for 2027.

Attachment 3: Individuals who have Participated in the Development of the Economic Model

State Water Board staff and contractors
Kartiki Naik, Water Resource Control Engineer, State Water Resources Control Board
Max Gomberg, Environmental Program Manager, State Water Resources Control Board
Bruce Macler, Toxicologist, Environmental Protection Agency, Region 9
Frank Loge, Professor, Civil and Environmental Engineering, University of California Davis
Katrina Jessoe, Associate Professor, University of California Davis
Amanda Rupiper, PhD Candidate, Environmental Engineering, University of California Davis
Joakim Weill, PhD Student, Agricultural and Resource Economics, University of California Davis

Individuals involved in publications used to derive scientific findings
Individuals directly involved in informing the economic model:
Reinhard Sturm, CEO/President, Water Systems Optimization, Inc.
Kate Gasner, Vice President, Water Systems Optimization, Inc.
George Kunkel Jr., Principal, Kunkel Water Efficiency Consulting
Steve Cavanaugh, Cavanaugh
Will Jernigan, Director of Water Efficiency, Cavanaugh
Tory Wagoner, Cavanaugh
Drew Blackwell, Cavanaugh
Alan Wyatt, Independent Consultant
Gary Trachtman, Principal Water Engineer, Arcadis Inc.
Julian Thornton, Owner and Senior Consultant, Thornton International
Sue Mosberg, American Water Works Association
Amy McNulty, Irvine Ranch Water District
Fiona Sanchez, Irvine Ranch Water District
Clifford Chan, East Bay Municipal Utility District
Casey Leblanc, East Bay Municipal Utility District
Sofia Marcus, Los Angeles Department of Water and Power
Tim Worley, American Water Works Association
Sita Ramakrishnan, California Nevada Section, American Water Works Association
Lucy Andrews, Water Systems Optimization, Inc.
Kris Williams, Water Systems Optimization, Inc.
Todd Thompson, Retired, Department of Water Resources
Nirmala Benin, Department of Water Resources
Ed Osann, Natural Resources Defense Council
Tom Chestnutt, A & N Technical Services Inc.

Individuals involved in contributing to key references informing the economic model:
Roland Liemberger, Non Revenue Management Advisor, Miya Water

Heather Cooley, Director of Research, Pacific Institute
Rapichan Phurisamban, Pacific Institute
Mary Ann Dickinson, President/CEO, Alliance for Water Efficiency
Lindsey Geiger, American Water Works Association
Tim Worley, American Water Works Association
Edward R. Osann, Natural Resources Defense Council
Elio F. Arniella, Smart Water Analytics
Reid Campbell, Halifax Water
Andrew Chastain-Howlet, Black & Veatch
James E. Fisher, Echologics Engineering Inc.
Craig Hannah, Johnson Controls Inc.
Ramsey T. Hemaidan, Pure Technologies
David M. Hughes, American Water
Thomas M. Kennedy, Rainbow Municipal Water District
Allan Lambert, ILMSS Ltd.
Kevin Laven, Echologics Engineering Inc.
Paul Meschino, Utility Service Co. Inc.
Stephen K. Rupar, Tata & Howard, Inc.
Michael D. Simpson, M.E. Simpson Company Inc.
Brian M. Skeens, CH2M Hill
Daniel Strub, Austin Water Utility
Russell G. Titus, New Jersey American Water
John H. Van Arsdel, M.E. Simpson Company Inc.
Joseph Berg, Municipal Water District of Orange County
Sam Newman, Pacific Gas and Electric Company
Dustin Hardwick, California Rural Water Association
Lon House, California Rural Water Association
Michael Sims, California Rural Water Association
Liliya Yasinskaya, California Rural Water Association

Agencies to be regulated using standards calculated using the economic model

The following agencies would be subject to the proposed regulation and would potentially be needed to implement water loss control actions to meet the standards. Additionally, State Water Board staff have been incorporating input from these agencies into the proposed regulation.

Adelanto, City Of
Alameda County Water District
Alco Water Service
Alhambra, City Of
Amador Water Agency
American Canyon, City Of
Anaheim, City Of
Anderson, City Of
Antioch, City Of
Apple Valley Ranchos Water Company

Arcadia, City Of
Arcata, City Of
Arroyo Grande, City Of
Arvin Community Service District
Atascadero Mutual Water Company
Atwater, City Of
Azusa Light and Water
Bakersfield, City Of
Bakman Water Company
Banning, City Of
Bear Valley Community Services District
Beaumont-Cherry Valley Water District
Bella Vista Water District
Bellflower-Somerset Mutual Water Company
Benicia, City Of
Beverly Hills, City Of
Big Bear Community Services District
Big Bear Lake, City Of
Blythe, City Of
Brawley, City Of
Brea, City Of
Brentwood, City Of
Buena Park, City Of
Burbank, City Of
Burlingame, City Of
Calaveras County Water District-Ebbetts Pass
Calaveras County Water District-Jenny Lind
Calexico, City Of
California American Water Company-Los Angeles Division
California City
California Water Service Company
Camarillo, City Of
Cambria Community Service District
Camrosa Water District
Carlsbad Municipal Water District
Carmichael Water District
Carpinteria Valley Water District
Castaic Lake Water Agency Santa Clarita Water Division
Ceres, City Of
Cerritos, City Of
Chino, City Of
Chino Hills, City Of
Citrus Heights Water District
Cloverdale City Of
Clovis, City Of
Coachella, City Of
Coachella Valley Water District

Coalinga, City Of
Coastside County Water District
Colton, City Of
Contra Costa Water District
Corcoran, City Of
Corona, City Of
Covina, City Of
Covina Irrigating Company
Crescent City
Crescenta Valley Community Water District
Crestline Village Water District
Cucamonga Valley Water District
Cupertino, City Of
Daly City
Davis, City Of
Del Oro Water Company
Delano, City Of
Desert Water Agency
Diablo Water District
Dinuba, City Of
Discovery Bay Community Services District
Downey, City Of
Dublin San Ramon Services District
East Bay Municipal Utility District
East Niles Community Services District
East Orange County Water District
East Palo Alto, City Of
East Valley Water District
Eastern Municipal Water District
El Centro, City Of
El Dorado Irrigation District
El Monte, City Of
El Segundo, City Of
El Toro Water District
Elk Grove Water District
Elsinore Valley Municipal Water District
Escondido, City Of
Estero Municipal Improvement District
Eureka, City Of
Exeter, City Of
Fair Oaks Water District
Fairfield, City Of
Fallbrook Public Utilities District
Folsom, City Of
Fortuna, City Of
Fountain Valley, City Of
Fresno, City Of

Fruitridge Vista Water Company
Fullerton, City Of
Galt, City Of
Garden Grove, City Of
Georgetown Divide Public Utility District
Gilroy, City Of
Glendale, City Of
Glendora, City Of
Golden State Water Company
Goleta Water District
Great Oaks Water Company Incorporated
Greenfield, City Of
Groveland Community Services District
Hawthorne, City Of
Hayward, City Of
Healdsburg, City Of
Helix Water District
Hemet, City Of
Hesperia Water District
Hi Desert Water District
Hillsborough Town Of
Hollister, City Of
Humboldt Community Services District
Huntington Beach, City Of
Huntington Park, City Of
Imperial, City Of
Indian Wells Valley Water District
Indio, City Of
Inglewood, City Of
Irvine Ranch Water District
Joshua Basin Water District
Jurupa Community Service District
Kerman, City Of
Kingsburg, City Of
La Habra, City Of
La Palma, City Of
La Verne, City Of
Laguna Beach County Water District
Lake Arrowhead Community Services District
Lake Hemet Municipal Water District
Lakeside Water District
Lakewood, City Of
Lamont Public Utility District
Las Virgenes Municipal Water District
Lathrop, City Of
Liberty Utilities(Park Water)Corp
Lincoln Avenue Water Company

Lincoln, City Of
Linda County Water District
Livermore, City Of
Livingston, City Of
Lodi, City Of
Loma Linda, City Of
Lomita, City Of
Lompoc, City Of
Long Beach, City Of
Los Angeles City Department Of Water And Power
Los Angeles County Waterworks District29
Los Banos, City Of
Lynwood, City Of
Madera, City Of
Mammoth Community Water District
Manhattan Beach, City Of
Manteca, City Of
Marin Municipal Water District
Marina Coast Water District
Martinez, City Of
Mc Kinleyville Community Services District
Menlo Park, City Of
Merced, City Of
Mesa Water District
Mid-Peninsula Water District
Millbrae, City Of
Milpitas, City Of
Mission Springs Water District
Modesto, City Of
Monrovia, City Of
Monte Vista Water District
Montebello Land And Water Company
Montecito Water District
Monterey Park, City Of
Morgan Hill, City Of
Morro Bay, City Of
Moulton Niguel Water District
Mountain House Community Services District
Mountain View, City Of
Myoma Dunes Mutual Water Company
Napa, City Of
Nevada Irrigation District
Newhall County Water District
Newman, City Of
Newport Beach,, City Of
Nipomo Community Service District
Norco, City Of

North Coast County Water District
North Marin Water District
North Tahoe Public Utilities District
Norwalk, City Of
Oakdale, City Of
Oceanside, City Of
Oildale Mutual Water Company
Olivehurst Public Utilities District
Olivenhain Municipal Water District
Ontario, City Of
Orange, City Of
Orangevale Water Company
Orchard Dale Water District
Otay Water District
Oxnard, City Of
Padre Dam Municipal Water District
Palmdale Water District
Palo Alto, City Of
Paradise Irrigation District
Paramount, City Of
Pasadena, City Of
Paso Robles, City Of
Patterson, City Of
Petaluma, City Of
Phelan Pinon Hills Community Services District
Pico Rivera, City Of
Pico Water District
Pismo Beach, City Of
Pittsburg, City Of
Placer County Water Agency
Pleasanton, City Of
Pomona, City Of
Port Hueneme, City Of
Porterville, City Of
Poway, City Of
Quartz Hill Water District
Rainbow Municipal Water District
Ramona Municipal Water District
Rancho California Water District
Red Bluff, City Of
Redding, City Of
Redlands, City Of
Redwood City
Reedley, City Of
Rialto, City Of
Rincon Del Diablo Municipal Water District
Rio Linda-Elverta Community Water District

Rio Vista, City Of
Riverbank, City Of
Riverside, City Of
Riverside Highland Water Company
Rohnert Park, City Of
Rosamond Community Service District
Roseville, City Of
Rowland Water District
Rubidoux Community Service District
Rubio Canyon Land And Water Association
Sacramento, City Of
Sacramento County Water Agency
Sacramento Suburban Water District
San Bernardino, City Of
San Bernardino County Service Area
San Bruno, City Of
San Buenaventura, City Of(Ventura)
San Clemente, City Of
San Diego, City Of
San Dieguito Water District
San Fernando, City Of
San Francisco Public Utilities Commission
San Gabriel County Water District
San Gabriel Valley Water Company
San Jacinto, City Of
San Jose, City Of
San Jose Water Company
San Juan Capistrano, City Of
San Juan Water District
San Lorenzo Valley Water District
San Luis Obispo, City Of
Santa Ana, City Of
Santa Barbara, City Of
Santa Clara, City Of
Santa Cruz, City Of
Santa Fe Irrigation District
Santa Fe Springs, City Of
Santa Margarita Water District
Santa Maria, City Of
Santa Monica, City Of
Santa Paula, City Of
Santa Rosa, City Of
Scotts Valley Water District
Seal Beach, City Of
Shafter, City Of
Shasta Lake, City Of
Sierra Madre, City Of

Signal Hill, City Of
Soledad, City Of
Sonoma, City Of
Soquel Creek Water District
South Coast Water District
South Feather Water and Power
South Gate, City Of
South Pasadena, City Of
South Tahoe Public Utility District
Stockton, City Of
Suburban Water Systems
Suisun-Solano Water Authority
Sunny Slope Water Company
Sunnyslope Community Water District
Sunnyvale, City Of
Susanville, City Of
Sweetwater Authority
Sweetwater Springs Water District
Tehachapi, City Of
Thousand Oaks, City Of
Torrance, City Of
Trabuco Canyon Water District
Tracy, City Of
Triunfo Sanitation District-Oak Park Water Service
Truckee-Donner Public Utilities District
Tulare, City Of
Tuolumne Utilities District
Turlock, City Of
Tustin, City Of
Twentynine Palms Water District
Ukiah, City Of
Upland, City Of
Vacaville, City Of
Valencia Water Company
Vallecitos Water District
Vallejo, City Of
Valley Center Municipal Water District
Valley County Water District
Valley Of The Moon Water District
Valley Water Company
Vaughn Water Company
Ventura County Waterworks District No. 01-Moorpark
Ventura County Waterworks District No. 08-Simi Valley
Vernon, City Of
Victorville Water District
Vista Irrigation District
Walnut Valley Water District

Wasco, City Of
Watsonville, City Of
West Kern Water District
West Sacramento, City Of
West Valley Water District
Westborough Water District
Western Municipal Water District Of Riverside
Westminster, City Of
Whittier, City Of
Windsor Town Of
Woodland, City Of
Yorba Linda Water District
Yreka, City Of
Yuba City
Yucaipa Valley Water District

Attachment 4: References Cited

Introduction

All references will be provided at an FTP site or are accessible using the links below. In addition, the spreadsheet that includes the model assumptions and findings to calculate the water loss standards is provided on the FTP site. This spreadsheet provides additional context on calculation of standards using underlying assumptions.

References

American Water Works Association. (2016). *Water Audits and Loss Control Programs.* Denver: Fourth Edition.

European Union. (2015). *EU Reference Document: Good Practices on Leakage Management.* Luxembourg: European Union.

Fanner, P., Thornton, J., Liemberger, R., & Sturm, R. (2007). *Evaluating Water Loss and Planning Loss Reduction Strategies.* Denver: Water Research Foundation.

Metropolitan Water District of Southern California. (2020). *Fiscal Years 2020/21 and 2021/22 Cost of Service Report for Proposed Water Rates and Charges.* Los Angeles: Metropolitan Water District of Southern California.

Metropolitan Water District of Southern California. (2020, September 15). *Metropolitan Water District of Southern California - Historical Water Rates*. Retrieved from Metropolitan Water District of Southern California - Water Rates and Charges: http://www.mwdh2o.com/PDF_Who_We_Are/Historical_Water_Rates.pdf

Natural Resources Defense Council. (2016). Issue Brief, Proceed with Caution II: Calfornia Droughts and Desalination in Context. Natural Resources Defense Council.

Pacific Gas and Electric. (2015). *Water System Leak Identification and Control Field Evaluation.* Sacramento.

Pacific Institute. (2016). *The Cost of Alternative Water Supply and Efficiency Options in California.* Pacific Institute.

Sturm, R., Gasner, K., Wilson, T., Preston, S., & Dickinson, M. (2014). *Real Loss Component Analysis: A Tool for Economic Water Loss Control.* Denver: Water Research Foundation.

United States Bureau of Labor Statistics. (2020, September 15). *Consumer Price Index: West Region (All commodities)*. Retrieved from United States Bureau of Labor Statistics: https://www.bls.gov/cpi/data.htm

Water Research Foundation. (2007). *Leakage Management Technologies.* Denver: Water Research Foundation.

Economic (Benefit-Cost) model to calculate water loss performance standards developed by State Water Board staff, 2020

CALIFORNIA
Water Boards

Gavin Newsom
Governor

Jared Blumenfeld
Secretary for
Environmental Protection

State Water Resources Control Board

October 20, 2020

Joseph H. Cook, Ph.D., Associate Professor
School of Economic Sciences
Washington State University
Pullman, WA 99164

SUBJECT: INITIATION OF REVIEW OF THE SCIENTIFIC BASIS OF ECONOMIC MODEL FOR THE DEVELOPMENT OF WATER LOSS PERFORMANCE STANDARDS

Dear Professor Cook,

I recently approved you to be a peer reviewer. The purpose of this letter is to initiate the external peer review.

Components of the review:

1. Request for External Scientific Peer Review, with the following attachments:
    - Attachment 1: Plain English Summary.
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2. Document(s) for review.
3. Electronic copies of references cited.
4. Guidance for reviewers, as described after my signature. (Please pay particular attention to the section titled, “The review.”)

All components of the review are posted at a secure FTP site, or addressed in this letter:

- https://ftp.waterboards.ca.gov
- username: gbowes-ftp24
- password: p74TMt

E. Joaquin Esquivel, chair | Eileen Sobeck, executive director

1001 I Street, Sacramento, CA 95814 | Mailing Address: P.O. Box 100, Sacramento, CA 95812-0100 | www.waterboards.ca.gov

The findings, assumptions, and conclusions that need review are listed in Attachment 2 of the review request. Please address the subjects you noted you would cover with confidence, in your November 17th, 2020 email to me: You will address Conclusions 5, 6, 9, 12a,12b, 12c, 12d, and 12e.

I will help with any questions you have. To ensure a clear record of our communication, all of our communications should be in writing (email is preferred).

Please email your reviews to me by **Friday December 18th, 2020.** I will subsequently forward all reviews and the curricula vitae of all reviewers to the State Water Resources Control Board, Office of Research, Planning, and Performance. All of this information will be posted at the State Water Board website.

The organization requesting the review may require clarification or additional information on a specific subject. If this occurs, I will contact you to supplement your review to address those comments.

Your acceptance of this review assignment is most appreciated.

Sincerely,

Gerald W. Bowes, Ph.D.
Manager, CalEPA External Scientific Peer Review Program
Office of Research, Planning, and Performance
State Water Resources Control Board
1001 “I” Street, 13th Floor Sacramento, California 95814
Gerald.Bowes@waterboards.ca.gov

Guidance for Reviewers

Communication with the Peer Review Program. As noted above, to ensure a clear record of our communication, all of our communications should be in writing (email is preferred).

Confidentiality. You are required to help maintain the confidentiality of this review process.

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- You not allowed to discuss the proposal with employees of the requesting organization or individuals who participated in development of the proposal. The

individuals who participated in development are listed in Attachment 3 of the review request.

Independence. If you learn what you are reviewing was developed by someone with whom you share a common supervisor or have or had a working relationship, you must let us know so that we can determine whether to seek another peer reviewer. For example, if the CalEPA organization asking for the review contracted with someone in your department or organization to help develop the material you were asked to review, you have a potential conflict of interest.

The review. The statutory mandate for external scientific peer review (California Health and Safety Code Section 57004) states that the reviewer's responsibility is to determine whether "the scientific portion of the proposed rule is based upon sound scientific knowledge, methods, and practices." Your task is to make this determination for the assumptions, findings, or conclusions that the CalEPA External Scientific Peer Review Program has determined you can address with confidence, based on expertise and experience. (If you decide to address other assumptions, findings, or conclusions, identify the expertise and experience you are relying on to do so.) We also invite you to address these questions:

- Are there any scientific subjects that are part of the scientific basis of the proposal that are not described above?
- Taken as a whole, is the proposal based upon sound scientific knowledge, methods, and practices?

You may have been asked to review the implementation or application of established work. In some cases, there is a clear, previously-reviewed scientific basis for what you are reviewing but the scientific basis of the specific implementation of it still must be reviewed. For example, a United States Environmental Protection Agency criterion may have a solid peer review record, but you might determine that the proposed implementation or application of the criterion is not based upon sound scientific knowledge, methods, or practices.

You may ask for clarification or for additional specific supporting documents. We will provide what we can to you and all reviewers. Send clarification questions to Dr. Yoram Rubin (rubin@ce.berkeley.edu).

Text to include in your review:

- Your name, professional affiliation, and the date.
- The name of the item you are reviewing.
- Begin your review with, “Based on my expertise and experience, I am reviewing the findings, assumptions, or conclusions I agreed I could review with confidence:” and list them by number, as they are referred to in Attachment 2 of the review request.

Formatting your review. To ensure all people can perceive, understand, navigate, and interact with the materials posted on CalEPA websites, files posted on these websites must meet accessibility criteria. Your peer review may be posted on a CalEPA website so you should submit your review in an accessible format. The recommended way to make your file accessible is to use Microsoft Word to write your review and to use only basic text and headings during document creation. Then, run the built-in Word Accessibility Checker and resolve any accessibility issues.

Making your review accessible is your responsibility. We want to avoid, as much as possible, CalEPA staff making any kind of modification to your final peer review after you submit it. If your document does not meet accessibility requirements, we may send it back to you to fix and resubmit.

General accessibility criteria include:

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The links below provide some information on accessible online content:

- Resources for Creating Accessible Content (created by the California Department of Rehabilitation).
- Microsoft video lessons for accessible Word documents (created by Microsoft).
- State, Federal, and Other Related Laws & Regulations on Digital Accessibility (created by the California Department of Rehabilitation).

You may be asked to supplement your review. The organization requesting the review may require clarification or additional information on a specific subject. If this occurs, I will contact you to revise your review to address those comments.

If you are asked to discuss your comments. After you have submitted your review, you may be approached by third parties, the press, or by colleagues. You are under no obligation to discuss your comments with them and we recommend that you do not. Outside parties are provided an opportunity to address a proposed regulatory action during the public comment period. Discussions outside the provided avenues for comment could seriously impede the established process for vetting the proposal under consideration. Please direct third parties to us.

CALIFORNIA
Water Boards

GAVIN NEWSOM
GOVERNOR

JARED BLUMENFELD
SECRETARY FOR
ENVIRONMENTAL PROTECTION

State Water Resources Control Board

October 20, 2020

William K. Jaeger, Ph.D., Professor
Department of Applied Economics
College of Agricultural Sciences
Oregon State University
213 Ballard Extension Hall
Corvallis, Oregon 97331

SUBJECT: INITIATION OF REVIEW OF THE SCIENTIFIC BASIS OF ECONOMIC MODEL FOR THE DEVELOPMENT OF WATER LOSS PERFORMANCE STANDARDS

Dear Professor Jaeger,

I recently approved you to be a peer reviewer. The purpose of this letter is to initiate the external peer review.

Components of the review:

1. Request for External Scientific Peer Review, with the following attachments:
    - Attachment 1: Plain English Summary.
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    - Attachment 3: Individuals who Participated in the Development of the Proposal.
    - Attachment 4: References Cited.
2. Document(s) for review.
3. Electronic copies of references cited.
4. Guidance for reviewers, as described after my signature. (Please pay particular attention to the section titled, “The review.”)

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- https://ftp.waterboards.ca.gov
- username: gbowes-ftp24
- password: p74TMt

The findings, assumptions, and conclusions that need review are listed in Attachment 2 of the review request. Please address the subjects you noted you would cover with confidence, in your November 20th, 2020 email to me: You will address Conclusions 5, 6, 9, and 12.

I will help with any questions you have. To ensure a clear record of our communication, all of our communications should be in writing (email is preferred).

Please email your reviews to me by **Friday December 18th, 2020.** I will subsequently forward all reviews and the curricula vitae of all reviewers to the State Water Resources Control Board, Office of Research, Planning, and Performance. All of this information will be posted at the State Water Board website.

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Your acceptance of this review assignment is most appreciated.

Sincerely,

Gerald W. Bowes, Ph.D.
Manager, CalEPA External Scientific Peer Review Program
Office of Research, Planning, and Performance
State Water Resources Control Board
1001 “I” Street, 13th Floor Sacramento, California 95814
Gerald.Bowes@waterboards.ca.gov

Guidance for Reviewers

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- The name of the item you are reviewing.
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CALIFORNIA
Water Boards

Gavin Newsom
Governor

Jared Blumenfeld
Secretary for
Environmental Protection

State Water Resources Control Board

October 20, 2020

Professor Avi Ostfeld, P.E., D.WRE
Professor ATS Staff Academic Chair
Deputy Vice President for Academic Affairs
Civil an Environmental Engineering
Technion – Israel Institute of Technology
Rabin Building, Room 610
Haifa, 32000, Israel

SUBJECT: INITIATION OF REVIEW OF THE SCIENTIFIC BASIS OF ECONOMIC MODEL FOR THE DEVELOPMENT OF WATER LOSS PERFORMANCE STANDARDS

Dear Dr. Ostfeld,

I recently approved you to be a peer reviewer. The purpose of this letter is to initiate the external peer review.

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Gerald W. Bowes, Ph.D.
Manager, CalEPA External Scientific Peer Review Program
Office of Research, Planning, and Performance
State Water Resources Control Board
1001 “I” Street, 13th Floor Sacramento, California 95814
Gerald.Bowes@waterboards.ca.gov

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- The name of the item you are reviewing.
- Begin your review with, “Based on my expertise and experience, I am reviewing the findings, assumptions, or conclusions I agreed I could review with confidence:” and list them by number, as they are referred to in Attachment 2 of the review request.

Formatting your review. To ensure all people can perceive, understand, navigate, and interact with the materials posted on CalEPA websites, files posted on these websites must meet accessibility criteria. Your peer review may be posted on a CalEPA website so you should submit your review in an accessible format. The recommended way to make your file accessible is to use Microsoft Word to write your review and to use only basic text and headings during document creation. Then, run the built-in Word Accessibility Checker and resolve any accessibility issues.

Making your review accessible is your responsibility. We want to avoid, as much as possible, CalEPA staff making any kind of modification to your final peer review after you submit it. If your document does not meet accessibility requirements, we may send it back to you to fix and resubmit.

General accessibility criteria include:

- Text. Text should be black, in Arial, size 12 points or larger.
- Non-text elements. If you use them, graphs, figures, images, charts, or tables must follow accessibility criteria regarding meaningful captions and alternative text.
- Layout. Avoid complex document layouts, such as having text in more than one column, use of text boxes, use of color, and applying different font styles (i.e., bolding, underlining, etc.). It’s best to avoid letterhead, headers, and footers, aside from page numbers.
- Other requirements. There are also additional accessibility formatting requirements, including meaningful hyperlink text and appropriate use of styles for headings and lists.

The links below provide some information on accessible online content:

- Resources for Creating Accessible Content (created by the California Department of Rehabilitation).
- Microsoft video lessons for accessible Word documents (created by Microsoft).
- State, Federal, and Other Related Laws & Regulations on Digital Accessibility (created by the California Department of Rehabilitation).

You may be asked to supplement your review. The organization requesting the review may require clarification or additional information on a specific subject. If this occurs, I will contact you to revise your review to address those comments.

If you are asked to discuss your comments. After you have submitted your review, you may be approached by third parties, the press, or by colleagues. You are under no obligation to discuss your comments with them and we recommend that you do not. Outside parties are provided an opportunity to address a proposed regulatory action during the public comment period. Discussions outside the provided avenues for comment could seriously impede the established process for vetting the proposal under consideration. Please direct third parties to us.

CALIFORNIA
Water Boards

Gavin Newsom
Governor

Jared Blumenfeld
Secretary for
Environmental Protection

State Water Resources Control Board

November 24, 2020

Jordyn M. Wolfand, Ph.D., P.E., Assistant Professor
Department of Civil Engineering
Donald P. Shiley School of Engineering
University of Portland
5000 N. Willamette Blvd.
Portland, Oregon 97203

SUBJECT: INITIATION OF REVIEW OF THE SCIENTIFIC BASIS OF ECONOMIC MODEL FOR THE DEVELOPMENT OF WATER LOSS PERFORMANCE STANDARDS

Dear Professor Wolfand,

I recently approved you to be a peer reviewer. The purpose of this letter is to initiate the external peer review.

Components of the review:

1. Request for External Scientific Peer Review, with the following attachments:
    - Attachment 1: Plain English Summary.
    - Attachment 2: Scientific Assumptions, Findings, and Conclusions to Review.
    - Attachment 3: Individuals who Participated in the Development of the Proposal.
    - Attachment 4: References Cited.
2. Document(s) for review.
3. Electronic copies of references cited.
4. Guidance for reviewers, as described after my signature. (Please pay particular attention to the section titled, “The review.”)

