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EPA

Real Loss Component Analysis: A Tool for Economic Water Loss Control

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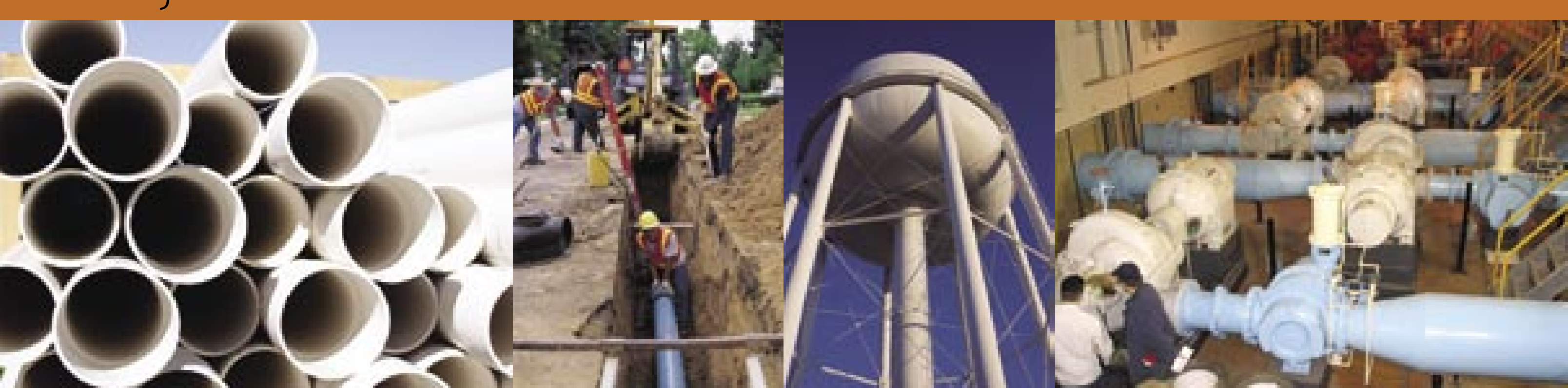

Real Loss Component Analysis: A Tool for Economic Water Loss Control

About the Water Research Foundation

The Water Research Foundation (WRF) is a member-supported, international, 501(c)3 nonprofit organization that sponsors research that enables water utilities, public health agencies, and other professionals to provide safe and affordable drinking water to consumers.

WRF's mission is to advance the science of water to improve the quality of life. To achieve this mission, WRF sponsors studies on all aspects of drinking water, including resources, treatment, and distribution. Nearly 1,000 water utilities, consulting firms, and manufacturers in North America and abroad contribute subscription payments to support WRF's work. Additional funding comes from collaborative partnerships with other national and international organizations and the U.S. federal government, allowing for resources to be leveraged, expertise to be shared, and broad-based knowledge to be developed and disseminated.

From its headquarters in Denver, Colorado, WRF's staff directs and supports the efforts of more than 800 volunteers who serve on the board of trustees and various committees. These volunteers represent many facets of the water industry, and contribute their expertise to select and monitor research studies that benefit the entire drinking water community.

Research results are disseminated through a number of channels, including reports, the Website, Webcasts, workshops, and periodicals.

WRF serves as a cooperative program providing subscribers the opportunity to pool their resources and build upon each other's expertise. By applying WRF research findings, subscribers can save substantial costs and stay on the leading edge of drinking water science and technology. Since its inception, WRF has supplied the water community with more than $460 million in applied research value.

More information about WRF and how to become a subscriber is available at www.WaterRF.org.

Real Loss Component Analysis: A Tool for Economic Water Loss Control

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DISCLAIMER

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FOREWORD

The Water Research Foundation (WRF) is a nonprofit corporation dedicated to the development and implementation of scientifically sound research designed to help drinking water utilities respond to regulatory requirements and address high-priority concerns. WRF's research agenda is developed through a process of consultation with WRF subscribers and other drinking water professionals. WRF's Board of Trustees and other professional volunteers help prioritize and select research projects for funding based upon current and future industry needs, applicability, and past work. WRF sponsors research projects through the Focus Area, Emerging Opportunities, and Tailored Collaboration programs, as well as various joint research efforts with organizations such as the U.S. Environmental Protection Agency and the U.S. Bureau of Reclamation.

This publication is a result of a research project fully funded or funded in part by WRF subscribers. WRF's subscription program provides a cost-effective and collaborative method for funding research in the public interest. The research investment that underpins this report will intrinsically increase in value as the findings are applied in communities throughout the world. WRF research projects are managed closely from their inception to the final report by the staff and a large cadre of volunteers who willingly contribute their time and expertise. WRF provides planning, management, and technical oversight and awards contracts to other institutions such as water utilities, universities, and engineering firms to conduct the research.

A broad spectrum of water supply issues is addressed by WRF's research agenda, including resources, treatment and operations, distribution and storage, water quality and analysis, toxicology, economics, and management. The ultimate purpose of the coordinated effort is to assist water suppliers to provide a reliable supply of safe and affordable drinking water to consumers. The true benefits of WRF's research are realized when the results are implemented at the utility level. WRF's staff and Board of Trustees are pleased to offer this publication as a contribution toward that end.

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Water Research Foundation

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EXECUTIVE SUMMARY

OBJECTIVES

The primary objectives of the Water Research Foundation (WRF) project, *Real Loss Component Analysis: A Tool for Economic Water Loss Control*, were:

- Review North American and international literature and best practices on component analysis of leakage and economic leakage analysis and guidelines.
- Develop a utility-tested software tool to undertake a leakage component analysis and economic leakage evaluation, enabling utilities to plan cost effective leakage control interventions.
- Develop a tool that complements the American Water Works Association (AWWA) Free Water Audit Software and the 3rd edition of AWWA's Manual 36 (Water Audits and Loss Control Programs).
- Establish utility data collection guidelines for proper documentation of all leakage occurrences.
- Provide thorough instructions for use of the tools developed.
- Promote the adoption of the tools and the benefits of proactive leakage management.

The software tool and guidelines developed from this project will benefit and advance industry wide leakage management on several levels. This project is relevant to the following fields:

- Regulatory Agencies: Federal, State, Regional, Municipal
- Water Industry Wide: Private and Public Utilities, Consultants, and Contractors
- General Utility Management
- Distribution System Operation
- Water Conservation
- Planning and Engineering

BACKGROUND

Water utilities, regulatory agencies, and a variety of stakeholders continue to increase focus on infrastructure management and water efficiency due to continuing droughts, the increasing cost of providing potable water to customers, potential health risks posed by leaking pipes, and heightened awareness of the increasing cost of leakage. In fact, the WRF project #4109, *Criteria for Optimized Distribution Systems*, considers leakage as one of three key indicators of distribution system management performance (Friedman et al. 2010) and is being considered for adoption by AWWA's Partnership for Safe Water Program.

Nevertheless, the vast majority of North American water utilities only employ a reactive leakage management strategy, repairing failures that have been reported to them in a more or less timely manner. As a result, water utilities continue to see an increase in leakage losses (water lost by leaks in the distribution system) due to a rising backlog of unreported failures in their distribution system. This is in spite of the fact that industry research and case studies have sufficiently demonstrated the benefits of proactive leakage management. The drinking water industry stands to benefit greatly in transitioning from purely reactive leakage management to proactive leakage management allowing them to achieve and sustain substantial reductions in leakage losses in an efficient and economic manner. (The terms real losses and leakage losses as well as the terms water audit and water balance have been used interchangeably in this report).

Generally, North American water utilities are still under little or no regulatory pressure to efficiently control leakage losses; however, a few agencies recently created water loss control related regulations or are closely evaluating the International Water Association (IWA)/ American Water Works Association (AWWA) Water Audit Methodology. In this context of growing acknowledgement around the importance of proactive leakage management, the software tool and research provided by this project are especially timely.

The available AWWA and WRF literature provides all the necessary theoretical background on how to accurately assess leakage losses and plan efficient and economic leakage control interventions. There are three major steps in developing a real loss reduction strategy:

- "Top-down" water audit
- Component analysis of real losses
- Evaluation of least cost real loss reduction strategies

The AWWA Manual 36 (3rd edition) provides comprehensive guidance for all steps involved in undertaking a "top-down" water audit, component analysis of real losses, and planning and implementing a real loss control program. The AWWA Free Water Audit Software serves as a basic tool to compile a "top-down" water audit, which is the first step in developing a water loss control program. A "top-down" water audit calculates the overall system wide volume of real losses by deducting the authorized consumption volume and the apparent losses volume (customer meter inaccuracies, data handling errors, and unauthorized consumption) from the system input volume. Once the overall system wide volume of real losses has been determined, this volume needs to be broken down into individual components of real losses/leakage by use of component analysis modeling.

A leakage component analysis disaggregates the total volume of real losses as calculated in the "top-down" water audit into its three components: Background Leakage, Unreported Leakage, and Reported Leakage. By combining the component analysis with an evaluation of least cost real loss reduction strategies it is possible to calculate how much of each leakage component can be economically reduced through the right combination of intervention tools. Very few water utilities have the necessary expertise in leakage loss management to efficiently undertake a leakage component analysis and design the correct leakage control program. This means that utilities often invest money in leakage control activities (such as simple leak detection programs) that are not based on sound Economic Level of Leakage (ELL) analysis. It is very likely that those programs do not yield the best results. There is industry-wide room for improvement in creating cost-effective and well informed and leakage intervention strategies. Figure ES.1 provides an overview of the literature that includes guidance for each step of developing a real loss reduction strategy and the available software tools for completing each step.

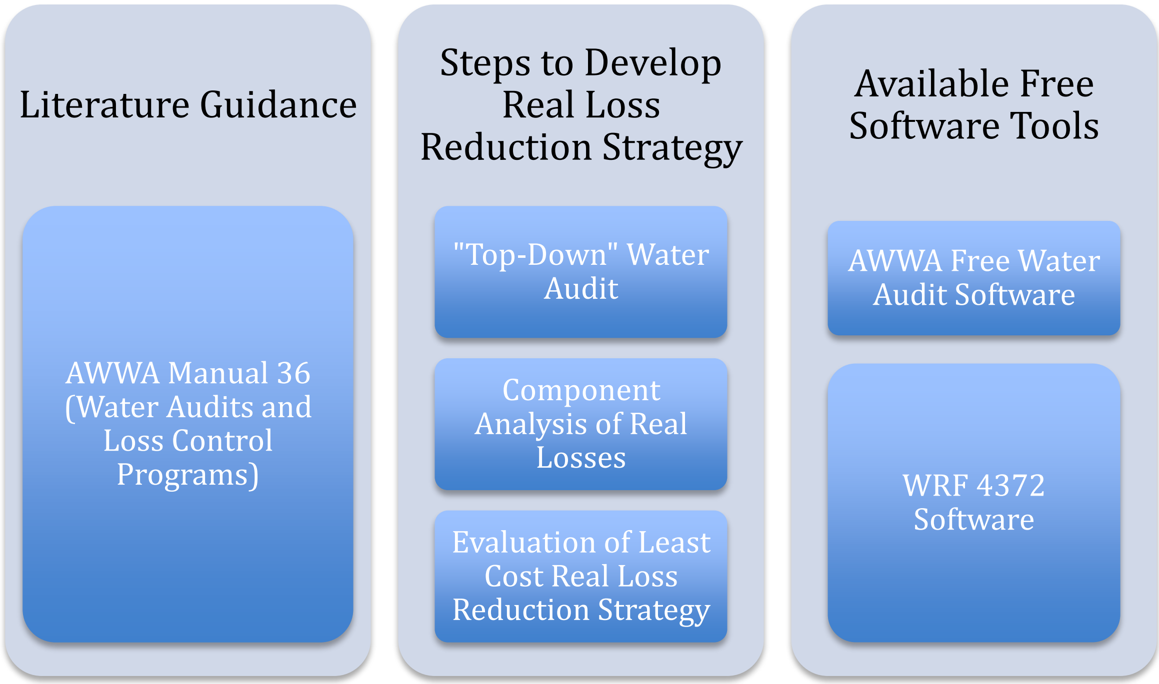


Figure ES.1 Steps to Develop a Real Loss Reduction Strategy and Available Literature and Software Tools for Each Step

This project provides North American water utilities with an analysis tool to better understand the sources of their real losses (reported, un-reported, or background) and a means of analyzing their economic intervention strategies. The tool created, called the Component Analysis Model (the Model) is utility-tested, user-friendly, and accessible while still maintaining a reasonable level of complexity.

APPROACH

The research team worked with 10 participating utilities, representing small, medium, and large water utilities from a variety of geographic regions. The participating utilities were instrumental in assuring that the Model was developed as an accessible tool that fits the needs of utilities nationwide.

The first step in this research project involved surveying the group of participating utilities to gauge general expectations for the Model in its content and complexity. Next, the research team collected and validated the data necessary to run the Model. This data collection included receipt of the following:

- AWWA Water Audit results
- Data on reported and unreported failures repaired during the audit period
- Information on current leakage management practices
- Utility cost data (total cost of operating the system, customer retail cost, variable production cost, cost of most expensive water source)

In parallel, the research team conducted a limited international review of water loss reporting guidelines. This research focused on select countries (Australia, Austria, and New Zealand) where the IWA/AWWA water balance and water loss performance indicators are recommended as best practice by the countries' water industry association/s and where water balance software tools are used to aid the water industry in achieving efficient management of water resources.

The research team also reviewed the guidelines and regulations from nine North American state agencies and organizations that have the most progressive approaches to water loss control. The agencies examined within this research report include the Alberta Urban Municipalities Association, California Urban Water Conservation Council, Delaware River Basin Commission, Georgia Board of Natural Resources, New Mexico Office Of The State Engineer, Tennessee Comptroller of the Treasury, Texas Water Development Board, Washington State Department of Health, and the Wisconsin Public Services Commission. This component of the research effort aimed to position the research project in the context of water loss management throughout the nation. In developing the Model and expanding the array of resources available for utility water loss control programs, it is important to fully appreciate how currently available software tools, such as the AWWA Free Water Audit Software, have been received and adopted.

In the next phase of the project the research team conducted a literature review with the goal of providing an industry average failure frequency and an industry failure frequency benchmark. It is important to note that the term "failure" encompasses all types of utility leaks and breaks. In this effort, literature that addresses the condition of distribution systems was reviewed with reports that included average failure frequencies (defined as the number of failure incidents per length of distribution main per year).

The research team began the Model development in June 2012 and completed the Model in July 2013. Throughout this process the participating utilities were active participants in providing feedback and improving the Model. Upon validating the data from each utility, the research team tested the Model's functionality and use. Working with the participating utilities in this way enabled the research team to develop the Model so that it accommodates most data system approaches. Each participating utility was given a thorough introduction of the Model wherein the research team reviewed the purpose and use of each worksheet. After a couple weeks of using the Model independently, the participating utilities reconnected with the research team to share feedback. This was a critical process in identifying areas of the Model that needed clarification and more instruction.

RESULTS/CONCLUSIONS

The main findings and conclusions of this research project are:

Exemplary countries that pursue proactive leakage management feature freely available software tools. This statement was based on a limited international review focusing on countries (Australia, Austria, and New Zealand) where the IWA/AWWA water balance and water loss performance indicators were a recommended best practice. The review also provided an interesting perspective of water loss performance achieved or targeted in these three countries. Especially in Austria and Australia, water utilities have achieved, on average, very low levels of real losses. For example the Australian Government National Water Commission in its 2011 Annual National Performance Reports reported an average real loss volume for water utilities with more than 100,000 service connections of 18.5 gallons/connection/day.

The adoption and understanding of existing AWWA Free Water Audit Software shows room for improvement. The results from the examination of state agency efforts to require and collect water audits from their member water providers was a very important exercise in understanding the extent to which water loss control software tools have been successfully adopted and properly used. The research team reviewed state agencies that exemplify proactive approaches by applying the industry's best practices in creating regulations and policies around water loss control. In general, the research team found that the data quality of water audits produced by water utilities for their reporting requirements leaves ample room for improvement. For example the water audit results received by the California Urban Water Conservation Council (CUWCC) showed that about 35% of water audits produced by the CUWCC's member agencies contained implausible results. Similar data quality issues were found when reviewing the water audit results from other state agencies. This highlights the industry wide need for further outreach, education, and training in how to conduct a water audit, validate the audit data, and develop water loss control strategies.

Real Loss Component Analysis is relatively new. The first step in this research project involved surveying the group of participating utilities to gauge general expectations for the Model in its content and complexity. Here, the research team found that a majority of the participating utilities selected the "Beginner" (focused on data validation and establishing benchmark performance indicators) or "Intermediate" (focused on implementing initial intervention strategies and improving an existing water loss control program) in describing their water loss control activities. This level of experience appears to be representative of the North American water industry.

The Component Analysis Model was successfully developed and employed by two utilities. The research team successfully developed the Model with significant input from the participating water utilities and the project advisory committee. The Model was designed using a standard Microsoft Office Excel™ software program. The Model was developed with the needs of the utility users in mind to provide a water loss analysis software tool that is accessible, user-friendly, and has a reasonable level of complexity. Each of the participating utilities utilized and tested the model with the results of Eastern Municipal Water District and Water and Wastewater Authority of Wilson County being discussed in this report. For both water utilities the Model helped in breaking down their real loss volume, as determined through the AWWA Free Water Audit, into its components, assessed the volume of hidden leakage (detectable leaks currently running undetected), and evaluated least cost real loss reduction strategies.

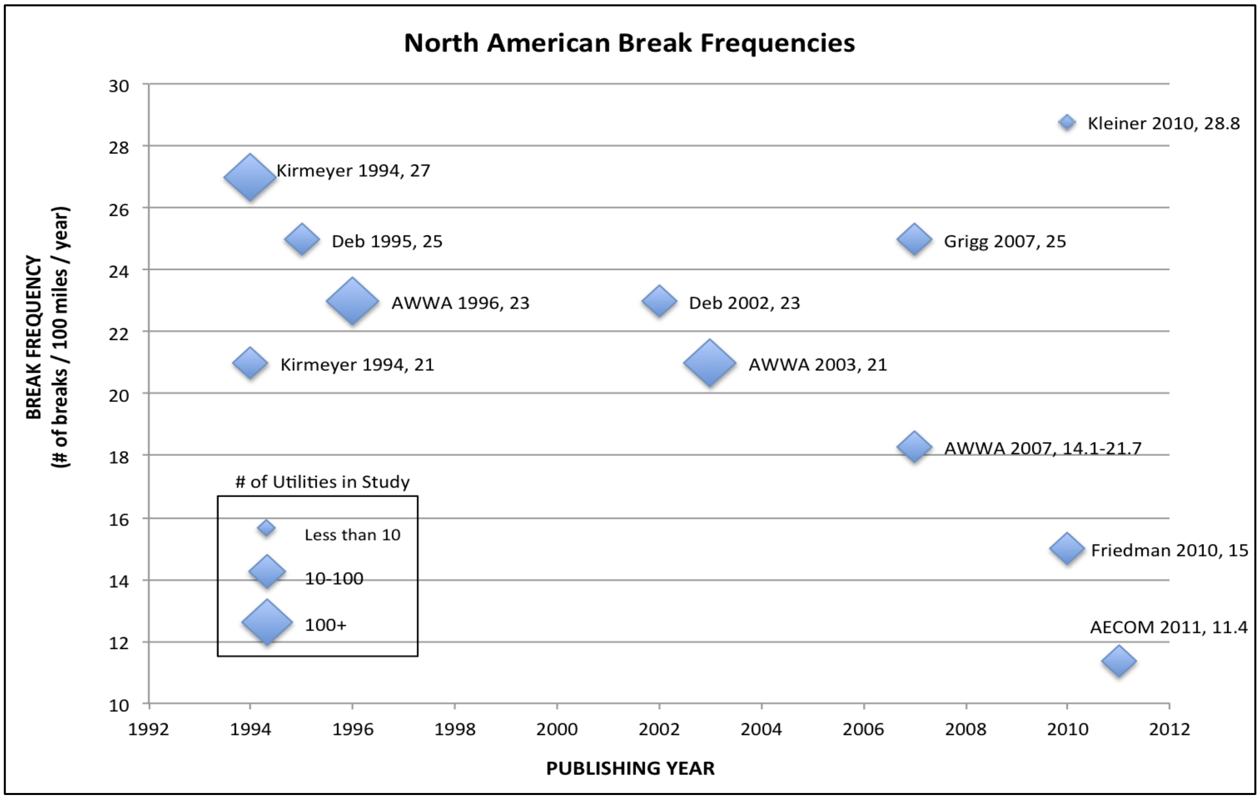
There is ample room for improvement in the data quality of failure records collected by North American water utilities. The research team's failure frequency literature review revealed that the failure repair records collected by North American water utilities are often incomplete (a finding that was supported by the participating utilities' dataset). In light of this, the average failure frequencies as assessed by various industry studies are only best estimates reflecting the quality of available failure data. A majority of the documented failure frequencies in the reviewed literature do not have well characterized source data. In other words, the failure frequencies are reported in aggregate without much detail on the original data or the quality assurance measures taken to calculate the aggregate failure frequency. In this context, it is difficult to distinguish between the failure frequencies on the basis of data source, confidence, and reliability. Several areas in the collection of leak repair data need to be improved in order to achieve a better and more accurate understanding of failure frequencies.

Terminology for documenting pipe failures needs to be consistent. The terminology used by water utilities for documenting pipe failures is highly inconsistent. The terms leak, break, and burst are all used throughout the industry and they may all have different interpretations/definitions depending on the water utility. Some utilities for example categorize a break as a failure event of significant nature that requires immediate action and the term leak is used for smaller pipe failures, which do not require immediate response. Therefore, it was important to feature clear definitions for the failure data inputs needed for the Model developed for this research project. Every failure event in the transmission system, distribution system, and on service connections needs to be documented and used in the Model's leakage component analysis. The term 'failure' is used throughout this report and the model to encompass all leak/break terminology.

A Leak Repair Data Collection Guide was developed. The need to provide clear guidance on failure data collection and documenting was addressed by the research team through the development of a Leak Repair Data Collection Guide in form of an open source MS Office Excel spread sheet.

Failure frequency benchmarks were identified during the literature review. The goal of the failure frequency literature review (see Figure ES.2) was to isolate two failure frequency benchmarks that can be used in the Model for comparison to a typical North American distribution system or to a suggested target for an optimized distribution system. The following failure frequency benchmarks were assessed:

- Aggregate North American failure frequencies based on the data in six studies in the literature review: approximately 25 failures / 100 miles / year.
- Failure frequency goal for an optimized distribution system: 15 failures / 100 miles / year (taken from Friedman et al. 2010).



Source: Compiled. See Table 2.14

Figure ES.2: Diagram of reports that feature North American failure frequencies, organized by year and failure frequency value[1]

APPLICATIONS/RECOMMENDATIONS

The Component Analysis Model (the Model) was developed to provide the water industry with a computer-based model for leakage component analysis, failure frequency analysis, economic leakage control intervention strategy evaluation, and display of key water loss performance indicators. The Model is a complementary analysis tool to the AWWA Free Water Audit Software and was designed using a standard Microsoft Office Excel software program. The Model was developed with the needs of the utility users in mind to provide a water loss analysis software tool that is accessible, user-friendly, and has a reasonable level of complexity.

The research team is careful to acknowledge that the Model is only as useful and instructive as the quality of the user's inputs. Throughout the instructions provided in the Model (and throughout this report), there is particular emphasis on the importance of data quality and validation. In making the Model freely available and encouraging its adoption, the research team will continue to highlight the importance of data quality.

[1]NOTE: the break frequency as provided in Friedman 2010 represents a goal for an optimized distribution system and is therefore not directly comparable to the other average break frequencies as cited by the other studies.

Furthermore it is important to highlight that the Model requires a significant amount of validated data and its "outputs" are meant to provide opportunities to test scenarios but do not represent concrete goals or hard and fast targets. The Model is a dynamic tool meant for guidance and not a mechanism for direct reporting like the AWWA software or regulatory target setting.

In addition to the model the research team developed a Leak Repair Data Collection Guide in the form of an open source MS Office Excel spreadsheet to aid the industry in collecting consistent failure data. This tool offers guidance to water utilities as a standardized format to document failure events; thereby generating the appropriate data to execute a reliable leakage component analysis. Utilities that carefully document all failure events have a means to define failure trends occurring in their system.

MULTIMEDIA

The Component Analysis Model and the Leak Repair Data Collection Guide, both MS Office Excel spreadsheets, can be downloaded from the WRF Website by clicking on their respective links.

CHAPTER 1
INTRODUCTION

BACKGROUND

Water utilities, regulatory agencies and a variety of stakeholders continue to increase focus on infrastructure management and water efficiency due to continuing droughts, the increasing cost of providing potable water to customers, potential health risks posed by leaking pipes, and heightened awareness of the increasing cost of leakage. In fact, the Water Research Foundation (WRF) project #4109 *Criteria for Optimized Distribution Systems* considers leakage as one of three key indicators of distribution system management performance (Friedman et al. 2010) and is being considered for adoption by AWWA's Partnership for Safe Water Program.

Nevertheless, the vast majority of North American (NA) water utilities only employ a reactive leakage management strategy, repairing failures that have been reported to them in a more or less timely manner. As a result of employing reactive leakage management strategies, water utilities continue to see an increase in leakage losses due to a rising backlog of unreported failures in their distribution system. This is in spite of the fact that industry research and case studies have sufficiently demonstrated the benefits of proactive leakage management. The drinking water industry stands to benefit greatly in transitioning from purely reactive leakage management, as employed by most water utilities today, to proactive leakage management allowing them to achieve and sustain substantial reductions in leakage losses in an efficient and economic manner.

The first step towards proactive leakage management is to conduct a standard International Water Association (IWA)/American Water Works Association (AWWA) water audit. In 2009, the AWWA Water Loss Control Committee (WLCC) published its 3rd edition of the AWWA Manual M36 *Water Audits and Loss Control Programs*, providing the NA water industry with guidance on the IWA/AWWA water auditing methodology. It details proactive and advanced leakage management technologies and approaches. The WLCC also released its AWWA Free Water Audit Software, allowing water utilities to quickly compile a standardized preliminary water audit. These AWWA resources are well complemented by the latest two water loss control related WRF reports; *Evaluating Water Loss and Planning Loss Reduction Strategies* and *Leakage Management Technologies* and by the McGrawHill textbook *Water Loss Control 2nd Edition.*

Figure 1.1 provides the standard IWA/AWWA water balance format and the following section provides the respective water balance definitions (adapted from Fanner et al. 2007).

<table>
<tr><td rowspan="9">System Input Volume (allow for known errors)</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="7">Non-Revenue Water (NRW)</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Apparent Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Customer Metering Inaccuracies and Data Handling Errors</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage on Transmission and/or Distribution Mains</td></tr>
<tr><td>Losses at Utility's Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to Point of Customer Use</td></tr>
</table>

Source: Adapted from Fanner et al. 2007

Figure 1.1 Standard water balance and terminology for finished water systems

Water Balance Definitions

In the following, all terms used in Figure 1.1 are listed in hierarchical order – as one would read the water balance form from left to right. Some of the terms are self-explanatory but are still listed and briefly explained in order to having a complete list available.

System Input Volume

The volume of treated water input to that part of the water supply system to which the water balance calculation relates. Equal to Own Sources plus Water Imported:

- Own Sources: The volume of (treated) water input to a distribution system from the water supplier's own sources allowing for known errors (for example source meter inaccuracies). The quantity should be measured after the utility's treatment plant(s). If there are no meters installed after the treatment plant, the output has to be estimated based on raw water input and treatment losses.
- It is important to note that water losses at raw water transmission pipelines and losses during the treatment process are not part of the Annual Water Balance calculations shown in this report. However, a separate audit of the transmission system and water treatment works can be performed if desired.
- Water Imported: The volume of bulk supplies imported across operational boundaries. Water imported can be either
  - Measured at the boundary meter (if already treated)
  - Measured at the outflow of the treatment plant (if raw water is imported and there is a separate treatment plant)

  - In either case, corrected for known errors (for example transfer meter inaccuracies).
- Mix of raw water: If raw waters imported are mixed with own source raw water in the treatment plant, there is no need for a differentiation and the total production (output) of this one or more plant(s) is used as basis for the System Input. As always, corrections have to be made for known errors As with the 'Own Sources', it is important to note that water losses at raw water transmission systems and losses during the treatment process are not part of the Annual Water Balance calculations. In case the utility has no distribution input meters, or they are not used and the key meters are the raw water input meters, because these are the meters that they buy the raw water on, the system input has to be based on the raw water meters and treatment plant use/loss has to be taken into account.

Authorized Consumption

The volume of metered and/or unmetered water taken by registered customers, the water supplier and others who are implicitly or explicitly authorized to do so by the water supplier, for residential, commercial and industrial purposes. It also includes water exported across operational boundaries.

Authorized consumption may include items such as firefighting and training, flushing of mains and sewers, street cleaning, watering of municipal gardens, public fountains, frost protection, building water, etc. These may be billed or unbilled, metered or unmetered.

Water Losses

The difference between System Input and Authorized Consumption. Water losses can be considered as a total volume for the whole system, or for partial systems such as transmission or distribution systems, or individual zones. Water Losses consist of Real Losses and Apparent Losses.

Billed Authorized Consumption

Those components of Authorized Consumption which are billed and produce revenue (also known as Revenue Water). Equal to Billed Metered Consumption plus Billed Unmetered Consumption.

Unbilled Authorized Consumption

Those components of Authorized Consumption which are legitimate but not billed and therefore do not produce revenue. Equal to Unbilled Metered Consumption plus Unbilled Unmetered Consumption.

Apparent Losses

Includes all types of inaccuracies associated with customer metering as well as data handling errors (meter reading and billing), plus unauthorized consumption (theft or illegal use).

It is important to note that reducing apparent losses will not reduce physical water losses but will recover lost revenue.

Note: Over-registration of customer meters, leads to under-estimation of Real Losses. Under-registration of customer meters, leads to over-estimation of Real Losses.

Real Losses

Physical water losses from the pressurized system and the utility's storage tanks, up to the point of customer use. In metered systems this is the customer meter. In unmetered situations this is the first point of use within the property, as illustrated in Figure 2 4.

The annual volume lost through all types of leaks, breaks and overflows depends on frequencies, flow rates, and average duration of individual leaks, breaks and overflows.

Note: Although physical losses, after the point of customer use, are excluded from the assessment of Real Losses, this does not necessarily mean that they are not significant or worthy of attention for demand management purpose.

Billed Metered Consumption

All metered consumption which is also billed. This includes all groups of customers such as domestic, commercial, industrial or institutional and also includes water transferred across operational boundaries (water exported) which is metered and billed.

Billed Unmetered Consumption

All billed consumption which is calculated based on estimates or norms but is not metered. This might be a very small component in fully metered systems (for example billing based on estimates for the period a customer meter is out of order) but can be the key consumption component in systems without universal metering. This component might also include water transferred across operational boundaries (water exported) which is unmetered but billed.

Unbilled Metered Consumption

Metered Consumption which is for any reason unbilled. This might for example include metered consumption by the utility itself or water provided to institutions free of charge, including water transferred across operational boundaries (water exported) which is metered but unbilled.

Unbilled Unmetered Consumption

Any kind of Authorized Consumption which is neither billed nor metered. This component typically includes items such as firefighting, flushing of mains and sewers, street cleaning, frost protection, etc. It is a small component which is very often substantially overestimated. Theoretically this might also include water transferred across operational boundaries (water exported) which is unmetered and unbilled – although this is an unlikely case.

Unauthorized Consumption

Any unauthorized use of water. This may include illegal water withdrawal from hydrants (for example for construction purposes), illegal connections, bypasses to customer meters or meter tampering.

Customer Metering Inaccuracies and Data Handling Errors

Customer Metering Inaccuracies. Apparent water losses caused by customer meter inaccuracies, typically from meters under-registering customer consumption due to a variety of causes; thereby measuring a lower volume than the customer population actually consumed.

Data Handling Errors. Apparent losses caused by structural or random errors existing in the customer reading, data transfer (to the billing system), accounting or archival functions of customer consumption management. Billing systems – designed chiefly for revenue collection and financial accounting – often fail to include sufficient controls to maintain customer consumption data integrity. Inaccurate estimates, poor adjustment protocols and lack of accountability procedures to ensure that all users exist with active accounts in the billing system are several of the many possibilities that can understate or omit actual water volumes in customer consumption records.

Leakage on Transmission and/or Distribution Mains

Water lost from leaks and breaks on transmission and distribution pipelines. These might either be small leaks which are still unreported (e.g. leaking joints) or large breaks which were reported and repaired but did leak for a certain period before that.

Losses at Utility's Storage Facilities

Losses from leaking treated water storage facilities caused by e.g. operational or technical problems. These losses include leakage through the tank structure, overflows, evaporation etc.

Leakage on Service Connections up to point of Customer Use

Water lost from leaks and breaks of service connections from (and including) the tapping point until the point of customer use. In metered systems this is the customer meter, in unmetered situations this is the first point of use within the property. Leakage on service connections might be reported breaks but will predominately be small leaks which do not surface and which run for long periods (often years).

Revenue Water

Those components of Authorized Consumption which are billed and produce revenue (also known as Billed Authorized Consumption). Equal to Billed Metered Consumption plus Billed Unmetered Consumption.

Non-Revenue Water

Those components of System Input which are not billed and do not produce revenue. Equal to Unbilled Authorized Consumption plus Real and Apparent Water Losses.

Generally, NA water utilities are still under little or no regulatory pressure to efficiently control leakage losses; however, a few agencies have created new regulations or are closely evaluating the IWA/AWWA Water Audit Methodology. These include the Alberta Urban Municipalities Association, California Urban Water Conservation Council, Delaware River Basin Commission, Georgia Board of Natural Resources, New Mexico Office of the State Engineer, Tennessee Comptroller of the Treasury, Texas Water Development Board, Washington State Department of Health, and the Wisconsin Public Services Commission.

The benefits of proactive leakage management have also seen increasing interest from energy providers and regulators of energy utilities. A recent research study conducted by Water Systems Optimization (WSO) for Southern California Edison (SCE) and the California Public Utilities Commission (CPUC) assessed the potential for achieving sustainable leakage loss savings and related embedded energy savings by implementing proactive leakage loss control programs in several California water utilities. This research study included detailed AWWA water audits, component based leakage analyses, design of economically optimum leakage intervention strategies, and implementation of leakage loss reduction pilots. The independent evaluation of the research study results revealed that proactive leakage loss control provided the highest savings in water and embedded energy when compared against eight other research pilots, which all focused on demand side water conservation and related energy savings.

The available AWWA and WRF literature provides all the necessary theoretical background on how to accurately assess leakage losses and plan efficient and economic leakage control interventions. The AWWA Manual 36 provides comprehensive guidance for all steps involved in undertaking a “top-down” water audit, component analysis of real losses and planning and implementing a real loss control program. The AWWA Free Water Audit Software serves as a basic tool to compile a “top-down” water audit, which is the first step in developing a water loss control program. Once the overall system wide volume of real losses has been determined, this volume needs to be broken down into individual components of real losses/leakage by use of component analysis modeling. A leakage component analysis disaggregates the total volume of Real Losses as calculated in the water audit into its three components: Background Leakage, Unreported Leakage and Reported Leakage. By combining the component analysis with an economic intervention strategy analysis it is possible to calculate how much of each leakage component can be economically reduced through the right combination of intervention tools. Only very few water utilities have the necessary expertise in leakage loss management to efficiently undertake a leakage component analysis and design the correct leakage control program. This means that, for the most part, when utilities invest money in leakage control activities such as simple leak detection programs, they are usually not based on sound Economic Level of Leakage (ELL) analysis. As a result it is very likely that those programs do not yield the best results.

This project provides NA water utilities with a utility-tested software analysis tool that complements the AWWA Free Audit Software to undertake leakage component analyses and economic intervention strategy analyses, named the Component Analysis Model (Model). Access to this tool will enable utilities to design and implement efficient, sustainable, and optimized leakage control programs.

This project has been designed to provide NA water utilities with the missing water loss analysis software tools in form of an accessible, user-friendly computer based tool that has a reasonable level of complexity.

REPORT STRUCTURE

This report outlines the main functions of the Model and provides case studies that detail how two utility datasets were applied to the Model. It also outlines the background research that provided valuable lessons in the development of the Model.

Chapter 2 provides a review of the research conducted for this project. This chapter has two main parts: 1) it provides context for the Model's development, detailing the landscape of relevant regulations, guidelines, and similar software models in the water loss field (both in the United States and internationally), and 2) it compiles average failure frequencies in North American utilities for use in a comparison featured in the Model.

Chapter 3 provides a description of the utilities that participated in the Model's development ("Participating Utilities"). The Participating Utilities provided water audit data and infrastructure repair data to allow for beta-testing of the Model. This section describes the basic characteristics of the Participating Utilities and summarizes how they contributed to the Model development.

Chapter 4 outlines the Model in detail. It addresses the functionality and intended use of each worksheet featured in the Model.

Chapter 5 provides two case studies, outlining all of the necessary data inputs for use of the Model from two utilities, Eastern Municipal Water District and the Water and Wastewater Authority of Wilson County. For each worksheet of the Model, each case study provides background information and outlines the data validation steps taken for all input data. This report includes detailed examples of Model application to stress the importance of the quality of the input data.

Chapter 6 summarizes the results and application recommendations for utilities.

Appendix A outlines the literature review of North American and international average failure frequencies.

CHAPTER 2
REVIEW OF NORTH AMERICAN AND INTERNATIONAL WATER LOSS REPORTING GUIDELINES

INTRODUCTION

The goal of this research component was to conduct a limited review of NA and international literature:

- to present select international water loss control reporting guidelines,
- to review water audit reporting guidelines of several US states and Canadian territories and collected water audit data sets from these states and territories,
- to provide a general review of the spectrum of free and commercially available water loss control software tools,
- and to review failure frequency literature to provide utilities a failure frequency comparison against an industry average failure frequency.

LITERATURE REVIEW OF SELECT INTERNATIONAL WATER LOSS REPORTING GUIDELINES

Background

The research team has focused the limited international review of water loss reporting guidelines on select countries where the IWA/AWWA water balance and performance indicators for assessing water losses are recommended as best practice by the countries' water industry association/s, and where water balance software tools are used to aid the water industry in achieving efficient management of water resources. Australia, New Zealand, and Austria are the countries reviewed in this section.