All components of the review are posted at a secure FTP site, or addressed in this letter:

- https://ftp.waterboards.ca.gov
- username: gbowes-ftp24
- password: p74TMt

The findings, assumptions, and conclusions that need review are listed in Attachment 2 of the review request. Please address the subjects you noted you would cover with confidence, in your November 23rd, 2020 email to me: You will address Assumption 1, 2, 3, 4, 7, 8, Finding 10, Findings/Conclusion 11, and Findings/Conclusions 12a and 12d.

I will help with any questions you have. To ensure a clear record of our communication, all of our communications should be in writing (email is preferred).

Please email your reviews to me by **Friday December 18th, 2020.** I will subsequently forward all reviews and the curricula vitae of all reviewers to the State Water Resources Control Board, Office of Research, Planning, and Performance. All of this information will be posted at the State Water Board website.

The organization requesting the review may require clarification or additional information on a specific subject. If this occurs, I will contact you to supplement your review to address those comments.

Your acceptance of this review assignment is most appreciated.

Sincerely,

Gerald W. Bowes, Ph.D.
Manager, CalEPA External Scientific Peer Review Program
Office of Research, Planning, and Performance
State Water Resources Control Board
1001 "I" Street, 13th Floor Sacramento, California 95814
Gerald.Bowes@waterboards.ca.gov

Guidance for Reviewers

Communication with the Peer Review Program. As noted above, to ensure a clear record of our communication, all of our communications should be in writing (email is preferred).

Confidentiality. You are required to help maintain the confidentiality of this review process.

- Confidentiality began at the point you were contacted by the University of California, Berkeley.
- You should not inform others about your role as reviewer.
- You will not know the names of other reviewers until all reviews are complete and the organization decides to release reviews.

- You not allowed to discuss the proposal with employees of the requesting organization or individuals who participated in development of the proposal. The individuals who participated in development are listed in Attachment 3 of the review request.

Independence. If you learn what you are reviewing was developed by someone with whom you share a common supervisor or have or had a working relationship, you must let us know so that we can determine whether to seek another peer reviewer. For example, if the CalEPA organization asking for the review contracted with someone in your department or organization to help develop the material you were asked to review, you have a potential conflict of interest.

The review. The statutory mandate for external scientific peer review (California Health and Safety Code Section 57004) states that the reviewer's responsibility is to determine whether "the scientific portion of the proposed rule is based upon sound scientific knowledge, methods, and practices." Your task is to make this determination for the assumptions, findings, or conclusions that the CalEPA External Scientific Peer Review Program has determined you can address with confidence, based on expertise and experience. (If you decide to address other assumptions, findings, or conclusions, identify the expertise and experience you are relying on to do so.) We also invite you to address these questions:

- Are there any scientific subjects that are part of the scientific basis of the proposal that are not described above?
- Taken as a whole, is the proposal based upon sound scientific knowledge, methods, and practices?

You may have been asked to review the implementation or application of established work. In some cases, there is a clear, previously-reviewed scientific basis for what you are reviewing but the scientific basis of the specific implementation of it still must be reviewed. For example, a United States Environmental Protection Agency criterion may have a solid peer review record, but you might determine that the proposed implementation or application of the criterion is not based upon sound scientific knowledge, methods, or practices.

You may ask for clarification or for additional specific supporting documents. We will provide what we can to you and all reviewers. Send clarification questions to Dr. Yoram Rubin (rubin@ce.berkeley.edu).

Text to include in your review:

- Your name, professional affiliation, and the date.
- The name of the item you are reviewing.
- Begin your review with, “Based on my expertise and experience, I am reviewing the findings, assumptions, or conclusions I agreed I could review with confidence:” and list them by number, as they are referred to in Attachment 2 of the review request.

Formatting your review. To ensure all people can perceive, understand, navigate, and interact with the materials posted on CalEPA websites, files posted on these websites must meet accessibility criteria. Your peer review may be posted on a CalEPA website so you should submit your review in an accessible format. The recommended way to make your file accessible is to use Microsoft Word to write your review and to use only basic text and headings during document creation. Then, run the built-in Word Accessibility Checker and resolve any accessibility issues.

Making your review accessible is your responsibility. We want to avoid, as much as possible, CalEPA staff making any kind of modification to your final peer review after you submit it. If your document does not meet accessibility requirements, we may send it back to you to fix and resubmit.

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- Layout. Avoid complex document layouts, such as having text in more than one column, use of text boxes, use of color, and applying different font styles (i.e., bolding, underlining, etc.). It’s best to avoid letterhead, headers, and footers, aside from page numbers.
- Other requirements. There are also additional accessibility formatting requirements, including meaningful hyperlink text and appropriate use of styles for headings and lists.

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- State, Federal, and Other Related Laws & Regulations on Digital Accessibility (created by the California Department of Rehabilitation).

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If you are asked to discuss your comments. After you have submitted your review, you may be approached by third parties, the press, or by colleagues. You are under no obligation to discuss your comments with them and we recommend that you do not. Outside parties are provided an opportunity to address a proposed regulatory action during the public comment period. Discussions outside the provided avenues for comment could seriously impede the established process for vetting the proposal under consideration. Please direct third parties to us.

JOSEPH H. COOK

School of Economic Sciences *(updated November 2020)*
Washington State University
Pullman, WA 99164
509-335-3817 joe.cook@wsu.edu

ACADEMIC APPOINTMENTS

Associate Professor, School of Economic Sciences, Washington State University, Pullman, WA. (Partial extension appointment: Sustainable Stormwater, Washington Stormwater Center, WSU Puyallup). Fall 2017-current.

Associate Professor, Daniel J. Evans School of Public Policy & Governance, University of Washington, Seattle, WA, 2013-2017. **Assistant Professor**, 2007 - 2013.

Visiting Professor, University of Colorado. Fall 2014 (Economics, CU-Boulder), Spring 2015 (School of Public Affairs, CU-Denver).

EDUCATION

University of North Carolina, Chapel Hill, NC
Department of Environmental Sciences and Engineering, School of Public Health
Environmental Management and Policy, M.S. 2004, Ph.D 2007.

Cornell University, Ithaca, NY
Natural Resources, B.S. 1996

WORKING PAPERS (*paper co-authored with students and mentees.)

Cook, J., J. Brühl, and M. Visser. 2020. "Distributional statistics of municipal water use during Cape Town's drought: implications for affordability, conservation and tariff design." *Revising to resubmit, Water Resources Research, November 2020.*

Brent, D., **J. Cook**, and A. Lassiter. 2019. "Who signs up for free raingardens? Distributional effects of green infrastructure subsidies". *Under review October 2020.*

J. Cook and D. Brent. 2020. "Do customers respond to marginal or average prices?" Invited contribution to ORE Global Public Health. *Under review July 2020.*

Cook, J., J. Kabubo-Mariara and Peter Kimuyu. 2018. "Happy at work in Africa? Measuring time use and affect among water carriers in rural Kenya using the Experience Sampling Method". RFF-EfD Working Paper Series (Jan 2018). *Under review October 2020.*

Cook, J., J. Kabubo-Mariara and Peter Kimuyu. 2018. "The short-run impacts of exogenously reducing water collection times in rural Kenya". *Working paper*.

*Masuda, Y. and **J. Cook**. "Does improved water access increase child schooling? A quasi-experimental approach from rural Ethiopia". Evans School Working Paper 2013-02.

PEER-REVIEWED JOURNAL ARTICLES (*paper co-authored with students and mentees)

28. Brent, D., C. Lott, M. Taylor, **J. Cook**, K. Rollins and S. Stoddard. 2020. "What causes heterogeneous responses to social comparison messages for water conservation?". *Environmental and Resource Economics*, 77(3): 503-537.

27. Hills, K., G. Yorgey, and **J. Cook**. 2020. "Demand for bio-based fertilizers from dairy manure in Washington State: a small-scale discrete choice experiment." *Renewable Agriculture and Food Systems*, 1-8. https://doi.org/10.1017/S174217052000023X

26. ***Cook, J.,** J. Wagner, and G. Newell. 2020. "A decision support tool for rural water supply planning". *J Water Sanitation and Hygiene for Development*, 10(3): 447-457. Tool available at: www.ruralwaterdecision.org

25. **Cook, J.**, D. Fuente, and D. Whittington. 2020. "Choosing among pro-poor policy options in providing municipal water services". *Water Economics and Policy*, 6(3).

24. *Wagner, J., **J. Cook**, and P. Kimuyu. 2019. "Household demand for water in rural Kenya". *Environmental and Resource Economics*, 74(4): 1563-1584.

23. Whittington, D. and **J. Cook**. 2019. "Valuing Changes in Time Use in Low and Middle-Income Countries." *Journal of Benefit-Cost Analysis*, 10(S1): 51-72.

22. ***Cook, J.** and S. Lahren. 2017. "Why do water points fail? Learning from open-ended failure descriptions in the WPDx dataset." *J Water Sanitation and Hygiene for Development*, 7(4): 535-545.

21. Yoder, J., J. Adam, M. Brady, **J. Cook**, S. Katz, D. Brent, S. Johnston, K. Malek, J. McMillan, Q. Yang. 2017. "Benefit-cost analyses of Integrated Water Resource Management: The Yakima Basin Integrated Plan. *Journal of the American Water Resources Association*, 53(2):456-477.

20**. *Cook, J.,** Kimuyu, P., A. Blum, and J. Gatua. 2016. "Estimating the value of travel time in rural Africa from a stated preference experiment on water source choices". *Journal of Benefit Cost Analysis*, 7(2): 221-247. Available as RFF-EfD Working Paper 15-09.

19. **Cook**, J., P. Kimuyu, and D. Whittington. 2016. "The costs of coping with poor water supply in rural Kenya." *Water Resources Research* 52: 841-859. Available as EfD Working Paper 15-08.

18. Yoder, J., M. Brady and **J. Cook**. 2016. "Water markets and storage: Substitutes or complements for drought risk mitigation?" *Water Economics and Policy*, 2(2).

17*. Brent, D., **J. Cook**, and S. Olsen. 2015. "Social comparisons, household water use and participation in utility conservation programs: Evidence from three randomized trials." *Journal of the Association of Environmental and Resource Economists* 2(4): 597-627. Working paper version.

16*. Donfouet, H., **J. Cook** and P.W. Jeanty. 2015. "The economic value of improved air quality in urban Africa: Results from Douala, Cameroon". *Environment and Development Economics* 20(5):630-649.

15. **Cook, J**. and S. Rabotyagov. 2014. "Assessing irrigators' preferences for water market lease attributes with a stated preferences approach". *Water Resources and Economics* 7: 19-38.

14*. Masuda, Y., L. Fortmann, M.K. Gugerty, M. Smith-Nilson, and **J. Cook**. 2014. "Pictorial approaches for measuring time use in rural Ethiopia." *Social Indicators Research*, January 2012. (Corresponding author).

13. **Cook, J.**, S. Chatterjee, D. Sur and D. Whittington. 2013. "Measuring risk aversion among the urban poor in Kolkata, India". *Applied Economics Letters,* 20(1): 1-13.

12*. R. Chaudhri, K. Lieberg, R. Sodt, J. Chilton, G. Borriello, Y. Masuda and **J. Cook**. 2012. "Low power sensors and smartphones for tracking water collection in rural Ethiopia". *IEEE Pervasive Computing.* March 2012: 15-24. (Special Issue on Information Communication Technologies for Development (ICT4D).

11. **Cook**, **J**., B. Maskery, M. Jeuland and D. Whittington, 2012. "The case for giving stated preference respondents 'time to think': results from four countries." *Environmental and Resource Economics,* 51: 473-496.

10. **Cook, J.,** M. Jeuland, B. Maskery, D. Lauria, D. Sur, J. Clemens, and D. Whittington. 2009. "Using private demand studies to calculate socially optimal vaccine subsidies in developing countries." *Journal of Policy Analysis and Management,* 28(1): 6-28.

9. **Cook, J.**, D. Sur, J. Clemens, and D. Whittington. 2009. "Evaluating investments in typhoid vaccines in two Kolkata slums." *Journal of Health, Population and Nutrition,* 27(6): 711-724.

8. Jeuland, M., **J. Cook**, C. Poulos, J. Clemens, D. Whittington, and DOMI Cholera Economics Study Group. 2009. "Cost-effectiveness of new-generation oral cholera vaccines: A multi-site analysis". *Value in Health,* 12(6): 899-908.

7. Whittington, D., D. Sur, **J. Cook**, S. Chatterjee, B. Maskery, M. Lahiri, C. Poulos, S. Boral, A. Nyamete, J. Deen, L. Ochiai and S. K. Bhattacharya. 2008. "Rethinking cholera and typhoid vaccination policies for the poor: Private demand in Kolkata, India." *World Development,* 37(2): 399-409.

6. **Cook, J**., M. Jeuland, D. Whittington, C.Poulos**,** J. Clemens, D.Sur, D. D.Anh, M. Agtini, and Z.Bhutta. 2008. "The cost-effectiveness of typhoid Vi vaccination programs: Calculations for four urban sites in four Asian countries." *Vaccine,* 26: 6305-6316.

5. Kim, D., D. G. Canh, C. Poulos, L. T. K. Thoa, **J. Cook**, N. T. Hoa, A. Nyamete, D. T. D. Thuy, J. Deen, N. D. Son, J. Clemens, D. D. Trach, V. D. Thiem, D. D. Anh, and D. Whittington. 2008. "Private demand for cholera vaccines in Hue, Vietnam." *Value in Health,* 11(1): 119-128.

4. **Cook, J.**, D. Whittington, D.G. Cahn, F. Reed Johnson, and A. Nyamete. 2007. "Reliability of stated preferences for cholera and typhoid vaccines with time to think in Hue, Vietnam." *Economic Inquiry,* 45(1): 100-114.

3. Sur, D., **J. Cook**, S. Chatterjee, J. Deen, D. Whittington. 2006. "Increasing the transparency of stated choice studies for policy analysis: designing experiments to produce policy graphs." *Journal of Policy Analysis and Management*, 26(1): 189-199. (Corresponding author)

2. Blackman, A., S. Newbold, J.-S. Shih, D. Evans, **J. Cook** and M. Batz. 2006. “The benefits and costs of informal sector pollution control: Traditional Mexican brick kilns.” *Environment and Development Economics* 11(5): 603-627.

1. Whittington, D., D. Lauria, V. Prabhu and **J. Cook**. 2004. “An economic reappraisal of the Melamchi water supply project – Kathmandu, Nepal.” *Portuguese Economic Journal* 3: 157-178.

BOOK CHAPTERS and OTHER (Peer-reviewed)

B4. **Cook, J**. 2020. “Customer Assistance Programs and Affordability Issues in Water Supply and Sanitation”. *ORE Global Public Health*. Oxford University Press. *Forthcoming.*

B3. **Cook, J**., D. Fuente, M. Matichich, and D. Whittington. 2020. “A global assessment of non-tariff customer assistance programs in water supply and sanitation.” In Z. Chen, W. M. Bowen, and D. Whittington, eds. *Development Studies in Regional Science: Essays in Honor of Kingsley E. Haynes*. Springer Nature.

B2. **Cook, J.** 2013. **“**Principles and standards for benefit-cost analysis of public health preparedness and pandemic mitigation programs”. In *Principles and Standards for Benefit-Cost Analysis*. Eds. R. Scott Farrow and Richard O. Zerbe. Edward Elgar.

B1. Blackman, A., S. Newbold, J.-S. Shih, D.A. Evans, **J. Cook**, and M. Batz. 2006. “The benefits and costs of controlling small-firm pollution: informal brickmaking in Ciudad Juarez, Mexico”. Chapter 2 in “Small Firms and the Environment in Developing Countries: Collective Impacts, Collective Action”. RFF Press, Washington DC. 246 pp.

REPORTS AND OTHER NON-PEER REVIEWED WORK

Amaechina, E., A. Amoah, F. Amuakwa-Mensa, S. Amuakwa-Mensa, E. Bbaale, J. Bonilla, J. Bruhl, **J. Cook**, N. Chukwuone, D. Fuente, R. Madrigal-Ballestero, R. Marin, P. Khanh Nam, J. Otieno, R. Ponce, C. Saldarriaga, F. Vasquez Lavin, B. Viguera, and M. Visser. 2020. “Policy Responses to Ensure Access to Water and Sanitation Services During COVID-19: Snapshots from the Environment for Development (EfD) Network.” *Water Economics and Policy,* 6(4): 2071002. [Corresponding author]

Cook, J. and D. Whittington. 2020. “Editorial - Water Tariffs and Affordability: The Economics and Policy of Protecting the Poor.” Introduction from Guest Editors to Special Issue of *Water Economics and Policy*. 6(3): 1-9.

Katz, S., H. Beecher, M. Brady, **J. Cook**, K. Gates, J. Padowski, G. Pess, M. Scheuerell, and J. Yoder. 2019. “Technical Supplement: Determining Net Ecological Benefit”, appendix to “Final Guidance for Determining Net Ecological Benefit” https://fortress.wa.gov/ecy/publications/documents/1911079.pdf

Yoder, J., J. Adam, M. Brady , **J. Cook** and S. Katz. 2014. "Benefit-cost analysis of the Yakima Basin Integrated Plan Projects." Submitted to the Washington State Legislature December 15, 2014.

Cook, J. and J. Onjala. “Microfinance in the water supply and sanitation sector in Kenya” (August 2009). Prepared for Global Water Challenge, with support from the Packard Foundation. Online at: http://water.3cdn.net/cedec9aa55ab5b6ed9_slm6ivaye.pdf

Cook, J. "Confusion in risk aversion experiments in low-income countries". SSRN Working Paper.

Borger, T. and **J. Cook.** 2017 “Giving respondents ‘time to think’ reduces the randomness of responses in repeated discrete choice tasks”. University of St. Andrews Discussion Papers in Environmental Economics 2016-13.

GRANTS

“Subsidies, incentives, and information: Testing approaches to improve customer bill payment in Nairobi, Kenya.” Richard Mulwa (PI), David Fuente, Fridah Nyakundi, Jackson Otieno and Joseph Cook. Environment for Development initiative. ~$**60,000**. 2020-2021

“Water use in the Kenyan commercial Sector: Measuring price elasticity and coping strategies to deal with unreliability.” Jackson Otieno (PI), David Fuente, Fridah Nyakundi, and Joseph Cook. Environment for Development initiative. ~$**70,000**. 2020-2021

“Technology for trade: new tools and new rules for water use efficiency in agriculture and beyond”. USDA National Institute of Food and Agriculture (NIFA). PI Jon Yoder. Total award **$4,966,223**. Co-I Cook leading component on simulation games to identify how irrigators interact with technologies and institutional innovations, and test behavioral responses and outcomes; direct budget ~$553,000. 2018-2022.

“Defining Net Ecological Benefit for implementation of ESSB 6091”. Washington State Department of Ecology. PI Jon Yoder. **$72,000**. 2018-19.

“Short- and long-term effects of exogenously reducing water collection times on school attendance, hours studying and time use: Meru County, Kenya.” Environment for Development Initiative. Co-PI (with Jane Mariara and Peter Kimuyu). **$75,000**. 2016-2017.

“Evaluating Truckee Meadows Water Authority’s Conservation Messaging, Co-Investigator (with Kim Rollins (PI), Shawn Stoddard, Michael Taylor, Daniel Brent, and Corey Lott), Truckee Meadows Water Authority, **$69,002**. 2015-2016.

"Benefit-cost analyses of the Yakima Basin Integrated Plan Projects." Washington State Legislature, Section 5057, State of Washington Capital Budget 2013. Co-investigator (with Jon Yoder (PI), J. Adam, M. Brady, S. Katz, D. Brent, S. Johnston, K. Malek, J. McMillan, and Q. Yang). **$300,000**. 2013-2014.

"How does improving access to safe water change household time use in rural Ethiopia?" University of Washington Royalty Research Fund. PI. **$39,750**. June 2010 – June 2011.

"Adapting to climate-induced hydrological changes in the Yakima River basin of Washington State: unlocking water markets”. University of Washington Environmental Institute (College of the Environment). Co-PI (with Sergey Rabotyagov) **$143,468**. March 2010 – June 2012.

AWARDS

Excellence in Teaching Award (Evans School (UW), student-awarded),
- 2010-2011
- 2015-2016

Dean's Excellence in Teaching Award, 2013

Bruce Gardner Memorial Prize for Applied Policy Analysis, Agricultural and Applied Economics Association, 2016, for "Benefit-cost analyses of the Yakima Basin Integrated Plan Projects".

EXTENSION, MEDIA & TESTIMONY

- Invited presentation "Water Marketing" for Seminar Group conference "Water Law in Central Washington", August 2020.
- Invited testimony on water markets to Washington State Legislature, House Rural Development and Natural Resources subcommittee. February 25, 2020.
- KUOW "The Record", interviewed on water markets, August 21, 2019.
- NPR "Marketplace", interviewed on water markets, February 17, 2017.
- "WSU report says water plan overvalues fish recovery." *Seattle Times*, December 18, 2014. (Yakima Report to Legislature)
- "WSU Study: Yakima Basin projects don't pencil out." *Capital Press*, December 15, 2014 (Yakima Report to Legislature)
- "WSU study challenges economics of Yakima Basin water plan." Yakima Herald-Republic. December 4, 2014. (Yakima Report to Legislature).

OTHER RESEARCH-RELATED WORK EXPERIENCE

Field experience in Ethiopia, Kenya, Mozambique, India, Vietnam, and the U.S.

Millennium Challenge Corporation (subcontract to CH2M and CVM), Washington DC. October 2017 - June 2018. Led a team that reviewed the existing literature on pro-poor water pricing policies around the world, including "customer assistance programs" (CAPs) in the U.S. and Europe.

Global Water Challenge, Washington, D.C. August 2008 – August 2009. Consultant. Examined the potential for using microfinance and other innovative forms of financing to improve access to water supply and sanitation in Kenya and Ethiopia.

The Hopi Tribe, Kykotsmovi, AZ, June 2005-2008. Consultant. With Dale Whittington and Michael Hanemann. Led survey of households living on the Hopi reservation to support the Tribe's water rights claim in the Little Colorado River Basin adjudication.

International Vaccine Institute, June 2003 – May 2006, Research assistant (UNC-CH) and consultant. Led stated preference (contingent valuation and discrete choice) studies of private household willingness-to-pay for improved cholera and typhoid vaccines in Kolkata, India. Supported similar study in Hue, Vietnam. Led survey of costs-of-illness of contracting cholera in Beira, Mozambique.

Asian Development Bank, March 2003, consultant. With Dale Whittington, Donald Lauria, and Vimalanand Prabhu. Designed a user-interfaced, probabilistic spreadsheet model of the economic costs and benefits of the Melamchi Water Supply Scheme in Kathmandu, Nepal to support an economic reappraisal of the project.

UNC-CH Environmental Finance Center, May 2002 – May 2003. Built financial models for the Orange County solid waste department examining different ways to fund recycling and solid waste programs.

Resources for the Future, Washington DC, March 1999 – June 2001. Research assistant for Allen Blackman, Alan Krupnick, Dallas Burtraw and Winston Harrington. Projects included a benefit-cost analysis of regulating air pollution in small brickyards in Ciudad Juarez, Mexico; stated preference studies of willingness-to-pay for mortality risk reductions and for recovery of acidified lake ecosystems in Adirondack Park (NY); and an analysis of 8,000 FHA-insured mortgages in Chicago to evaluate the Location Efficient Mortgage (LEM) program.

TEACHING EXPERIENCE

Washington State University

- EconS 301 Intermediate Microeconomics with Calculus (undergrad; Fall 2017, 2018, 2019)
- EconS 581 Resource Economics (doctoral; Spring 2018, Fall 2018, Fall 2019)

University of Washington (all masters-level courses)

- PBAF 594 Economic Approaches to Environmental Management (2015)
- PBAF 595 Water Resource Economics (2009, 2011, 2012, 2017)
- PBAF 517 Economics for Policy Analysis and Management II (2011,2012, 2013)
- PBAF 587 Water and Sanitation Policy in Developing Countries (2008,2009,2010,2011, 2013)
- PBAF 518 Applied Benefit-Cost Analysis (2010, 2012,2017)
- PBAF 527 Quantitative Analysis (2008, 2009, 2010)
- PBAF 521/CFR 529/ESRM 429 Water Center Seminar (2011)
- PBAF 599D Special Topics: Updating the principles and guidelines used in benefit-cost analyses of large water projects by the Army Corps of Engineers (for the Congressional Research Service). Co-taught with Richard Zerbe. (2009)

ACADEMIC SERVICE & PROFESSIONAL AFFILIATIONS

University

Advising:

Washington State University
Nicholas Potter (PhD, Economics, member)
Chelsea Pardini (PhD, Economics, member)
Ajay Barman (PhD, Economics, member)
Linda Umwali (MS, Economics, member)
Pedro Jimenez (MS, Economics, member)
Jake Wagner (PhD, Economics, chair, 2020)
Richard Houghton (MS, Economics, chair, 2020)
Rokas Piliusenko (MS, Economics, chair, 2020)

University of Washington
Yuta Masuda (PhD, Evans, 2014, primary advisor)
Skylar Olsen (PhD, Economics, 2014, GSR)

Julie Vano (PhD, Civil and Environmental Engineering, 2013, GSR)
Laura Fricke (MS, Evans, 2013)
Daniel Brent (PhD, Economics, 2013, committee member)
Matthew Schoellhamer (MS, Forest Resources, committee member)
Patrick Green (MUP, Urban Planning, 2012, committee member)
Erin Donley (MS, Forest Resources, 2010, committee member)
Evans School Degree Projects: Cairns, Cammarano, Gilbert, Levin, Rosenberg, Smith, Stampher, Sztern, Trimble)
Kevin Feltes (BS, UNC-CH, 2005, committee member)

University Committees & Service:

Director's Advisory Committee, WSU, 2019-current
Search committee, WSU, 2019-2020
Undergraduate studies, WSU, 2018-current
Co-advisor, University of Washington chapter of Engineers without Borders (2014-16)
Graduate Program Coordinator (2012-2014)
UW Graduate School Council (2012-2014)
Faculty Council (2011-2013)
Peace Corps Master International (PCMI), Faculty Director (2008-2014)
Admissions (2010-11)
Curriculum (2007-08, 10-11)
Research Committee (2008-09)
Diversity Oversight (2009)

External

Member, Expert Consultative Group on Global Monitoring of Water, Sanitation, and Hygiene (WASH) Affordability, Joint Monitoring Programme (WHO, UNICEF), 2018-2020.

Member, Washington State Academy of Sciences (WSAS) Committee to advise the Washington Department of Fish and Wildlife on fish hatchery reform. 2018-2019

Network member, Environment for Development (EfD) Kenya, School of Economics, University of Nairobi, 2013 – present.

Member, Editorial Board. Environment for Development (EfD) Discussion Paper Series. 2019-current.

Resource Person (responsible for proposal reviews and mentoring) for *Center for Environmental Economics and Policy in Africa* (CEEPA), Pretoria, South Africa, 2009 – 2015.

Referee: National Science Foundation (SES-Economics), *Proceedings of the National Academy of Sciences (PNAS), Journal of Environmental Economics and Management, American Journal of Agricultural Economics, Environmental & Resource Economics, Environment and Development Economics, Health Economics, Water Resources Research, Agricultural Economics, Social Science and Medicine, Journal of Environmental Management, J. Contemporary Water Research and Education*

Affiliations

American Economic Association
Association of Environmental and Resource Economists
International Water Resource Economics Consortium

Society for Benefit-Cost Analysis
Association for Public Policy Analysis and Management

WILLIAM K. JAEGER

Department of Applied Economics
213 Ballard Extension Hall, Oregon State University
Corvallis, Oregon 97331-3601
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EDUCATION

Ph.D., Stanford University 1985.
Master of Arts, Stanford University 1981.
Bachelor of Arts, Washington State University, 1976.