Australia

The Australian Water Industry consists of some 300 water utilities. The Water Services Association of Australia (WSAA) represents the urban water industry, and has twenty members that provide services to 60% of the population. Another 70 Utilities service 20% of the population, and the remainder (around 200) serve the remaining 20% of the population (Fantozzi et al. 2006).

Most authorities/utilities are publicly owned in Australia and many are still overtly part of Government or Local Governments. Much of Australia has suffered long and severe droughts over the past five years, and water loss management has gained a high priority nationally. Therefore, the Australian water industry has seen some significant progress in leakage management regulations and practices over the past several years. The IWA Standard Water Balance has been adopted by all of the key associations in Australia; nationally by the WSAA, and on State basis by organizations such as the Queensland Water Directorate, the New South Wales Water Directorate, etc. (Fanner et al. 2007).

In 2004, an intergovernmental agreement - the National Water Initiative (NWI) - was signed, with the Tasmanian Government joining in June 2005 and the Western Australia Government joining in April 2006. The NWI represents a shared commitment by governments to increase the efficiency of Australia's water use, leading to greater certainty for investment and productivity, for rural and urban communities, and for the environment (National Water Commission 2011b).

Queensland: In July 2010, the Director-General of the Department of Environment and Resource Management (DERM), the regulator, issued guidelines for the preparation of a System Leakage Management Plan (SLMP).Under this Act, each registered water service provider in Queensland must prepare a SLMP in accordance with the guidelines and submit it to the regulator for approval. The guidelines do not specifically prescribe a methodology for determining distribution system leakage volumes or measures for reducing and managing leakage losses. However, it references existing guidelines and manuals that describe best practices in relation to water loss assessment and management. These reference guidelines are all in accordance with IWA best practice for water audits and water loss control.

Under this Act the service providers have to determine and report the volume of water currently lost from the distribution system through leakage and identify and document the leakage reduction measures to be implemented. The service provider has to determine and document leakage reduction measures that are cost-effective. The guidelines prescribe a rather comprehensive cost effectiveness assessment, requiring the service providers to consider the following in determining cost effective measures:

- Cost of water (retail cost of water) currently lost through leakage that can be reduced by the documented intervention measures.
- Cost of developing and implementing the leakage reduction program.
- Estimated reduction in operation and maintenance cost by considering reduction in cost for power and chemicals, reduced incidents of pipe bursts, and reduced cost of bulk water purchased.
- Estimated cost saved by deferral or avoiding the need to construct new water infrastructure such as water treatment plants and augmentation of water sources such as dams, weirs and bores.

The cost effectiveness has to be assessed for a period appropriate for the leakage reduction measure – a minimum period of five years is to be used. The SLMP required by the Queensland Government appears to be very progressive and comprehensive with requirements aimed at achieving and maintaining low levels of system leakage, following principles of cost effectiveness (DERM 2010).

On a statewide level the Australian Government National Water Commission is providing annual National Performance Reports. The latest in a series of annual National Performance Reports was published in April 2011. The National Performance Reports provide a public and independent report on the performance of Australian Water Utilities. The report states that; "governments, industries and the community have a vital interest in obtaining good quality information on how well their water utilities are performing, and whether their water needs are being met efficiently and sustainably" (National Water Commission 2011a). The report also provides information on mains failure frequencies and the real loss performance indicator (real losses (liters) / service connection/ day). Table 2.1 provides a summary of the real loss performance indicators reported by Australian water utilities grouped utility size. The published real loss performance indicators for 2009-2010 show that Australian water utilities have achieved – on average – very low levels of real losses in their systems.

Table 2.1
Real loss performance indicator results from Australian National Performance Reports

	Real Losses (L/service connection/day)		
Size Group	High	Average	Low
100,000+ connected properties	113	70	46
50,000 to 100,000 connected properties	162	60	21
20,000 to 50,0000 connected properties	445	82	28
10,000 to 20,000 connected properties	349	119	24
	Real Losses (gal/service connection/day)		
Size Group	High	Average	Low
100,000+ connected properties	29.9	18.5	12.2
50,000 to 100,000 connected properties	42.8	15.9	5.5
20,000 to 50,000 connected properties	117.6	21.7	7.4
10,000 to 20,000 connected properties	92.2	31.4	6.3

Source: National Water Commission 2011a

A standardized software package (Benchloss) for developing an IWA water balance and performance indicators was published in 2000 and was commissioned by WSAA. This clearly aided the industry to assess and report water loss volumes in a standardized way allowing for meaningful performance metrics and process benchmarking. In 2009, the WSAA funded and released a revised water balance software that replaced Benchloss. The updated water balance software (provisionally named Australian National Water Balance Software, ANWBS) is free to all Australian water utilities including non-WSAA members and was designed to facilitate ongoing National Performance Reporting by all Australian Water Utilities that meet the National Performance Framework size criteria (currently 10,000 or more service connections) (WSAA 2009). In addition there are customized water balance software packages for Queensland and New South Wales reflecting their regional regulations and reporting requirements. Both the customized software packages for Queensland and New South Wales follow the standardized IWA water balance and performance indicator best practices.

New Zealand

In 2002, New Zealand was one of the first countries to adopt the IWA best practice for establishing a water balance and calculating water loss performance indicators. Water New Zealand (the New Zealand Water & Wastes Association Wairoa Aotearoa) commissioned the development of a water audit and performance indicator software BenchlossNZ, which was published together with a user manual in 2002. In 2008 the software and user manual were updated to include the World Bank Institute's real loss performance banding system (see Table 2.2).

However, since providing the update to the software tool and user guide, Water New Zealand has not maintained its proactive trajectory due to a lack of implementation and enforcement. "Despite being one of the first countries (in 2002) to produce nationally available standard best practice water balance software based on the IWA methodology, updated in 2008, New Zealand now increasingly lags behind many other countries in using these tools. There is no national requirement in New Zealand to report and publish performance in managing non-revenue water and its components. Although a few water suppliers in the Auckland area have achieved real losses within the top World Bank Institute Band (A), in others the level of losses are still too high, and in many system it appears that no assessments of losses have yet been made" (Water New Zealand 2010).

In February 2010, Water New Zealand published Water Loss Guidelines for the New Zealand water industry. These Water Loss Guidelines – in combination with the already available software packages (BenchlossNZ and CheckCalcsNZ) – were developed to provide water suppliers in New Zealand with the necessary tools to analyze the level of water losses in a distribution network and to help water suppliers to reduce water losses to a level deemed reasonable and appropriate. The Water Loss Guidelines are structured into six sections. Section One provides a summary of the recommended approach to a successful water loss control strategy. All water loss assessment and control activities considered appropriate for water utilities in New Zealand are listed with a distinction between basic and advanced levels of operation. Section Two discusses the recommended approach for assessing the real losses for any given system. Depending on system size and whether residential customers are metered or not, the IWA water balance and/or the Minimum Night-Time Flow analysis are recommended. Section Two also discusses the available software tools, IWA Standard Water Balance terminology, performance indicators, and benchmarking. Section Three provides guidance in understanding the effects of uncertainties in the data used for water loss assessment. Section Four outlines how to best reduce data errors, and Section Five presents information on assessing real losses from the IWA water balance and/or the Minimum Night-Time Flow analysis. Section Six provides practical and basic explanations of leakage and pressure management analysis and concepts deemed to be fundamental for effectively managing Real Losses.

In summary, "these Water New Zealand Water Loss Guidelines are aimed at providing all Water Suppliers in New Zealand with the means to first assess their water losses, then develop an effective water loss strategy for any distribution system, large or small. The objective of a water loss strategy should be to reduce the level of real water losses from the water distribution network to an acceptable level based on Public Health, Customer Service, Ecological, Environmental and Economic aspects" (Water New Zealand 2010).

Austria

In 2009, the Austrian Association of Gas and Water (OVGW) published new guidelines for water loss assessment and management. These guidelines OVGW W63 are entitled; Water Losses in Water Supply Systems: Assessment, Evaluation and Measurement for Water Loss Reduction (OVGW 2009). This guideline was developed to reflect current international best practice in water loss assessment and management and to aid Austrian water utilities in evaluating, monitoring and reducing system water losses. Guideline W63 helps Austrian water utilities achieve the goals of the OVGW W100 guideline, which calls for the limitation of water losses as a major maintenance aim for any drinking water supply system.

Water losses are assessed and reported annually in Austria following the guidelines of the OVGW W63. It is worth noting that the guidelines provide five key arguments for water loss management and reduction in Austria; ecological arguments, hygiene arguments, economical arguments, legal arguments, and supply technical arguments.

The W63 guideline describes and explains how to conduct a standard IWA water balance and describes five recommended water loss performance indicators to be used; namely water loss as a percentage of system input volume (note: it is explicitly stated not to use this indicator for technical interpretation), real losses per mains length, real losses per service connection per day, Infrastructure Leakage Index, and non-revenue water as a ratio of system input volume. The updated Austrian guidelines also introduced a real loss performance classification scheme that is based upon the World Bank Institute's banding system, which utilizes the Infrastructure Leakage Index (ILI) to classify the leakage loss performance of distribution systems. The World Bank Institute's grading system is shown in Table 2.2.

Table 2.2
World Bank Institute real loss banding system

Classification	ILI	Level of Losses
A	Below 2	low leakage losses
B	Between 2 & 4	medium leakage losses
C	Between 4 & 8	high leakage losses
D	Above 8	very high leakage losses

Source: Liemberger and McKenzie 2005.

From the ILI grading system, the Austrian guidelines have created a "Real Losses per service connection per day" classification scheme, which enables the consideration of structural parameters such as service connection density and average system pressure. This modified classification scheme has been created on the basis of the Unavoidable Annual Real Loss (UARL) formula (see Table 2.3 for UARL components).

Table 2.3
Unavoidable Annual Real Loss Components

Infrastructure Component	Units	Real Loss Component			
		Background Leakage	Reported Failures	Unreported Failures	Total
Mains	(g/mile of underground pipe/day/psi)	2.87	1.75	0.77	5.39
Services, Main to Curb-stop	(g/conn/day/psi)	0.112	0.007	0.030	0.149
Services, Curb-stop to Meter	(g/mile of underground pipe/day/psi)	4.78	0.57	2.12	7.47

Source: Adapted from Lambert et al. 1999

An example of the Austrian leakage classification scheme utilizing the Operational Performance Indicator (OP24), real losses per connection per day, converted from metric units to the volume unit of gallons is provided in Table 2.4 for systems with average system pressure between 28psi and 57psi and service connection densities between 16 and 80 service connections per mile of distribution main.

Table 2.4
Austrian Classification Scheme for Real Losses per Connection per Day

service connection density (No./mile)	Real losses per connection per day [gal/(connection*d)] at an average service pressure of											
	28 psi				43 psi				57 psi			
16	<29	29-58	58-115	>115	<44	44-86	86-173	>173	<58	58-115	115-230	>230
	A	B	C	D	A	B	C	D	A	B	C	D
24	<22	22-45	45-90	>90	<34	34-67	67-135	>135	<45	45-90	90-180	>180
	A	B	C	D	A	B	C	D	A	B	C	D
32	<20	20-38	38-77	>77	<29	29-58	58-116	>116	<38	38-77	77-154	>154
	A	B	C	D	A	B	C	D	A	B	C	D
48	<16	16-32	32-65	>65	<24	24-49	49-96	>96	<32	32-65	65-129	>129
	A	B	C	D	A	B	C	D	A	B	C	D
64	<15	15-29	29-58	>58	<22	22-44	44-87	>87	<29	29-58	58-116	>116
	A	B	C	D	A	B	C	D	A	B	C	D
80	<13	13-28	28-54	>54	<20	20-41	41-82	>82	<28	28-54	54-108	>108
	A	B	C	D	A	B	C	D	A	B	C	D

Source: Koelbl 2009.

The new Austrian guidelines W63 have now been in place for two years and the Austrian OVGW (Committee of experts for water supply technologies, TAK water losses) has reported that the new guidelines have been well received and adopted with about 50 percent of the distribution systems reaching an ILI below 2 or real loss classification band A (Koelbl 2012 and 2009).

The OVGW provides its members with an Excel spreadsheet for calculating water losses according to the guidelines set forth in the OVGW W63.

Summary

The limited international review of water loss reporting guidelines on select countries where the IWA/AWWA water balance and performance indicators for assessing water losses are recommended as best practice by the countries water industry association/s, indicates that the availability of free water balance software tools to aid the water industry in achieving efficient management of water resources is an important component. The review also provided an interesting prospective of water loss performance achieved or targeted in these three countries. Especially water utilities in Austria and Australia appear to have achieved, on average, very low levels of real losses in their systems.

REVIEW OF NORTH AMERICAN WATER AUDIT REPORTING REGULATIONS AND GUIDELINES

Background

This component of the research effort aims to position the research project in the context of water loss management throughout the nation. In developing the Model and expanding the array of resources available for utility's water loss control programs, it is important to fully appreciate how available software tools, such as the AWWA Free Water Audit Software, have been received and adopted. Toward that end, the research team reviewed the guidelines and regulations from the state agencies and organizations that have the most progressive approaches to water loss control. As of 2013 the California Urban Water Conservation council was the only agency/organization requiring that a leakage component analysis is carried out by its member agencies.

It is important to note that these state agencies are not representative of the average nationwide positions in regard to water loss management. In fact, the Alliance for Water Efficiency's analysis of all 50 states' regulations and policies on water efficiency and conservation, "The Water Efficiency and Conservation State Scorecard", shows that only 21 states have any regulation or policy that specifically address distribution water loss (AWE 2012).

The research team selected specific case studies that exemplify proactive approaches that apply the industry's best practices in creating regulations and policies around water loss control. Policies detailed in The Water Efficiency and Conservation State Scorecard (specifically those in New Hampshire and New Jersey) were not reviewed because they do not adhere to the recommended best practices of AWWA. Table 2.11 at the end of this section lists all of the agencies reviewed and summarizes each water loss guideline or regulation. In addition to a review of the regulatory frameworks, this section describes insights from interviews with agency representatives, providing useful information on the adoption and implementation of water loss control tools and regulations.

Alberta Urban Municipalities Association (AUMA)

Accounting & Reporting Regulations or Guidelines

AUMA represents 277 urban municipalities throughout Alberta, and in November 2009 the organization adopted a Conservation, Efficiency and Productivity Plan (CEP) with the support of its members. The CEP outlines conservation targets. The most recent version – approved in February of 2011 – articulates the following goal: "By December 31, 2012, urban municipalities will complete a water audit and identify ways to reduce leaks" (AUMA 2011).

The CEP does not aim for every single utility to participate by this date. Instead the plan outlines a staged adoption by size. By the deadline, 100% of municipalities with populations greater than 10,000 will comply; 75% of municipalities with populations between 2,500 and 10,000 will comply; and 50% of municipalities with populations under 2,500 will comply (AUMA 2011). The CEP highlights the AWWA/IWA methodology as the recommended industry standard in completing this guideline.

Implementation Experience

Discussion with AUMA revealed that implementation of the water audit components of the CEP has been challenging. Those who participated in the approval of AUMA's targets were elected officials and chief administrative officers, whereas those responsible for implementing the goals around water auditing are the operations and engineering teams, who did not participate as actively in the approval and evaluation of these goals (Bocock and Fisher 2012).

Though the goal-setting process was regarded as successful, the actual water audit implementation and collection process has proven difficult. A majority of AUMA's member utilities serve less than 2,500 people. It was reported that these utilities have little internal capacity to compile the data for a water audit. Further, they have received feedback that the AWWA Free Water Audit software does not work well with small service connection densities; it provides limited performance indicator data. (Bocock and Fisher 2012).

AUMA is currently reconsidering how best to encourage implementation of the water auditing process. Collaboration with the Alberta Department of the Environment and Sustainable Resource Development and/or private water service provides are being explored as possible solutions. (Bocock and Fisher 2012).

California Urban Water Conservation Council (CUWCC)

Accounting & Reporting Regulations or Guidelines

The CUWCC is an organization that brings urban water agencies, public interest organizations, and private entities together to achieve water use efficiency gains in California. To date, 195 retail water utilities have signed a Memorandum of Understanding, and in doing so, each utility committed to implementing fourteen conservation Best Management Practices (BMP) (CUWCC 2011).

Two of the BMP categories are considered "foundational" as they are essential to operations; therefore, all signatories have agreed to implement them on an ongoing basis. Within the foundational BMP category of "Utility Operations", BMP 1.2 as revised in September 2009 outlines the requirements of a water loss control program. The components of the 10-year program are included in Table 2.5, which highlights the different components of the implementation expectations. It is important to note that the first half of the 10-year program focuses on data validation and water loss accounting. The second phase of the program will establish benchmarks and holds each agency accountable for water loss improvement. (CUWCC 2009).

Table 2.5
CUWCC Implementation Components of BMP 1.2

Water Loss Control Program Component	Instruction Description	Frequency/Timing
Standard Water Audit & Water Balance	Complete the AWWA Water Loss software to quantify the volumes and costs of real and apparent losses.	Annually
Validation	Follow AWWA methods to improve the validity of the data used for water balance to achieve an AWWA data validity score of 66 and later satisfy data validity Level IV. By the 2nd year of implementation, test all source import and production meters annually.	4 years allotted for data validity score 66 attainment; by 5th year, Level IV
Economic Values	Determine the economic value of real loss recovery, using the guidelines outlined in the Council's Avoided Cost Model.	Annually
Component Analysis	Conduct a component analysis to failure apparent and real losses down into volumes categorized by cause.	At least once every 4 years
Interventions	Reduce real losses to the extent cost-effective: repairing all reported and unreported leaks as dictated by economic analysis. By the second year of implementation, maintain a record keeping system for repair of reported leaks.	Continuous
Customer Leaks	Alert and advise customers when leaks appear on customer's side of the meter.	Continuous

Source: Adapted from California Urban Water Conservation Council 2009.

The CUWCC commits its signatories to these to achieve water savings via recovery of distribution water losses. The following progress is outlined in the BMP 1.2:

Beginning in the fifth year of implementation, through the tenth year of implementation, agencies shall demonstrate progress in water loss control performance as measured by the AWWA software real loss performance indicator 'gallons per service connection per day', 'gallons per mile of mains per day' or other appropriate indicator by one of the following:

a) Achieving a performance indicator score less than the agency's score the previous year;
b) Achieving a performance indicator score less than the average of the agency's scores for the previous three years; or
c) Achieving a performance indicator score in the top quintile (20%) of all signatory agencies reporting such performance indicator with a Data Validity Level IV; or ;

d) In year 6 and beyond reducing real losses to or below the benchmark value (CUWCC 2009).

The benchmark value referred to in part "d" will be determined by the Council in 2015 upon collecting the first five years of water balance data from its signatory agencies.

Implementation Experience:

The CUWCC provided six two-day workshops for CUWCC member agencies between September 2010 and May 2012. The workshops were designed to provide training on water audit concepts, data validation, reporting requirements, how to use the AWWA Free Audit Software, design of water loss control programs, and hands on leak detection training. CUWCC member agencies provided their first full BMP 1.2 report by December 1, 2010 for years 2008-2009 and 2009-2010.

Review of BMP1.2 Water Audit Data Set

The CUWCC provided their complete water audit data set for the all of their BMP1.2 reporting periods. All water audits were provided in the AWWA Free Audit Software as received by the CUWCC from its member agencies. The research team then compiled the most recent audit for each participant in the AWWA Free Audit Software Compiler for further analysis. A total of 130 water audits were reviewed.