RECENT PROFESSIONAL EXPERIENCE

2007-present	Professor, Department of Applied Economics, Oregon State University.
Sept. 2016- Jan. 2017	Visiting Fellow, Robert Schuman Centre for Advanced Studies, European University Institute, Florence, Italy
Fall 2010	Professor, Consortium of Universities for International Studies, CIMBA Program, Paderno del Grappa, Italy.
Fall 2007	Fulbright Scholar, University Ca' Foscari of Venice, Italy (Department of Economics), and visiting researcher, Fondazione Eni Enrico Mattei (FEEM), Venice, Italy.
2001-2007	Associate Professor, Department of Applied Economics (formerly Agricultural and Resource Economics), Oregon State University.

RELEVANT AND OTHER PUBLICATIONS

Jaeger W.K., Amos A, Conklin D.R., Langpap C, Moore K, Plantinga A.J. Scope and limitations of drought management within complex human–natural systems. *Nature Sustainability*. 2019 Jul 15:1.

Jaeger, W.K., Amos, A., Bigelow, D.P., Chang, H., Conklin, D.R., Haggerty, R., Langpap, C., Moore, K., Mote, P.W., Nolin, A.W. and Plantinga, A.J., C.L. Schwartz, D. Tullos, D. P. Turner, 2017. Finding water scarcity amid abundance using human–natural system models. *Proceedings of the National Academy of Sciences*, p.201706847.

Jaeger, W.K., A. J. Plantinga, H. Chang, K. Dello, G. Grant, D. Hulse, J. J. McDonnell, S. Lancaster, H. Moradkhani, A. T. Morzillo, P. Mote, A. Nolin, M. Santelmann and J. Wu. Toward a formal definition of water scarcity in natural-human systems. *Water Resources Research*, Volume 49. Published online: 8 JUL 2013 | DOI: 10.1002/wrcr.20249

Jaeger, WK, 2011. The welfare effects of environmental taxation. *Environmental and Resource Economics*. Volume 49(1): 101-119.

Boehlert, B. B., and W. K. Jaeger, 2010. Past and future water conflicts in the Upper Klamath Basin: An economic appraisal, *Water Resources Research*, Volume 46, W10518, doi:10.1029/2009WR007925.

Jaeger, W.K., “The effects of land use regulations on property values” *Environmental Law*, Vol. 36, Spring 2006.

BOOKS & BOOK CHAPTERS

Jaeger, William K. 2015. Chapter 2: Institutions and Water. In <u>Handbook of Water Economics</u> (Ariel Dinar and Kurt Schwabe, eds.). Edward Elgar Publishing, Northhampton, MA.

TEACHING EXPERIENCE

Graduate teaching (Oregon State University, University of Oregon, University of Washington): environmental and resource economics, institutional economics, microeconomics, water law and policy, water economics.

Graduate teaching (Williams College Center for Development Economics): environmental and resource economics, agricultural economics, sustainable development

Undergraduate teaching (Williams College and Oregon State University): institutional economics, intermediate microeconomics, sustainable development, environmental and resource economics, open economy macroeconomics, introduction to economics, applied welfare topics in economics, development economics.

RECENT RESEARCH FUNDING

National Institute of Food and Agriculture (USDA), Reducing Uncertainty to Advance Sustainable Groundwater Use Using an Integrated Hydro-Economic System Model: Investigations in the Harney Basin, Oregon, 2019-2023 ($500,000)

NSF Water Sustainability & Climate Category 2: Anticipating water scarcity and informing integrative water system response in the Pacific Northwest, 2010-15 ($4.3m)

US Forest Service. Evaluating Land Markets and the Effects of Land Use Regulations: A Comparative GIS Approach. 2008-2009 ($23,000)

AWARDS

Fulbright Scholar, Italy 2007-2008 (at University Ca’ Foscari of Venice and Fondazione Eni Enrico Mattei (FEEM), Venice.
James and Mildred Oldfield/E.R. Jackman Team Award, Oregon State University, 2005.

August 2020

November 10, 2020

AVI OSTFELD
ATS Staff Academic Chair

SHORT CV
(Personal website and full CV can be found at: https://ostfeld.net.technion.ac.il/)

Dr. Avi Ostfeld is a full Professor and the ATS Staff Academic Chair at the Faculty of Civil and Environmental Engineering at the Technion – Israel Institute of Technology. Dr. Ostfeld was a Senior Engineer and Project Manager at TAHAL – Consulting Engineers Ltd. in Tel – Aviv from 1997 to 2000; a Research Associate at the Department of Civil Engineering, the University of Arizona, Tucson, AZ, from 1996 to 1997; and a Research Associate at the Technion Water Research Institute from 1994 to 1996.

During 2008/2009 Dr. Ostfeld spent sabbaticals as Visiting Professor at the University of Illinois at Urbana Champaign and at the University of Kyoto, and was appointed Affiliate Professor, Zhejiang University, China in May 2012.

Dr. Ostfeld's research contributions and professional activities are in the fields of water resources systems, and in particular in the area of water distribution systems optimization using evolutionary computation: water distribution systems security through optimal monitoring, water quality event detection, and booster chlorination station allocations, optimal design and operation of water distribution systems, and integrating water quality and reliability into water distribution systems management and control.

Dr, Ostfeld received in 2009 the International Visiting Scholarship Award, Research Center for Environmental Quality Management (RCEQM), Graduate School of Engineering, Kyoto University, Japan, in 9/2009 the Best CCWI09 Paper Award, for: Preis A., Whittle A., Ostfeld A., and Perelman L. (2009). "On-line hydraulic state estimation in urban water networks using reduced models’", and was appointed in 2012 the prestigious recognition of Fellow of the American Society of Civil Engineers (ASCE) and Fellow of the International Water Association (IWA). In 5/2013 Dr. Ostfeld received the EWRI (Environmental and Water Research Institute)-Fellow grade, and in 2/2016 the ASCE/EWRI 2016 Service to the Profession Award.

Dr. Ostfeld published 131 manuscripts in refereed professional journals and 146 papers in conference proceedings; is the Editor of four books; was the Editor in Chief of the Journal of Water Resources Planning and Management Division of ASCE 2010-2016 which is the leading journal worldwide in water resources systems analysis in general, and in water distribution systems optimization in particular, an Editor for the IWA Journal of Water Science and Technology, was Associate Editor for Water Resources Research, and currently Associate Editor for Urban Water, and Engineering Optimization. Dr. Ostfeld served also as the director of the advisory board of Peak Dynamics (Energy Management in Water Systems), member of the advisory board of Visenti (Improving Infrastructure Management); chaired the Water Distribution Systems Analysis (WDSA) EWRI-ASCE standing committee; and as of February 2013 member of the national interdisciplinary appointed Israeli professional committee on water security.

Dr. Ostfeld’s research citations are: h-index = 43, citations = 7450 on GOOGLE SCHOLAR, and h-index = 35, citations = 5115 on SCOPUS.

ACADEMIC DEGREES

D.Sc.	1994, Civil Engineering, Technion, Haifa, Israel.
M.Sc.	1990, Civil Engineering, Technion, Haifa, Israel.
B.Sc.	1987, Agricultural Engineering, Technion, Haifa, Israel.

RELEVANT PUBLICATIONS (last three years)

1. Sankary N. and Ostfeld A. (2017). "Inline mobile sensors for contaminant early warning enhancement in water distribution systems", Journal of Water Resources Planning and Management Division, ASCE, 04016073-1 - 04016073-12, http://dx.doi.org/10.1061/(ASCE)WR.1943-5452.0000732
2. Taormina R., Galelli S., Tippenhauer N. O., Salomons E., and Ostfeld A. (2017). "Characterizing cyber-physical attacks on water distribution systems." Journal of Water Resources Planning and Management Division, ASCE, 04017009-1 - 04017009-12, http://dx.doi.org/10.1061/(ASCE)WR.1943-5452.0000749
3. Sankary N. and Ostfeld A. (2017). "Scaled multi-objective optimization of an intensive early warning system for water distribution system security." Journal of Hydraulic Engineering, 04017025-1 - 04017025-16 http://dx.doi.org/10.1061/(ASCE)HY.1943-7900.0001317
4. Salomons E., Skulovich O., and Ostfeld A. (2017). "The battle of water networks DMAs – a multistage design approach", Journal of Water Resources Planning and Management Division, ASCE, http://dx.doi.org/10.1061/(ASCE)WR.1943-5452.0000830, 04017059-1 - 04017059-7
5. Lifshitz R. and Ostfeld A. (2018). "Clustering for analysis of water distribution systems", Journal of Water Resources Planning and Management Division, ASCE, Vol. 144, No. 5, 04018016-1 - 04017091-6 https://doi.org/10.1061/(ASCE)WR.1943-5452.0000917
6. Sankary N. and Ostfeld A. (2018). "Stochastic scenario evaluation in evolutionary algorithms used for robust scenario based optimization", Water Resources Research, http://dx.doi.org/10.1002/2017WR022068
7. Sankary N. and Ostfeld A. (2018). "Multi-objective optimization of inline mobile and fixed wireless sensor networks under demands uncertainty", Journal of Water Resources Planning and Management Division, ASCE, Vol. 144, No. 8, 04018043-1 - 04018043-13 http://dx.doi.org/10.1061/(ASCE)WR.1943-5452.0000930
8. Sankary N. and Ostfeld A. (2018). "Analyzing multi-variate water quality signals for water quality monitoring station placement in water distribution systems", Journal of Hydroinformatics, Vol. 20, No. 6, pp. 1323-1342 https://doi.org/10.2166/hydro.2018.162
9. Lifshitz R. and Ostfeld A. (2019). "Clustering for real time response to water distribution systems contamination event intrusions", Journal of Water Resources Planning and Management Division, ASCE, Vol. 145, No. 2, 04018091 - 1 - 04018091-9 https://doi.org/10.1061/(ASCE)WR.1943-5452.0001031
10. Sankary N. and Ostfeld A. (2019). "Bayesian localization of water distribution system contamination intrusion events using inline mobile sensor data." Journal of Water Resources Planning and Management Division, ASCE, Vol. 145, No. 8, 04019029-1 - 04019029-10 (featured in the Editor’s Choice section). https://doi.org/10.1061/(ASCE)WR.1943-5452.0001086
11. Cao H., Hopfgarten S., Ostfeld A., Salomons E., and Li P. (2019). "Simultaneous sensor placement and pressure reducing valve localization for pressure control of water distribution systems." Water, Vol. 11, No. 7, pp. 1352-1370; https://doi.org/10.3390/w11071352
12. Vrachimis S. G., Lifshitz R., Eliades D. G., Polycarpou M. M., and Ostfeld A. (2020). "Active contamination fault detection in water distribution systems." Journal of Water Resources Planning and Management Division, ASCE, Vol. 146, No. 4. https://doi.org/10.1061/(ASCE)WR.1943-5452.0001176 (Editor’s Monthly Choice)
13. Qiu M., Salomons E., and Ostfeld A. (2020). "A framework for real-time assembling of decontamination plan for a contamination event." Water Research, Vol. 174, No. 1, https://doi.org/10.1016/j.watres.2020.115625
14. Qiu M., Housh M., and Ostfeld A. (2020). "A two-stage LP-NLP methodology for the least-cost design and operation of water distribution systems." Water, Vol. 12, No. 5, 1364, https://www.mdpi.com/2073-4441/12/5/1364
15. Qiu M., Housh M., and Ostfeld A. (2020). "An analytical optimization approach for simultaneous design and operation of water distribution systems optimization." Journal of Water Resources Planning and Management Division, ASCE (accepted).

Jordyn M. Wolfand, Ph.D., P.E.

Assistant Professor
University of Portland
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(503) 943-8751

EDUCATION

PhD	**Stanford University, Stanford, CA** (2018) Civil and Environmental Engineering – Environmental Engineering
MS	**Stanford University, Stanford, CA** (2015) Civil and Environmental Engineering – Environmental Fluid Mechanics and Hydrology
BS	**Tufts University, Medford, MA** (2011) Civil and Environmental Engineering – *summa cum laude* with Highest Thesis Honors

ACADEMIC AND RESEARCH POSITIONS

2020–	**Assistant Professor,** Shiley School of Engineering, University of Portland, Portland, OR
2019	**Postdoctoral Research Fellow**, Colorado School of Mines, Golden, CO *Civil & Environmental Engineering – Supervisor Dr. Terri Hogue*
2014–2018	**Graduate Research Assistant**, Stanford University, Stanford, CA *Re-inventing the Nation's Urban Water Infrastructure (ReNUWIt), Civil & Environmental Engineering – Advisor Dr. Richard Luthy*
2010–2011	**Undergraduate Research Assistant**, Tufts University, Medford, MA *Integrated Multiphase Environmental Systems Lab, Civil & Environmental Engineering*
2007	**Research Intern**, University of Maryland, College Park, MD *Aquatic Pathobiology Center, Department of Veterinary Medicine*

REFEREED JOURNAL ARTICLES

Submitted	Abdi, R., Rogers, J.B., Rust, A., **Wolfand, J.M.,** Philippus, D., Taniguchi-Quan, K., Irving, K., Stein, E.D., Hogue, T.S., Evaluating the thermal impact of substrate temperature on ecological restoration in shallow urban rivers.
In Review	Helinski, O., **Wolfand, J. M.** Ridding Our Rivers of Plastic: A Framework for Plastic Pollution Reduction Device Selection.
	Panos, C.L., **Wolfand, J.,** Hogue, T.S. Assessing resilience of a dual drainage urban system to redevelopment and climate change. *Journal of Hydrology.*
In Press	Blount, W.K., **Wolfand, J.,** Bell, C.D., Ajami, N., Hogue, T.S. Satellites to sprinklers: Assessing the role of climate and land cover change on patterns of urban outdoor water use. *Water Resources Research.*
2020	Bell, C.D., **Wolfand, J.,** Hogue, T.S. Regionalization of default parameters for urban stormwater quality models. *Journal of the American Water Resources Association.* DOI: 10.1111/1752-1688.12878
	Panos, C.L., **Wolfand, J.,** Hogue, T.S. SWMM Sensitivity to LID Siting and Routing Parameters: Implications for Stormwater Regulatory Compliance. *Journal of the American Water Resources Association.* DOI: 10.1111/1752-1688.12867

	Bell, C.D., **Wolfand, J.,** Panos, C., Bhaskar, A., Gilliom, R., Hogue, T., Hopkins, K., Jefferson, A. Stormwater control impacts on runoff volume and peak flow: a meta-analysis. *Hydrological Processes*. DOI: 10.1002/hyp.13784
	Luthy, R.G., **Wolfand, J.,** Bradshaw, J.L. The Urban Water Revolution: Sustainable Water Futures for California Cities. *Journal of Environmental Engineering.* DOI: 10.1061/(ASCE)EE.1943-7870.0001715
	Boehm, A.B., Bell, C.D., Fitzgerald, N.J.M, Gallo, E, Higgins, C.P., Hogue, T.S., Luthy, R.G., Portmann, A.C., Ulrich, B.A., **Wolfand, J.M.** Biochar-augmented biofilters to improve pollutant removal from stormwater - can they improve receiving water quality? *Environmental Science: Water Research & Technology*. DOI: 10.1039/D0EW00027B
2019	**Wolfand, J.,** Seller, C., Bell, C.D., Cho, Y.M, Oetjen, K., Hogue, T.S., Luthy, R.G. Occurrence of urban-use pesticides and management with enhanced stormwater control measures at the watershed scale. *Environmental Science & Technology.* 53(7), 3634–3644, DOI: 10.1021/acs.est.8b05833
2018	Pritchard, J.C., Cho, Y.M., Ashoori, N., **Wolfand, J.,** Sutton, J.D., Carolan M.E., Gamez, E., Doan, K., Wiley, J.S., Luthy, R.G. Benzotriazole Uptake and Removal in Vegetated Biofilter Mesocosms Planted with *Carex praegracilis. Water.* 10(11), 1605, DOI: 10.3390/w10111605
	Wolfand, J., Bell, C.D., Boehm, A.B., Hogue, T.S., Luthy, R.G., Multiple pathways to bacterial load reduction by stormwater best management practices: tradeoffs in performance, volume, and treated area. *Environmental Science & Technology.* 52, 6370–6379, DOI: 10.1021/acs.est.8b00408.
2016	**Wolfand, J.**, LeFevre, G., and Luthy, R. Metabolization and Degradation Kinetics of the Urban-use Pesticide Fipronil by White Rot Fungi *Trametes versicolor. Environmental Science: Processes & Impacts.* 18(10) 1249–1362, DOI: 10.1039/c6em00344c.

TEACHING

2020–	**Assistant Professor**, Shiley School of Engineering, Civil Engineering, University of Portland, Portland, OR
2019	**Instructor**, Hydrology and Water Resources Laboratory (CEEN 482), Colorado School of Mines, Golden, CO
2017–2018	**Instructor,** Stormwater Seminar, Stanford, CA
2017	**Project Mentor & Guest Lecturer**, San Jose State University, San Jose, CA
2016	**Teaching Assistant**, Physical and Chemical Treatment Processes, Stanford, CA
2008–2012	**Outdoor Educator and Section Head**, North Country Camps, Keeseville, NY

MENTORSHIP

2020–	**Undergraduate Research Mentor,** University of Portland, Portland, OR
2020–	**Senior Capstone Advisor,** University of Portland, Portland, OR
2019–2020	**Graduate and Undergraduate Research Mentor**, Colorado School of Mines, CO
2014–2018	**Volunteer Tutor**, East Palo Alto Tennis and Tutoring, Stanford, CA
2015–2018	**Undergraduate Research Mentor**, Stanford University, Stanford, CA

OUTREACH

2019	**Volunteer Instructor**, Research Experience for Teachers, Water-Energy Education for the Next Generation, Colorado School of Mines, CO
2014–2019	**Volunteer**, ReNUWIt, Stanford, CA
2017	**Rising Environmental Leader**, Rising Environmental Leaders Program, Stanford, CA
2007–2011	**Instructor and Board Member**, Center for Engineering Education Outreach, Medford, MA

OTHER PUBLICATIONS

2019	Gordon, B., Quesnel, K.Q., Hamel, P., **Wolfand, J.** Using Nature to Tackle Water Infrastructure Challenges: Frontiers of Green Infrastructure Research at Stanford. *Water in the West – Insights.*
2015	ReNUWIt. Briefing book from Technology Diffusion Workshop on Open Water Unit Process Wetlands, Berkeley, CA. (**J. Wolfand** as contributor on regulatory framework).
2011	**Wolfand, J.** Fate and Transport of Nanoscale Buckminsterfullerene Aggregated (nC_{60}) in Heterogeneous Porous Media. *Senior Honors Thesis*, Tufts University, Medford, MA.
2007	**Wolfand, J.** Active Ingredient in Oral Contraceptives Alters Male Competitive Courtship Behaviors and Secondary Sexual Characteristics in Fathead Minnows. *Journal of the U.S. Stockholm Junior Water Prize.*

PROFESSIONAL EXPERIENCE

2020	**Independent Contractor**, Colorado School of Mines, Golden, CO
2012–2019	**Senior Staff Engineer** (part time since 2013), Geosyntec Consultants, Brookline, MA
2012	**Engineering Co-op**, Geosyntec Consultants, Columbia, MD
2009	**Stockholm Junior Water Prize Intern**, Water Environment Federation, Alexandria, VA

SELECT PRESENTATIONS

2019	Wolfand, J., Seller, C., Bell, C.D., Cho, Y.M., Oetjen, K., Hogue, T.S., Luthy, R.G. Managing urban-use pesticides with enhanced green infrastructure on the watershed scale. **11th National Monitoring Conference**, Denver, CO. *Talk.* March 2019.
2018	Wolfand, J., Seller, C., Bell, C.D., Cho, Y.M., Oetjen, K., Hogue, T.S., Luthy, R.G. Managing urban-use pesticides with enhanced green infrastructure on the watershed scale. **AGU Fall Meeting**, Washington D.C. *Talk.* December 2018.
	Wolfand, J. Managing urban water quality with enhanced stormwater control measures. **Colorado State University.** *Invited Talk.* October 2018.
	Wolfand, J., Seller, C., Cho, Y.M., Hogue, T.S., Luthy, R.G. Modeling reduction of bacteria and pyrethroids by enhanced stormwater best management practices (BMPs) on a watershed scale. **EWRI Congress**, Minneapolis, MN. *Talk.* June 2018.
	Brown, P., Wolfand, J., Luthy R.G., Amirbahman, A., James, C. Optimization and Development of a Biodegradable Scaffold to Remove Nutrients from Stormwater. **EWRI Congress**, Minneapolis, MN. *Talk.* June 2018.
2017	Wolfand, J., Bell, C.D., Boehm, A.B., Hogue, T.S., Luthy, R. G. Modeling Removal of Fecal Indicator Bacteria by Enhanced Stormwater Best Management Practices (BMPs)

on a Watershed Scale. **Annual AWRA Conference**, Portland, OR. *Talk.* November 2017.

Wolfand, J., Hogue, T., Boehm, A., Luthy, R. Predicting Fecal Indicator Bacteria Fate and Removal in Urban Stormwater at the Watershed Scale. **EWRI Congress**, Sacramento, CA. *Talk.* May 2017.

Wolfand, J. Fungi for Filtration and Other Natural Systems for Stormwater Treatment, Department of Environmental Studies Public Seminars, **San Jose State University**, San Jose, CA. *Invited Talk.* March 2017.

2016 Wolfand, J., Hogue, T., Boehm, A. Luthy, R. Predicting Fecal Indicator Bacteria Fate and Removal in Urban Stormwater at the Watershed Scale. **AGU Fall Meeting**, San Francisco, CA. *Talk.* December 2016.

Wolfand, J., LeFevre, G., and Luthy, R. Metabolization and degradation kinetics of the urban-use pesticide fipronil by white rot fungi *Trametes versicolo*r. **ACS Fall Meeting**, Philadelphia, PA. *Invited Talk.* August 2016.

Wolfand, J., LeFevre, G., and Luthy, R. Fungal Degradation of the Urban Use Pesticide Fipronil. **CA-NV Section AWWA Spring Conference**, Sacramento, CA. *Invited Talk.* March 2016.

Quesnel, K. and Wolfand, J. Water Energy Nexus. **Vail Global Energy Forum**, Beaver Creek, CO. *Video Presentation.* January 2016.

SELECT POSTERS

2017 Wolfand, J., Bell, C.D., Boehm, A.B., Hogue, T.S., Luthy, R. G. Predicting Bacteria Removal by Enhanced Stormwater Control Measures (SCMs) at the Watershed Scale. **AGU Fall Meeting**, New Orleans, LA. December 2017.

2016 Wolfand, J., Hogue, T., Boehm, A. Luthy, R. Modeling enhanced stormwater treatment technologies for fecal indicator bacteria at the watershed scale. **Symposium on Urban Water Infrastructure; Stormwater Capture, Treatment and Reuse**, Golden, CO. November 2016.

Wolfand, J., Hogue, T., Luthy, R. Modeling enhanced stormwater treatment technologies for water quality benefit and regulatory compliance. **Statewide Water Reuse Forum**, Sacramento, CA. September 2016.

Wolfand, J., LeFevre, G., and Luthy, R. White rot fungi for enhanced stormwater treatment: degradation of the urban-use pesticide, fipronil. **Gordon Conference: Environmental Sciences – Water**, Holderness, NH. June 2016.

2011 Walker, D.I., Wolfand, J., Wang, Y., Bai, C., Li, Y., Abriola, L.M., Pennell, K.D. Transport and Retention of Fullerene Aggregates in Heterogeneous Two Dimensional (2-D) Aquifer Cells Containing Natural Aquifer Sands. **AGU Fall Meeting**, San Francisco, CA. December 2011.

SERVICE

2020– **Member**, Graduate School Application Task Force, University of Portland

2016–2017 **Treasurer**, ReNUWIt Student Leadership Council

2014–2016 **Campus Representative**, ReNUWIt Student Leadership Council

2013–2016 **Founder and Member**, Stanford Environmental Engineering Student Committee

2014–2015	**Representative**, Environmental Engineering Seminar Committee

AWARDS AND HONORS

2016	Association of Environmental Engineering and Science Professors Video Contest – Honorable Mention
2015	Stanford Energy Club Video Competition for the Vail Global Energy Forum – Winner
	University of South Florida Reclaim Video Contest – Winner
2011	Tufts Civil and Environmental Engineering Earle F. Littleton Award
2010	Tufts Civil and Environmental Engineering Cataldo Award
	Howard Sample Prize in Physics
2007	U.S. Stockholm Junior Water Prize – Maryland State Winner and National Finalist

GRANTS AND FELLOWSHIPS

2020	University of Portland Provost’s Initiative for Undergraduate Research - $1,500
	Shiley Grant for Faculty Research and Development - $3,000
2015	UPS Endowment Fund - $100,000
2013	Stanford Goldman Graduate Fellowship - $148,000
	Stanford Akiko Yamazaki & Jerry Yang Engineering Fellowship - $74,000
2010	Tufts Summer Scholar - $5,500

ACTIVE PROFESSIONAL CREDENTIALS AND MEMBERSHIPS

Professional Engineer, Civil Engineering, Oregon (#96332)

American Geophysical Union

December 18, 2020

To: Gerald Bowes, PhD, Manager, CalEPA Scientific Peer Review Program

From: Joseph Cook, PhD, Associate Professor, School of Economic Sciences, Washington State University

Re: Peer review of “Technical Report on Economic Model for the Development of Water Loss Performance Standards”

Based on my expertise and experience, I am reviewing the findings, assumptions, or conclusions I agreed I could review with confidence: items 5, 6, 9 and 12 (all subitems) of the proposed water loss control standards.

General comments

Taken as a whole, I find that the proposal is based on sound scientific methods and practices. Overall, the benefit-cost approach is implemented appropriately, and I found only one error in the assumptions, methods or conclusions of the proposed economic model. I provide more detailed feedback on the specific items requested below.

I have one general criticism of the implementation of the model, which is the treatment of uncertainty. A simplistic, binary (yes/no) approach may be necessary from a regulatory standpoint. But from a conceptual point of view, there is large uncertainty in many of the parameters of the model and ignoring this uncertainty may lead to poor decisions. It has for some time been standard practice in applied benefit-cost analysis (see Boardman et al 2018 “Cost-benefit analysis: concepts and practice”) to include some type of uncertainty analysis. I expect requiring a probabilistic “Monte Carlo” uncertainty analysis would be challenging since it would require utilities to have specialized software or technical skills. It may be more feasible, however, to require three sets of results from three implementations of the model. One would use the base case parameters and two would be sensitivity analyses, one using a “worst case” parameter set and one using a “best case” set. If discounted net benefits are negative (or positive) under all three scenarios, the best decision for the regulated utility would be clear. When the sign of net benefits differs in the sensitivity analyses, however, the utility might be allowed more latitude in the rulemaking process to argue for the approach that they believe best fits their situation.

Specific comments

Item 5: Assumption of avoided costs and variable production costs

I reviewed the reports from the Pacific Institute (2016) and NRDC (2016) on which the Board relied for this item. The Board appears to have relied much more heavily on the Pacific Institute report. I found the Pacific Institute's estimates to be credibly constructed. They also seem to be the most appropriate ones, to my knowledge, for use in this proposed model since they are specific to California and are relatively recent.

In the spirit of my comment above on uncertainty, the Pacific Institute report usefully provides a range of estimates (low, median, high) for water supply alternative projects at different scales. For example, the Pacific Institute report finds that large (>10,000 AFY) brackish desalination facilities have lower median costs (median $1,100) than small (<10,000 AFY) brackish desalination plants (median $1,600) because of economies of scale.

Table 3 in Attachment 5, however, abstracts from that detail in a seemingly arbitrary way. The value for "stormwater" is given as $590. This corresponds to the "low" estimate for "small" stormwater capture facilities in the Pacific Institute report (see Table 1 in that report), but does not include the cost of groundwater pumping and treatment. The Pacific Institute reports the "total" cost for the "low" estimate to be $930. No explanation is given for why $590 is more appropriate than $930, and why a "small" stormwater facility is the default. Similarly, the value for indirect potable reuse in Table 3 in Attachment 5 ($1800) seems to correspond to the median "total" cost for a "large" project (see Table 4 in Pacific Institute 2016). Again, no explanation is given for why the median (rather than the "low" estimate) is now used, and a "large" facility is now more appropriate than a "small" facility. The documentation for the value for imported water ($1015) should be included in the technical report; it is now only listed in the "CollectedData/References" tab of the spreadsheet. These four estimates are then simply averaged and inflated to 2020 dollars to arrive at the parameter assumed of $1093.

Although the assumed value of $1093 is plausible, I found it to be poorly justified and overly precise given the range of uncertainty; the Pacific Institute report notably provided only two significant digits. Appendix 5 says that "suppliers will be able to provide their system-specific value for water through the rulemaking or adjustment processes." In that spirit, I might suggest that Appendix 5 include the full set of relevant tables from the Pacific Institute report for utilities to draw from.

Although it is conceptually correct to inflate the costs from 2015 to 2020 dollars, in this case the role of inflation (which has been quite modest in that time period) is less important than the overall uncertainty in these estimates. I believe the Board could be justified in ignoring inflation in these estimates and/or presenting only two significant digits (i.e. $570, not $567.43). This is also a case of what seems to be an error: the 2020 costs are smaller than the 2015 costs, so I suspect the inflation calculation was inverted. When I plug $590 (2015 dollars) into the CPI calculator, I get a 2020 value of $657, not $567. However, this could also be due to the staff using only the "Commodities" component of the CPI. I did not see any justification for why that portion of the consumer "bundle" is most relevant here. Although I do not have expertise in the components of the CPI, I know that standard practice in benefit-cost analysis is to use the "all prices" index unless there is some strong justification to focus only on one component. I also believe commodity prices would fluctuate more than the overall CPI and could be declining while the overall CPI increases because of short-term fluctuations in the gold, oil and ag commodities markets.

Overall, I might recommend using as a base case what the Board feels is a plausible but conservative estimate for the type of project that most utilities could be expected to implement. This might, for example, be a "small" stormwater capture facility (using the "high" cost from the Pacific Institute report) or imported water. Again, one would expect utilities to ask to adjust this parameter to fit what they feel is the most appropriate marginal project to expand water supply.

Item 6: Assumption in the rise of price of water

The Board uses the average increase in MWD's treated water prices during the period 2008-2020, finding that this was averaged 5.9% per year. Given MWD's role in the state, this choice of overall approach seems appropriate. I have three suggestions, however.

First, Appendix 5 says that the estimate of 5.9% is intended to represent an expected price increase "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." My understanding is that both AB756 (PFOA and PFAS) and the GMA are just now beginning implementation, so any additional compliance costs due to these rules have not yet been reflected in MWD's treated water prices (2008-2020). This argues for adding some additional compliance costs on top of the 5.9% expected increase. This would be a matter of staff judgment, and I have no expertise to suggest a value.

Second, my understanding is that suppliers may request to use a different value of avoided costs (see item 5 above) but they must use this value of 5.9%. Since the two values are conceptually related, it seems logical to allow flexibility for both. Suppliers who do not rely on MWD might wish to use their own historical data on the increase in prices or their expectations about increased compliance costs under AB756 or the GMA (particularly those suppliers who source primarily from groundwater).

Third, in calculating the increase in real prices, I would recommend using the "all prices" index rather than only the "commodities" component, as discussed above. (The difference may not be economically significant, however: the CPI for commodities rose

8% during 2008-2020 while the CPI-All rose 18%, by my calculations). At a minimum, it would be helpful to provide a justification for why the “commodities” component only is the most relevant, given that I do not believe “water” is included in the index as one of those commodities.

Finally, I would note that there is an alternate approach to calculating the average price increase. The Board calculates the percentage increase in real prices each year, and then averages these twelve values to arrive at 5.9%. A different approach is to calculate the total percentage increase over the time period and divide by the number of years. This approach gives: ($1078 – 549.8)/549.8 = 96% increase / 12 years = 8.0% real increase per year. I do not have an informed opinion which is more appropriate but I wished to point this out. If my calculations are correct, I believe the issue is how one wants to weight the large price increases in 2008-9 and 2009-10.

Item 9: Conclusion: projection of benefits and costs across 30-year time horizon using a real discount rate and a real rise in the price of water.

The proposed model uses a real discount rate of 3.5% on both costs and benefits over a 30-year time horizon. This choice of real discount rate (3.5%) is appropriate and defensible. The justification given is rather thin, however. There is no justification in Appendix 5 for this choice, and the excel model simply says “based on stakeholder input”. My understanding is that the DWR uses a discount rate of 6% real (based on DeSouza et al 2011 “Guidelines for Preparing Economic Analysis for Water Recycling Projects”). The real discount rate to be used in federal water resource projects for 2020 is 2.75% (*Federal Register* 84(242):68943).

It is common practice in applied benefit-cost analysis to essentially ignore inflation by using a real discount rate and ignoring inflation in prices of benefits and costs. The technical report could be clearer that it is making an important, and in my view warranted, diversion from this approach: it assumes the price of water will rise faster than overall inflation. The report says “inflation [is] excluded from both benefits and costs,” which is not accurate. The assumption is that the price of alternative water sources will increase 5.9% faster than overall inflation (the “all prices” CPI). Again, I believe this is warranted. Water and sewer rates charged to customers have been increasing faster than inflation nationwide, and there is good reason to believe that the value of water in California will rise faster than inflation.

Another important and unstated assumption is that cost of leak detection and repair will increase at the same rate as overall goods and services. This is defensible, but I do wonder whether multiple water suppliers bidding simultaneously for the services of leak detection firms and consultants circa 2022-23 might drive the cost of these services up substantially, potentially faster than overall prices.

I will not comment on whether the thirty-year time horizon is appropriate. This issue is raised in Item 7. The time horizon should be based on the useful life of capital investments, and I have no expertise on the useful life of leak detection equipment or pipe repair materials.

Item 12: Findings/conclusions benefit-cost analysis of water loss control actions

Item 12(a): water saved due to water loss control actions

The calculations in the spreadsheet model appear correct.

Item 12(b): Benefit associated with water loss control actions

The calculations in the spreadsheet model appear correct. I would note that cell A41 appears to be mislabeled: this should be the “real” not “nominal” discount rate.

Item 12(c): number of unreported leaks and efficiency of leak detection equipment

The calculations in the spreadsheet model appear correct.

Item 12(d): Cost associated with water loss control action

The calculations in the spreadsheet model appear correct.

Item 12(e): Water loss over the year 2027

The calculations in the spreadsheet model appear correct. I was a bit confused and concerned that net benefits were being discounted twice. Column 15 (O) applies a discounting factor to calculate the present value of the costs of leak detection and repair. Column 18 (R) applies a discounting factor to calculate the present value of the benefits of leak detection. One could simply subtract the first from the second to get the present value of net benefits. Instead, Column 19 (S) then subtracts the undiscounted costs (col. N) from undiscounted benefits (col Q) and column 20 applies a discounting factor to Column 19. I believe this is correct, but I would recommend making it more clear by removing columns O and R, or calculating the PV of net benefits directly using O and R.

December 18, 2020

To: Gerald Bowes, PhD, Manager, CalEPA Scientific Peer Review Program

From: Joseph Cook, PhD, Associate Professor, School of Economic Sciences,
Washington State University

Re: Peer review of “Technical Report on Economic Model for the Development of Water Loss Performance Standards”

Based on my expertise and experience, I am reviewing the findings, assumptions, or conclusions I agreed I could review with confidence: items 5, 6, 9 and 12 (all subitems) of the proposed water loss control standards.

General comments

Taken as a whole, I find that the proposal is based on sound scientific methods and practices. Overall, the benefit-cost approach is implemented appropriately, and I found only one error in the assumptions, methods or conclusions of the proposed economic model. I provide more detailed feedback on the specific items requested below.

I have one general criticism of the implementation of the model, which is the treatment of uncertainty. A simplistic, binary (yes/no) approach may be necessary from a regulatory standpoint. But from a conceptual point of view, there is large uncertainty in many of the parameters of the model and ignoring this uncertainty may lead to poor decisions. It has for some time been standard practice in applied benefit-cost analysis (see Boardman et al 2018 “Cost-benefit analysis: concepts and practice”) to include some type of uncertainty analysis. I expect requiring a probabilistic “Monte Carlo” uncertainty analysis would be challenging since it would require utilities to have specialized software or technical skills. It may be more feasible, however, to require three sets of results from three implementations of the model. One would use the base case parameters and two would be sensitivity analyses, one using a “worst case” parameter set and one using a “best case” set. If discounted net benefits are negative (or positive) under all three scenarios, the best decision for the regulated utility would be clear. When the sign of net benefits differs in the sensitivity analyses, however, the utility might be allowed more latitude in the rulemaking process to argue for the approach that they believe best fits their situation.

Specific comments

Item 5: Assumption of avoided costs and variable production costs

I reviewed the reports from the Pacific Institute (2016) and NRDC (2016) on which the Board relied for this item. The Board appears to have relied much more heavily on the Pacific Institute report. I found the Pacific Institute's estimates to be credibly constructed. They also seem to be the most appropriate ones, to my knowledge, for use in this proposed model since they are specific to California and are relatively recent.

In the spirit of my comment above on uncertainty, the Pacific Institute report usefully provides a range of estimates (low, median, high) for water supply alternative projects at different scales. For example, the Pacific Institute report finds that large (>10,000 AFY) brackish desalination facilities have lower median costs (median $1,100) than small (<10,000 AFY) brackish desalination plants (median $1,600) because of economies of scale.

Table 3 in Attachment 5, however, abstracts from that detail in a seemingly arbitrary way. The value for "stormwater" is given as $590. This corresponds to the "low" estimate for "small" stormwater capture facilities in the Pacific Institute report (see Table 1 in that report), but does not include the cost of groundwater pumping and treatment. The Pacific Institute reports the "total" cost for the "low" estimate to be $930. No explanation is given for why $590 is more appropriate than $930, and why a "small" stormwater facility is the default. Similarly, the value for indirect potable reuse in Table 3 in Attachment 5 ($1800) seems to correspond to the median "total" cost for a "large" project (see Table 4 in Pacific Institute 2016). Again, no explanation is given for why the median (rather than the "low" estimate) is now used, and a "large" facility is now more appropriate than a "small" facility. The documentation for the value for imported water ($1015) should be included in the technical report; it is now only listed in the "CollectedData/References" tab of the spreadsheet. These four estimates are then simply averaged and inflated to 2020 dollars to arrive at the parameter assumed of $1093.

Although the assumed value of $1093 is plausible, I found it to be poorly justified and overly precise given the range of uncertainty; the Pacific Institute report notably provided only two significant digits. Appendix 5 says that "suppliers will be able to provide their system-specific value for water through the rulemaking or adjustment processes." In that spirit, I might suggest that Appendix 5 include the full set of relevant tables from the Pacific Institute report for utilities to draw from.

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Review conducted for the California State Water Resources Board

Name of report: Technical Report on Economic (Benefit-Cost) Model to Calculate Water Loss Standards. File dated November 12, 2020.

Reviewer: William K. Jaeger, Professor, Dept. of Applied Economics, Oregon State University

Date: December 23, 2020

Based on my expertise and experience, I am reviewing the findings, assumptions, and conclusions I agreed I could review with confidence. These items are: No. 5 (assumptions for avoided costs and variable production costs), No. 6 (rise in price of water), No. 9 (conclusions about projected benefits and costs across 30-year time horizon), and No. 12 (findings/ conclusions from benefit-cost analysis for water control actions).

On the first item (No. 5: assumptions for avoided costs and variable production costs), the information being relied upon for these assumptions appear to be high quality, credible estimates. As noted in the report, both the avoided costs from reduced water loss, and the variable production costs to increase supply, can vary greatly across regions and water systems. Nevertheless, the ranges of values proposed appear to fit the reality well. The values were chosen drawing on information assembled and analyzed in reports by the Pacific Institute and an Issue Brief from the Natural Resource Defense Council. Both of these documents appear to be high quality and relatively recent. In the case of the variable production cost, estimates for this metric are regularly reported as part of water loss audits.

Importantly the values integrated into the analysis used the higher of the variable production cost and the avoided cost of water based on available alternative sources to value water saved. This is an important element for the analysis since for a resource like water we have good theoretical reasons to expect the long-run marginal cost to rise in the future. This future-looking perspective is introduced by calculating the avoided cost of future water suppliers as a result of current water losses. The method incorporates an average of the anticipated cost of water for alternative sources such as imported water, recycled water, storm water reuse, etc., based on the Pacific Institute 2016 study.

The authors of the report recognize that these values will vary by location and time frame, but by requiring these estimates to be the basis for the calculations, the model is consistent with the expectation of relatively higher costs in the future. These values could, of course, be revised at some point in the future.

On the second item (No. 6: assumption for future water price rise), the report explains the reasoning for assuming a 5.9% annual increase in the real (inflation-adjusted) price of water. The authors recognize the high degree of uncertainty for predicting future price increases: there are examples and time periods during which urban water prices have risen or fallen in the past 30 years. Nevertheless, by looking at the past trend in water rates set by the Metropolitan Water District of California, from 2008 to the present, and then adjusting these to real prices using the Consumer Price Index (for western States), the average rate of growth in the water price over that period was 5.9%. It is worth noting that if the time period over which the average growth rate was estimated included earlier years (e.g., 2004-2007), the average would be lower (4.8%). However, given the many reasons mentioned in the report to expect the costs of water delivery to increase (e.g., higher water quality requirements, environmental factors), the rate of change being chosen for the benefit-cost analyses is defensible and prudent. It is worth noting that as a check on this assumption, one can compare the assumed average annual rise in the price of water to the assumed real discount rate (3.5%, discussed below): the price or value of a unit of water today will be lower than the present value of that same unit of water years in the future because the price of water is assumed to increase faster than its value be discounted over time. This is expected for a resource like water that we expect to rise in value relative to the general price level dominated by goods that can be produced in increased quantities at decreased costs (see Sterner, T., and U. M. Persson. "An even sterner review: Introducing relative prices into the discounting debate." *Review of Environmental Economics and Policy* 2.1 (2008): 61-76).

On the third item (No. 9: conclusions about projected benefits and costs across 30-year time horizon), the analysis combines the two elements already discussed with a) the choice of time frame of 30 years and b) the selection of a discount rate for weighing future benefits and costs. Choosing the rate at which to discount investments that involve public goods and public resources is a complex question that has been debated by economists for decades. There is a case to be made for a social discount rate that is lower than the private market opportunity cost of capital. There is also a case to be made for a declining discount rate for time periods farther into the future (due to uncertainty about the “true” or “correct” discount rate). In this case, the argument that the discount rate should reflect the opportunity cost of the funds being used – that these public funds could be used for other projects with a rate of return at or above market rates – is a strong argument. In this report State Water Board staff proposed a real discount rate of 3.5% based in part on stakeholder input. Given an inflation rate of about 2%, this implies a nominal discount rate of 5%. One could further complicate the question about the choice of discount rate by recognizing the way that risk plays a role in determining market interest rates, as does the capital gains tax (these factors likely put upward pressures on the market interest rate). In the end, there is no right answer. Nevertheless, the number chosen by the State Water Board staff seems like a very good point estimate to choose.

Related to the benefit-cost analysis framework is the time frame of 30 years. One consideration is the durability of the investments being made, the depreciation of the capital investments, many of which will have a relatively long “life cycle.” These factors appear to argue for a relatively long time horizon, such as 30 years or longer. There is a tradeoff, however, due to the heightened uncertainty about future benefits and costs resulting from unforeseen changes in technological or other dimensions of water systems and society values. Beyond 30 years there is reason to believe that the specific numbers being assumed as benefit or costs become highly speculative. As a result of these tradeoffs, 30 years seems like an appropriate time frame for the analysis.

On the fourth and final item (No. 12: findings/conclusions based on benefit-cost analysis for water loss control actions). The benefit-cost analysis set-up follows the correct framing of the question: compare the benefits and costs of the “with” scenario to the benefits and costs of the “without” scenario. First, the water saved is estimated by comparing the estimated water lost with the water loss control actions, and then subtracting the water lost estimate without any water loss control actions. This produces an estimate of the water saved due to the water loss control action (active leak detection and repair). Second, the benefit is calculated based on item No. 5 discussed above, and applying the assumed rise in price, discounted using the 3.5% discount rate to compute the present value of benefits.

I take as justifiable the number of unreported leaks and efficiency of leak detection, which is supported by documentation (AWWA M36). The cost estimates for leak detection appear to be well-grounded in empirical data. And these are appropriately projected over the 30 year time horizon. These estimates are also appropriately compounded by the number of leaks per mile and the costs of repairing each reported leak, summed with costs calculated over the time horizon, and discounted. This procedure is correct and rigorous, but without being so complex as to be unwieldy.

The components of the report combine to provide a very useful guide to decision making for reducing water loss. The modeling detail is sophisticated but will not be overwhelming to those who will be asked to put it to use. It allows for some flexibility to accommodate individualized conditions and local information, but within what appear to be appropriate limits.

William K. Jaeger

Avi Ostfeld, PhD. Faculty of Civil and Environmental Engineering, Technion - Israel Institute of Technology, Haifa 3200003, ISRAEL
Date of review submission: 18 December 2020

Subject: Scientific peer review of the scientific basis of economic model for the development of water loss performance standards

Based on my expertise and experience, I am reviewing the findings, assumptions, or conclusions I agreed I could review with confidence. Those are assumptions/findings/conclusions: 1, 2, 3, 4, 7, 8, 10, 11, 12a, and 12d.

General assessment

This peer review report is on engineering and cost related aspects of the Economic (Benefit-Cost) Model to Calculate Water Loss Standards, developed by the California State Water Resources Control Board.

In all cities worldwide, the water is regularly transmitted to its habitants using underground pipelines running through its nooks and corners serving as the arteries of the cities. Thus, in terms of urban planning, one of the most important infrastructures is the design of water distribution systems (WDSs). However, following rapid urbanization, it has become more challenging to satisfy the water demand of the city inhabitants. Access to reliable potable water is an increasing pressure for many water supply industries, especially in developing countries. In this regard, it is no surprise to realize that the sustainable development of any city inevitably comprises the sustainable usage of water.

Unfortunately, significant amounts of water get lost from WDSs during the transmission to customers due to pipe failures and leaks. It is estimated that over 32 billion m^3 of potable water is lost from WDSs all over the world, which accounts for about 35% of the total water supplied (Xu et al. 2014). Water distribution pipes every so often lose an average of 20-30% of the water transmitted through them, and this can escalate to above 50% in systems suffering from inefficient maintenance (El-Zahab and Zayed 2019). The most common way for water loss in a WDS is leakage. Leakage is considered to contribute more than 70% of the loss in distribution pipes, and this value may increase in networks with critical structural and hydraulic integrity issues (Van Zyl and Clayton 2007). Apart from resource loss, leakages in WDSs also induce serious economic burden on the water utilities. The monetary impact of the repairs is estimated to be around 10 billion US$ annually (El-Zahab and Zayed 2019). Another aspect of leakages is their tendency to grow over time. This may allow the introduction of pathogens and contaminants from the surrounding environment into the WDSs (Fontanazza et al. 2015).

Leakage in WDSs can be categorized into the following three types based on the manner of their occurrence (American Water Works Association 2016):

1. Reported leakage (RL). These leaks are reported by customers, traffic authorities, or any other party due to their visible and/or disruptive nature. Furthermore, the leaks detected by high flows associated with/without perceptible drops in water pressure can be categorized as reported leaks.

2. Unreported leakage (UL). These leaks escape the public eye and hence, can be only identified through active leakage detection and control works. Unfortunately, many water utilities around the world do not perform active leak detection surveys regularly.

3. Background leakage (BL). This type of leakage corresponds to collective weeps and seeps at joint and fittings that may occur at very low flow rates but may exist prevalently across the WDS, particularly if the problem of structural integrity persists. These leakages are not acoustically detectable. Due to this reason, it cannot be addressed by conventional leak detection surveys. In the past, the leaks falling under the category of BL may have been viewed as unavoidable leakage, in the sense that it was not cost - effective to detect and repair them. However, the use of pressure management has emerged to challenge these notions and offer a successful means to reduce, though not eliminate, their existence.

For many utilities around the world, most of the leakage losses occur from UL and/or BL. For those systems with a reactive leakage control policy for controlling only the RL, it is possible that these control policies are monitoring only a minority of the leakage occurrences in their distribution systems.

The proposed Economic (Benefit-Cost) Model to Calculate Water Loss Standards that is reviewed in this report becomes significant in this regard. The model calculates the three components mentioned above, and specifically the UL component - based on the length of distribution mains, number of connections owned by the supplier, the average operational pressure and the total leakage (TL) estimate provided by the supplier. Leakage estimates are then computed for consecutive time intervals through a volumetric mass balance equation, in which: **TL = RL+UL+BL**

In this mass balance equation, RL and BL are computed through empirical relationships found at the AWWA M36 manual, where the UL is estimated through subtracting from the TL the RL and BL figures. Once leaks are estimated, it then allows users to conduct a reliable life cycle assessment (LCA) that permits water utilities to set a system-specific, cost-effective leakage management strategy. At the end, the LCA-based model outputs are aimed at assisting the decision - makers to prioritize the anticipated actions that can be taken to reduce water loss (specifically the UL and BL losses) to an economically feasible level.

The proposed Economic (Benefit-Cost) Model to Calculate Water Loss Standards that is reviewed in this report, is casted in an excel spreadsheet, with tabs for: inputs, calculations, output, equations, and references for the collected data. Its primary objective is to compute water loss performance values from leakage for urban retail water suppliers in California, for conducting cost-benefit analysis for future actions anticipated to be taken by urban retail water suppliers for reducing water loss from leakage.

Water loss audit reports submitted annually in California, industry and literature based estimates for costs and benefits associated with water loss control actions, serve as model inputs. The model calculates water loss performance standards based on economically feasible water loss reductions, to the year of 2028 from active leak detection and repair only due to availability of data.

The model uses **25 input parameters** of three types: **(1) system characteristics** from water loss inspections, such as water distribution system size, service connection density, and operating pressure, **(2) system leakage** profile with **default values taken from the AWWA M36 manual,** such as, reported, unreported, and background leakage and additional underlying leakage characteristics, and **(3) associated costs and benefits**, such as cost of water and intervention (unit costs per leak detection, repair), variable production cost of water, avoided cost of water, discount rate, and average annual rise in price of water.

Out of the twenty-five input parameters, twenty-two are adjustable through systems specific case values that suppliers can modify, while **three** parameters: the *real discount rate (3.5%)*, the *average annual rise in price of water (5.9%)*, and *the effective timeline for lifecycle benefit-cost analysis (30 years),* **are assumed fixed.**

In summary, the proposed Economic (Benefit-Cost) Model to Calculate Water Loss Standards that is reviewed in this report is based on empirical relationships to estimate leaks and rise of leaks, as well as on water loss audit reports, all embedded into a consecutive mass balance equation using assumptions on UL repair duration and extent. With that respect, the model does not account directly for the hydraulic pressure influence on leaks. Its capability to provide a reliable and realistic estimation decision support tool depends on these simplified assumptions. Fig. 1 is a schematic flowchart of the reviewed model, as implemented in the provided excel spreadsheet.

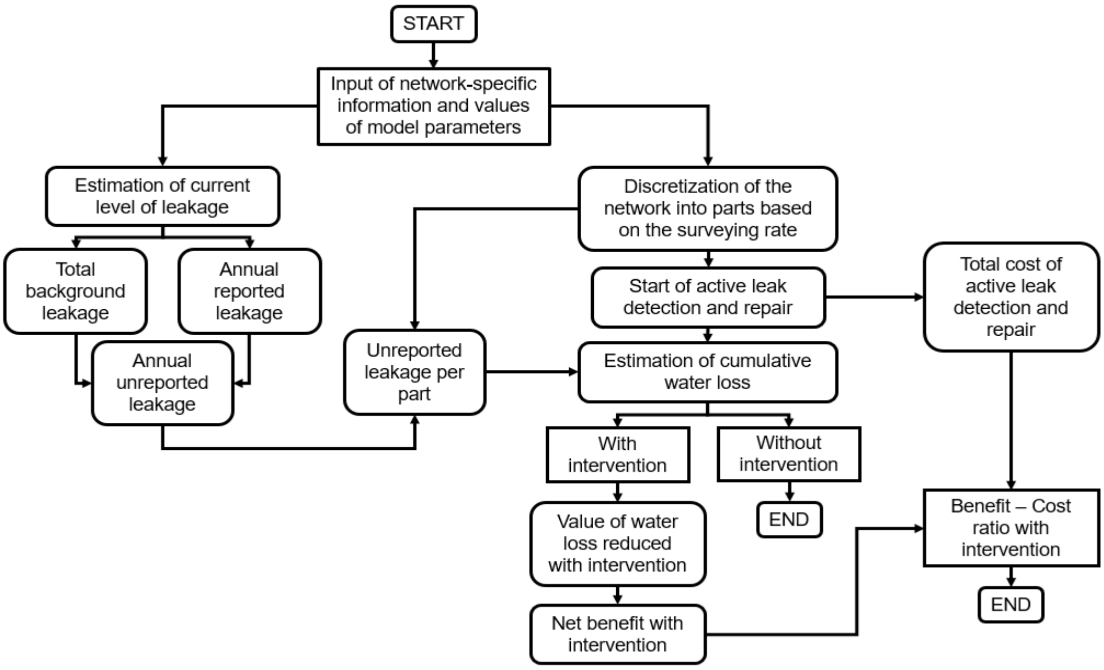

Fig. 1: A schematic flowchart description of the reviewed model

Example applications

With an aim to assess and evaluate performance, the proposed Economic (Benefit-Cost) Model to Calculate Water Loss Standards that is reviewed in this report, was applied to two WDSs from the WDSs research literature, with diverse characteristics. This exercise is undertaken and reported to better understand and demonstrate the proposed model capabilities, and to enhance the review on the model specific subjects listed further below.

The first WDS is a well-tested problem which has been provided as an Example network 3 in manual of the commonly used hydraulic modeling software EPANET 2.0 (Rossman 2000). The system is the adaptation of the WDS of the North Marin Water District, USA. It consists of 92 connections (demand nodes), and the total water demand met by the system is 11241 gpm. In addition, the WDS consists of three tanks and two reservoirs (source nodes). The WDS has 117 pipes and the total pipe length is 215712 ft. The second WDS selected for the model performance evaluation is the Balerma Network (Saldarriaga et al. 2020) consisting of four reservoirs (source nodes), 443 connections (demand nodes), and 454 pipes. The total water demand met by this system is 17515 gpm, and its total pipe length is 328946 ft. The first and second WDSs will be denoted as DS-1 (Fig. 2) and DS-2 (Fig. 3), respectively. The model assessment reported further below, is based on the investigations conducted on these two systems.