The water audit data set and its standard water loss performance indicators were reviewed for general data quality issues. The first step was to eliminate results that are physically impossible, such as negative water losses. This happens when the reported volume of water sold to customers is larger than the reported volume of water supplied into the distribution network.

Once the data from utilities reporting negative water losses was removed, the Infrastructure Leakage Index (ILI) performance indicator was used as the next filter/data evaluation criteria. The ILI is a dimensionless ratio between the Current Annual Real Loss volume (CARL) and the Unavoidable Annual Real Loss volume (UARL). UARL is the technical minimum volume of leakage losses that can be achieved in any given water system by utilizing all available water loss management best practices. For example:

- ILI = 1: means that the real losses of a water utility are at the lowest technical level.
- ILI = 2: means that the real losses of a water utility are two times the lowest technical level.
- ILI = 3: means that the real losses of a water utility are three times the lowest technical level.

Utilities reporting an ILI<1, meaning reporting real losses below the lowest technical level, were also excluded from the data set. Once the data from utilities reporting an ILI<1 was removed from the data set the data from utilities reporting an ILI>20 was also removed. An ILI of >20is highly unlikely to be found in water utilities in California and upon reviewing the utilities with ILI values higher than 20 it was clear that data quality issues were the cause for these erroneous results.

As part of the data validation process one more utility had to be excluded since erroneous infrastructure data was reported by the utility in the audit form. See Table 2.6 for the data set validation steps.

Table 2.6
CUWCC BMP 1.2 – 2010 Water Audit Data Set Validation Steps

	Count	Percentage
Number of Utilities Reporting Water Audit Result	130	100%
Number of Utilities Reporting Negative Water Losses	5	4%
Number of Utilities Reporting ILI<1	36	28%
Number of Utilities Reporting ILI>20	3	2%
Number of Utilities Reporting Erroneous Infrastructure Data	1	1%
Final Data Set After Removal of Erroneous Water Audit Reports	85	65%

Although 130 water utilities reported water loss data to the CUWCC, some of the reported water loss volumes are unrealistic and questions of data reliability arose in the review of the dataset. Filtering the data set to exclude implausible results reduced the data set to 85 audit reports in total. In other words 35% of the reporting utilities reported implausible results.

The AWWA Free Audit Software provides a grading matrix feature that allows the user to assign data validity grades (from 1 being the lowest to 10 being the highest data validity) to each water audit component. Examining the data validity reported by all 130 water utilities showed an average data validity score of 75.2 (100 is the highest combined data validity score). It is noteworthy to mention that the five utilities that reported negative water losses show an average data validity score of 77.0.

Another problem in the data set was identified in the field for reporting the "average length of customer service line". Fifty-nine utilities – or 45% of all reporting utilities – reported an average length of customer service line greater than zero. However, for water utilities in California, the average length of customer service line is nearly always zero since the curb stop is located inside the meter box. This is a particularly important error because this field is used for calculation of the UARL value: overestimating the customer length inflates UARL values and results in artificially low ILI values.

The cost data required for calculating the financial performance indicators in the AWWA Free Audit Software was another area where the data quality displayed shortcomings. It was therefore decided to not include the financial performance indicators in the final analysis of water audit data set performance indicators. The water loss performance indicators of the reduced water audit dataset of 85 utilities are presented in Table 2.7 and Table 2.8.

Table 2.7
CUWCC BMP 1.2 – 2010 Water Audit Data Set Validation Steps

ILI Grouping of Reduced Data Set	Count	Percentage of Reduced Data Set
ILI<1.5	21	25%
1.5<ILI<2	16	19%
2<ILI<3	23	27%
3<ILI<5	19	22%
ILI>5	6	7%
Total	**85**	**100%**

Table 2.8
CUWCC BMP 1.2 – 2010 Water Audit Data Set Validation Steps

Water Loss Performance Indicator	Average	Median	Min	Max	Standard Deviation
Non-revenue water as percent by volume	9.6%	8.0%	3.9%	30.6%	4.8%
Apparent Losses – gallons per service connection per day	9.6	6.4	0.1	128.8	15.0
Real Losses – gallons per service connection per day	43.7	37.1	13.5	194.5	30.5
Real Losses – gallons per length of main per day	2,130.6	2,130.6	1,352.1	2,909.0	1,100.9
Real Losses – gallons per service connection per day per psi pressure	0.7	0.5	0.2	3.5	0.5
Unavoidable Annual Real Losses (UARL) (MG)	462.0	250.1	12.6	13,145.2	1,423.0
Infrastructure Leakage Index (ILI) [Real Losses/UARL]	2.7	2.1	1.0	11.8	1.9

The findings of this data review are particularly significant in the context of CUWCC's future water loss performance target setting. In 2015 the CUWCC will develop a benchmark for a state-wide water loss performance indicator. It is especially important to note that meaningful target setting requires reliable data; the initial review of the data set's reliability to date suggests that the audit information submitted would not properly inform a benchmark deliberation. Many of these issues could be resolved by more thorough validation of the data, preferably by independent audit.

Delaware River Basin Commission (DRBC)

Accounting & Reporting Regulations or Guidelines

The Delaware River Basin Commission develops policies, regulations, and management plans relating to the waters of the Delaware River Basin, which covers parts of New York, New Jersey, Pennsylvania, and Delaware. Over 600 water agencies are affected by the policies and regulations of DRBC.

In 2009, DRBC revised its Water Code (DRBC 2010) to include specific water audit provisions. In order to receive approval for any new or expanded water withdrawals, water purveyors must include a water conservation plan in their application. As of the last revision, a water audit program must be included in this conservation plan. “Resolution No. 2009-1” states the following: “Effective January 1, 2012 the owners of each water supply system serving the public with sources or service areas located in the Delaware River Basin shall implement an annual calendar year water audit program conforming to IWA/AWWA Water Audit Methodology (AWWA Water Loss Control Committee (WLCC) Water Audit Software) and corresponding AWWA guidance” (DRBC 2010). Beyond using the AWWA Water Audit Software, DRBC also requires additional documentation of each agency’s breakdown of water sources and services.

Further, DRBC requires water purveyors of a certain service capacity (those that distribute more than an average of 100,000 gallons per day during any 30-day period) to institute a leak detection program. Every three years, in addition to the annual reporting of non-revenue water, these utilities will submit plans for programs that will minimize leakage. It is required that these programs include periodic leak detection surveys, determinations of infrastructure status, and an implementation schedule.

Implementation Experience

In March of 2013, the approximately 250 water utilities subject to the revised Water Code water audit provisions, will submit a water audit for the 2012 calendar year. In anticipation of this first regulated submission, DRBC has been conducting training and outreach efforts throughout the region. A full-day training and multiple conference presentations have been made to best educate and prepare the water utilities for the value and process behind water audits (Sayers 2012).

Notably, the water audit requirement will be directly administered by DRBC. In the past, DRBC typically relied on its member state agencies (various Departments of Environmental Protection) to collect data and transfer it to DRBC as necessary. This program will require water utilities to work directly with DRBC in submitting their water audits and water loss control plans, which may pose administrative and processing challenges.

As far back as the late 1980’s, DRBC required reporting on “unaccounted for water” (UFW) and a corresponding leak detection and repair program. However, due to problems with the UFW approach and lack of consistency between reported data, the reports were not deemed reliable and were not an effective regulatory or planning tool. It is anticipated that the new audit methodology will produce more reliable data to support sound decision-making by regulators and water agencies.

Georgia Board of Natural Resources

Accounting & Reporting Regulations or Guidelines

The Georgia Water Stewardship Act (GWSA) enacted by the Georgia Senate Bill 370 in the 2010 legislative session, introduced requirements that public water providers throughout the state complete water audits based on the IWA/AWWA method. In response to severe drought and multi-state water resource management challenges, this piece of legislation requires an accounting of water losses and calls for further elaboration of minimum standards and performance metrics.

GWSA also required that the Board of the Department of Natural Resources ("DNR Board") establish "minimum standards and best practices for monitoring and improving the efficiency and effectiveness of water use by public water systems to improve water conservation" (GSB370 2010). GWSA requires the DNR Board to include the following components in the development of these guiding standards:

- The establishment of an infrastructure leakage index as a standard performance indicator
- The establishment of categories for utilities of different system sizes and service populations
- A program that requires public water systems to submit an annual water audit as outlined by the IWA water audit methodology
- A requirement using a phase-in approach for public water systems to implement water loss detection programs
- A technical assistance program to provide guidance to public water systems

  More specifically, GWSA instituted the following timeline to establish a targeted and phased-in approach (SB370 2010):
- Public water systems that serve more than 3,300 individuals must submit an annual water audit to the Georgia Environmental Protection Division (EPD) by:
  - March 2012 for systems that serve over 10,000 individuals
  - March 2013 for systems that serve over 3,300 individuals and under 10,000 individuals

Notably, GWSA does not articulate any requirements around water loss performance indicators; it mandates the submission of water audits but does not mandate particular improvements around water loss beyond the accounting process.

It is also instructive to examine an example of a regional water loss program and provide a case study of the implementation of GWSA. One of the state's eleven water planning regions is the Metropolitan North Georgia Water Planning District ("Metro District"). The Metro District "was created by the Georgia General Assembly in 2001 (O.C.G.A. §12-5-572) to serve as the water planning organization for the greater metropolitan Atlanta area. The Metro Water District's purpose is to establish policy, create plans and promote intergovernmental coordination of water issues in the District from a regional perspective." (Metro Water District 2009).

Water loss control guidelines were provided in the Metro District's Water Supply and Water Conservation Management Plan, originally adopted in 2003. The 2009 revision features water loss accounting requirements and water loss reduction techniques in its "Action Item 5.6".

As dictated by GWSA, the Metro District requires its member governments to provide an annual water audit using the IWA/AWWA method. Further, it requires that they each establish a goal for reducing the real water losses, to be attained by the end of five years (Metro Water District 2009).

The 2011 amendments to the Water Supply and Water Conservation Plan added another Action Item, entitled "Expedited Water Loss Reduction", which specifies a shorter timeline for achieving water loss reduction. Here, water systems with over 10% water losses are held to a particular goal: such systems are mandated to cut the difference between their water loss and 10% in half by 2025. An example is provided for clarity: "A water provider with a 16% water loss would reduce water loss by 3% to 13%" (Metro Water District 2011b). This amendment also requires annual revision of each water system's goals.

Implementation Experience

Upon mandating the water audit program as described above, the Georgia Environmental Protection Division (EPD) and the Georgia Environmental Finance Authority (GEFA) contracted with the Georgia Association of Water Professionals (GAWP) to develop a manual as part of a technical assistance program for public water providers required to submit water audits by GWSA. In addition to the manual, GAWP held five full-day workshops for the large water systems in the Fall of 2011 to provide training on water audit concepts, reporting requirements and how to use the AWWA Free Audit Software (GAWP 2011). In the spring of 2012, the Georgia Rural Water Association (GRWA) conducted six full-day workshops for small water systems (those serving less than 10,000) individuals) on water audit concepts and software training.

Survey responses from the DNR staff suggest that the timeframe and use of the software have posed challenges for some of the state's water agencies. Extensions and support for completion of the water audit were provided wherever necessary (Moeti 2012a). As of this writing, the validation and review of the set of submitted water audits (for systems that serve above 10,000 individuals) is underway. Another round of technical training sessions are planned for the upcoming year and high levels of participation are anticipated (Moeti 2012b).

The Metro District reported their region's progress in their "2011 Plan Implementation Review", which details the progress of their member agencies (55 of the 56 responded to the survey). Seventy percent of the respondents established a goal for reducing system water losses. The GWSA language does not specify parameters for the goals. In response to a survey question that asks "What is your water system's water loss reduction goal(s)?" member agencies display wide range of responses. Twenty-one responses simply list a percentage reduction without any narrative about whether real losses or non-revenue water will be used for calculation. Some responses did specify whether their goals were specific to non-revenue water or real losses, but two agencies articulated their goals in terms of 'unaccounted-for' water. Another two agencies specified their goals in terms of the Infrastructure Leakage Index. (Metro Water District 2011a). As this sample set displays, the range of water loss goals shows an inconsistent and highly variable process of improvement planning.

The 2011 Plan Implementation Review also shows that over 80% of the member agencies already have a leak detection program in place. However, only forty percent of the member agencies completed a water audit using the AWWA software to assess their system's water losses (Metro Water District 2011a).

New Mexico Office of the State Engineer

Accounting & Reporting Regulations or Guidelines

New Mexico Office of the State Engineer (OSM) has not instituted any state-wide legislation that mandates water loss accounting or control. Discussion with OSM revealed that it has engaged with three utilities over the past many years to assess water losses using the AWWA Free Water Audit Software (Vogel 2012).

Beyond these pilots, OSM incorporates water loss performance when reviewing a utility's application for new water permits or new infrastructure permits. These applications give OSM an opportunity to discuss water loss control and require a water audit yearly or every five years. Thus through the permitting process, OSM assesses water losses of its utilities on a case-by-case basis.

OSM ultimately confirmed that – despite the lack of binding legislation – water loss accounting is of focus. OSM appreciates the importance of moving away from the "unaccounted-for water" approach and has embraced the AWWA Free Water Audit Software. Some of the challenges for OSM in the effective adoption of the AWWA methodology include that over 90% of their utilities have less than 3,000 service connections and there is a need for education and outreach on the data validation and auditing process (Vogel 2012).

Pennsylvania Public Utility Commission (PA PUC)

Accounting & Reporting Regulations or Guidelines

The PA PUC adopted an order in December of 2008 to institute a pilot program that would implement the IWA/AWWA methodology for water audits. Five of Pennsylvania's large utilities voluntarily participated in this two-year pilot. After determining that the pilot program was successful, the PA PUC ordered the adoption of the IWA/AWWA water audit methodology in January of 2012 (PA PUC 2011). As of this writing, there are plans to codify this order within the next few months at which point it will officially take effect (Metcalf 2012).

As it stands now, the order consists of two significant parts. First, the five pilot utilities were required to submit their water audits using the IWA/AWWA methodology for the 2011 calendar year by April 2012. Secondly, the order requires that all other 'Class A' utilities (those that have over $1,000,000 in annual revenues) begin to file annual water audits using the IWA/AWWA methodology for the 2012 calendar year by April 2013. This component requires another six utilities (beyond the pilot participants) to submit annual water audits (PA PUC 2011).

Implementation Experience

The PA PUC largely credits the success of the pilot program to the development of the Technical Support Group (TSG). The TSG consisted of representatives from the pilot utilities, the Office of Consumer Advocate, and the PA PUC. Over the course of four extensive meetings, training presentations were held to thoroughly review the IWA/AWWA water audit methodology concepts and procedures (PA PUC 2011). George Kunkel of the Philadelphia Water Department and David Sayers of the Delaware River Basin Commission were cited as instrumental to the success of the training and implementation programs offered through the PA PUC.As of this writing no water audit results were available for evaluation by the research team.

Tennessee Comptroller of the Treasury

Accounting & Reporting Regulations or Guidelines

Water loss regulations and guidelines in Tennessee have recently been revised and the focus of much deliberation. The development of Tennessee's program is instructive in that it emphasizes the ongoing need to educate state legislative and regulatory bodies on the most valuable and validated water loss control methods and metrics.

In 2007, the water loss legislation in Public Chapter No. 243 was passed. The main components of this law require the following (General Assembly of the State of Tennessee 2007):

- "Public water systems to include in their annual audit the system's annual average unaccounted for water loss percentage."
- "The Comptroller of the Treasury shall file with the appropriate board (either the Utility Management Review Board (UMRB) or the Water and Wastewater Financing Board (WWFB) the audit report of any water system whose unaccounted for water loss as reported in the audit is excessive."
- "Each board is to define excessive unaccounted for water losses."

The legislation continues to enumerate the consequences for exceeding this "excessive" water loss – set at 35% unaccounted for water by the UMRB and the WWFB in 2010 – which include legal action to require water loss reduction and/or hiring new management.

Throughout the process of introducing and enacting this legislature, there was growing industry acceptance of the IWA/AWWA methodology as the more comprehensive and instructive approach to water auditing. In the summer of 2010, the Tennessee Association of Utility Districts (TAUD) issued a resolution from their Board of Directors that recommended the use of the AWWA Water Audit methodology. Soon thereafter, the UMRB and the WWFB adopted the AWWA method for the financial reports received on or after January 1, 2013 in acknowledgement of its advantages. Further, in the spring of 2011, legislation was enacted that transferred the authority to decide water loss accounting methodology from the Comptroller of the Treasury to the UMFB and the WWFB. These boards are now tasked with defining the threshold for "excessive" water loss in terms of the AWWA performance indicators (Leauber 2011).

Most recently, the boards accepted a plan that requires the submission of the AWWA Free Water Audit Software annually from each of its water providers. A utility that has incomplete data or an insufficient data validation score or high non-revenue water as a percent by cost of operating the system will be referred to the appropriate board and required to submit a plan for improvement.

Table 2.9 describes the parameters for data validity and water loss performance; water audits within any of these parameters will result in referral to the appropriate board.

Table 2.9
Requirements for water loss reporting and performance in Tennessee

Adoption and Effective Date	Data Validity Score	Non-Revenue Water as % of Operating Cost
1/1/2013	65 or less	30% or greater
1/1/2015	70 or less	25% or greater
1/1/2017	75 or less	20% or greater
1/1/2019	80 or less	20% or greater

Tennessee's transition from the "unaccounted-for water" approach to the IWA/AWWA water audit methodology will allow for more robust and useful water loss assessments throughout the state.

Texas Water Development Board

Accounting & Reporting Regulations or Guidelines

In 2003, the 78th Texas Legislature, Regular Session, enacted House Bill 3338 to help conserve the state's water resources by reducing water loss occurring in the systems of drinking water utilities. This statute requires that retail public utilities providing water within Texas file a standardized water audit once every five years with the Texas Water Development Board (TWDB).In response to the mandates of House Bill 3338, TWDB developed a water audit methodology for utilities that measures efficiency, encourages water accountability, quantifies water losses, and standardizes water loss reporting across the state.

The water audit worksheet developed by TWDB is comprised of data typically required for a water supply utility to conduct an internal "top-down" water audit approach, which is largely a desktop exercise gathering data and information from water consumption and loss reports already commonly compiled by many water utilities (Mathis et al. 2008).

In March 2008, the TWDB published an update of the Water Loss Audit Manual for Texas Utilities. This manual describes the water audit process and also includes the standard water audit worksheet to be used by utilities. The water audit approach and water audit worksheet is based on the AWWA recommended water audit methodology and terminology. The recommended water audit approach also asks water utilities to assess the validity of the data entered into the water audit. A grading matrix is provided to grade every data entry into the water audit sheet with a grade between 1 and 5 with grade 1 being the lowest data validity grade. In the Water Loss Audit Manual for Texas Utilities the TWDB encourages all water utilities to compile water audits annually.

In 2011, House Bill 3090 was passed requiring retail utilities with greater than 10,000 connections to submit annual audits. This bill also requires water utilities with outstanding loans with the TWDB to submit annual water audits.