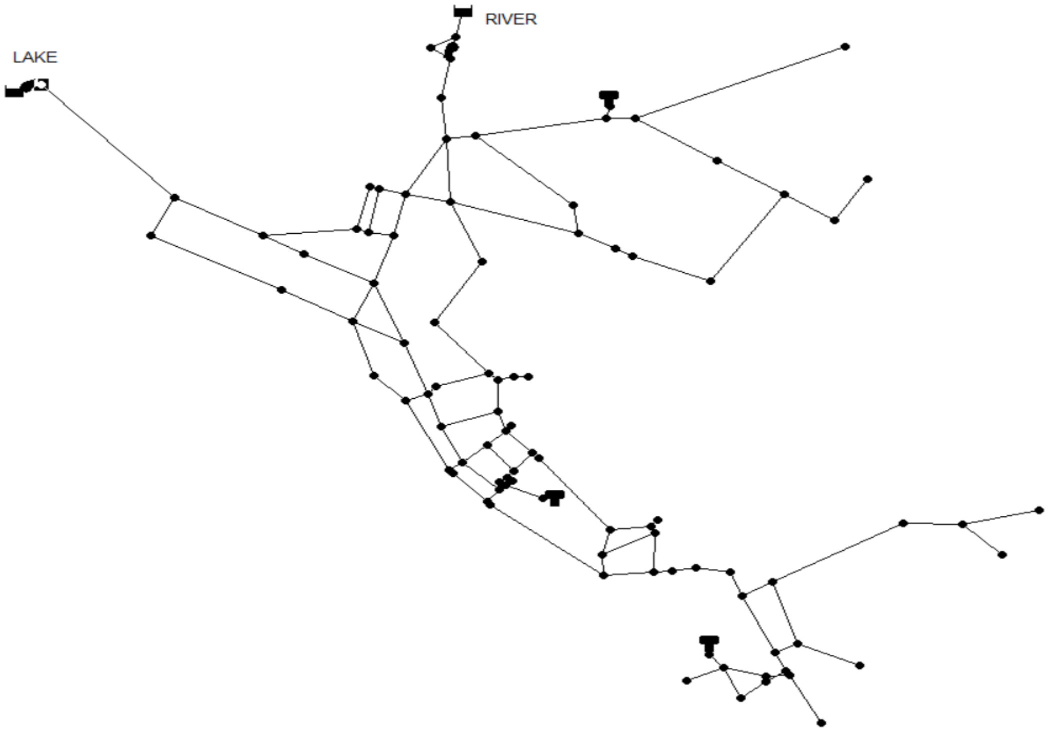

Fig. 2: Schematic of DS-1

Fig. 3: Schematic of DS-2

In order to apply the model to the two WDSs, the system-specific information has to be provided as input data in the ‘Inputs’ tab of its spreadsheet interface. The network details required for model application include:

1. Average baseline real loss (acre-feet per year).
2. Average length of mains (miles).
3. Average number of service connections.
4. Average variable production cost of water (US $ per acre-feet).
5. Average operating pressure (psi).

The average baseline real loss over 3347 miles long drinking water mains and 284399 active and inactive service connections was determined as 10171 acre-feet per year from the water audit conducted by the Department of Water Resources, State of California, the USA for the period of 2017-2020. Furthermore, the average production cost of water and the average operating pressure in the water utilities surveyed over the 2017-2020 time period was 1282 US $ per acre-feet and 95 psi.

In the absence of the audited data specifically concerning DS-1 and DS-2, two methods were selected to calculate the baseline real loss values of the two WDSs. The two methods applied are listed below.

Method 1

In this method, the water audit data by the Department of Water Resources, State of California, the USA, for the period of 2017-2020 is applied to determine the average baseline real loss.

Average baseline real loss for the WDS (acre-feet per year) = [10171 (acre-feet per year)/284399] x Number of service connections of WDS.

Method 2

Fifteen percent of the average water demand met by the service connections is approximated as the leakage to determine the real baseline loss from the WDS.

Average baseline real loss for the WDS (acre-feet per year) = 0.15 x Average water demand met by the service connections (gpm) x 60 (min/h) x 24 (h/day) x 365 (day/year)/325851 (acre-feet/gallons).

The model application of DS-1 and DS-2 using the average baseline real loss calculated by the Methods 1 and 2 are denoted as Case 1 and Case 2, respectively. The network - specific input data used for the model application of the two WDSs are given in Table 1.

Table 1: Values of the network-specific input parameters selected for applying the model to DS-1 and DS-2

Input parameter		**Value**	
		DS-1	**DS-2**
Average baseline real loss (acre-feet per year)	Case 1	3.3	15.8
	Case 2	33.5	573.9
Average length of mains (miles)		40.8	62.3
Average number of service connections		92	443
Average variable production cost of water (US $ per acre-feet)		1282	
Average operating pressure (psi)		57	46

The average operating pressure values of DS-1 and DS-2 were determined by performing 24 h hydraulic simulation of the two systems using EPANET 2.0. In the absence of the available data about the production cost of water, the value US $ 1282 per acre-feet determined by the water audit by the Department of Water Resources, State of California, the USA for the period of 2017-2020 was utilized.

Table 1 demarcates the differences between the two WDSs considered for the model application. DS-1 is constituted mainly by longer distribution mains, while DS-2 consists mainly of shorter laterals and service lines. The present model uses the value corresponding to the ratio between the average number of service connections and the average length of mains in miles to identify the relative significance of the pipes and the service connections contributing to leakage losses. By default, the model approximates 32 as the standard value and identifies distribution mains as the critical source of leakage if the ratio falls lower than 32. If vice versa, the service connections are identified as the critical leaking components of the WDS. For DS-1 and DS-2, the ratio between the average number of service connections and the average length of mains in miles were obtained as 2.2 and 7.1, respectively. Consequently, the model selected distribution mains as the critical component contributing to leakage in both systems.

Apart from the network-specific input parameters, the model developers' default values were selected for the other input parameters. These values are given in Table 2.

Table 2: Default values of the input parameters selected for applying the model to DS-1 and DS-2

Parameter*	Value
Rate of rise of (gallons per connection per day per year)	4
Infrastructure Condition Factor	1.0
Average duration between reporting of and repair of reported leaks on distribution mains (days)	3.0
Number of reported leaks per year on mains (leaks per mile per year)	0.20
Average flow rate for reported leaks on mains (GPM per leak)	50.0
Average duration between reporting of and repair of reported leaks on service connections (days)	8.0
Number of reported leaks per year on service connections (leaks per mile per year)	2.3
Average flow rate for reported leaks on service connections (gpm per leak)	7.0
Unit average cost of leak detection surveying per mile (US $ per mile)	595
Efficiency of leak detection equipment (%)	70
Average unit leak repair costs for mains (US $ per leak)	5946
Average unit cost of leak repair costs for laterals and service lines (US $ per leak)	2330
Marginal avoided cost of water (US $ per acre-feet)	1093
Real discount rate (%)	3.5
Average annual rise in price of water (%)	5.9
Effective timeline for lifecycle benefit-cost analysis (years)	30

* The average leak detection survey frequency is selected based on the following default survey frequencies: 6000 miles and above - 130 miles per month; 4000 miles and above - 114 miles per month; 1000 miles and above: Once in three years; 500 miles and above: Once in 2.5 years; Below 500 miles: Once every 2 years.

The model outputs corresponding to DS-1 and DS-2 are given in Table 3. The results corroborate the effects of network characteristics and the initial values of the average baseline real losses considered in determining the model predictions. For DS-1, under Case 1, the anticipated actions towards leakage reductions were found inadequate to possibly decrease the water losses in the distribution pipes (Table 3). On the other hand, for the same system, under Case 2, the possible reduction in water losses from the year 2022 to 2028 was predicted as 11 acre-feet per year from 33.5 acre-feet per year (67%).

Interestingly, the benefit-cost ratio over the 30-year time horizon under Case 1 for DS-1 was found irrelevant. This could be attributed to the negligible effect of the possible interventions on water loss reduction. For Case 1 considered, the total water loss occurring per month in DS-1 with the intervention was predicted to be lower than the water loss occurring without intervention. This could be attributed to the fact that the average baseline real loss considered under Case 2 for DS-1 (3.3 acre-feet per year) is lower than the sum of the total background leakage (TBL) (7.3 acre-feet per year) and annual reported leakage (3.7 acre-feet per year) conditions considered (Tables 1 and 2). It may be noted that such a condition is practically non-existing. Due to this reason, it would be impossible to propose additional interventions for active leak detection and repair (Table 3). Therefore, the proposed interventions happened to induce only a negative impact on increasing the value of water loss reduced for each month. As a result, the model predicted no net benefit for additional interventions towards active leak detection and repair by the supplier, and DS-1 was established as best performing under the current conditions considered.

Table 3: Model outputs corresponding to DS-1 and DS-2 corresponding to input conditions specified in Tables 1 and 2

Performance Indicator	DS-1		DS-2	
	Case 1	Case 2	Case 1	Case 2
Estimated real loss for distribution system for 2022 (acre-feet per year)	3.3	33.5	15.8	573.9
Estimated real loss for distribution system for 2028 (acre-feet per year)	3.3	11	15.8	15
Water loss volumetric performance standard for 2028 (gallons per mile per day)	72	248	227	220
Average annual leakage reduced with active leak detection and repair (acre-feet per year)	N/A	21	1	539
Benefit-Cost Ratio over 30 years	N/A	4.3	0.1	71.0
Benefit-Cost Ratio over 20 years	N/A	3.7	0	61.0
Benefit-Cost Ratio over 10 years	N/A	2.9	0	47.8
Benefit-Cost Ratio over 2022-27	N/A	2.4	0	39.6

N/A – Not applicable

An entirely different picture appeared when Case 2 was considered for DS-1. The model predicted the benefit-cost ratio over 30 years for possible interventions towards active leak detection and repair as 4.3. This value specified that the anticipated actions towards leakage reduction would increase the value of water loss reduced for each month. The results demonstrated that the duration required for the benefits in terms of the water's price saved to appear after implementing active leak detection and repair strategies was 11 months.

For DS-2, contrasting results compared to DS-1 were obtained. It may be noted that the average baseline real losses in DS-2 considered under Case 2 was 36 times higher than that under Case 1. Under Cases 1 and 2 for DS-2, the water loss reduction from 2022 to 2028 was predicted by the model, as 0% and 97%, respectively (Table 3). Interestingly, the active leak detection and repair strategies were found ineffective in bringing down the real losses in DS-2 under Case 1. As a result, the estimated real losses in DS-2 under Case 1 in the year 2028 was found to be the same as the current water loss amount (15.8 acre-feet per year). However, under Case 2, the anticipated actions towards leakage reduction were effective in reducing the water loss in DS-2 to 15 acre-feet per year in 2028. This could be attributed to the values of the benefit-cost ratio obtained under both the cases considered. Under Case 1, the benefit-cost ratio over 30 years was obtained as 0.1, while the same under Case 2 was found to be 71. These values specified that the relative returns in economic scale from applying active leak detection and repair strategies in DS-2 are determined by the value of the average baseline real losses.

As mentioned before, DS-1 resembles more like a transmission system with distribution mains while DS-2 signifies more as a distribution network with laterals and service connections. Hence, it would be interesting to examine the differences in the results obtained for DS-1 and DS-2 under the two cases considered. Under Case 1, the possible interventions towards leakage reduction were predicted uneconomical by the model for both DS-1 and DS-2. The DS-1 and DS-2 were established as best performing in terms of water loss under the average baseline real loss values considered under Case 1. However, under Case 2, the model demonstrated the positive effects of implementing active leak detection and repair strategies in both DS-1 and DS-2. These results prove that the model assumes a benchmark leakage level for every WDS, based on the network characteristics and other model parameter values, below which the additional interventions towards active leak detection and repair become uneconomical.

The results reported in Table 3 also revealed the effects of the network characteristics in determining the model predictions. Under Case 2, the model predicted a leakage reduction to the magnitude of 67% and 97% in DS-1 and DS-2, respectively. In this context, it is worth noticing that the average baseline losses in DS-1 was 33.5 acre-feet per year and the same in DS-2 was 573.9 acre-feet per year. Even though the leakage losses in DS-2 was 17 times higher than that in DS-1, the active leak detection and repair strategies have shown more promising outcomes in DS-2 compared to that in DS-1. This could be attributed to the more significant number of service connections and the lower average operating pressure in DS-2 relative to DS-1.

Based on the results obtained from the analysis conducted on DS-1 and DS-2, the following conclusions can be drawn regarding the performance of the model:

The model applies several empirical models to determine the background leakage, reported leakage in the mains and the service connections, and the unreported leakage in the WDSs based on the network-specific data. After determining the three leakage components, the active detection and repair strategies applied in the water utilities are modeled based on leak detection survey frequency, the natural rise in leakage, and the leak detection and repair costs. The model divides the water lost during regular leak detection and surveying into three elements for ease of calculation: (1) water lost due to backlog of unreported leakage, (2) water lost due to natural rise in leakage for the never surveyed parts of the system, and (3) water lost due to natural rise in leakage for the rest of the parts of the system not being surveyed.

Empirical relationships are then applied to represent water loss occurring in one part, after which the water loss is summed up to represent the entire system. Later, the model conducts a cost-benefit analysis to evaluate cost-effectiveness between reducing the real loss and maintaining the real current loss. The benefits associated with real loss reduction depending on the rise of price water, discount rate, and the volume of real loss reduced are utilized to determine the economically possible volumetric water loss in the system.

Due to the models' empirical nature, it could be stated that the current model does not reflect the actual system physics. Still, it may be argued that the approaches used and the assumptions adopted are rationally sound. Thus, it is concluded that the present modeling approach could prove useful for determining the cost-effectiveness of active leak detection and repair strategies in real-world WDSs.

Another interesting aspect worth mentioning is that the present model does not use a hydraulic simulation engine's assistance. The model attempts to identify WDS's characteristics from the user's network - specific input data (Table 1). **This makes the model more user-friendly and facilitates the users without expert knowledge in WDS modeling to apply the model and derive its outputs.**

The current model uses the MS Excel spreadsheet interface to provide inputs, display the calculations, and exhibit the results. This makes the model very user-friendly in terms of input and very easy to make modifications.

As already mentioned, the model does not utilize the data of the hydraulic analysis of WDSs. This may sound reasonable from an abstract sense and has enhanced the user - friendliness of the model also. However, from a practical sense, **the model may prove disadvantageous in terms of system characterization. The system's characterization is the most critical step in determining reported and unreported leakages in real-world problems. The present model identifies and categorizes the system based on the average length of pipes and the average demand locations. Hence, the model does not physically distinguish between the mains and laterals. Besides, WDS's vital physical attributes, such as its configuration, topography, pipe sizes, and pipe materials, are not at all addressed in this process.**

The rest of the report includes revisions of specific requests.

Specific assessment
Below is my specific revision of assumptions/findings/conclusions of subjects: 1, 2, 3, 4, 7, 8, 10, 11, 12a, and 12d.

Assumption 1
*The assumed default infrastructure condition factor value.*The model uses a default value of 1.0. This is used to calculate the minimum amount of background leakage in a system.

Review of assumption 1

The existing structural and hydraulic integrity of the distribution system is incorporated in the model, for leakage estimation, by utilizing a parameter entitled as the infrastructure condition factor (ICF). The ICF is established as the ratio between the actual level (volume) of background leakage in a zone or district metered area and the calculated unavoidable background leakage (UBL) volume of a well-maintained system. By this way, the ICF parameter directly distinguishes the avoidable background leakage with the unavoidable fraction. The UBL is the summation of tiny weeps and seeps at pipe and customer service connection piping joints that are acoustically undetectable. This parameter multiplied by the ICF gives the TBL value, which represents a portion of the potentially recoverable leakage. The TBL is significant towards setting the leakage management strategy, and hence, the right selection of ICF becomes vital in assessing the system background leakage.

The model used a default ICF value of 1.0 based on the presumption that the actual level of background leakage in the system is the same as the unavoidable leakage value. However, this assumption turns out to be questionable for vast majority of systems worldwide. The TBL value would fall greater than the UBL value, and due to this reason, their ratio i.e., ICF would be greater than 1.0. In this regard, a sensitivity analysis to understand the importance of ICF in determining the model outputs becomes significant. This is performed below for DS-1 and DS-2.

The sensitivity of the model outputs to the ICF value was determined by applying the model to DS-1 and DS-2 under Cases 1 and 2 (Table 1) and by varying the value of ICF as 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, and 5.0. All other parameters (except ICF) were kept at their base values during the analysis. The variations of the annual reported leakage, annual unreported leakage, and total background leakage with ICF for DS-1 and DS-2 under the two cases considered are shown in Fig. 4. The effects of the ICF value in determining the model estimation of the real loss in the WDS in the year 2028 is given in Fig. 5. The model predicted benefit-cost ratio values over 30-year, 20-year, 10-year, and for the period from 2022-2027 for the two systems considered, are reported in Table 4.

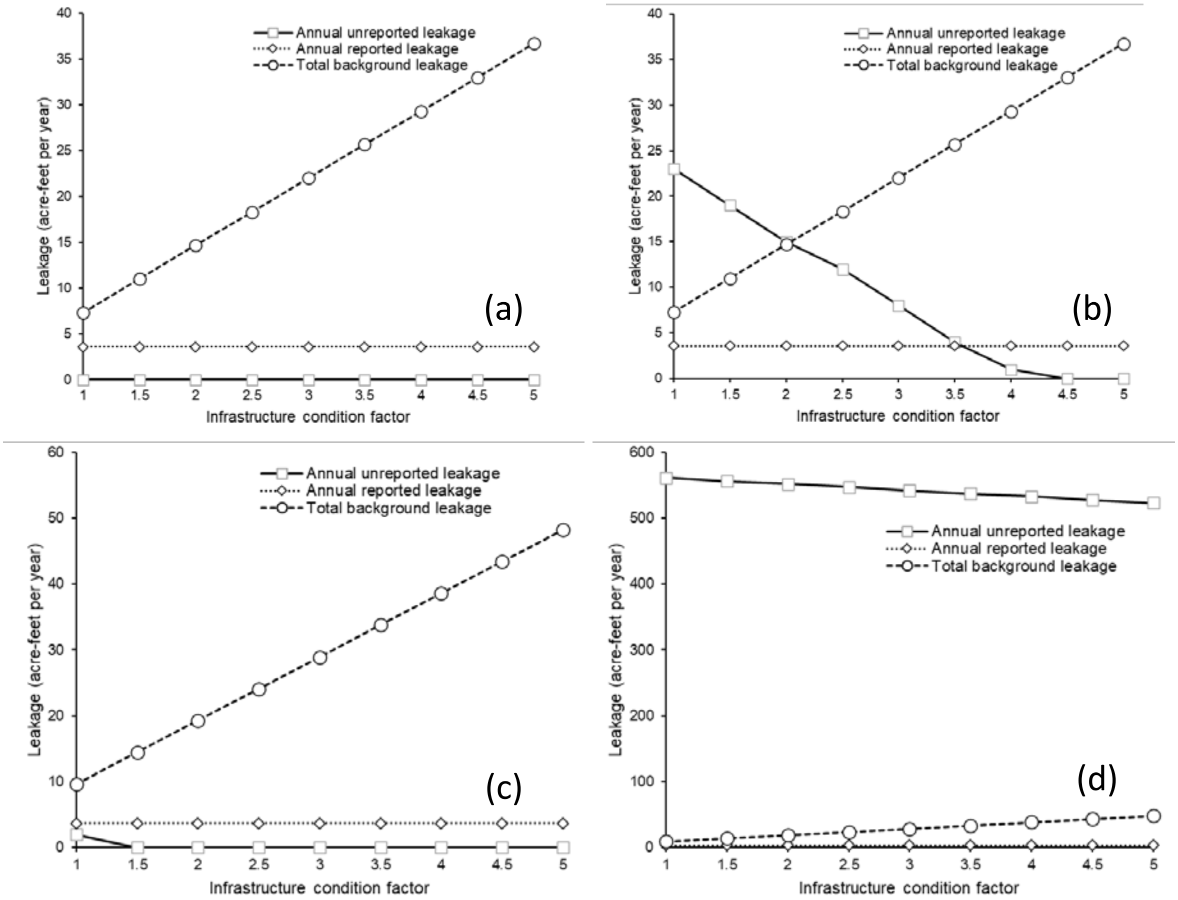

Fig. 4: Variations of the annual reported leakage, annual unreported leakage, and total background leakage with ICF for (a) DS-1 under Case 1, (b) DS-1 under Case 2, (c) DS-2 under Case 1, and (d) DS-2 under Case 2

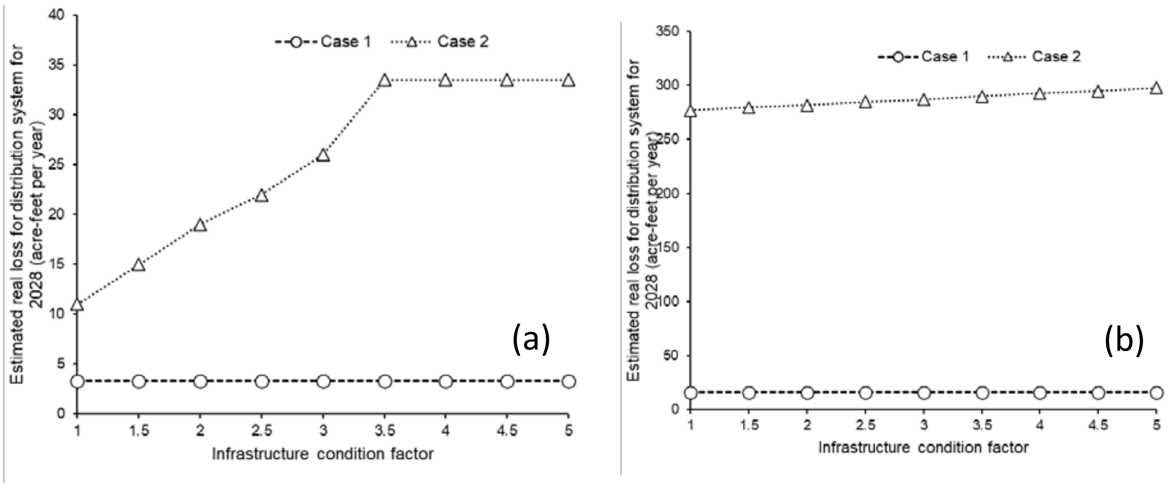

Fig. 5: Variations of the model estimated real loss in the WDS for the year 2028 with ICF for (a) DS-1 and (b) DS-2

Table 4: Influence of infrastructure condition factor in determining the model predicted benefit-cost ratio of the active leak detection and repair strategies

ICF	Benefit-cost ratio over 30 years				Benefit-cost ratio over 20 years				Benefit-cost ratio over 10 years				Benefit-cost ratio over 2022-27			
	DS-1		DS-2		DS-1		DS-2		DS-1		DS-2		DS-1		DS-2	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
1.0	N/A	4.3	0.1	294.2	N/A	3.7	0	229.0	N/A	2.9	0	119.8	N/A	2.4	0	65.0
1.5	N/A	3.6	N/A	291.7	N/A	3.1	N/A	227.1	N/A	2.4	N/A	118.8	N/A	2.0	N/A	64.5
2.0	N/A	2.9	N/A	289.1	N/A	2.5	N/A	225.1	N/A	1.9	N/A	117.7	N/A	1.5	N/A	63.9
2.5	N/A	2.1	N/A	286.6	N/A	1.8	N/A	223.1	N/A	1.4	N/A	116.7	N/A	1.2	N/A	63.3
3.0	N/A	1.4	N/A	284.1	N/A	1.2	N/A	221.2	N/A	1.0	N/A	115.7	N/A	0.8	N/A	62.8
3.5	N/A	0.7	N/A	281.6	N/A	0.6	N/A	219.2	N/A	0.5	N/A	114.6	N/A	0.4	N/A	62.2
4.0	N/A	0	N/A	279.0	N/A	0	N/A	217.2	N/A	0	N/A	113.6	N/A	0	N/A	61.7
4.5	N/A	N/A	N/A	276.5	N/A	N/A	N/A	215.3	N/A	N/A	N/A	112.6	N/A	N/A	N/A	61.1
5.0	N/A	N/A	N/A	274.0	N/A	N/A	N/A	213.3	N/A	N/A	N/A	111.5	N/A	N/A	N/A	60.5

N/A – Not applicable

The model uses empirical equations, given as Eq. (1) and Eq. (2), to determine the total background leakage (acre-feet per year) and annual reported leakage and a mass-balance equation, given as Eq. (3), to determine the annual unreported leakage (acre-feet per year) in the system.

$$\text{UBL} = [0.2 \times \mathrm{L_m} + 0.008 \times \mathrm{N_c}] \times (\mathrm{Pav}/70)^{1.5} \times (1000/325851) \times 365 \qquad (1a)$$

$$\text{TBL} = \text{UBL x ICF} \qquad (1b)$$

Where:
$\mathrm{L_m}$ = Total length of mains (miles)
$\mathrm{N_c}$ = Total number of connections
Pav = Average operational pressure (psi)

Annual reported leakage = Reported leakage from mains + Reported leakage from service connections (2a)

Reported leakage from mains = Average flow rate for reported leaks × Number of reported leaks per year × $\mathrm{L_m}$ x Average duration between reporting of and repair of reported leaks x [60 (min/h) × 24 (h/day)/325851 (acre-feet/gallons)] (2b)

Reported leakage from service connections = Average flow rate for reported leaks × Number of reported leaks per year × $\mathrm{N_c}$ x Average duration between reporting of and repair of reported leaks x [60 (min/h) × 24 (h/day)/325851 (acre-feet/gallons)] (2c)

Annual unreported leakage = Average baseline real loss – Annual reported leakage – TBL (3)

The results (Fig. 4) revealed the direct correlation between the ICF and the TBL. This is expected as the empirical equation (Eq. 1) establishes TBL as the product of UBL and ICF. It may be noted that the TBL is a system characteristic, and the only parameter that determines its value is ICF. However, the reported leakage from the mains and the service connections were found to be determined by three parameters:

- average flow rate for reported leaks
- number of reported leaks per year, and
- the average duration between reporting of and repair of reported leaks

However, for this present analysis, these three parameters were kept constant, and hence, the annual reported leakage was constant for all the cases considered (Fig. 4). In the absence of the data pertaining to annual unreported leakage, the model employs Eq. (3) to determine the difference between the annual baseline real loss and the sum of the annual reported leakage and TBL. It may be noted that the reported annual leakage cannot become zero, and hence, the model assumes a zero value if the sum of annual reported leakage and the TBL exceeds the average baseline real loss. Thus, it may be stated that the ICF value that causes the sum of the annual reported leakage and TBL to exceed the average baseline real loss is practically non-existing. In this regard, Eq. (4) may be formulated to determine the maximum ICF value that can be selected for a system if the average baseline real loss in the system is known in advance.

$$\text{ICFmax} = (\text{Average baseline real loss} - \text{Annual reported leakage}) / \text{UBL} \qquad (4)$$

By applying Eq. (4), the maximum permissible ICF value for DS-1 under Cases 1 and 2 were determined as -0.04 and 4.1, respectively. The similar values for DS-2 were estimated as 1.3 and 59.4, respectively. The negative value of ICF max under Case 1 for DS-1 indicated that the condition corresponding to average baseline real loss as 3.3 acre-feet per year is practically non-existing under the input conditions considered (Tables 1 and 2). Due to this reason, it would be impossible to propose additional interventions for active leak detection and repair (Table 3). Apparently, this appears to be a significant limitation. Even though the existence of water loss equivalent to 3.3 acre-feet per year is physically impossible for DS-1 (based on the input conditions considered), the model estimated the real loss for the system to 3.3 acre-feet per year for the year 2028.