Implementation Experience

The first set of water audit data was received by the TWDB by March 31, 2006. The Bureau of Reclamation provided funding for analyzing the water audit data received in 2006. Some of the key findings of this research project were that:

- Approximately 50 percent of all Texas retail public utilities reported their water loss data to the TWDB, with those reporting utilities serving about 84 percent of the state's population.
- Reported water losses between 5.6 to 12.3 percent of all water entering the reporting systems[2].
- The first water balance matrix used by the TWDB also included a balancing adjustment volume, which is not reflecting the recommended AWWA water audit best practice. The review of water audit data received in 2006 showed that – among many factors – the use of the balancing adjustment volume did not allow the utilities to develop successful water loss control strategies.
- Data quality and validly was found to be an issue with the first set of audit data reported.

In 2010 a total of 1,888 water utilities reported their water audits to the TWDB using the water audit format as defined in the *Water Loss Audit* Manual for Texas Utilities. The form was updated in 2008 and does not include the use of a balancing adjustment anymore.

Washington State Department of Health (WA DOH)

Accounting & Reporting Regulations or Guidelines

The Washington Administrative Code (WAC) 246-290-820 regulates the statewide water loss control program. It requires that all state water municipalities (approximately 2,200) determine their distribution leakage volume &percentage annually by submitting annual data from source and customer meters (as defined by: (System Input Volume – Authorized Consumption) / System Input Volume). System Input volume is defined as all metered water from all sources + any water that is purchased from another water supplier. Authorized Consumption is defined as all metered customer water use + any authorized unmetered uses (such as tank cleaning, line flushing, etc.). The state requirement is to achieve less than 10% distribution leakage for the last three-year average (Washington State Legislature 2008).

Each water municipality submits this water loss information each year through an online annual report and every six years through a comprehensive water system plan. If a utility has not satisfied the 10% water loss standard, they must implement a water loss control action plan detailing the methods used to get under 10% water loss. These actions often include – but are not limited to – a water audit, leak detection survey, and fixing failures. Such utilities must report annual progress in achieving conservation goals and explain efforts they are implementing to

[2] The smaller number is the total reported by the utilities. The larger number is based on the assumptions that the entire balancing adjustment is water loss.

achieve the 10% water loss standard (Dexel 2012). The water audit methodology adopted by the WA DOH does not comply 100% with the IWA/AWWA water audit methodology.

Implementation Experience

The annual report submittal rate has been about 93% (over the first 3 years of implementation). The annual state average water loss percentage has averaged between 13.2% and 14%. WA DOH developed an online reporting system and data collection worksheet for utilities to use when collecting and reporting data. The guidance documents clearly demonstrate how to report authorized consumption (metered data from customers and unmetered authorized uses) and total water produced and purchased. In some cases, municipalities have not taken the time to understand the components of the reporting requirements or the effect of poor data collection, ultimately resulting in poor water loss percentage performance (Dexel 2012).

To provide support and assistance with these reporting requirements, WA DOH has conducted or contracted out training since 2007 at various locations, hosting 50+ different training events. Training events have focused on thorough explanation of all requirements to comply with the Water Use Efficiency regulations. WA DOH has also published guidance documents. One notable example is the explanation of the water loss reporting program and expectations through a quarterly newsletter that reaches over 4,000 water systems statewide (Dexel 2012).

Wisconsin Public Services Commission

Accounting & Reporting Regulations or Guidelines

The Wisconsin Public Service Commission (PSC) regulates a total of 583 water utilities throughout the state, including both municipal and investor owned systems. Over half of the state's water utilities serve less than 1,000 customers while 76 of the state's utilities serve over 4,000 customers (PSC 2011). In 1997, operating requirements that addressed water loss standards were established. The following excerpt of the PSC's "Standards for Water Public Utility Service" enumerates the water loss administrative rule requirements: "system losses" (the difference between metered input into the distribution system and metered consumption) must be minimized. Specifically, for smaller utilities (less than 4,000 customers), the legislation allows no more than 25% system losses, and for those that serve more than 4,000 customers, the legislation allows no more than 15% system losses (PSC 1997).

More recently, a study was prepared for the PSC and the Wisconsin Department of Natural Resources (DNR) that examined water loss control measures and demand-side conservation efforts. The purpose of the study is to "provide PSC and DNR decision makers with cost-effectiveness data for water conservation measures and technologies when setting water conservation program goals, priorities, and funding levels" (Camp, Dresser & McKee Inc. and Water Accountability, LLC 2011).

The study used the IWA/AWWA methodology for the basis of its analysis and recommendations for water loss control efforts. Operational data is submitted to the PSC from each water utility on an annual basis. This study's research team extracted the required water balance information for each system from the PSC's 2009 annual report data. Minimal data validation was pursued: 18 utilities were excluded for reporting water losses equal to or less than zero and 31 utilities were excluded for reporting real losses equal to or less than zero. In the end, 520 water utilities were used in calculating the water loss performance indicators for this study.

Using the IWA/AWWA water balance methodology to assess water losses, this study established a baseline of water loss levels: the report offers average performance indicators for each size class of utility, as shown in Table 2.10.

Table 2.10
Average Wisconsin water loss performance indicators by utility size class

Utility Size	Non-Revenue Water as % by Volume	Apparent Losses (gal / service connection / day / psi)	Real Losses (gal (gal / service connection / day)	Infrastructure Leakage Level
Large (4,000+ customers)	17%	0.55	39.05	2.1
Medium (1,000 – 4,000 customers)	19%	0.02	35.11	1.8
Small (< 4,000 customers)	23%	0.05	39.38	1.4

Source: Adapted from Camp, Dresser & McKee Inc. and Water Accountability, LLC. 2011

Using these baselines, the benefits and costs of implementing different water loss control guidelines and regulations were evaluated. Different implementation scenarios and their associated costs and benefits were presented. The following four implementation schemes were investigated: 1) a scenario wherein the current PSC guidelines are enforced, 2) a scenario wherein the technical minimum of losses is achieved, 3) a scenario wherein the economically optimum volume of water losses is achieved (where costs of recovery equal the value of water saved), and 4) a scenario wherein the authors describe a "realistically" achievable water loss control effort (Camp, Dresser & McKee Inc. and Water Accountability, LLC 2011).

Presenting the volumes, costs, and savings for each scenario, the report aims to equip decision makers with the tools to more thoroughly address distribution water losses. As of the date of writing this report, administrative rules that would mandate the fourth scenario of "realistically" achievable water loss control efforts have been submitted to the state legislature for approval and are expected to go into effect in August 2012 (Ripp and Schmidt 2012).

The new rules require that each utility submit water loss performance indicators, specifying non-revenue water and water loss as percentages of system input volume. A water loss control plan is required if a utility submits either: a percentage of non-revenue water that exceeds 30 percent or a percentage of water loss that exceeds 15 percent for utilities with over 4,000 customers or 25 percent for utilities with less than 4,000 customers. This regulation improves the previous requirements by using water loss performance indicators that reflect terminology used in the AWWA water audit methodology. Though the use of the AWWA Free Water Audit Software is not required, utilities are encouraged to use it as a means to calculate the performance indicators. The rules also specify that the PSC can mandate a leak detection survey if the utility exceeds these metrics of water loss performance for three consecutive years (Ripp and Schmidt 2012).

Summary

The examination of state agency efforts to require and collect water audits from their member water providers (as summarized in Table 2.11) was a very important exercise in understanding whether or not water loss control software tools have been successfully adopted. The research team selected to review state agencies that exemplify proactive approaches that apply the industry's best practices in creating regulations and policies around water loss control. In general, this research presented that the data quality of water audits produced by water utilities for their reporting requirements leaves ample room for improvement. This highlights the industry wide need for further outreach, education and training in how to conduct a water audit, validate the audit data and develop water loss control strategies.

These findings were also an important note of caution for the research team in developing the Model: the software tool's utility is only as good as the data quality of its inputs. Stressing data quality to the utilities that choose to use the Component Analysis Model(Model) will be of utmost importance.

Table 2.11
Summary of State Agency Regulations & Guidelines

Agency	Regulation / Guideline	AWWA / IWA Methodology?	Training?	Timeframe
Alberta Urban Municipalities Association	Conservation, Efficiency and Productivity Plan	Yes	Yes	First submission due December 2012
California Urban Water Conservation Council	Best Management Practice 1.2	Yes	Yes	Annual Submissions
Georgia Department of Natural Resources	Georgia Water Stewardship Act	Yes	Yes	First submission by March 2012 for large utilities
Delaware River Basin Commission	DRBC Water Code	Yes	Yes	First submissions by March 2013
New Mexico Office of the State Engineer	NA	Piloted	Yes	Required for permitting new water sources
Pennsylvania Public Utility Commission	PUC Docket No. M-2008-2062697	Yes	Yes	First submissions by April 2013
Tennessee Comptroller of the Treasury	Public Chapter No. 243	Yes (recently adopted)	Yes	Annually (submissions on or after January 1, 2013 will use AWWA method)
Texas Water Development Board	House Bill 3338 and House Bill 3090	No		Once every 5 years, annually for large utilities
Washington State Department of Health	Washington Administrative Code (246-290-820)	Adopted in guidance materials	Yes	Annual submissions
Wisconsin Public Services Commission	Operating Requirements	No	Yes	Updated administrative rules requiring annual submissions expected to pass in 2012

REVIEW OF AVAILABLE WATER BALANCE AND COMPONENT ANALYSIS SOFTWARE TOOLS

Background

The research team used discussions with industry contacts and online research to undertake a general review of available water balance and component analysis software tools. It is important to note that this does not represent a complete review of available software tools currently available. This research component aims to review the components and functionalities of existing software tools. A total of 14 water loss software packages were reviewed. However, since a significant number of those software packages are only commercially available it was not possible to actually review the functionalities of the software. In these instances, the general description of functionalities provided by the developers of the software packages were reviewed.

The availability of water loss software packages, free or commercially available, goes back more than a decade. In general the water loss software packages can be grouped into three functionality categories:

- Software that provides IWA/AWWA standard water balance and performance indicator calculation.
- Software that provides IWA/AWWA standard water balance and performance indicator calculation in addition to a component analysis of real losses.
- Software that provides IWA/AWWA standard water balance and performance indicator calculation in addition to a component analysis of real losses while also designed to calculate economically optimized leakage control strategies.

Another distinction between software models is whether or not they include the use of confidence limits for the data entries or data quality grading matrices. These features allow the user to evaluate the impact of possible input data inaccuracies on the water balance and performance indicator results.

In addition to the above mentioned software tools, grouped by general functionality, specific software tools exist that were designed to offer more specialized analyses. These tools evaluate specific components of leakage control strategies such as pressure management or proactive leakage control for example. The following section provides a general description of researched software tools listed in alphabetical order.

Aqualibre

This water balance software was commissioned by Bristol Water Services and developed by IWDC Ltd. to assist water utilities in undertaking a water balance for their system using the latest IWA methodology in conjunction with the Burst and Background Estimate (BABE) approach. The software model also includes the 95% confidence limits and standard water loss performance indicator calculations. The software is commercially available through IWDC Ltd.

AquaLite

The AquaLite Benchmarking Software was developed by Ronnie Mckenzie with support of various individuals for the South African Water Research Commission. The software features the calculation of a water balance in line with the IWA best practice methodology and water loss performance indicators for benchmarking of performance in managing water losses from public water supply transmission and distribution systems. Also included in the software are 95% confidence limits for each water balance component. The software is freely available through the South African Water Research Commission or WRP (Pty) Ltd (adapted from WRC 2007).

AuditSolve

AuditSolve is a software suite developed by Water Systems Optimization, Inc. (WSO) that includes a standard IWA/AWWA water balance calculation, component analysis of real and apparent losses, 95% confidence limits, ranking of water balance components by level of variance, full set of water loss performance indicators, graphic comparison of performance indicators against a North American and a California data set, and an economic level of leakage tool. The software is commercially available.

AWWA Free Water Audit Software

It is a water audit software tool that was developed by the AWWA Water Loss Control Committee. The AWWA Free Water Audit Software includes ten worksheets in a spreadsheet file. The majority of data is entered on the second worksheet, “The Reporting Worksheet”, which prompts the user to enter standard water supply information such as the volume of water supplied, customer consumption, distribution system attributes and quantities of losses. Knowing that many water utilities don't typically tabulate all of this data, the software allows the user to enter either known (measured) or estimated (quantities that must be approximated) values. The software then calculates a variety of water loss performance indicators, which are useful in making performance comparisons among water utilities. The software also includes a data grading capability. This feature provides a basic validation of the results from the Reporting Worksheet. The software also provides a priority list of three water audit components that should be targeted for data quality improvement in order to improve the overall validity of the water audit results (adapted from AWWA 2010, the AWWA Water Loss Control Resource Community).

Benchleak

Benchleak is a software tool provided by the South African Water Research Commission designed to calculate a standard IWA water balance and water loss performance indicators. This software has now been replaced by the Aqualite software suite, also provided by the South African Water Research Commission.

Benchloss and Benchloss NZ

Benchloss and Benchloss NZ are software tools that are provided by the Water Services Association of Australia (WSAA) and the New Zealand Water & Wastes Association respectively. Both software tools are designed to calculate a standard IWA water balance and water loss performance indicators. The software tools feature 95% confidence limits for data entries and also include the World Bank Institute's real loss performance banding system.

ECONOLEAK

ECONOLEAK is a software model that is aimed specifically at determining when a water supplier should invest in active leakage control for a specific zone metered area. The Economic Model for Leakage Management (ECONOLEAK) has been developed through the Water Research Commission (WRC)-funded project titled "Development of an Economic Model for Evaluating Leakage in South Africa". The ECONOLEAK model represents one of several models and supporting user guides that have been developed through the WRC in order to assist water suppliers to manage and reduce their levels of leakage losses. The model is supplied free-of-charge through the WRC for use within South Africa.

LEAKS

LEAKS is a set of software suites covering all aspects of water auditing and water loss control. The most basic software tool, CheckCalcs, is free of charge and provides a basic IWA water balance and performance indicators. The other more sophisticated software tools include PIFastCalcs (water balance, performance indicator data asset and comparison, 95% confidence limits and valuation of Non-revenue water components), PressCalcs (evaluation of pressure management options for leakage control, failure frequency reduction, and control of repair and operating costs), ALCCalcs (economic frequency of active leakage control intervention), SRELLCalcs (for calculation of economic level of leakage combining pressure management, active leakage control and speed and quality of repair). The software suites are commercially available through ILMSS Ltd.

WB-EasyCalc

WB-EasyCalc is a software suite developed by Liemberger and Partners to calculate an IWA/AWWA standard water balance and performance indicators. The software also includes the use of error margins assigned to each water balance component and the comparison of system specific water loss performance indicators against an international performance indicator data set. The software also features a "What If" component that allows the user to see the impact changes in supply pressure, supply time, or system coverage have on water loss performance indicators. The software is available free-of-charge.

Summary

The review of available water balance and component analysis software tools has shown that a significant number of free and commercially available software tools already exist. The more complex and comprehensive software tools are, for the most part, commercially available or have been commissioned by industry organizations and are now available for free to their member agencies. While many software tools are available only six are available for component analysis and only five of those include analysis of leakage economics and out of these only one is freely available from South Africa. It is important to consider that as the software models become more comprehensive and complex, the user needs to have a higher level of water loss control understanding. Training for such software tools is recommended. Further, increasingly complex software models require more complex data. In general a larger amount of data also needs to be collected and entered in such software models. Especially in the context of more complex and less readily available data, it is important to emphasize the utility of software features like data grading systems or statistical confidence concepts for water audit and component analysis tools. These features help make the user aware of the possible limitations in data quality, which will impact the accuracy and reliability of the model results. A summary of the software review is provided in Table 2.12.

Table 2.12
Summary of Water Balance and Leakage Component Analysis Software Tools

Software Name	Author(s)	Region?	IWA /AWWA Water Balance	Water Loss PI'S	Component Analysis	Use of Confidence Limits	Analysis of Leakage Economics	Free of Charge	Training needed/recommended
Aqualibre	Bristol Water Services & WDC Ltd.	International	Yes	Yes	Yes	Yes	No	No	No
AquaLite	South African Water Research Commission	South Africa	Yes	Yes	No	Yes	No	Yes	No
AuditSolve	Water Systems Optimization, Inc.	International	Yes	Yes	Yes	Yes	Yes	No	Recommended
AWWA Free Water Audit Software	AWWA	North America	Yes	Yes	No	Grading System	No	Yes	Recommended
Benchleak	South African Water Research Commission	South Africa	Yes	Yes	No	No	No	Yes	Recommended
Benchloss	Water Services Association of Australia	Australia	Yes	Yes	No	Yes	No	Yes	Recommended
BenchlossNZ	Water New Zealand	New Zealand	Yes	Yes	No	Yes	No	Yes	Recommended
ECONOLEAK	South African Water Research Commission	South Africa	Yes	Yes	Yes	No	Yes	Yes	Recommended
LEAKS ALCCalcs	ILMSS Ltd	International	Yes	Yes	Yes	Yes	Yes	No	Strongly Recommended
LEAKS CheckCalcs	ILMSS Ltd	International	Yes	Yes	No	No	No	Yes	No
LEAKS PIFastCalcs	ILMSS Ltd	International	Yes	Yes	Yes	Yes	Yes	No	Strongly Recommended
LEAKS PressCalcs	ILMSS Ltd	International	Yes	Yes	No	Yes	Yes	No	Strongly Recommended
LEAKS SRELLCalcs	ILMSS Ltd	International	Yes	Yes	Yes	Yes	Yes	No	Essential
WB-Easy-Calc	Liemberger & Partners	International	Yes	Yes	No	Error Range	No	Yes	No

REVIEW OF FAILURE FREQUENCIES DATA

Background

One of the objectives of this research project was to provide the NA water industry with a utility-tested software tool to undertake a leakage component analysis. In order to undertake a leakage component analysis, utilities need to collect and analyze every failure event on the transmission system, distribution system and service connections. The specific goal of this literature review was to provide utilities a comparison of their own utility specific failure frequency results against an industry average failure (encompasses all types of utility leaks and breaks) frequency and an industry failure frequency benchmark. Therefore, literature that addresses the condition of distribution systems was reviewed. Specifically, the research team isolated reports that include average failure frequencies (defined as the number of failure incidents, leak and breaks, per length of distribution main per year).

The failure frequency metric is especially valuable in assessing a utility's infrastructure integrity and is a critical piece of leakage component analysis and the development of water loss control strategies. Compiling the total number of failures for a given audit period and calculating an average failure frequency is an important step for informed pipe renewal and rehabilitation program development (Deb et al. 2002). In the context of water losses, the number of failures and the response/repair time are two pivotal components in evaluating the volume of real losses.

As an important performance indicator, the failure frequency analysis will be highlighted in the Component Analysis Model (Model) developed by this project. The purpose of this literature review is to provide context for the Model user's failure frequency value. In reviewing relevant publications on national and international distribution system failure frequencies, the research team isolated two benchmarks: an average failure frequency for North American distribution systems and a failure frequency goal for a hypothetically optimized system. Both of these comparison points will be useful in contextualizing the current integrity of the user's infrastructure and its room for improvement.

Approach & Data Reviewed

The literature review included a search of reports, white papers, journal publications, and manuals that are related to distribution system condition. The research team then identified the subset of materials that featured a compilation of failure frequency data or discussed the role of failure frequency data in distribution system management. Table 2.13 lists these materials reviewed, and Appendix A details the relevance and content of each of these selected reports.