On the other hand, the ICF max value corresponding to Case 2 for DS-1 was obtained as 4.1. Subsequently, for ICF values beyond 4.1, a zero value was predicted by the model for the annual unreported leakage (Fig. 4b). Similar trends can be observed for DS-2 (Figs. 4c and 4d). It is interesting to notice the direct relationship between the annual unreported leakage and the benefit-cost ratio of the active leak detection and repair strategies. The possible interventions towards leakage control were found to be uneconomical for all the cases, with annual reported leakage being zero (Figs. 4-5 and Table 4).

Assumption 2

Calculation of minimum amount of reported and unreported leakage. The model uses the AWWA M36 manual to estimate the minimum amount of reported and background leakage that could occur in a system. This is subject to supplier inputs as they get improved data.

Review of assumption 2

The equations used in the model to estimate the amount of reported and background leakage that occur in a system were shown as Eq. (1) and (2) above. The only parameter that directly determines the TBL in the system was found to be the ICF. The sensitivity of the model outputs to the ICF has been explained above. To understand the impacts of the input parameters, such as average flow rate for reported leaks, number of reported leaks per year, and the average duration between reporting of and repair of reported leaks on to the model outputs, sensitivity analysis was performed by varying these parameters one by one. The input parameters considered for performing the sensitivity analysis are given in Table 5.

The variations of the annual reported leakage, annual unreported leakage, and total background leakage for DS-1 and DS-2 under the two cases considered (Table 5) are shown in Figs. 6-11. The model predicted benefit-cost ratio values over 30-year, 20-year, 10-year, and for the period from 2022-2027 for the two systems considered are reported in Table 6.

Table 5: Parameter values considered for performing the sensitivity analysis to determine the effects of input parameters on the annual reported leakage from mains and service connections

Average duration between reporting of and repair of reported leaks in the distribution mains (days)	Number of reported leaks per year in the distribution mains (per mile per year)	Average flow rate for reported leaks in the distribution mains (gpm per leak)	Average duration between reporting of and repair of reported leaks in the service connections (days)	Number of reported leaks per year in the service connections (per mile per year)	Average flow rate for reported leaks in the service connections (gpm per leak)
0.5	0.05	25	4	1.15	3.5
1	0.1	50	8	2.3	7
2	0.2	75	16	3.45	10.5
3	0.3	-	20	4.6	14
4	0.4	-	-	6.9	-
5	-	-	-	-	-
6	-	-	-	-	-

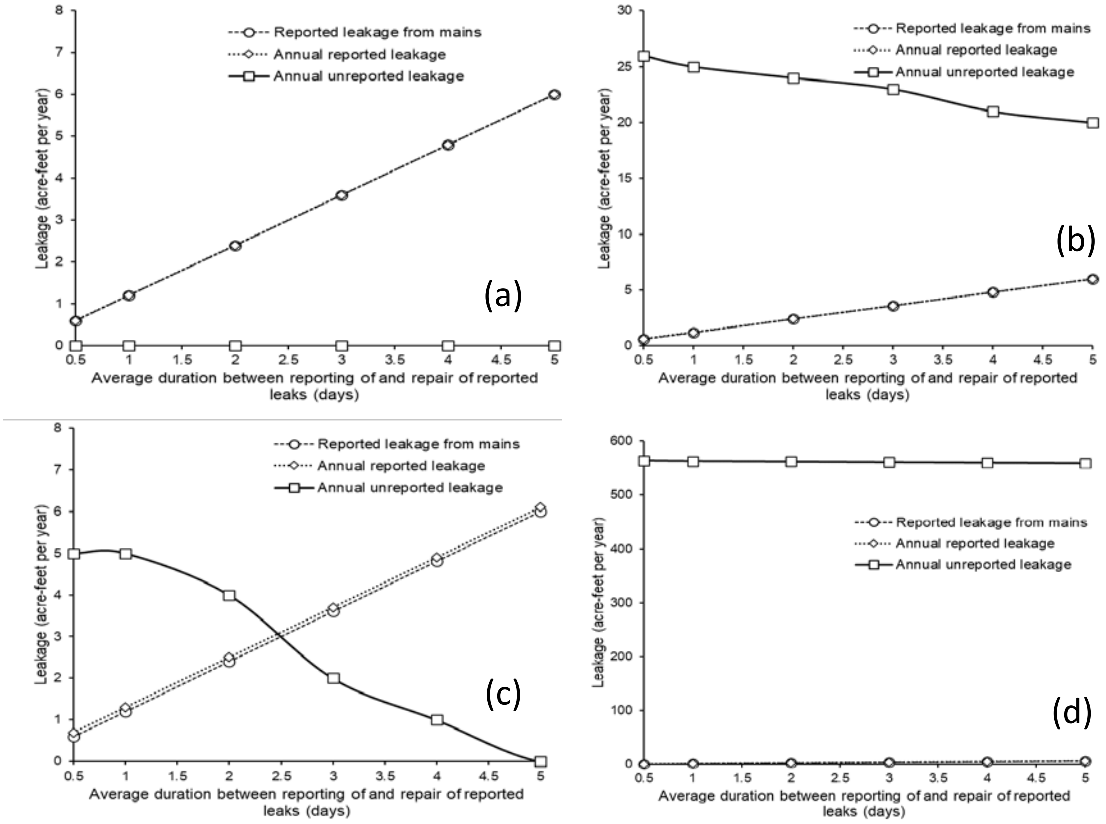

Fig. 6: Variations of the leakage with average duration between reporting of and repair of reported leaks in distribution mains for (a) DS-1 under Case 1, (b) DS-1 under Case 2, (c) DS-2 under Case 1, and (d) DS-2 under Case 2

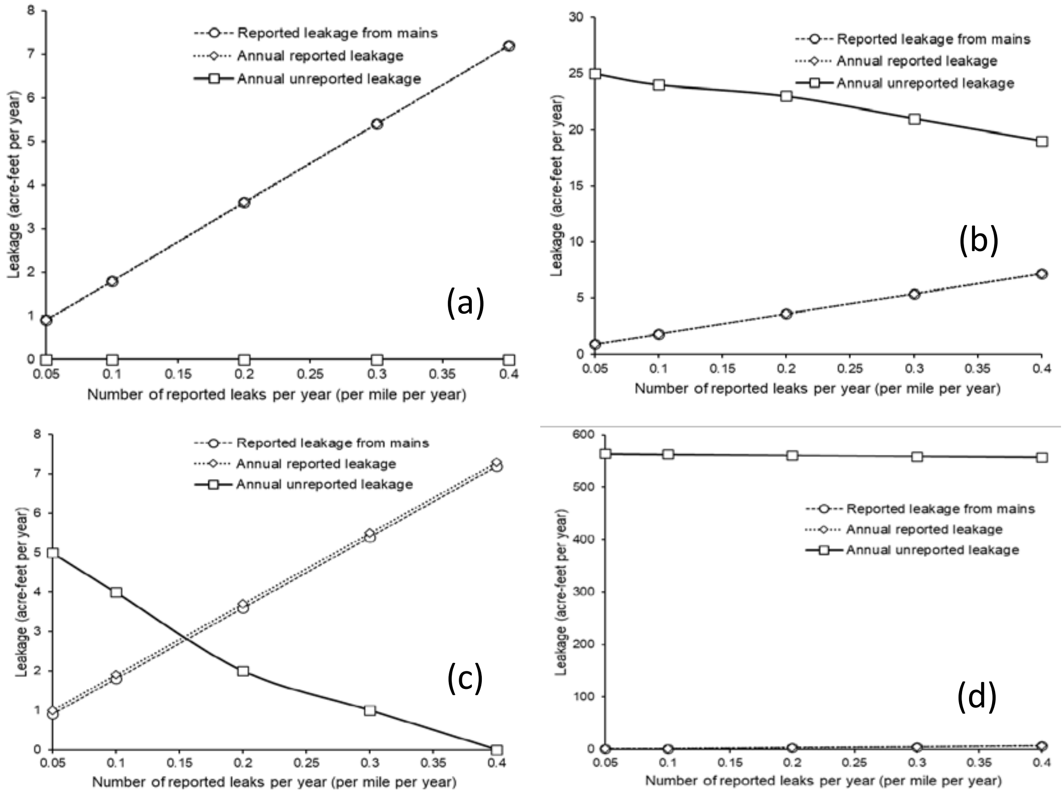

Fig. 7: Variations of the leakage with number of reported leaks per year in distribution mains for (a) DS-1 under Case 1, (b) DS-1 under Case 2, (c) DS-2 under Case 1, and (d) DS-2 under Case 2

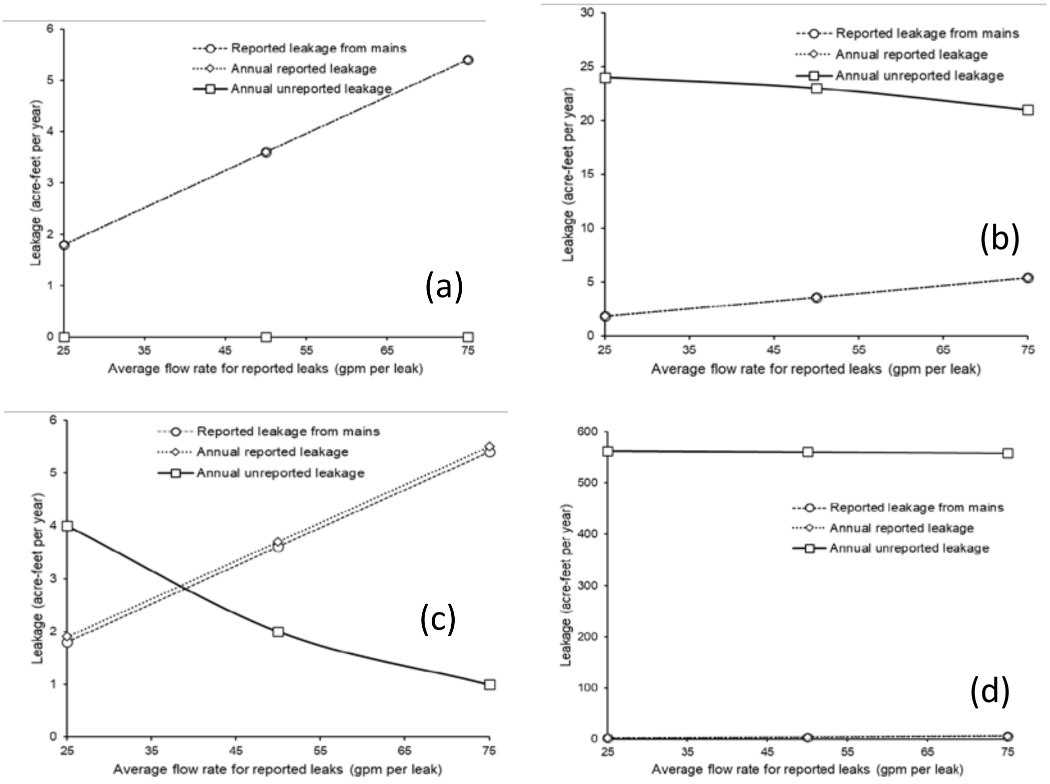

Fig. 8: Variations of the leakage with average flow rate for reported leaks in distribution mains for (a) DS-1 under Case 1, (b) DS-1 under Case 2, (c) DS-2 under Case 1, and (d) DS-2 under Case 2

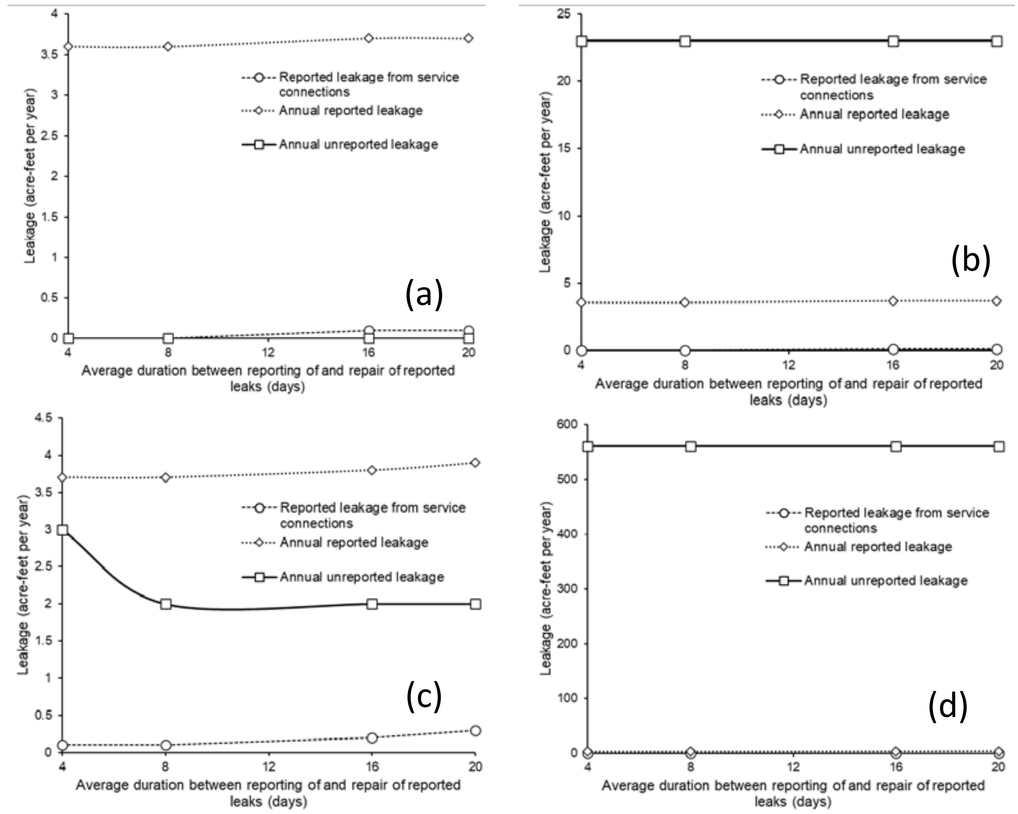

Fig. 9: Variations of the leakage with average duration between reporting of and repair of reported leaks in service connections for (a) DS-1 under Case 1, (b) DS-1 under Case 2, (c) DS-2 under Case 1, and (d) DS-2 under Case 2

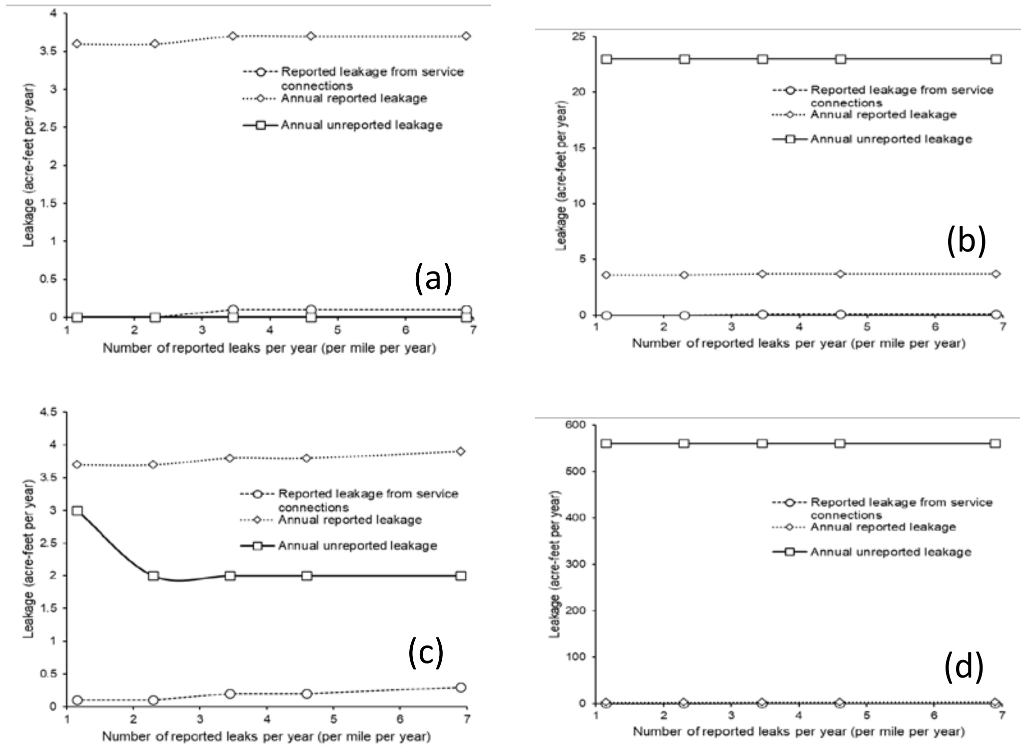

Fig. 10: Variations of the leakage with number of reported leaks per year in service connections for (a) DS-1 under Case 1, (b) DS-1 under Case 2, (c) DS-2 under Case 1, and (d) DS-2 under Case 2

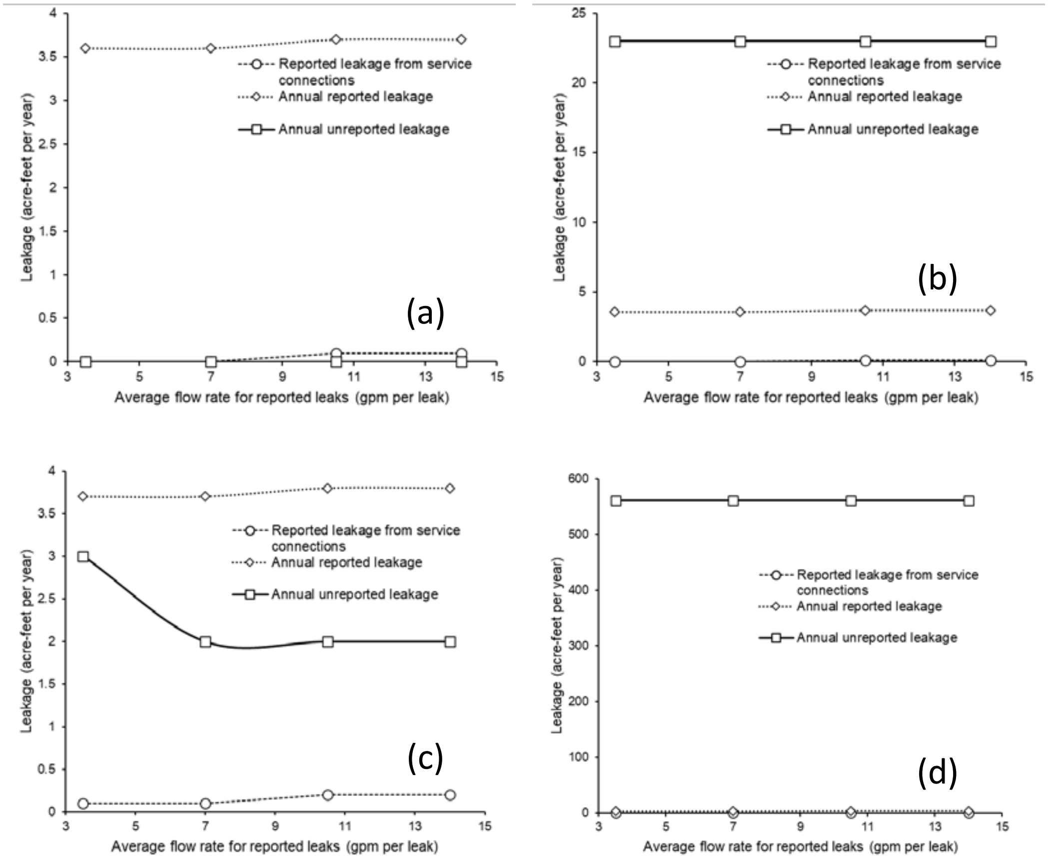

Fig. 11: Variations of the leakage with average flow rate for reported leaks in service connections for (a) DS-1 under Case 1, (b) DS-1 under Case 2, (c) DS-2 under Case 1, and (d) DS-2 under Case 2

The results depicted in Figs. 6-11 establishes the direct correlation between the values of the parameters such as average flow rate for reported leaks, number of reported leaks per year, and the average duration between reporting of and repair of reported leaks on the model estimated annual reported leakage from the mains and service connections. The impacts of the parameters mentioned above on the reported leakage from the mains were more significant than those on the reported leakage from the service connections. This could be attributed to the physical characteristics of the two systems considered and the parameter values considered for the analysis. The ratio between the average number of service connections and the average length of mains in miles were obtained as 2.25 and 7.11 for DS-1 and DS-2, respectively. Hence, as expected, the parameters concerning the leakage estimation from service connections greatly impacted the outputs on DS-2 rather than on DS-1. The variation in the reported annual leakage observed in Figs. 6-11 is attributed mainly to the mass balance approach considered for determining unreported leakage losses in the model. It may be noted that the parameters considered for the analysis (Table 4) do not directly influence TBL estimation. Therefore, for a fixed average baseline real loss (Cases 1 and 2), the immediate increase in the annual reported leakage from the mains and service connections was observed to affect the annual unreported leakage prediction directly.

Table 6: Influence of average flow rate for reported leaks, number of reported leaks per year, and the average duration between reporting of and repair of reported leaks in determining the model predicted benefit-cost ratio of the active leak detection and repair strategies

Average duration between reporting of and repair of reported leaks in distribution mains (days)	Benefit-cost ratio over 30 years				Benefit-cost ratio over 20 years				Benefit-cost ratio over 10 years				Benefit-cost ratio over 2022-27			
	DS-1		DS-2		DS-1		DS-2		DS-1		DS-2		DS-1		DS-2	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
0.5	N/A	4.9	0.4	295.7	N/A	4.2	0.3	230.2	N/A	3.3	0.3	120.4	N/A	2.7	0.2	65.4
1	N/A	4.7	0.3	295.4	N/A	4.1	0.3	230.0	N/A	3.2	0.2	120.3	N/A	2.7	0.2	65.3
2	N/A	4.5	0.2	294.8	N/A	3.9	0.2	229.5	N/A	3.0	0.1	120.1	N/A	2.5	0.1	65.2
3	N/A	4.3	0.1	294.2	N/A	3.7	0	229.0	N/A	2.9	0	119.8	N/A	2.4	0	65.0
4	N/A	4.1	N/A	293.6	N/A	3.5	N/A	228.5	N/A	2.7	N/A	119.5	N/A	2.3	N/A	64.9
5	N/A	3.8	N/A	292.9	N/A	3.3	N/A	228.0	N/A	2.6	N/A	119.3	N/A	2.1	N/A	64.8
6	N/A	3.6	N/A	292.3	N/A	3.1	N/A	227.6	N/A	2.4	N/A	119.0	N/A	2.0	N/A	64.6

Number of reported leaks per year in distribution mains (per mile per year)	Benefit-cost ratio over 30 years				Benefit-cost ratio over 20 years				Benefit-cost ratio over 10 years				Benefit-cost ratio over 2022-27			
	DS-1		DS-2		DS-1		DS-2		DS-1		DS-2		DS-1		DS-2	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
0.05	N/A	4.8	0.4	295.6	N/A	4.1	0.3	230.1	N/A	3.2	0.3	120.4	N/A	2.7	0.2	65.3
0.1	N/A	4.6	0.3	295.1	N/A	4.0	0.2	229.7	N/A	3.1	0.2	120.2	N/A	2.6	0.1	65.2
0.2	N/A	4.3	0.1	294.2	N/A	3.7	0	229.0	N/A	2.9	0	119.8	N/A	2.4	0	65
0.3	N/A	3.9	N/A	293.2	N/A	3.4	N/A	228.3	N/A	2.7	N/A	119.4	N/A	2.2	N/A	64.8
0.4	N/A	3.6	N/A	292.3	N/A	3.1	N/A	227.6	N/A	2.4	N/A	119	N/A	2.0	N/A	64.6

Table 6 (contd.): Influence of average flow rate for reported leaks, number of reported leaks per year, and the average duration between reporting of and repair of reported leaks in determining the model predicted benefit-cost ratio of the active leak detection and repair strategies

Average flow rate for reported leaks in distribution mains (gpm per leak)	Benefit-cost ratio over 30 years				Benefit-cost ratio over 20 years				Benefit-cost ratio over 10 years				Benefit-cost ratio over 2022-27			
	DS-1		DS-2		DS-1		DS-2		DS-1		DS-2		DS-1		DS-2	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
25	N/A	4.6	0.3	295.1	N/A	4.0	0.2	229.7	N/A	3.1	0.2	120.2	N/A	2.6	0.1	65.2
50	N/A	4.3	0.1	294.2	N/A	3.7	0	229.0	N/A	2.9	0	119.8	N/A	2.4	0	65.0
75	N/A	3.9	N/A	293.2	N/A	3.4	N/A	228.3	N/A	2.7	N/A	119.4	N/A	2.2	N/A	64.8

Average duration between reporting of and repair of reported leaks in service connections (days)	Benefit-cost ratio over 30 years				Benefit-cost ratio over 20 years				Benefit-cost ratio over 10 years				Benefit-cost ratio over 2022-27			
	DS-1		DS-2		DS-1		DS-2		DS-1		DS-2		DS-1		DS-2	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
4	N/A	4.3	0.1	294.2	N/A	3.7	0.1	229.0	N/A	2.9	0	119.8	N/A	2.4	0	65.0
8	N/A	4.3	0.1	294.2	N/A	3.7	0	229.0	N/A	2.9	0	119.8	N/A	2.4	0	65.0
16	N/A	4.3	0	294.1	N/A	3.7	0	229.0	N/A	2.9	0	119.8	N/A	2.4	0	65.0
20	N/A	4.3	0	294.1	N/A	3.7	0	228.9	N/A	2.9	0	119.8	N/A	2.4	0	65.0

Table 6 (contd.): Influence of average flow rate for reported leaks, number of reported leaks per year, and the average duration between reporting of and repair of reported leaks in determining the model predicted benefit-cost ratio of the active leak detection and repair strategies

Number of reported leaks per year in service connections (per 1000 connections per year)	Benefit-cost ratio over 30 years				Benefit-cost ratio over 20 years				Benefit-cost ratio over 10 years				Benefit-cost ratio over 2022-27			
	DS-1		DS-2		DS-1		DS-2		DS-1		DS-2		DS-1		DS-2	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
1.15	N/A	4.3	0.1	294.2	N/A	3.7	0.1	229.0	N/A	2.9	0	119.8	N/A	2.4	0	65.0
2.3	N/A	4.3	0.1	294.2	N/A	3.7	0	229.0	N/A	2.9	0	119.8	N/A	2.4	0	65.0
3.45	N/A	4.3	0	294.2	N/A	3.7	0	229.0	N/A	2.9	0	119.8	N/A	2.4	0	65.0
4.6	N/A	4.3	0	294.1	N/A	3.7	0	229.0	N/A	2.9	0	119.8	N/A	2.4	0	65.0
6.9	N/A	4.3	0	294.1	N/A	3.7	0	229.0	N/A	2.9	0	119.8	N/A	2.4	0	65.0
Average flow rate for reported leaks in service connections (gpm per leak)	Benefit-cost ratio over 30 years				Benefit-cost ratio over 20 years				Benefit-cost ratio over 10 years				Benefit-cost ratio over 2022-27			
	DS-1		DS-2		DS-1		DS-2		DS-1		DS-2		DS-1		DS-2	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
3.5	N/A	4.3	0.1	294.2	N/A	3.7	0.1	229.0	N/A	2.9	0	119.8	N/A	2.4	0	65.0
7	N/A	4.3	0.1	294.2	N/A	3.7	0	229.0	N/A	2.9	0	119.8	N/A	2.4	0	65.0
10.5	N/A	4.3	0	294.2	N/A	3.7	0	229.0	N/A	2.9	0	119.8	N/A	2.4	0	65.0
14	N/A	4.3	0	294.1	N/A	3.7	0	229.0	N/A	2.9	0	119.8	N/A	2.4	0	65.0

N/A – Not applicable

Due to the direct relationship between the annual unreported leakage and the economic advantages of the active leak detection and repair strategies, **the parameters corresponding to the reported leakage from mains and service connections were found to have direct impacts on the benefit-cost ratio of the possible interventions concerning leakage control (Table 6). All in all assumption 2 was found to be sound and reasonable.**

Assumption 3
Average leak detection survey frequency. The model assumes that a range of two to three years per different system sizes.

Review of assumption 3
In real-world WDSs, the most appropriate leak detection survey frequency is fixed based on communications with vendors and water suppliers to maintain the leakage within the economic leakage level. The entire system is divided into several parts, based on the value of the leak detection survey frequency, and the divided parts are then surveyed serially. The number of parts to which the system is divided and surveyed directly influences the duration (months) required to survey the whole network and the associated cost of leak detection with intervention each month. Hence, it is logical to surmise that the leak detection frequency is an essential factor that impacts the economic aspects of leak detection and repair strategies in real-world WDSs.

The model calculates the average survey frequency based on the length of distribution mains of a WDS. The procedure adopted for selecting the leak detection survey frequency in the model is as follows:

- 6000 miles and above - 130 miles per month.
- 4000 miles and above - 114 miles per month.
- 1000 miles and above: Once in three years.
- 500 miles and above: Once in 2.5 years.
- Below 500 miles: Once every two years.

The suitability of a survey frequency depends on the particular analyzed system. Sensitivity analysis was conducted by applying the model on DS-1 and DS-2 under Cases 1 and 2 by varying the average leak detection frequency as 1, 2, 5, 10, and 20 miles per month to evaluate the effects of leak detection survey frequency on the model performance. The variations in the model outputs in terms of the estimated water loss for the year 2028 with the average leak detection frequency is depicted in Fig. 12. The model predicted benefit-cost ratio values over 30-year, 20-year, 10-year, and for the period from 2022-2027 for the two systems considered, are reported in Table 7.

The results depicted (Fig. 12) correlates the direct effects of leak detection survey frequency on the model outputs. For DS-1 under Case 1, the average bassline real loss considered (3.3 acre-feet per year) is physically non-existing. Hence, the detection survey frequency was observed to impart no effect on the model predictions. On the contrary, an inverse relationship between the leak detection frequency and the attainable leakage loss reduction was obtained for the other cases considered. Under Case 2 of DS-1, the real water loss value for the year 2028 decreased initially with average leak detection frequency (Fig. 12b). Nevertheless, as the frequency exceeded the economically acceptable range, the benefit-cost ratio corresponding to the possible interventions became less than one, and the estimated water loss for 2028 reached the current leakage level.

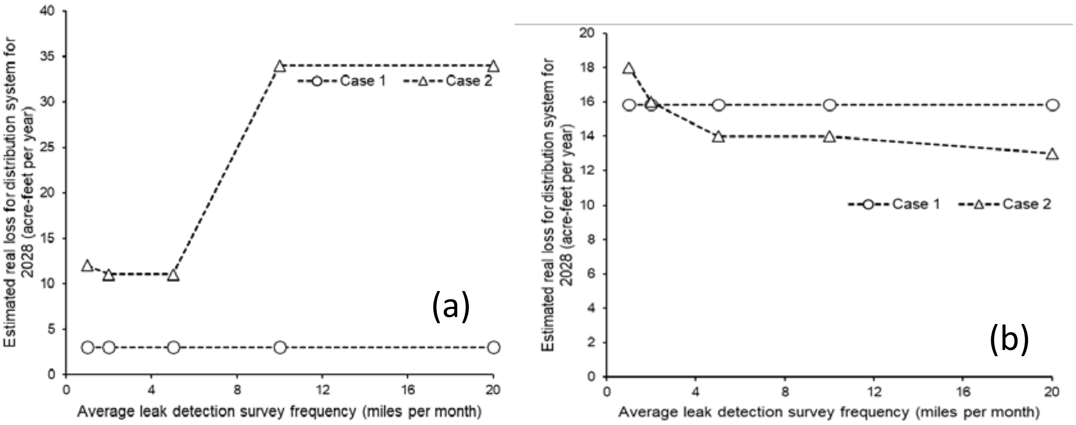

Fig. 12: Variations of the model estimated real loss in the WDS for the year 2028 with average leak detection survey frequency for (a) DS-1 and (b) DS-2

Table 7: Influence of average leak detection survey frequency in determining the model predicted benefit-cost ratio of the active leak detection and repair strategies

Input Parameter^{+}	Benefit-cost ratio over 30 years		Benefit-cost ratio over 20 years		Benefit-cost ratio over 10 years		Benefit-cost ratio over 2022-27	
	DS-1							
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
1	N/A	6.9	N/A	5.9	N/A	4.4	N/A	3.4
2	N/A	3.7	N/A	3.2	N/A	2.5	N/A	2.1
5	N/A	1.5	N/A	1.3	N/A	1.1	N/A	1.0
10	N/A	0.8	N/A	0.7	N/A	0.6	N/A	0.5
20	N/A	0.4	N/A	0.3	N/A	0.3	N/A	0.3
Input Parameter^{+}	Benefit-cost ratio over 30 years		Benefit-cost ratio over 20 years		Benefit-cost ratio over 10 years		Benefit-cost ratio over 2022-27	
	DS-2							
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
1	N/A	169.6	N/A	140.9	N/A	97.9	N/A	66.0
2	N/A	90.9	N/A	77.7	N/A	59.7	N/A	48.1
5	0.1	37.9	0.1	32.9	0.1	26.7	0.1	23.2
10	0.1	19.2	0.1	16.8	0	13.8	0	12.3
20	0	9.7	0	8.5	0	7.0	0	6.4

$^{+}$ Average leak detection survey frequency (miles per month)
N/A - Not applicable

Such an increasing trend was not observed under Case 2 for DS-2 (Fig. 12b). This showed that the leak detection frequency as high as 20 miles per month is economic under the case considered (Table 7). The survey frequency can be further increased based on communications with water suppliers for improved leakage control. **These results shed light on the fact that the economic leak detection frequency that can be adopted for a system depends on the system's network characteristics and the average baseline real losses.**

It can also be inferred from the results reported in Table 7 that the economic aspects of the active leak detection and repair strategies on a WDS are greatly affected by the frequency of the leak detection survey adopted. Under Case 2 for DS-1, increasing the average leak detection frequency value from 10 miles per month to 20 miles per month effectuated towards decreasing the 30-year benefit-cost ratio of the leakage control interventions from 13.8 to 7.0. However, the corresponding decrease in the estimated real loss for the distribution system for 2028 was only one acre-feet per year (Fig. 12b). Hence, it may be argued that a trade-off between the economic aspects of the leakage control interventions and the sustainability aspects of water loss control may be required to arrive at the system's best leak detection control frequency. Unfortunately, the sustainability aspect is missing in the model. The water loss reduction is only perceived from the angle of economics, and the environmental angle of the same is plainly ignored. **Hence, it is suggested that the required modifications concerning the environmental cost of water loss reduction may be incorporated in the future modified versions of the model.**

Assumption 4

Annual rate of natural rise of leakage. State Water Board staff assumed a default value of 4 gallons per connection per day in the model, which can be updated by urban retail water suppliers.

Review of assumption 4

During active leak detection and repair strategies, the WDS is divided into parts, based on the economic leak detection survey frequency, and each part is surveyed serially. However, each part will have its natural rate of rising of leakage, which has to be overcome; otherwise, leakage will return to previous levels undoing the benefits of the leakage reduction interventions. The natural rate of rising of unreported leakage is a measure of the infrastructure's condition and its propensity to burst. It is the amount by which leakage would rise in a year if all the active leak detection and control operations are suspended. This rate may vary widely between systems, depending on the ground and the underlying geology (European Union 2015). Thus, for efficient and effective leakage management, the natural rise in leakage must be considered as a critical parameter.

The present 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 the first survey).

- Water lost due to the natural rise in leakage for the rest of the parts of the system not being surveyed.

The water lost due to the second and the third elements are entirely influenced by the value of the natural rate of rise in the leakage adopted in the model. A low rate of rise of leakage means that the reported leakage from the mains and service connections contribute most to the leakage. Hence, active leak detection and repair strategies could be more effective in bringing down the leakages to lower limits. The natural rise in leakage impacts the cost associated with leak repair in each month with intervention, and the value of the water loss reduced each month with intervention. Thereby, it affects the benefit-cost ratio of possible leakage control interventions.

The model uses a default value of 4 gallons per connection per day for the natural rise in leakage (European Union 2015). In order to assess the sensitivity of the model outputs to the value of the natural rate of rise in leakage, an analysis was performed by varying the natural rate of rise in leakage as 0.5, 1, 2, 4, 6, 8, and 10 gallons per connection per day. Apart from the natural rate of rise in leakage, all other model input parameters were kept as default (Table 2). The results of the sensitivity analysis are depicted in Fig. 13. The model predicted benefit-cost ratio values over 30-year, 20-year, 10-year, and for the period from 2022-2027 for the two systems considered are reported in Table 8.

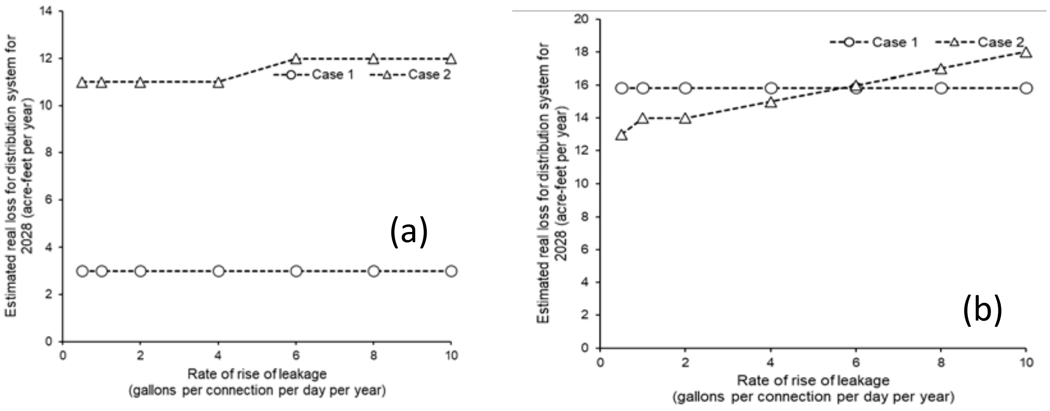

Fig. 13: Variations of the model estimated real loss in the WDS for the year 2028 with rate of rise of leakage for (a) DS-1 and (b) DS-2

Table 8: Influence of rate of rise in leakage in determining the model predicted benefit-cost ratio of the active leak detection and repair strategies

Input Parameter⁺	Benefit-cost ratio over 30 years		Benefit-cost ratio over 20 years		Benefit-cost ratio over 10 years		Benefit-cost ratio over 2022-27	
	DS-1							
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
0.5	N/A	4.4	N/A	3.8	N/A	2.9	N/A	2.4
1	N/A	4.4	N/A	3.8	N/A	2.9	N/A	2.4
2	N/A	4.3	N/A	3.7	N/A	2.9	N/A	2.4

Input Parameter[+]	Benefit-cost ratio over 30 years		Benefit-cost ratio over 20 years		Benefit-cost ratio over 10 years		Benefit-cost ratio over 2022-27	
	DS-1							
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
4	N/A	4.3	N/A	3.7	N/A	2.9	N/A	2.4
6	N/A	4.2	N/A	3.6	N/A	2.9	N/A	2.4
8	N/A	4.2	N/A	3.6	N/A	2.9	N/A	2.4
10	N/A	4.1	N/A	3.6	N/A	2.8	N/A	2.3
Input Parameter[+]	Benefit-cost ratio over 30 years		Benefit-cost ratio over 20 years		Benefit-cost ratio over 10 years		Benefit-cost ratio over 2022-27	
	DS-2							
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
0.5	0.3	73.6	0.2	63.3	0.2	49.6	0.2	41.1
1	0.2	73.6	0.2	63.3	0.2	49.5	0.1	41.0
2	0.2	73.5	0.1	63.2	0.1	49.5	0.1	41.0
4	0.1	73.4	0	63.0	0	49.4	0	40.9
6	N/A	73.2	N/A	62.9	N/A	49.2	N/A	40.8
8	N/A	73.0	N/A	62.8	N/A	49.1	N/A	40.7
10	N/A	72.8	N/A	62.6	N/A	49.0	N/A	40.6

[+] Rate of rise in leakage (gallons per connection per year)
N/A - Not applicable

For DS-1 under Case 1, the rate of rise of leakage was observed to impart no effect on the model predicted real loss for the distribution system for the year 2028. This could be attributed to the lower average baseline real loss (3.3 acre-feet per year) selected for DS-1 under Case 1 and its physical non-existence under the conditions considered. Under Case 2, the estimated real loss for DS-2 for the year 2028 was found to be increasing with the increase in the rate of rise of leakage in the system (Fig. 13a). Interestingly, the effects of the increase in the rate of rise of leakage on DS-1 under Case 1 was found to be subservient compared to that in DS-2 (Fig. 13b). This could be attributed to the network characteristics and the average baseline real loss considered for the analysis.

The low rate of rising of leakage means that the backlog leakage is much more significant than both the leakage in the system's parts not surveyed and natural rise in leakage. Thus, under increased values of the rise of leakage rate, the model estimated more significant unreported leakage in the WDSs. Consequently, the potency of the active leak detection and repair strategies to control water loss is reduced. Consequently, the model estimated higher values for real loss for the system in the anticipated future.

The values reported in Table 8 show the apparent influence of the rate of rising in leakage on the economic aspects of the active leak detection and control strategies. Those are case dependent. For DS-1 and DS-2, the effects were found to be comparatively negligible. Hence, it may be argued that for the conditions considered in DS-1 and DS-2, the value of the parameter corresponding to the natural rate of rise in leakage does

not substantially affect the model outputs in terms of cost-effectiveness of the possible leak reduction interventions.

Assumption 7
Assumed life cycle time horizon. The assumed time horizon over which any benefits and costs associated with water loss control actions and the useful life of repair as a result of active leak detection is 30 years.

Review of assumption 7
Setting a time horizon for the assessment might be viewed as equal to the application of discounting (Lueddeckens et al. 2020). Both very long-and concise-time horizons of the assessment are impractical depending on LCA topic. Concise time horizon may offend the principle of intergenerational equality, while very long ones would marginalize short-term actions and thus reduce the incentives to act. The LCA time horizon considered in the current model marks the timeline covering the lifecycle of active leak detection and repair implementation and associated leakage reduction or maintenance and continued maintenance of leakage per the standard.

Once launched, the varying anticipated actions of the water loss control program have to be conducted concurrently. In this way, multiple objectives are pursued, and hence, the leak detection and control activities should be maintained in an ongoing manner. The ability to enact the control actions varies significantly from one utility to another. The size of the utility, fund availability, and other numerous factors play crucial roles in implementing leak detection and repair programs in real-world WDSs. Some water utilities may take 1 to 2 years, while other utilities with more restrictive conditions may require a 5 to 10-year horizon to affect the same interventions (American Water Works Association 2016).

The present model assumes an LCA time horizon of 30 years. This time cycle appears to be long enough to accommodate the implementation of all short-term, medium-term, long-term, and ongoing interventions in a WDS and to cover the associated water loss reduction. However, the present model does not provide an option to vary the time horizon (this parameter is assumed to be fixed), which appears to be a limitation. It is suggested that the model allows the user to change the LCA time horizon. This would make the model flexible and foresee the effects of short-term and medium-term interventions on the water loss control program in WDSs.

Assumption 8
Leak detection and repair costs. The default values of leak detection costs and efficiency and leak repair costs used in the model are calculated from available data from vendors and water suppliers.

Review of assumption 8
The present model divides the entire WDSs into several surveying parts based on the leak detection frequency value. Once the system is divided, active leak detection and repair strategies are implemented to detect and repair the

leakages in the distribution mains and the service connections. The model used the US $ 595 as the cost to detect the leaks in the mains. Based on the data from two real-world WDSs, the model uses US $ 5946 and US $ 2330 as the average unit leak repair costs for mains and average unit cost of leak repair costs for laterals and service lines, respectively. The efficiency of the leak detection equipment is approximated at 70%.

The cost detection, repair, and the efficiency of the leak detection equipment directly influence the calculations on the determination of costs due to additional leakage reduction intervention. In this connection, a sensitivity analysis was conducted by varying the values of the cost to detect the leaks in the mains, unit leak repair costs for mains, unit cost of leak repair costs for laterals and service lines, and leak detection equipment efficiency. The values considered for the analysis are reported in Table 9.

The model predicted benefit-cost ratio values over 30-year, 20-year, 10-year, and for the period from 2022-2027 for DS-1 and DS-2 based on the different cases considered (Table 9), are reported in Table 10. It may be noted that while varying the parameters mentioned in Table 9 one by one, all the other parameters were kept equal to their default values (Table 2).

Table 9: Parameter values considered for performing the sensitivity analysis to determine the effects of input parameters on the costs due to additional intervention for leakage reduction

Unit average cost of leak detection surveying per mile (US $ per mile)	Average unit leak repair costs for mains (US $ per leak)	Average unit cost of leak repair costs for laterals and service lines (US $ per leak)	Efficiency of leak detection equipment (%)
297.5	2973	1165	60
446.25	4459.5	1747.5	70
595	5946	2330	80
743.75	7432.5	2912.5	-
892.5	8919	3495	-

Out of the four parameters considered, the average cost of leak detection surveying per mile was the most significant parameter for the model outputs. As expected, the increased cost detection surveying increased the cost of additional intervention for leakage reduction benefits. It decreased the overall benefit-cost ratio of active leak detection and repair strategies. The unit leak repair costs for mains and service connections were found to induce no net effects on the leakage control interventions' overall cost. The efficiency of leak detection equipment was obtained to positively affect the benefits due to additional intervention for leakage reduction. However, the magnitude of these effects was found negligible.

Table 10: Influence of average cost to detect the leaks in the mains, average unit leak repair costs for mains, average unit cost of leak repair costs for laterals and service lines, and leak detection equipment efficiency in determining the model predicted benefit-cost ratio of the active leak detection and repair strategies

Unit average cost of leak detection surveying per mile (US $ per mile)	Benefit-cost ratio over 30 years				Benefit-cost ratio over 20 years				Benefit-cost ratio over 10 years				Benefit-cost ratio over 2022-27			
	DS-1		DS-2		DS-1		DS-2		DS-1		DS-2		DS-1		DS-2	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
297.5	N/A	8.4	0.1	139.3	N/A	7.2	0.1	119.1	N/A	5.6	0.1	91.9	N/A	4.5	0	74.7
446.2	N/A	5.7	0.1	94.0	N/A	4.9	0.1	80.7	N/A	3.8	0	62.9	N/A	3.1	0	51.7
595	N/A	4.3	0.1	71.0	N/A	3.7	0	61.0	N/A	2.9	0	47.8	N/A	2.4	0	39.6
743.8	N/A	3.4	0	57.0	N/A	3.0	0	49.0	N/A	2.3	0	38.5	N/A	1.9	0	32.0
892.5	N/A	2.9	0	47.6	N/A	2.5	0	41.0	N/A	2	0	32.3	N/A	1.6	0	26.9

Average unit leak repair costs for mains (US $ per leak)	Benefit-cost ratio over 30 years				Benefit-cost ratio over 20 years				Benefit-cost ratio over 10 years				Benefit-cost ratio over 2022-27			
	DS-1		DS-2		DS-1		DS-2		DS-1		DS-2		DS-1		DS-2	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
2973	N/A	4.3	0.1	71.5	N/A	3.7	0.1	61.6	N/A	2.9	0	48.5	N/A	2.5	0	40.6
4459.5	N/A	4.3	0.1	71.2	N/A	3.7	0	61.3	N/A	2.9	0	48.1	N/A	2.4	0	40.1
5946	N/A	4.3	0.1	71.0	N/A	3.7	0	61.0	N/A	2.9	0	47.8	N/A	2.4	0	39.6
7432.5	N/A	4.3	0.1	70.7	N/A	3.7	0	60.7	N/A	2.9	0	47.4	N/A	2.4	0	39.1
8919	N/A	4.2	0.1	70.4	N/A	3.6	0	60.4	N/A	2.8	0	47.0	N/A	2.3	0	38.6

Table 10 (contd.): Influence of average cost to detect the leaks in the mains, average unit leak repair costs for mains, average unit cost of leak repair costs for laterals and service lines, and leak detection equipment efficiency in determining the model predicted benefit-cost ratio of the active leak detection and repair strategies

Average unit cost of leak repair costs for laterals and service lines (US $ per leak)	Benefit-cost ratio over 30 years				Benefit-cost ratio over 20 years				Benefit-cost ratio over 10 years				Benefit-cost ratio over 2022-27			
	DS-1		DS-2		DS-1		DS-2		DS-1		DS-2		DS-1		DS-2	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
1165	N/A	4.3	0.1	71.1	N/A	3.7	0	61.1	N/A	2.9	0	47.9	N/A	2.4	0	39.8
1747.5	N/A	4.3	0.1	71.0	N/A	3.7	0	61.0	N/A	2.9	0	47.8	N/A	2.4	0	39.7
2330	N/A	4.3	0.1	71.0	N/A	3.7	0	61.0	N/A	2.9	0	47.8	N/A	2.4	0	39.6
2912.5	N/A	4.3	0.1	70.9	N/A	3.7	0	60.9	N/A	2.9	0	47.7	N/A	2.4	0	39.5
3495	N/A	4.3	0.1	70.8	N/A	3.7	0	60.9	N/A	2.9	0	47.6	N/A	2.4	0	39.4

Efficiency of leak detection equipment (%)	Benefit-cost ratio over 30 years				Benefit-cost ratio over 20 years				Benefit-cost ratio over 10 years				Benefit-cost ratio over 2022-27			
	DS-1		DS-2		DS-1		DS-2		DS-1		DS-2		DS-1		DS-2	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
60	N/A	4.3	0.1	70.7	N/A	3.7	0	60.7	N/A	2.9	0	47.4	N/A	2.4	0	39.2
70	N/A	4.3	0.1	71.0	N/A	3.7	0	61.0	N/A	2.9	0	47.8	N/A	2.4	0	39.6
80	N/A	4.3	0.1	71.1	N/A	3.7	0	61.2	N/A	2.9	0	48.0	N/A	2.4	0	39.9

N/A – Not applicable

Finding 10

Correlation of leakage reduction with unreported leakage. The sensitivity of the required water loss reduction to unreported leakage is high with an R-squared value of over 0.9.

Review of finding 10

To assess the correlation between the required water loss reduction by the target year predicted by the model and the unreported leakage, the dataset obtained from the analysis conducted by varying the ICF values were used. Under Case 2, the average unreported leakage obtained and the estimated real loss for the year 2028 obtained for DS-1 and DS-2 from the model are reported in Table 11. The leakage reduced by the year 2028 can be estimated using the equation given below:

Leakage reduction by the year 2028 (acre-feet per year) = Average real loss for the year 2022 (acre-feet per year) - Estimated real loss for the system for the year 2028 (acre-feet per year) (5)

Using Eq. (5), the leakage reduced by the year 2028 was determined for DS-1 and DS-2 under Case 2 for different values of ICF and is reported in Table 11.

Table 11: Leakage reduced by the year 2028 and the annual reported leakage in DS-1 and DS-2 under Case 2 for different values of ICF

ICF	Estimated real loss for distribution system for 2028 (acre-feet per year)		Leakage reduced by the year 2028 (acre-feet per year)		Annual unreported leakage (acre-feet per year)	
	DS-1	DS-2	DS-1	DS-2	DS-1	DS-2
1	11	277	22.5	297	23	561
1.5	15	280	18.5	294	19	556
2	19	282	14.5	292	15	552
2.5	22	285	11.5	289	12	547
3	26	287	7.5	287	8	542
3.5	33.5	290	0	284	4	537
4	33.5	293	0	281	1	533
4.5	33.5	295	0	279	0	528
5	33.5	298	0	276	0	523

Graphs were plotted between leakage reduced by the year 2028 and annual unreported leakage for all the values of reported annual leakage greater than zero to evaluate the sensitivity of the leakage reduction with the unreported leakage. The curves obtained are shown in Fig. 14.

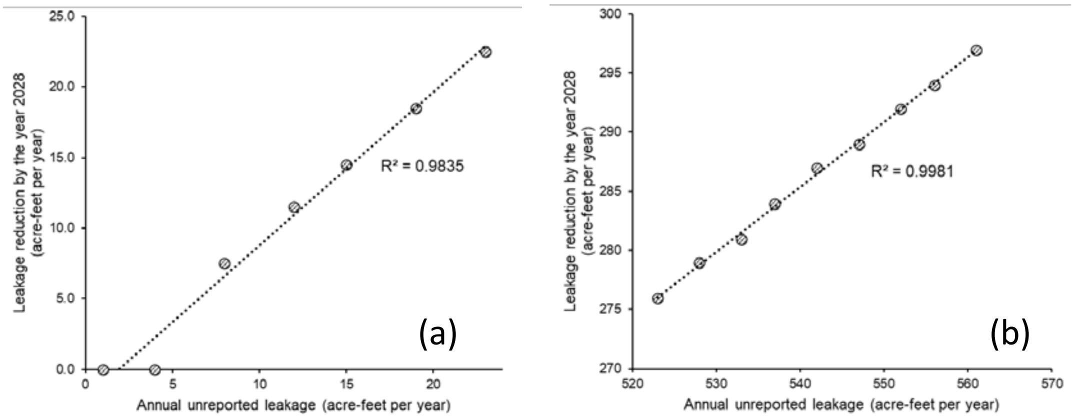

Fig. 14: Correlation between leakage reduction and annual unreported leakage for the year 2028 for (a) DS-1 and (b) DS-2

A linear relationship was established between the leakage reduction and the unreported leakage (Fig. 14). **The R^2 values for DS-1 and DS-2 were obtained as 0.98 and 0.99, respectively. This confirmed the direct effects of controlling the unreported leakage of the system on the overall leakage reduction.**

Findings/Conclusions 11

Calculating reduction in leakage with regular surveying per the assumed survey frequencies. The calculation of reduction in leakage with regular active leak detection and repair per the assumed survey frequencies is shown below.

Review of findings/conclusions 11

The model employs empirical equations to determine the TBL and the reported leakage. Based on the TBL and the reported leakage values, a mass-balance approach is applied to derive the unreported leakage fraction. Once the leakage fractions are determined, the model then divides the WDS into a fixed number of parts based on the rate of surveying. The survey frequency can be provided as an input parameter. In its absence, the model assumes a surveying rate based on the length of the distribution mains. After discretization of the network, the leak detection survey is performed serially. For simplicity, the model assumes that at any point in time, only one part of the system is surveyed.

Once the active leak detection and surveying commences, the model splits the water lost into three elements for ease of calculation:

- Water lost due to backlog of unreported leakage (WL_1)
- Water lost due to natural rise in leakage for the never surveyed parts of the system (for the first survey) (WL_2)
- Water lost due to the natural rise in leakage for the rest of the parts of the system not being surveyed (WL_3)

As parts of the system are surveyed serially, the overall backlog of unreported leakage drops by a certain fraction in each time step. This fraction will be equivalent to the backlog unreported leakage per part which is calculated by dividing the annual unreported leakage by the number of parts to which the network is being divided.