Table 2.13
List of all references used in the literature review of failure frequencies.

Citation	Report Title
AECOM 2011	*2011 Public Report*
AWWA 1996	*Water:\STATS 1995 Distribution Survey*
AWWA 2003	*Water:\STATS 2002 Distribution Survey*
AWWA 2007a	*Benchmarking Performance Indicators for Water and Wastewater Utilities*
AWWA 2007b	*Distribution System Inventory, Integrity and Water Quality*
Cook et al. 2009	*Large Diameter Trunk Failures*
Deb et al. 1995	*Distribution System Performance Evaluation*
Deb et al. 1998	*Quantifying Future Rehabilitation and Replacement Needs of Water Mains*
Deb et al. 2002	*Prioritizing Water Main Replacement and Rehabilitation*
Friedman et al. 2010	*Criteria for Optimized Distribution Systems*
Grigg 2004	*Assessment and Renewal of Water Distribution Systems*
Grigg 2007	*Main Break Prediction, Prevention and Control*
Kirmeyer et al. 1994	*An Assessment of Water Distribution Systems and Associated Research Needs*
Kleiner et al. 2005	*Risk Management of Large-Diameter Water Transmission Mains*
Kleiner and Rajani2010	*Dynamic Influences on the Deterioration of Individual Water Mains (I-WARP)*
Laven and Lambert 2012	*What Do We Know About Real Losses on Transmission Mains?*
MacKellar 2006	*UKWIR National Mains Failure Database*
National Water Commission 2011a	*National Performance Report 2009-10: Urban Water Utilities*
Rajani and McDonald 1995	*Water Mains Break Data on Different Pipe Materials for 1992 and 1993*
Wood and Lence 2006	*Assessment of Water Main Break Data for Asset Management*

Findings

Organized chronologically, Table 2.14 outlines the failure (which includes both leaks and breaks for clarity) frequencies found in each of the literature review reports. This collection of studies includes average North American failure frequencies that range from 11.4 failures / 100 miles / year (AECOM 2011) to 28.8 failures / 100 miles / year (Kleiner and Rajani 2010). European average failure frequencies range from 29.9 failures / 100 miles / year (MacKellar 2006) to 50 failures / 100 miles / year (Deb et al. 2002).

A majority of the failure frequencies here applied generally to the whole distribution system – no size or material specific breakdowns were given. Kleiner and Rajani (2010), MacKellar (2006), and Cook et al. (2009) are exceptions in that they feature material specific failure frequency values, and Cook et al. (2009) also gives size specific rates.

Figure 2.1 shows a summary diagram of the studies that include specific failure frequencies for North America since 1994. The bigger the plotted point, the more utilities were considered in the study. In this figure, failure frequencies that are specific to material are not included.

It is an especially notable finding that a majority of the documented failure frequencies do not have well characterized source data. In other words, the failure frequencies are reported in aggregate without much detail on the original data. For example, Deb et al. (2002) reports the average failure frequency from its survey of distribution systems was between 21 and 25 failure / 100 miles / year. The only details on the source of this range are as follows: the survey respondents included 37 North American utilities (32 served more than 100,000 people and 5 served less than 100,000), and the data was collected between 1993 and 1997 (Deb et al. 2002). The following qualifications are not included: size and material breakdowns, reporting mechanism (whether or not the failure was reported by the customer, the general public or a utility worker or revealed through a proactive leak detection effort), data validation procedures and quality assurance measures.

This is a representative example of this collection of materials overall in that there is a consistently low level of reporting on the details of the source data and the quality assurance measures that were taken to calculate the aggregate failure frequency documented. In this context, it is difficult to distinguish between the failure frequencies on the basis of data source, confidence and reliability.

It is also important to note that a great deal of literature in this field currently outlines infrastructure assessment techniques or models (Deb et al. 2002 and Grigg 2007 does a thorough job of summarizing these efforts). In seeking out specific failure frequency values, the research team encountered numerous publications that approach the management of infrastructure condition through the development of predictive models. Kleiner and Rajani (2010) offers an example of one such study in its development of a software tool that aims to statistically determine failure frequencies for individual pipes, considering both static characteristics (e.g., pipe material, size, age, soil type) and dynamic characteristics (e.g., climate, cathodic protection, pressure zone changes).

Generally, the research team found that there is a misalignment of theory and practice in the field of infrastructure assessment and management. Sophisticated models have been developed that employ advanced statistical and physical concepts to allow for main failure predication and management strategies. However, these models require an equally sophisticated level of data input (i.e. an inventory that features documentation of numerous characteristics ranging from pipe material, size, age, soil corrosivity, and temperature). As Grigg (2007) states, data availability is a critical constraint: "The limits of model capabilities are not in mathematics or statistical analysis methods, but in lack of accurate and consistent data and in the complexity of analysis".

The failure frequency analysis that will be featured in the Model developed by this research project is far simpler than the predictive models discussed in the reviewed literature. Nonetheless, a similar qualification should be made about the importance of data availability and data quality. Whether complex or simple, a model is only as valuable as the quality of its input data. The low level of data availability and quality for pipe and failure information mentioned in the reviewed literature is an important finding. The research team can also confirm this conclusion through professional experience working with water utilities throughout NA on their water loss control strategies.

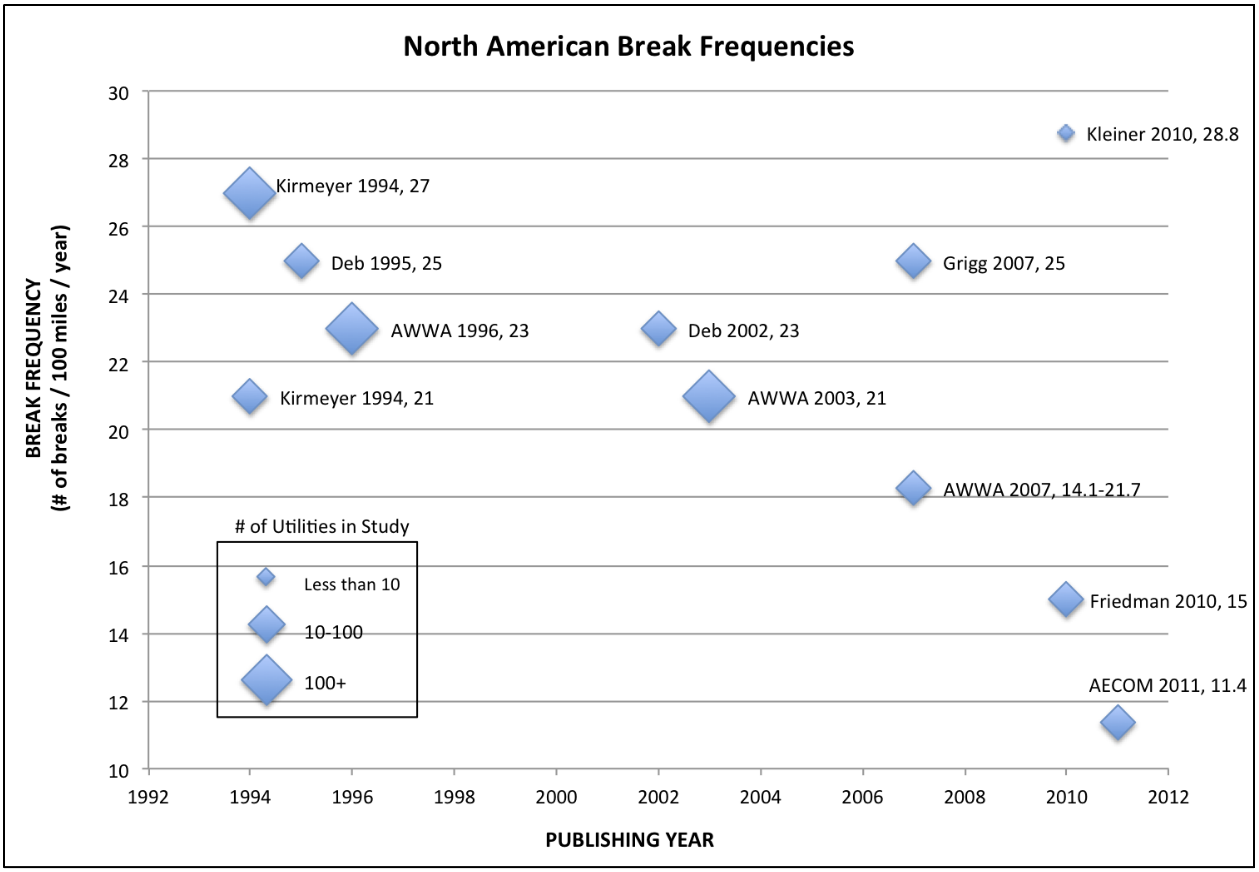
Table 2.14
Studies in literature review that report failure frequencies

Report	Failure Frequency Given (failures/100mi/yr)	Brief Description
Kirmeyer et al. 1994	27	Average for 1,092 utilities' failure data, reported from WIDB in 1992.
Kirmeyer et al. 1994	21	Average for 20 utilities' failure data via survey conducted for study.
Deb et al. 1995	20-30	Recommended range in discussion of performance goals.
AWWA 1996	23	1995 average for 702 U.S. utilities surveyed.
Deb et al. 2002	23	Average from 37 North American utilities surveyed between 1993 and 1997 reported failure rates between 21 and 25 failures/100mi/yr.
Deb et al. 2002	50	Average from 28 European utilities.
AWWA 2003	21	Average for 2002 dataset of 337 utilities (Grigg 2007)
MacKellar 2006	29.9	Average for 21 UK utilities, weighted by pipe material composition, between 1995 and 2003.
AWWA 2007	14.1-21.7	Top quartile performance of 150 utilities surveyed in 2007.
Grigg 2007	25	Average from 47 utilities' failure data from 1998.
Cook et al. 2009	6.11	Large diameter pipe failure data from 13 UK Utilities (~2007)
Friedman et al. 2010	15	Failure frequency goal for an optimized system. Based on top quartile performance in AWWA (2007a) data.
Kleiner and Rajani2010	28.8	Average for 4 utilities' failure data used to test the model developed in the study.

(continued)

Table 2.14 (continued)

Kleiner and Rajani 2010	57.8	Average for cast iron pipes, from 21 Canadian utilities for 1992 and 1993.
Kleiner and Rajani 2010	15.4	Average for ductile iron, from 21 Canadian utilities for 1992 and 1993.
Kleiner and Rajani 2010	9.3	Average for asbestos cement, from 21 Canadian utilities for 1992 and 1993.
Kleiner and Rajani 2010	1.1	Average for PVC, from 21 Canadian utilities for 1992 and 1993.
AECOM 2011	12.4	Median for 2009 of dataset of 34 Canadian utilities.
AECOM 2011	11.36	Five year average of medians of dataset of 34 Canadian utilities between 2004 and 2009
National Water Commission 2011a	43	Utilities surveyed with 100,000+ service connections for year 2009-2010.
National Water Commission 2011a	39	Utilities surveyed with 50,000 to 100,000 service connections for year 2009-2010.
National Water Commission 2011a	27	Utilities surveyed with 20,000 to 50,000 service connections for year 2009-2010.
Australian Government NPR 2011	26	Utilities surveyed with 10,000 to 20,000 service connections for year 2009-2010.
Laven and Lambert 2012	2.56	Unreported failures on transmission lines from a dataset of leak detection results on over 1800 miles of main



Source: Compiled. See Table 2.14

Figure 2.1: Diagram of reports that feature North American failure frequencies, organized by year and failure frequency value[3]

Application in Model

The goal of the literature review was to isolate two failure frequency benchmarks: an average failure frequency for North American distribution systems and a failure frequency goal for an optimized system.

Table 2.15 shows the studies selected for use in determining the average NA failure frequency value for the Model. These studies were selected because they featured a primary objective of conducting a survey of North American distribution systems. In other words, the failure frequencies reported here are the results of concerted efforts to aggregate distribution system data (as opposed to compilations used to test models that only briefly mention failure frequency results).

These aggregate North American failure frequencies were included in a weighted average (by number of utilities involved in the study) to determine an overall North American failure frequency. This was calculated to be approximately 25 failures / 100 miles / year. This value

[3] NOTE: the break frequency as provided in Friedman 2010 represents a goal for an optimized distribution system and is therefore not directly comparable to the other average break frequencies as cited by the other studies.

represents the average failure frequency for NA water utilities, based on the literature reviewed, and will be used as a benchmark for comparison to the Model user's results. It was assumed that the failure frequencies discussed in the reviewed literature do not include service connection failures and are only representing failure data for transmission and distribution pipelines. A further assumption is that the failure frequencies are for reported failures and do not include failures detected through proactive leak detection, since the vast majority of North American water utilities do not have proactive leak detection programs in place.

Table 2.15
Studies used to inform the average failure frequency used in Model

Report	Failure Frequency Given (failures/100miles/yr)	# of Utilities in Study
Kirmeyer et al. 1994	**27**	**1092**
Kirmeyer et al. 1994	**21**	**20**
AWWA 1996	**23**	**702**
Deb et al. 2002	**23**	**37**
AWWA 2003	**21**	**337**
Grigg 2007	**25**	**47**
WEIGHTED AVERAGE:	**24.68**	

The failure frequency goal was determined to be 15 failures / 100 miles / year (excluding service line failures). This value is directly extracted from the WRF study entitled "Criteria for Optimized Distribution Systems" (Friedman et al. 2010). This report describes the decision to select 15 failures / 100 miles / year as the infrastructure performance indicator goal as follows:

The goal was set based on the professional experience and judgment of, and extensive discussion among, the utility workgroup, research project team, and the PAC. While it is acknowledged that there may be many factors, such as system age, climate' density, ownership of service connections, and soil conditions that influence performance, it was decided to have a simple and challenging goal. The goal is also supported by data in two water industry publications (Friedman et al. 2010).

The two water industry publications referenced are Distribution System Performance Evaluation (Deb et al. 1995), which reports a range of 25 to 30 failures / 100 miles / year and the AWWA publication, Benchmarking Performance Indicators for Water and Wastewater Utilities:

2007 Annual Survey Data and Analysis Report (AWWA 2007a), which reported a top quartile performance ranging from 14.9 to 21.7 failures / 100 miles / year. Friedman et al. (2010) specifically defines the performance indicator goal as follows:

No more than 15 reported [failures] per 100 miles of utility-controlled distribution and transmission piping per year. This includes [failures] on appurtenances such as valves, blow-offs, fittings tapping sleeves/saddles and the connected tapping valves/corporation stops. It does not include service lines and appurtenances beyond the connecting point at the main, regardless of whether utility-owned/controlled or customer owned/controlled. Reported failures include both emergency events (i.e., needing immediate response and repair) and non-emergency events (i.e., addressed during norma.ly scheduled work hours) (Friedman et al. 2010).

As Model users determine their system-specific failure frequencies, these two failure frequencies extracted from this literature review will help contextualize how their infrastructure's failure frequency compares. For example, a utility using the model will enter the total number of reported failures from the audit period and the total mileage of distribution mains. The Model will calculate the failure frequency for this particular utility user. To make this determination more valuable, it will then be compared to the average North American failure frequency of 25 failures / 100 miles / year and the goal of 15 failures / 100 miles / year for an optimized distribution system. The user utility will be able to use this comparison to orient how its infrastructure management compares to the average North American utility and realize the room for improvement compared to the performance indicator goal.

Summary

The literature review indicates that the data quality of leak repair records collected by North American water utilities has ample room for improvement. In light of this, the average failure frequencies as assessed by various industry studies are only best estimates reflecting the quality of currently available failure data. A majority of the documented failure frequencies in the reviewed literature do not have well characterized source data. In other words, the failure frequencies are reported in aggregate without much detail on the original data or the quality assurance measures that were taken to calculate the aggregate failure frequency documented. In this context, it is difficult to distinguish between the failure frequencies on the basis of data source, confidence and reliability. Several areas in the collection of leak repair data need to be improved in order to achieve a better and more accurate understanding of failure frequencies.

- Terminology: the terminology used by water utilities for documenting pipe failures is highly inconsistent. The terms leak, break, and burst are all used throughout the industry and they may all have different interpretations/definitions depending on the water utility. Some utilities for example categorize a break as a failure event of significant nature that requires immediate action and the term leak is used for smaller pipe failures where the utility does not need to respond immediately. Therefore, it was important that the Model developed for this research project provides clear definitions for the failure data needed for the Model. Every failure event on the transmission system, distribution system and on service connections needs to be documented and used in the Model's leakage component analysis. The term 'failure' is used throughout this report and the model to encompass all leak/break terminology.

- Data collection and data quality assurance: infrastructure failures such as service line or distribution and transmission line failures are documented with a varying degree of accuracy and data completeness by North American water utilities.
- The need to provide clear guidance on failure data collection and documenting was addressed by the research team through the development of a Leak Repair Data Collection Guide in form of an open source MS Office Excel spreadsheet.

The goal of the literature review was to isolate two failure frequency benchmarks that can be used in the Model to highlight the user's failure frequency compares to other NA systems and against a target failure frequency of an optimized distribution system. The following failure frequency benchmarks were assessed for distribution systems not including service connection failures:

- Aggregate North American failure frequencies based on the literature review (data from six studies): approximately 25 failures / 100 miles / year
- Failure frequency goal for an optimized distribution system: 15 failures / 100 miles / year (taken from Friedman et al. 2010).

CHAPTER 3
PARTICIPATING UTILITY INFORMATION

INTRODUCTION

A primary goal of this research project is to allow a wide spectrum of water utility managers to take a detailed look at the components of their system's water loss. In order to make the Model as accessible and easy to use as possible, ten utilities from throughout the country helped the research team in developing the Model. The following chapter provides the details on the basic characteristics of the Participating Utilities and how they contributed to the Model.

PARTICIPATING UTILITIES: BACKGROUND INFORMATION

Table 3.1 outlines basic information for the ten Participating Utilities. The group includes utilities of a range of sizes in number of service connections and mileage of pipe. The group also includes a spectrum of leakage levels according to the water audit data submitted (see the column on Infrastructure Leakage Index).

A majority of the Participating Utilities had experience with component analyses before working with this research project and had proactive leak detection programs in place during the audit period examined for beta-testing the Model.

Table 3.1
Summary of Participating Utilities – Infrastructure Characteristics and Water Loss Experience

PARTICIPATING UTILITY	LOCATION	AUDIT YEAR	# OF SERVICE CONNECTIONS	MILEAGE OF PIPE	ILI	PROACTIVE LEAK DETECTION PROGRAM[1]?	COMPONENT ANALYSIS EXPERIENCE?
Austin Water Utility	*Austin, TX*	*FY 10/11*	*211,839*	*3,649*	*3.0*	*YES*	*YES*
City of Folsom	*Folsom, CA*	*CY 11*	*19,289*	*331*	*11.1*	*YES*	*YES*
City of Phoenix	*Phoenix, AZ*	*CY 11*	*436,178*	*6,884*	*3.0*	*NO*	*YES*
Eastern Municipal Water District	*Perris, CA*	*FY 09/10*	*146,025*	*2,117*	*1.7*	*NO*	*YES*
Halifax Regional Water Commission	*Halifax, Nova Scotia, Canada*	*FY 10/11*	*93,030*	*933*	*2.9*	*YES*	*YES*
Lake Arrowhead Community Services District	*Lake Arrowhead, CA*	*FY 10/11*	*8,487*	*125*	*2.39*	*NO*	*YES*
Metro Water Services	*Nashville, TN*	*FY 11/12*	*180,695*	*2,868*	*6.2*	*YES*	*YES*
South Central Connecticut Regional Water Authority	*New Haven, CT*	*CY 11*	*119,696*	*1,721*	*1.6*	*YES*	*NO*
San Antonio Water System	*San Antonio, TX*	*CY 11*	*410,000*	*4,988*	*2.1*	*YES*	*YES*
Water & Wastewater Authority of Wilson County	*Lebanon, TN*	*FY 10/11*	*7,001*	*322*	*1.1*	*YES*	*YES*

[1] This refers to a proactive leak detection program during the audit period examined.