Water loss occurring in time step '*i*' from all parts in the system due to only backlog leakage is represented as follows:

$$WL_1(i) = \Delta T \times I_o \times (N - i + 1) \quad (6)$$

where,
ΔT = time between surveys (months)
I_o = Unreported leakage per part (acre-feet per year)
N = Number of parts into which the distribution system is divided

After N time steps, the WL_1 will drops to zero.

Leakage level in the never surveyed parts increases at the natural rate of rise of leakage, till that part is surveyed. Total leakage due to this component in time step '*i*' from all parts of the system never surveyed before is given as follows:

$$WL_2(i) = (N - i + 1) \times r \times \Delta T^2 \times (i - 0.5) \quad (7)$$

where,
r = rate of natural rise of leakage per part (acre-feet per year per part per year)

After the entire system is surveyed once (after N time steps), WL_2 becomes zero.

Each part of the system starts leaking after a survey as the leakage rises naturally in the WDS after being surveyed. The leakage occurring in each time step is the rise in leakage that occurs over that time step for all parts in the system. Leakage due to this component in time step '*i*' from all parts of the system during the process of surveying can be estimated using the following equation.

$$WL_3(i) = (1/2) \times r \times \Delta T^2 \times (i - 1)^2 \quad (8a)$$

Once the system has undergone a complete survey, then and all parts will contribute to the third element of leakage. After the backlog of leakage is completely eliminated, WL_3 will be the only one that constitutes the overall leakage for the distribution system. After full survey, WL_3 is calculated as follows:

$$WL_3 = (1/2) \times r \times \Delta T^2 \times N^2 \quad (8b)$$

The model assumes that the system would continue to leak in the same rate as the current or baseline real loss in the absence of intervention. The leakage without intervention ($WL_{no\_intervention}$) for the system can be calculated as:

$$WL_{no\_intervention} = N \times \Delta T \times I_o \quad (9)$$

With an aim to verify the model and the equations adopted, the model was applied to DS-2 under Case 2. A survey rate of 12.5 miles per month was selected to divide the system into five parts as shown in Fig. 15. All other input parameters were kept at their default values (Table 2). The leakage components (WL_1, WL_2, WL_3, $WL_{no\_intervention}$) were calculated using Eq. 6-9 and the effects of active leak detection and repair strategies on controlling the water loss for a period of 12 months were verified.

The 12-month variations of the water loss due to the three components of leakage is depicted in Figs. 16-18. The cumulative water loss in DS-2 with and without leakage control interventions are shown in Fig. 19.

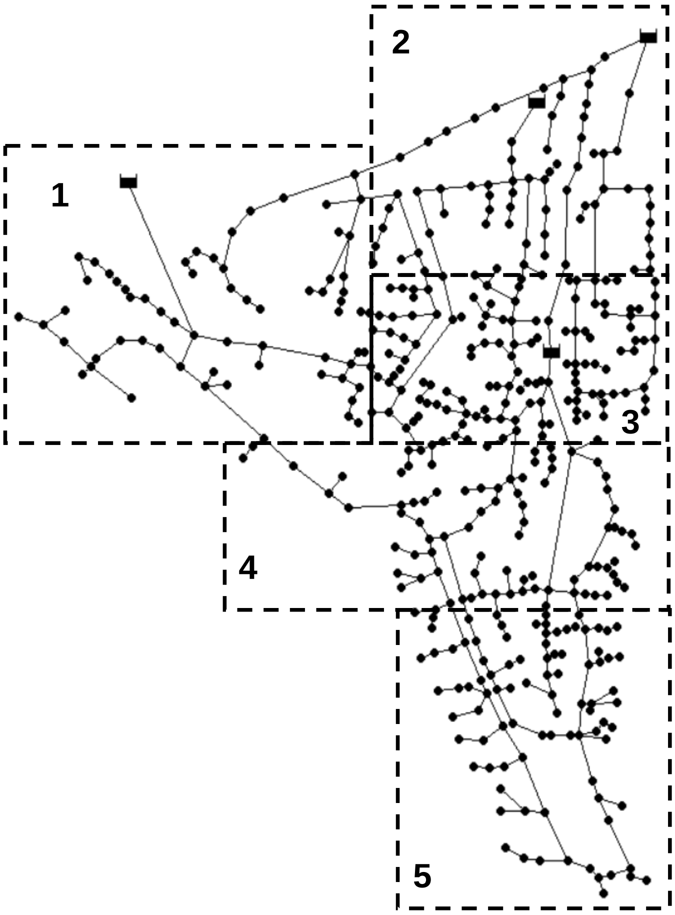

Fig. 15: Five-part discretization of DS-2 for conducting leak detection survey

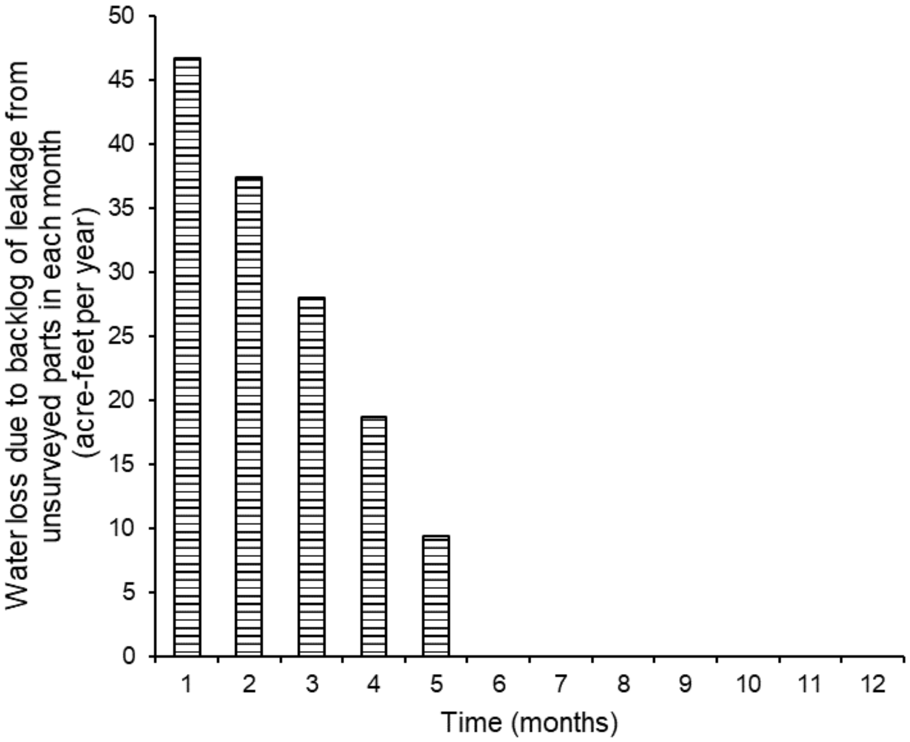

Fig. 16: 12-month variations of the water loss due to backlog of leakage from unsurveyed parts of DS-2

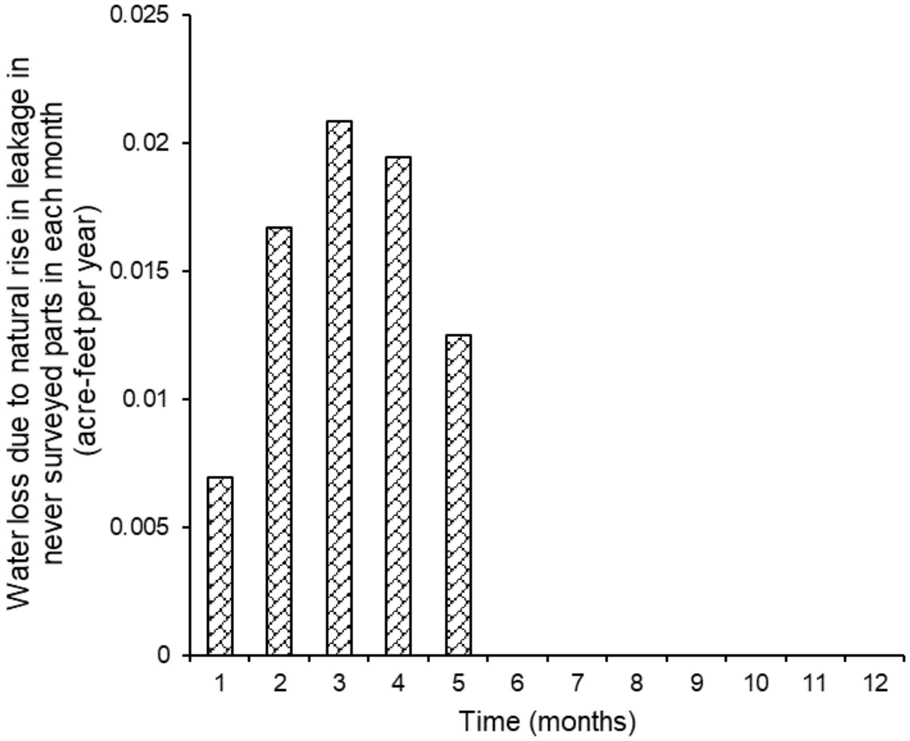

Fig. 17: 12-month variations of the water loss due to natural rise in leakage from never surveyed parts of DS-2

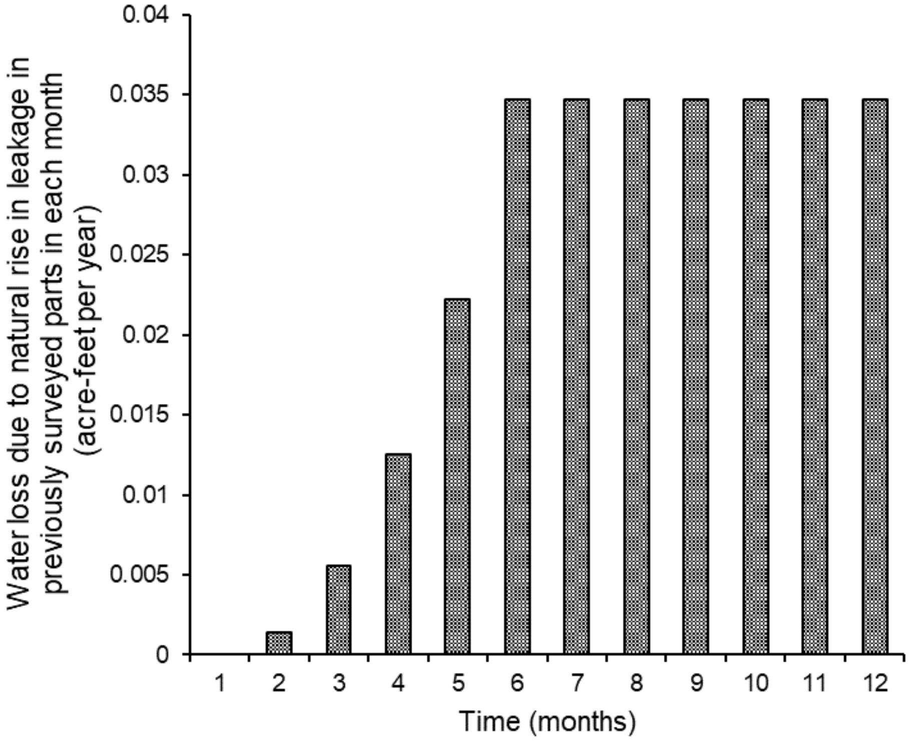

Fig. 18: 12-month variations of the water loss due to natural rise in leakage from previously surveyed parts of DS-2

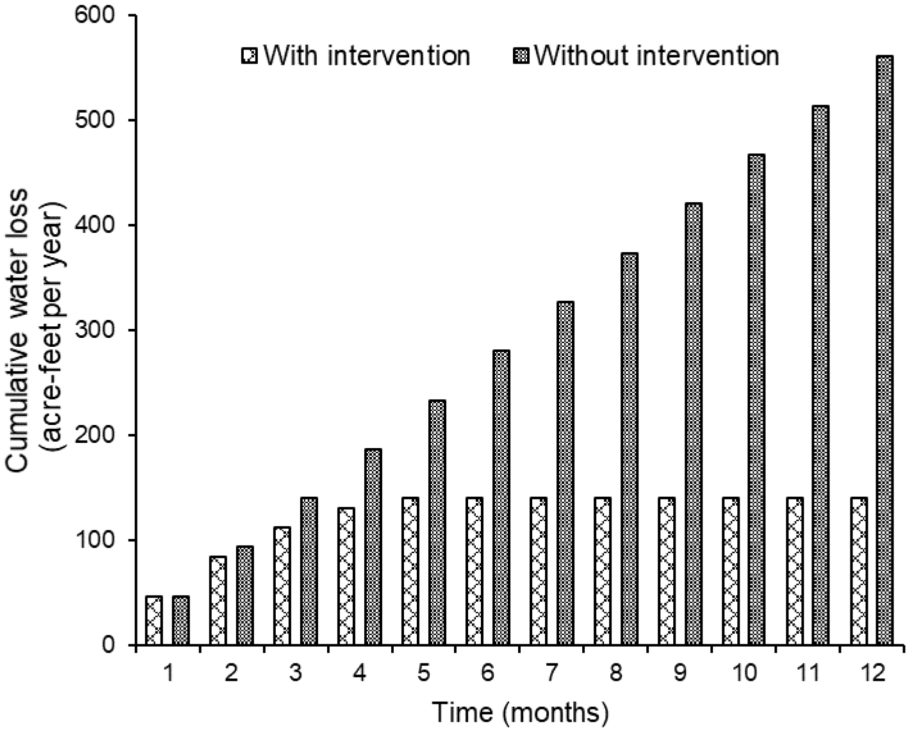

Fig. 19: 12-month variations of the cumulative water loss with and without interventions in DS-2

The results obtained indicated that the procedure adopted in the model for the calculation of reduction in leakage with regular active leak detection and repair per the assumed survey frequencies is conceptually sound and mathematically correct.

However, certain errors were identified in the basic equations stated in the 'Equations' tab of the spreadsheet interface of the model. Hence, it is suggested that these equations may be suitably corrected.

The equation used to derive the water loss due to natural rise in leakage from the never surveyed parts of the system is given as:

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

This may be corrected to the following form:

$(1/2) \times (r \times (i - 1) \times \Delta T + r \times i \times \Delta T) \times \Delta T = (r \times \Delta T \times (i - 0.5) \times \Delta T$
$= r \times \Delta T^2 \times (i - 0.5)$

Similarly, the equations used to derive the water loss due to natural rise in leakage from the previously surveyed parts of the system are given as:

$= (1/2) \times (r \times (j - 1) \times \Delta T + r \times j \times \Delta T)$

$= (1/2) \times (r \times j \times \Delta T - r \times \Delta T + r \times j \times \Delta T)$

This part of the equations may be corrected to the following form:

$= (1/2) \times (r \times (j - 1) \times \Delta T + r \times j \times \Delta T) \times \Delta T$

$= (1/2) \times (r \times j \times \Delta T - r \times \Delta T + r \times j \times \Delta T) \times \Delta T$

Findings/Conclusions 12

Benefit-cost analysis for water loss control actions.

The State Water Board staff request a review of the methodology used to assess the benefits and costs. Items 12 (a), (b), (c) and (d) describe the methodology used to calculate costs and benefits associated with water loss control actions.

Water saved due to water loss control actions 12a

The water lost is calculated by adding all three components together (Item 11 in technical report) over the 30-year time horizon. This sum is subtracted from the water lost without any water loss control actions to calculate the water saved due to water loss control actions (active leak detection and repair).

Review of water saved due to water loss control actions 12a

The model divides the water leakage from any system into three components 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 the first survey).

- Water lost due to the natural rise in leakage for the rest of the parts of the system not being surveyed.

The active leak detection and control strategies are implemented to control these three components. Once the survey gets completed, the model assumes that the third component corresponding to the natural rise in leakage will remain as the only component contributing to the water loss. In the absence of possible interventions to control leakage, the model assumes that the system would continue to leak at the same rate as the current or baseline real loss.

This approach's conceptual and mathematical aspects have been thoroughly verified and reported in the previous pages. Even though the current approach is based on a series of empirical assumptions, it appears to be conceptually sound and mathematically correct. More importantly, the assumptions adopted seems to be conceptually justifiable. Hence, it is stated that the present modeling approach is adequate to capture the water loss in a real-world WDS with and without leakage control interventions.

Cost associated with water loss control actions 12d

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 per Item. The sum of cost of leak detection and repair is calculated over the time horizon while applying a discount rate of 3.5%.

Review of cost associated with water loss control actions 12d

The model's sensitivity to the cost of leak detection per mile length of distribution mains and the cost of repairing unreported leaks have been thoroughly investigated by applying the model to DS-1 and DS-2 under Cases 1 and 2. The results obtained are reported in Table 10.

The model calculates the cost of leak detection during the leak detection survey by multiplying the average cost of leak detection per mile with the length of the mains surveyed in each part. Thus, as expected, the higher values of the cost detection per mile increased the leak detection surveying cost and increased the overall cost of the additional intervention for leakage reduction benefits. Hence, it was found to negatively impact the overall benefit-cost ratio of active leak detection and repair strategies.

On the other hand, based on the analysis results, the unit leak repair costs for mains and service connections were found to induce no net effects on the leakage control interventions' overall cost. It indeed increased the cost of leak repairs and increased the cost of leakage control interventions. However, the increase in the cost due to the increase in the average cost of repairing the unreported leaks was found not high enough to determine the overall benefit-cost ratio of active leak detection and repair strategies.

The model fixes the value of the discount rate at 3.5%. Hence, it would be interesting to understand what effect the value has on the model predicts.

A sensitivity analysis was performed with this aim by varying the value of the discount rate as 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, and 5%. Apart from the discount rate, all the other parameters were kept as their default values (Table 2). The values of the benefit-cost ratio over 30-year, 20-year, 10-year, and for the period from 2022-2027 obtained for DS-1 and DS-2 under Cases 1 and 2 for different values of the discount rate are reported in Table 12.

Table 12: Influence of discount rate in determining the model predicted benefit-cost ratio of the active leak detection and repair strategies

Input Parameter$^+$	Benefit-cost ratio over 30 years		Benefit-cost ratio over 20 years		Benefit-cost ratio over 10 years		Benefit-cost ratio over 2022-27	
	DS-1							
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
2.0	N/A	4.5	N/A	3.8	N/A	2.9	N/A	2.4
2.5	N/A	4.4	N/A	3.8	N/A	2.9	N/A	2.4
3.0	N/A	4.3	N/A	3.7	N/A	2.9	N/A	2.4
3.5	N/A	4.3	N/A	3.7	N/A	2.9	N/A	2.4
4.0	N/A	4.2	N/A	3.6	N/A	2.9	N/A	2.4
4.5	N/A	4.2	N/A	3.6	N/A	2.9	N/A	2.4
5.0	N/A	4.1	N/A	3.6	N/A	2.8	N/A	2.4
Input Parameter$^+$	Benefit-cost ratio over 30 years		Benefit-cost ratio over 20 years		Benefit-cost ratio over 10 years		Benefit-cost ratio over 2022-27	
	DS-2							
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
2.0	0.1	74.3	0	62.7	0	48.5	0	40.0
2.5	0.1	73.2	0	62.2	0	48.2	0	39.9
3.0	0.1	72.1	0	61.6	0	48.0	0	39.7
3.5	0.1	71.0	0	61.0	0	47.8	0	39.6
4.0	0.1	69.9	0	60.4	0	47.5	0	39.4
4.5	0.1	68.8	0	59.8	0	47.3	0	39.3
5.0	0.1	67.7	0	59.2	0	47.0	0	39.1

$^+$ Discount rate (%)
N/A - Not applicable

The cost-effectiveness between reducing real loss and maintaining current real loss depends clearly on the discount rate value. Hence, as expected, a decrease in the benefit-cost ratio values corresponding to the active leak detection and repair strategies was obtained with the discount rate value (Table 12). However, under the cases considered, this parameter's impacts in determining the overall benefit-cost ratio of active leak detection and repair strategies were found insignificant. **Nevertheless, the model performance was observed to be more sensitive to the value of the discount rate than that of the unit leak repair costs for mains and service connections.**

References

American Water Works Association (2016). Water Audits and Loss Control Programs (M36), Fourth Edition. https://www.awwa.org/Store/Product-Details/productId/51439782

El-Zahab S, Zayed T (2019). Leak detection in water distribution networks: an introductory overview. Smart Water 4, El-Zahab S, Zayed T (2019)

European Union (2015). EU Reference document Good Practices on Leakage Management WFD CIS WF PoM. Luxembourg
European Union (2015)

Fontanazza CM, Notaro V, Puleo V, et al (2015). Contaminant intrusion through leaks in water distribution system: Experimental analysis. Procedia Eng 119:426 – 433. Fontanazza CM, Notaro V, Puleo V, et al (2015)

Lueddeckens S, Saling P, Guenther E (2020). Temporal issues in life cycle assessment—a systematic review. Int J Life Cycle Assess 25:1385–1401. Lueddeckens S, Saling P, Guenther E (2020)

Rossman LA (2000). EPANET 2: user's manual. Natl. Risk Manag. Res. Lab. US Environ. Prot. Agency, Cincinnati.

Saldarriaga J., Páez D., Salcedo C., Cuero P., López L. L., León N., and Celeita D. (2020). A direct approach for the near-optimal design of water distribution networks based on power use. Water Vol. 12, 1037 Saldarriaga J. et al. (2015)

Van Zyl JE, Clayton CRI (2007). The effect of pressure on leakage in water distribution systems. In: Proceedings of the Institution of Civil Engineers: Water Management. pp 109–114, Van Zyl JE, Clayton CRI (2007)

Xu Q, Liu R, Chen Q, Li R (2014). Review on water leakage control in distribution networks and the associated environmental benefits. J Environ Sci (China) 26:955–961, Xu Q, Liu R, Chen Q, Li R (2014)

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December 22, 2020

Peer Review of the Scientific Basis of the Economic Model for the Development of California Water Loss Performance Standards

Based on my expertise and experience, I am reviewing the findings, assumptions, or conclusions I agreed I could review with confidence:

Assumption 1 – The assumed default infrastructure condition factor value. The model uses a default value of 1.0. This is used to calculate the minimum amount of background leakage in a system.

Comment: This assumption is based on *Water Research Foundation, 2015, Water Audits and Real Loss Component Analysis, Report 4372a.* I agree this assumption is valid. I suggest adding some guidance to Cell D20 in the model to suggest the user increase the ICF based on age of distribution network.

Assumption 2 – Calculation of minimum amount of reported and unreported leakage. The model uses the AWWA M36 manual to estimate the minimum amount of reported and background leakage that could occur in a system.

Comment: I agree this assumption is valid. For the assumed background leakage: I recommend providing information from the original reference (Lambert 2009) on how the equation was developed.

Assumption 3 – Average leak detection survey frequency. The model assumes that a range of two to three years per different system sizes.

Comment: Per the calculations within the model, default survey frequencies are assumed based on miles of main as follows:

6000 miles and above - 130 miles per month
4000 miles and above - 114 miles per month
1000 miles and above: Once in three years
500 miles and above: Once in 2.5 years
Below 500 miles: Once every 2 years

I wonder if the default values for systems with <1000 miles of main may be underestimated. The data provided from the Municipal Water District of Orange County shows that small suppliers currently may take over 30 years to survey their system, with an average survey rate of about 5 miles per month. There appears to be a nonlinear inverse relationship between total length of mains and the percent of the system to be surveyed annually. The 2-3 year time horizon may apply to large suppliers such as

LADWP and EBMUD but does not appear to be a good estimate of suppliers with <1000 miles of mains.

I suggest revisiting this assumption. Because the data is so variable, a simpler assumption of X miles per month, even for smaller suppliers may be a better estimate. I agree with the decision to keep cell B43 in the model blank for suppliers to enter their own estimate when possible.

Assumption 4 – Annual rate of natural rise of leakage. The model assumes a default value of 4 gallons per connection per day in the model, which can be updated by urban retail water suppliers.

Comment: I agree this assumption is valid and with the decision to keep the rate low so that the model relies more on the backlog of leakage than the default value rate of rise. Natural rise of leakage is specific to each system and likely relatively low in California.

Assumption 7 – Assumed life cycle time horizon. Leak detection equipment and pipe repair material have lifecycle periods that are longer than the compliance date (by 2028), due to which, the model accommodates for the useful life of repair in the time horizon.

Comment: An assumed life cycle time horizon of 30 years is reasonable.

Assumption 8 – Leak detection and repair costs. Assumed leak detection costs is $595 per mile; assumed leak repair costs for mains is $5,946 per leak; assumed leak repair costs for service lines is $2,330 per leak, assumed efficiency of leak detection to account for false positives is 70%.

Comment: The costs assumed are acceptable, given that, as mentioned, repair costs are highly variable depending on the type of pipe and severity of the leak. Suppliers can enter their own data.

Finding 10 – Correlation of leakage reduction with unreported leakage. a strong correlation of the water loss reduction per the model results is observed using default values for reported and background leakage to the unreported leakage.

Comment: Yes, the correlation of leakage reduction with unreported leakage makes sense – suppliers with large amounts of unreported leakage likely have a lot to gain in terms of reducing leakage in a cost-effective way.

Findings/Conclusion 11 – Calculating reduction in leakage with regular surveying per the assumed survey frequencies. 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.

Comment: What is the basis for the assumption that leaks will be repaired by the supplier within the same month as detected? This seems relatively quick, depending on the size of the leak.

Findings/Conclusion 12 – Benefit-cost analysis for water loss control actions.

a. Water saved due to water loss control actions - The water lost is calculated by adding all three components together (Item 11 in technical report) over the 30-year time horizon.
d. Cost associated with water loss control actions - The cost of leak detection per mile is multiplied by the number of miles surveyed over the time horizon of 30 years (Item 7). The cost of repairing each unreported leak is multiplied by the number of unreported leaks detected per Item 12(c). The sum of cost of leak detection and repair is calculated

Comment: I agree the approach to calculating benefit-cost analysis is sound. Water saved is calculated by adding water lost due to backlog, due to natural rise of leakage for the parts surveyed in that time step, and due to natural rise in leakage for the rest of the parts of the system not surveyed in the current time step.

Big Picture Comments

Overall, the proposed approach is scientifically sound. The model is logical and generally user-friendly. Several specific comments are provided below:

- On the *Calculations* sheet, should cells B24-26 be updated with information from the inputs sheet? If not, these cells on the *Inputs* sheet should be moved to section 3, as they are static and assumed by the model.

- On the *Outputs* sheet, clarify that if Benefit-Cost Ratio is N/A (Cells G7, G10, G13, and G16) that means it is less than 1. Otherwise it looks like a calculation error.

- On the *Outputs* sheet, clarify when current leakage level gallons per connection is used vs. gallons per mile is used.

- In the final version of the model, I suggest locking cells with equations that should remain unchanged.

- The information regarding assumptions was well synthesized in the water loss review report. I suggest providing a similar documentation file for the final model. While the *CollectedData_References* tab does include all the raw data, it is somewhat difficult to navigate and could be improved with better formatting and documentation. Documenting an example may also be helpful.

- Given the model assumptions, there is significant uncertainty within the model. I wonder how the uncertainty could be integrated into the implementation of the performance standards. Have you conducted a sensitivity analysis? What parameters are the most sensitive? I might suggest a “buffer” on the cost-benefit ratio of one (1) since ratios close to one may be artifacts of model uncertainty.