Participating Utility Beta-Testing of the Model

The research team worked with the Participating Utilities to guarantee that the Model would be developed as an accessible tool that fits the needs of utilities nationwide. The first step in this process involved surveying the group of Participating Utilities to gauge general expectations for the Model in its content and complexity. Here, the research team learned that a majority of the Participating Utilities selected the “Beginner” (focused on data validation and establishing benchmark performance indicators) or “Intermediate” (focused is on implementing initial intervention strategies and improving an existing water loss control program) in describing their water loss control activities. Another finding was that a priority for the Model’s offerings highlighted the anticipation of the short-term economic level of leakage analysis. It was also important to the Participating Utilities that the Model was user-friendly and time efficient.

The next step in engaging the Participating Utilities was to collect and validate the data necessary to run the Model. This data collection included receipt of the following:

- AWWA Water Audit results
- Data on reported and unreported failures repaired during the audit period
- Information on current leakage management practices
- Utility cost data

Overall, there was a wide range in the level of detail and sophistication used by the Participating Utilities in their documentation of this data, especially for the tracking of leakage repair information. By engaging with the Participating Utilities on this first step of data collection, the research team was able to develop the Model so that it accommodates most data system approaches. Upon validating the data from each utility, the research team tested the Model’s functionality and use with a wide spectrum of data sources.

Beyond transferring their systems’ data, the Participating Utilities were active participants in providing feedback and improving the Model. Each Participating Utility was given a thorough introduction of the Model (via web conference), wherein the research team reviewed the purpose and use of each worksheet. After a couple of weeks of using the Model independently, the Participating Utilities reconnected with the research team (via web conference) to share their feedback. This was a critical process in identifying areas of the Model that needed clarification and more instruction.

CHAPTER 4
COMPONENT ANALYSIS MODEL

INTRODUCTION

The AWWA Manual 36 (3rd edition) provides comprehensive guidance for all steps involved in undertaking a “top-down” water audit, component analysis of real losses and planning and implementing a real loss control program. The AWWA Free Water Audit Software serves as a basic tool to compile a “top-down” water audit, which is the first step in developing a water loss control program. A “top-down” water audit calculates the overall system wide volume of real losses by deducting the authorized consumption volume and the apparent losses volume (customer meter inaccuracies, data handling errors and unauthorized consumption) from the system input volume. Once the overall system wide volume of real losses has been determined, this volume needs to be broken down into individual components of real losses/leakage by use of component analysis modeling.

A leakage component analysis disaggregates the total volume of real losses as calculated in the “top-down” water audit into its three components: Background Leakage, Unreported Leakage and Reported Leakage. By combining the component analysis with an evaluation of least cost real loss reduction strategies it is possible to calculate how much of each leakage component can be economically reduced through the right combination of intervention tools. Very few water utilities have the necessary expertise in leakage loss management to efficiently undertake a leakage component analysis and design the correct leakage control program. This means that utilities often invest money in leakage control activities (such as simple leak detection programs) that are not based on sound Economic Level of Leakage (ELL) analysis. It is very likely that those programs do not yield the best results. There is industry-wide room for improvement in creating cost-effective and well informed and leakage intervention strategies.

This research project provides the NA water industry with a utility-tested software tool to undertake a leakage component analysis and to undertake economic evaluations of leakage intervention strategies in order to design efficient and sustainable leakage control programs. NA water utilities will therefore be able to take advantage of the benefits of designing and implementing economically optimized leakage control programs.

PURPOSE

The Component Analysis Model (Model) was developed to provide the water industry with a computer-based model for leakage component analysis, failure frequency analysis, economic leakage control intervention strategy evaluation, and display of key water loss performance indicators. The Model is a complementary analysis tool to the AWWA Free Water Audit Software. The Model was designed using a standard Microsoft Office Excel software program. The Model was developed with the needs of the utility users in mind to provide a water loss analysis software tool that is accessible, user-friendly and has a reasonable level of complexity.

The Model and guidelines developed from this project will benefit and advance industry wide leakage management on several levels:

- Regulatory Agencies: Federal, State, Regional, Municipal
- Water Industry Wide: Private and Public Utilities, Consultants and Contractors
- General Utility Management
- Distribution System Operation
- Water Conservation
- Planning and Engineering

COMPONENT ANALYSIS MODEL

Background

The following subsections provide an overview of the Component Analysis Model sections and functionalities. Further detail on the use of the model is provided in Chapter 5 Component Analysis Model Case Studies.

Instructions

The Instructions Page provides instructions on how to use each page within the model. Figure 4.1 provides an example of the instructions for the use of the Model's Start Page. Users can choose to print out the instructions before working on the model to guide them through all of the sheets within the model. In addition, instructions are also available on each individual sheet within model.

WaterRF 4372: Effective Organization and Component Analysis of Water Utility Leakage Data

Water Audit: City of Austin, TX, USA, 2011
INSTRUCTIONS

Welcome to the WaterRF 4372 Component Analysis of Real Losses Software Model. These instructions will provide a basic summary of each tab in this model. Instructions are also available on each tab. This spreadsheet based "Model" was designed to provide North American (NA) water utilities with a utility-tested software tool to undertake a leakage component analysis and to identify economic options for real loss reduction through improved speed and quality of leak repair, proactive leak detection and pressure management. This Model was also designed to assist NA water utilities in evaluating options for implementing efficient and sustainable leakage control programs. The models results should only be seen as a preliminary starting point for proactive management of Real Losses. The preliminary Real Loss control strategy needs to be refined as more results become available.

The WaterRF Model 4372 must be run in a Microsoft Windows environment with Excel 2003 or newer. The Model will not function properly using any Macintosh versions of Microsoft Excel.

Macros must be enabled to properly use the WaterRF 4372 Component Analysis Modeling Software

Due to the limitations of using Microsoft Excel, users may experience growing buttons and/or combination boxes. This is likely caused by a limitation of system resources. If this occurs, the user should immediately close the model without saving and close any other running programs and then reopen the model.

For a full definition of any term used within the Model, simply click the term and you will be taken to the glossary

Start Page
In the blue user input cells, enter the basic details of the Utility including the Name, State, Country and a description of the system being analyzed by the model (i.e. Entire System, Zone 1). An explanation of each data entry field follows:

- *Utility* - The name of the utility whose data is being inputted into the WaterRF 4372 Model Software
- *State/Province* - The state or province where the utility whose data is being inputted into the WaterRF 4372 Model Software is located
- *Country* - The country where the utility whose data is being inputted into the WaterRF 4372 Model Software is located
- *System Description* - The portion of the system that is being analyzed using the WaterRF 4372 Model Software. Examples may include "Entire System, "Zone 1A", "Potable Water Distribution System"
- *Date of Data Entry* - The date which the utility's data was entered into the WaterRF 4372 Model Software. This field has been included to allow utilities to maintain a version control of each model filled out for the utility.
- *Model User's Name* - The name of the user that is filling out the WaterRF 4372 Model Software. This field has been included to allow utilities to maintain a version control of each model filled out for the utility.

Enter the start and end date of the audit period being analyzed by the WaterRF 4372 Model. If no start and/or end dates are entered, the model will set a default audit period of 365 days. The model will also allow the user to define a custom audit period (e.g. 3 months, 2 years, etc).

Select the volume and mains length units that are to be used throughout the model using the dropdown boxes. For volume, the model can accommodate Million Gallons (MG), Acre-feet, and Megalitres (ML). For mains length, the model can accommodate miles and kilometres.

Figure 4.1 Model - Instructions

Main Menu

The Main Menu Page provides an overview of the available components of the model with buttons that direct the user to each model component (see Figure 4.2).

Figure 4.2 Model - Main Menu

Start Page

The Start Page provides a brief explanation of the purpose and use of the Model, and it introduces the user to the color-coding of fields used throughout the model. Cells highlighted blue require the user to enter data, white cells represent values that are automatically calculated by the model, and brown cells provide default values the user can select. On the start page (see Figure 4.3) the user also enters the audit period start and end dates, and selects the units to be used throughout the Model (million gallons, acre-feet, or mega liters and miles or kilometers). The water audit and component analysis period duration and component analysis year will be calculated automatically. For version control, the date of data entry and the Model user's name has also been included.

WaterRF 4372: Effective Organization and Component Analysis of Water Utility Leakage Data

Water Audit: City of Austin, TX, USA, 2011
START PAGE

Macros must be enabled to properly use the WaterRF 4372 Component Analysis Modeling Software

PURPOSE: This spreadsheet based "Model" was designed to provide North American (NA) water utilities with a utility-tested software tool to undertake a leakage component analysis and to identify economic options for real loss reduction through improved speed and quality of leak repair, proactive leak detection and pressure management. This Model was also designed to assist NA water utilities in evaluating options for implementing efficient and sustainable leakage control programs. The models results should only be seen as a preliminary starting point for proactive management of Real Losses. The preliminary Real Loss control strategy needs to be refined as more results become available.

The worksheets contained in this spreadsheet can be accessed by clicking on the tabs located at the bottom of the spreadsheet screen or by clicking the desired button in the Main Menu worksheet. **Definitions can be accessed by directly clicking the term or navigating to the 'Glossary' tab.**

CELL COLOR CODING: Three cell colors have been used through out this spreadsheet based Model:

- Value to be entered by the user
- Value is automatically filled in/calculated by Model
- Recommended default value

WATER AUDIT AND COMPONENT ANALYSIS DETAILS

Utility	State/Province	Country
City of Austin	**TX**	**USA**

System Description (e.g. Entire System, Zone A, etc.)	Date of Data Entry	Model User's Name (e.g. John Smith)
Entire System	**July 11, 2013**	**Tim Wilson**

Audit and Component Analysis Period Start Date	**October 01, 2010**
Audit and Component Analysis Period End Date	**September 30, 2011**
Audit and Component Analysis Period Duration	**365** days
Audit and Component Analysis Year	**2011**
Select Preferred Volumetric Units for AWWA Water Balance Results	Million Gallons
Select Preferred Mains Length Units for AWWA Water Balance Results	Miles

Audit and Component Analysis Period Description:

Audit and Component Analysis Period Produced By:

7/11/2013

Figure 4.3 Model – Start Page

Summary

The Summary Page is populated by the results and recommendations from the Real Losses Component Analysis, A-L-R Times, Economic Intervention and Pressure Management sheets (see Figure 4.4). The performance indicators from the AWWA Water Balance Results have also been added to this sheet for reference purposes. This page has been designed to provide the user with a one-page summary of the results from using the Model. This will be useful when presenting the results of the model to other parties within the model user's organization.

WaterRF 4372: Effective Organization and Component Analysis of Water Utility Leakage Data

Water Audit: City of Austin, TX, USA, 2011
WaterRF 4372 COMPONENT ANALYSIS MODEL SUMMARY

As the input data is filled into the model, this sheet will populate with the results and recommendations from the Real Losses Component Analysis, A-L-R Times, Economic Intervention and Pressure Management tabs. The performance indicators from the AWWA Free Water Audit Software have been added to show a brief review of the performance the system being analyzed

WATER AUDIT PERFORMANCE INDICATORS		
Financial		
Non-revenue water as percent by volume of water supplied:	10.3%	
Non-revenue water as percent by cost of operating system:	3.0%	
Annual cost of Apparent Losses:	$4,376,956	
Annual cost of Real Losses:	$1,429,630	
Operational Efficiency		
Apparent Losses per service connection per day:	13.7	gal/service conn/day
Real Losses per service connection per day*:	56.0	gal/service conn/day
Real Losses per length of main per day:	N/A	gal/mi/day
r service connection per day per 1787.62743734595 pressure:	0.7	gal/service conn/day/psi
Unavoidable Annual Real Losses (UARL):	1,453.52	MG/Yr
Current Annual Real Losses (CARL):	4,332.21	MG/Yr
Infrastructure Leakage Index (ILI) [CARL/UARL]:	3.0	

REAL LOSS COMPONENT ANALYSIS RESULTS				
System Component	Background Leakage	Reported Failures	Unreported Failures	Total
	(MG)	(MG)	(MG)	(MG)
Reservoirs	22.08	-	-	**22.08**
Mains and Appurtenances	372.61	217.12	173.49	**763.22**
Service Connections	844.15	39.55	17.46	**901.15**
Total Annual Real Loss	**1,238.83**	**256.66**	**190.95**	**1,686.44**
			Real Losses as Calculated by Water Audit	**4,332.21**
			Hidden Losses/Unreported Leakage Currently Running Undetected	**2,645.77**

AWARNESS, LOCATION AND REPAIR TIME REDUCTION RESULTS			
	Reported Failures	Unreported Failures	
Total Potential Savings if Location and Repair Duration is Reduced as Simulated on the A-L-R Times Options Sheet	182.3	32.9	(MG)
Total Potential Cost Savings if Location and Repair Duration is Reduced as Simulated on the A-L-R Times Options Sheet	$ 23,458	$ 10,837	Per Year

ECONOMIC INTERVENTION FREQUENCY FOR PROACTIVE LEAK DETECTION RESULTS		
Percentage of the System to be Surveyed per Year	31	%
Average Annual Budget for Intervention (Proactive Leak Detection)	283,187	$/year
Potentially Recoverable Leakage	1,787.63	MG/year

ALTERNATIVE PRESSURE MANAGEMENT SCENARIO RESULTS		
User-Inputted Reduction in Average System Pressure	5.0	PSI
Assumed % Reduction in Average System Pressure	6%	
Estimated Real Loss Reduction from Pressure Management Program	203.1	MG/Yr
Financial Savings from Pressure Management Program	67,026	$/Year
User-Estimated Cost of Pressure Reduction	100,000	$
Resulting Pressure Management Program Payback Period	1.5	Years

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Figure 4.4 Model – Summary

AWWA Water Balance Results

The AWWA Water Balance Page prompts the user to transpose the water audit data that was used in the AWWA Free Water Audit Software into the Model. This tab was designed to mirror the AWWA Free Water Software sheet for ease of transferring the data (see Figure 4.5). In case unrealistic results are calculated by the model, warnings flag the possibility of data entry errors. The Model also prompts the used to enter the overall data validity score as calculated by the AWWA Water Audit Software. If the entered water audit data validity score is less than 51, the Model warns that the user should not implement any of the real loss intervention strategies before improving the water audit data validity score of its water audit.

WaterRF 4372: Effective Organization and Component Analysis of Water Utility Leakage Data

Water Audit: City of Austin, TX, USA, 2011
AWWA - WATER BALANCE RESULTS

Value to be entered by the user
Value is automatically filled in/calculated by Model
Recommended default value

Instructions: Please enter the data in the blue cells below based on the AWWA WLCC Free Water Audit Software: Reporting Sheet. The white cells will be populated automatically

Reporting Units: MG

WATER SUPPLIED

WATER SUPPLIED:	53,912.998	MG/Yr

AUTHORIZED CONSUMPTION

Billed Metered:	48,165.313	MG/Yr
Billed Unmetered:	187.898	MG/Yr
Unbilled Metered:	70.479	MG/Yr
Unbilled Unmetered:	94.727	MG/Yr
AUTHORIZED CONSUMPTION:	48,518.417	MG/Yr

WATER LOSSES:	5,394.581	MG/Yr
APPARENT LOSSES:	1,062.368	MG/Yr
REAL LOSSES:	4,332.213	MG/Yr
NON REVENUE WATER:	5,559.787	MG/Yr

SYSTEM DATA

Length of mains:	3,649.0	miles
Number of active AND inactive service connections:	211,839	service connections
Service connection density:	58.1	conn./mile main
Average length of customer service line*:	-	feet
Average operating pressure:	77.3	PSI

*Note: pipe length between curb stop and customer meter or point of first use for un-metered service connections

COST DATA

Total annual cost of operating the water system:	194,664,459	$/Year
Customer retail unit cost (applied to Apparent Losses):	4.12	$/1,000 gallons (US)
Variable Production cost (applied to Real Losses):	330.00	$/MG

PERFORMANCE INDICATORS

Financial		
Non-revenue water as percent by volume of water supplied:	10.3%	
Non-revenue water as percent by cost of operating system:	3.0%	
Annual cost of Apparent Losses:	$4,376,956	
Annual cost of Real Losses:	$1,429,630	

Operational Efficiency		
Apparent Losses per service connection per day:	13.74	gal/service conn/day
Real Losses per service connection per day*:	56.03	gal/service conn/day
Real Losses per length of main per day:	N/A	gal/mi/day
Real Losses per service connection per day per PSI pressure:	0.72	gal/service conn/day/psi
Unavoidable Annual Real Losses (UARL):	1,453.52	MG/Yr
Current Annual Real Losses (CARL):	4,332.21	MG/Yr
Infrastructure Leakage Index (ILI) [CARL/UARL]:	3.0	

AWWA Water Audit Data Validity Score:	78

Please enter the Data Validity Score calculated by the AWWA WLCC Free Water Audit Software

Note: If the data validity of your AWWA Water Audit is less than 51 it is recommended to improve the data validity of your AWWA Water Audit data before any of the results of the following economic analysis are considered for implementation.

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Figure 4.5 Model – AWWA Water Balance Results

Performance Indicator Comparison

The Performance Indicator Comparison (see Figure 4.6), allows the user to view their AWWA Free Water Audit Software system characteristics and performance indicators alongside other utilities throughout North America. The comparison dataset is the Water Loss Control Committee 2012 dataset of validated North American water utility water audits (the "Validated Dataset"). The location of the utilities and audit year represented are provided for each utility in the comparison dataset. The performance indicator comparison also provides the 25th, 50th and 75th percentile of the data set for each of the system characteristics and water loss performance indicators.

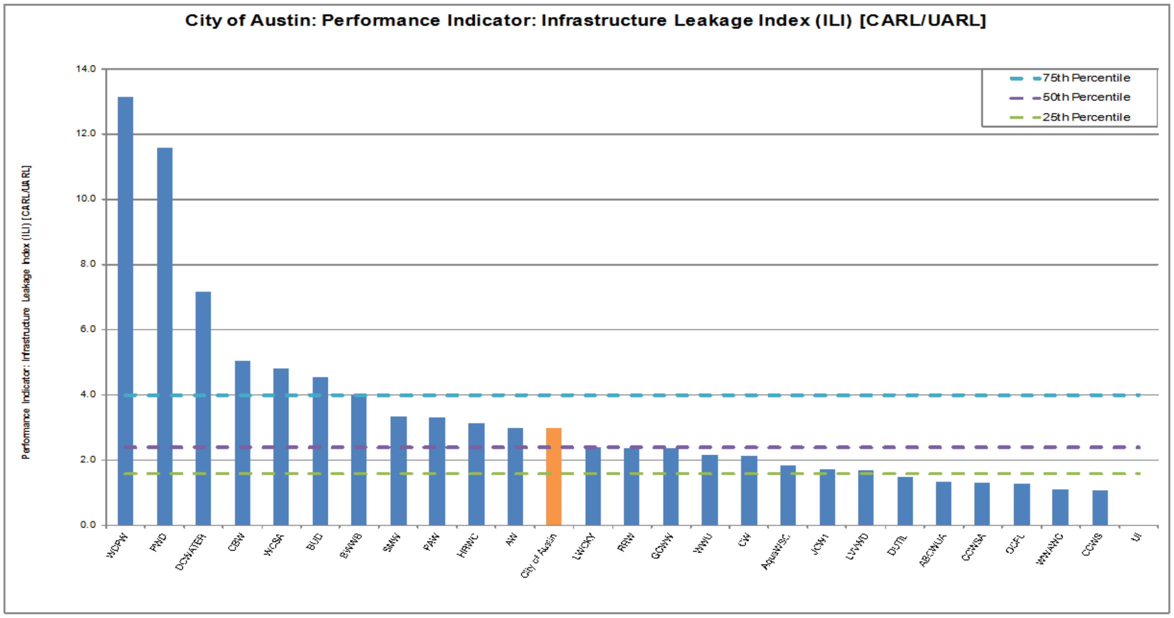
WaterRF 4372: Effective Organization and **Component Analysis of** Water Utility Leakage Data

Water Audit: City of Austin, TX, USA, 2011
PERFORMANCE INDICATOR COMPARISON

Instructions: Please select a performance indicator from the drop-down box to compare your utility's performance against the AWWA North American Validated Water Audit Data for 2012*. The performance indicator graph also displays the 25th, 50th and 75th percentile of the performance indicators data set.

Utility Name: City of Austin

Performance Indicator: Performance Indicator: Infrastructure Leakage Index (ILI) [CARL/UARL]



Abbreviation	Utility Name	State or Province	Country	Audit Year
GCWW	Greater Cincinnati Water Works	Ohio	USA	2010
SMW	City of Santa Monica	California	USA	2010
ABCWUA	ALBUQUERQUE BERNALILLO COUNTY WATER UTILITY	New Mexico	USA	2011
AquaWSC	Aqua WSC	Texas	USA	2011
AW	Austin Water Utility	Texas	USA	2011
BUD	City of Belmont	North Carolina	USA	2011
BWWB	Birmingham Water Works Board	Alabama	USA	2011
CW	The City of Calgary	Alberta	Canada	2011
CCWSA	Cherokee County Water & Sewerage Authority	Georgia	USA	2011
CCWS	Cobb County Water System WSID 67003	Georgia	USA	2001
CBW	City of Cranbrook, BC	British Colombia	Canada	2011
DUTIL	Dalton Utilities	Georgia	USA	2011
DCWATER	DC Water & Sewer Authority	District of Colombia	USA	2011
HRWC	Halifax Regional Water Commission	Nova Scotia	Canada	2010
LVVWD	Las Vegas Valley Water District	Nevada	USA	2011
LWCKY	Louisville Water Company	Kentucky	USA	2011
OCFL	Orange County Utilities Department	California	USA	2011
PAW	Pennsylvania American Water / Pittsburgh Division	Pennsylvania	USA	2011
PWD	Philadelphia Water Department	Pennsylvania	USA	2011
RRW	City of Rio Rancho	New Mexico	USA	2011
UI	Utilities Inc.	South Carolina	USA	2011
JCW1	Water District No. 1 of Johnson County	Kansas	USA	2011
WWU	City of Wauwatosa Water Utility	Wisconsin	USA	2011
WCSA	Washington County Service Authority	Virginia	USA	2011
WDPW	City of Wilmington, Delaware	Delaware	USA	2011
WWAWC	Water & Wastewater Authority of Wilson County	Tennessee	USA	2010

* The AWWA Validated Water Audit Data can be found at http://www.awwa.org/resources-tools/water-knowledge/water-loss-control.aspx

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Figure 4.6 Model – Performance Indicator

Real Losses Component Analysis

The Real Losses Component Analysis Page prompts the user to enter the data required for a real loss component analysis. This tab is structured into various sections/steps. The first section (see Figure 4.7) provides the summary of the real loss component analysis results. Based on the data entered later throughout this sheet, the Model calculates the volume of background losses, reported failures and unreported failures (organized by different components of the infrastructure) and provides an estimate of the hidden loss volume, which is caused by unreported failures currently running undetected.

WaterRF 4372: Effective Organization and Component Analysis of Water Utility Leakage Data

Water Audit: City of Austin, TX, USA, 2011
REAL LOSSES COMPONENT ANALYSIS

Value to be entered by the user
Value is automatically filled in/calculated by Model
Recommended default value

SUMMARY: REAL LOSS COMPONENT ANALYSIS

System Component	Background Leakage (MG)	Reported Failures (MG)	**Unreported Failures** (MG)	Total (MG)
Reservoirs	22.08	-	-	**22.08**
Mains and Appurtenances	372.61	217.12	173.49	**763.22**
Service Connections	844.15	39.55	17.46	**901.15**
Total Annual Real Loss	**1,238.83**	**256.66**	**190.95**	**1,686.44**
Real Losses as Calculated by Water Audit				**4,332.21**
Hidden Losses/Unreported Leakage Currently Running Undetected				**2,645.77**

Note: To the left you have the summary table of the real loss component analysis. Please enter the data in step 1 through 4 for the summary table to be populated.

Figure 4.7 Model – Real Losses Component Analysis Result Summary Section

Step 1 in the real loss component analysis requires the user to enter the total capacity of reservoirs in use during the audit period. The user then selects a default background leakage rate or a utility specific reservoir background leakage rate for calculating the background leakage volume stemming from reservoirs (see Figure 4.8).

Step 1: BACKGROUND LEAKAGE, REPORTED LEAKAGE AND UNREPORTED LEAKAGE FROM RESERVOIRS

Instructions: First enter the capacity of all distribution system reservoirs and tanks in use during the audit period. In case the system input volume is based on raw water meters located upstream of the Water Treatment Plant (WTP) then also include the capacity of the WTP reservoirs. Next select a reservoir background leakage rate - either the default value provided by the model or a utility specific flow rate. If reservoirs and tanks are well maintained and the utility does not suspect any background leakage from the reservoirs and tanks then enter zero as the utility specific flow rate. In case a reservoir or tank was reported leaking or has overflowed, enter the estimated volume in cell G27. If a proactive investigation/inspection of the system reservoirs and tanks has discovered a leaking reservoir or tank then enter the estimated annual volume lost in cell G28.

	Capacity (MG)	Background Leakage Rate (gpm/MG)	Annual Volume (MG)
Total Reservoir/Tank Capacity	168.00	0.25	22.08
Reported Reservoir Leakage and any recorded Reservoir and Tank Overflows			0.00
Unreported Reservoir Leakage			0.00
Total Background Leakage, Reported and Unreported leakage from Reservoirs			**22.08**

Select Reservoir Background Leakage Rate

⦿ **Default Value** 0.25 (gpm/MG)
OR
○ **Utility Specific Background Leakage Rate** - (gpm/MG)

Figure 4.8 Model – Real Losses Component Analysis - Step 1

Step 2 in the real loss component analysis requires the user to select an Infrastructure Condition Factor (ICF) based on the average age of the distribution network (the model provides default values for three general age groups) or enter a utility specific ICF in order for the model to calculate background leakage volume for the entire distribution network (see Figure 4.9). The default ICF values currently used have been set based on the results of currently ongoing data collections and discussions and exchanges between the research team and industry experts.

Step 2: BACKGROUND LEAKAGE ON MAINS AND SERVICES

Instructions: The background leakage volume from mains and service connections will be automatically calculated after selecting one of the default Infrastructure Condition Factors (ICF) based on infrastructure age or after a utility specific ICF has been selected and entered in cell P43. The level of background leakage tends to increase with infrastructure age and is higher for systems with higher pressure. The volume of background losses is generally a significant component of the total real loss volume, at times up to 50% of the total volume of real losses. Overestimating (ICF used in model is too high) or underestimating (ICF used in model is too low) the background leakage volume might lead to a real loss control strategy that is not truly optimized. Selecting the ICF based on general age of the distribution network should only be seen as a starting point. It is strongly recommended that over time a utility specific ICF is assessed and confirmed through field tests using one of the recommended approaches outlined in the AWWA M36 manual.

						Pressure Corrected Calculation	
System Component	Units	Quantity	Component UARL Values (g/unit/d/psi)	Infrastructure Condition Factor	Average Pressure (psi)	N1 (Leakage-Pressure Exponent)	Annual Volume (MG)
Mains	miles	3,649.0	2.87	1.2	77.3	1.5	372.61
Services - Main to Curb-Stop	number	211,839	0.112	1.2	77.3	1.5	844.15
Services - Curb-Stop to Meter	miles	-	4.78	1.2	77.3	1.5	-
						Total Background Leakage on Mains and Services	1,216.75

Select Infrastructure Condition Factor (ICF) based on age of distribution network

ICF 1 for System Age <50 years	1.0
ICF 1.5 for System Age 50 - 70 years	1.5
ICF 2.5 for System Age >70 years	2.5
OR	
Enter ICF values assessed through implementing the approaches outlined in the AWWA M36 manual	1.2

Figure 4.9 Model – Real Losses Component Analysis - Step 2

Step 3 in the real loss component analysis (see Figure 4.10) requires the user to enter the number of reported failures by mains size group, the average awareness duration and the average duration for location and repair/shut off of the failures. The user can then select a default average failure flow rate by mains size or enter a utility specific failure flow rate. The same steps are required for reported failures on service connections and on mains fittings/appurtenances. The Model will then calculate the real losses stemming from all the reported failures repaired during the audit period.

STEP 3: REPORTED FAILURES

Instructions: Drinking water utilities supply water through underground piping systems. Such systems - sooner or later - will incur failures in the form of leaks and breaks (ruptures) in distribution piping. Failures are categorized into three broad types: failures that occur on the primary water main piping , failures on customer service connection piping, and failures on appurtenances attached to water mains; including fire hydrants, valves and air valves or taps. This section "REPORTED FAILURES" of the model features a standardized calculation of the real loss volume stemming from failure events reported to the utility. Reported leaks and breaks (failure events) are defined as events that are brought to the attention of the water utility by the general public or other parties as a result of either water showing on the ground surface or other visible places, or of customer complaints. Follow Steps 3A,3B and 3C to calculate the real loss volume stemming from reported leaks and breaks.

STEP 3A: REPORTED FAILURES ON MAINS

Instructions: Enter the total number of failures by main size that were reported to and repaired by the water utility during the audit period in cells C58 to C77. Next enter the total length of mains for each mains size group in cells D58 to D77 (Note: this information is not required for the real loss component analysis but serves to calculate failure frequencies by mains size). Next enter the average awareness duration for reported failure events by mains size in cells I58 to I77 (Awareness duration is the average time from the occurrence of the failure event until the water utility becomes aware of its existence). Next enter the average duration of locating and containing reported failure events by mains size in cells K58 to K77. Next select either the default average leak flow rate provided by the model in cells P58 to P77 or select and enter your own utility specific average leakage flow rates in cells Q58 to R77.

Mains by Size	Number of Failures per Year	Length of Main	Failure Frequency (number / 100miles / yr)	Average Failure Flow Rate @ 70psi	Average Pressure	N1 (Leakage-Pressure Exponent) Value	AverageFailure Duration			Average Annual Loss per Failure	Total Annual Loss	Use Default Average Leak Flow Rate	Use Utility Specific Average Failure Flow Rate	Average Failure Flow Rate @ average system pressure
							Average Awareness Duration	Average Duration for Location and Repair/Shutoff Failure	Total Duration					
		miles		(gpm)	(psi)		(days)	(days)	(days)	(MG)	(MG)			(gpm)
Diameter 2"	60	53.3	113	13.90	77.3	0.50	3.00	1.00	4.00	0.08	5.05	◉	○	-
Diameter 3"	-	2.4	-	13.90	77.3	0.50	-	-	-	-	-	◉	○	-
Diameter 4"	29	74.8	39	44.00	77.3	0.50	0.50	1.10	1.60	0.11	3.09	◉	○	-
Diameter 6"	385	941.8	41	92.00	77.3	0.50	0.25	1.30	1.55	0.22	83.08	◉	○	-
Diameter 8"	147	1,100.7	13	92.00	77.3	0.50	0.25	1.19	1.44	0.20	29.47	◉	○	-
Diameter 10"	1	4.1	24	92.00	77.3	0.50	0.25	1.15	1.40	0.19	0.19	◉	○	-
Diameter 12"	46	585.6	8	222.00	77.3	0.50	0.25	1.03	1.28	0.43	19.78	◉	○	-
Diameter 14"	-	8.5	-	222.00	77.3	0.50	-	-	-	-	-	◉	○	-
Diameter 16"	-	47.4	-	222.00	77.3	0.50	-	-	-	-	-	◉	○	-
Diameter 18"	-	0.2	-	222.00	77.3	0.50	-	-	-	-	-	◉	○	-
Diameter 20"	1	24.8	4	222.00	77.3	0.50	0.10	5.43	5.53	1.86	1.86	◉	○	-
Diameter 24"	4	171.9	2	222.00	77.3	0.50	0.10	28.21	28.31	9.51	38.04	◉	○	-
Diameter 30"	-	-	-	222.00	77.3	0.50	-	-	-	-	-	◉	○	-
Diameter 36"	-	-	-	222.00	77.3	0.50	-	-	-	-	-	◉	○	-
Diameter 42"	-	-	-	222.00	77.3	0.50	-	-	-	-	-	◉	○	-
Diameter 48"	-	-	-	222.00	77.3	0.50	-	-	-	-	-	◉	○	-
Diameter 54"	-	-	-	222.00	77.3	0.50	-	-	-	-	-	◉	○	-
Diameter 60"	-	-	-	222.00	77.3	0.50	-	-	-	-	-	◉	○	-
Diameter > 60"	-	-	-	222.00	77.3	0.50	-	-	-	-	-	◉	○	-
Other Diameter	34	-	-	10.00	77.3	0.50	0.10	1.30	1.40	0.02	0.69	Enter avg flow rate		10.0
								SUB-TOTAL REPORTED FAILURES ON MAINS			181.24			

STEP 3B: REPORTED FAILURES ON DISTRIBUTION SYSTEM APPURTENANCES

Instructions: Enter the total number of failures by distribution system appurtenance type that were reported to and repaired by the water utility during the audit period in cells C86 to C89. Next enter the total number of appurtenances for each system appurtenance group in cells D86 to D89 (Note: this information is not required for the real loss component analysis but serves to calculate failure frequencies by appurtenance type). Next enter the average awareness duration for reported failure events by system appurtenance type in cells I86 to I89 (Awareness duration is the average time from the occurrence of the failure event until the water utility becomes aware of its existence). Next enter the average duration of locating and containing reported failure events by system appurtenance type in cells K86 to K89. Next select either the default average leak flow rate provided by the model in cells P86 to P89 or select and enter your own utility specific average leakage flow rates in cells Q86 to R89.

System Appurtenances by Type	Number of Failures per Year	Total Number of Appurtenances	Failure Frequency Number of Failures per 1000 Appurtenances	Average Failure Flow Rate @ 70psi	Average Pressure	N1 (Leakage-Pressure Exponent) Value	Average Failure Duration			Average Annual Loss per Failure	Total Annual Loss	Use Default Average Failure Flow Rate	Use Utility Specific Average Failure Flow Rate	Average Failure Flow Rate @ average system pressure
							Average Awareness Duration	Average Duration for Location and Repair/Shutoff Failure	Total Duration					
				(gpm)	(psi)		(days)	(days)	(days)	(MG)	(MG)			(gpm)
Hydrants	89	-	-	3.50	77.3	0.50	5.00	17.83	22.83	0.12	10.76	◉	○	-
Valves	98	-	-	6.90	77.3	0.50	5.00	5.36	10.36	0.11	10.60	◉	○	-
Meters	1,680	-	-	0.25	77.3	0.50	5.00	17.83	22.83	0.01	14.51	◉	○	-
Other (e.g. Blow-offs, etc.)	-	-	-	-	77.3	0.50	-	-	-	-	-	Enter avg flow rate		-
							SUB-TOTAL REPORTED FAILURES ON SYSTEM APPURTENANCES				35.87			

STEP 3C: REPORTED FAILURES ON SERVICE CONNECTIONS

Instructions: Enter the total number of failures by service connection size (< 1" or > = 1") that were reported to and repaired the water utility during the audit period in cells C98 to C99. Next enter the total number of service connections for each service connection size group in cells D98 to D99 (Note: this information is not required for the real loss component analysis but serves to calculate failure frequencies by service connection size group). Next enter the average awareness duration for reported failure events by service connection size group in cells I98 to I99 (Awareness duration is the average time from the occurrence of the failure event until the water utility becomes aware of its existence). Next enter the average duration of locating and containing reported failure events by service connection size group in cells K89 to K99. Next select either the default average leak flow rate provided by the model in cells P98 to P99 or select and enter your own utility specific average leakage flow rates in cells Q98 to R99.

Service Connections by Size	Number of Failures per Year	Total Number of Service Connections	Failure Frequency Number of Failures per 1000 Service Connections	Average Failure Flow Rate @ 70psi	Average Pressure	N1 (Leakage-Pressure Exponent) Value	Average Failure Duration			Average Annual Loss per Failure	Total Annual Loss	Use Default Average Failure Flow Rate	Use Utility Specific Average Failure Flow Rate	Average Failure Flow Rate @ average system pressure
							Average Awareness Duration	Average Duration for Location and Repair/Shutoff Failure	Total Duration					
				(gpm)	(psi)		(days)	(days)	(days)	(MG)	(MG)			(gpm)
Services < 1"	1,114	211,839	5	6.90	77.3	0.50	2.00	1.40	3.40	0.04	39.55	◉	○	-
Services > = 1"	-	-	-	13.90	77.3	0.50	-	-	-	-	-	◉	○	-
							SUB-TOTAL REPORTED FAILURES ON SERVICE CONNECTIONS				39.55			
							GRAND TOTAL REPORTED FAILURES				256.66			

Figure 4.10 Model – Real Losses Component Analysis - Step 3

Step 4 in the real loss component analysis (see Figure 4.11) asks the user if any proactive leak detection was carried out during the respective audit year. If yes, it requires the user to enter the number of unreported failures by mains size group detected by proactive leak detection, the average awareness duration and the average duration for location and repair/shut off of the failures. The user can then select a default average leak flow rate by mains size or enter a utility specific leak flow rate. The same steps are required for unreported failures on service connections and on mains fittings/appurtenances detected by proactive leak detection. The Model will then calculate the real losses stemming from all the unreported failures detected by proactive leak detection and repaired during the audit period.

Did your utility carry out proactive leak detection during the audit period? If NO then go to the Component Analysis Summary Table at the top of this sheet - If YES then provide the data requested in STEP 4A, 4B, and 4C

STEP 4: UNREPORTED FAILURES

Instructions: Drinking water utilities supply water through underground piping systems. Such systems - sooner or later - will incur failures in the form of leaks and breaks (ruptures) in distribution piping. Failures are categorized into three broad types: failures that occur on the primary water main piping , failures on customer service connection piping, and failures on appurtenances attached to water mains; including fire hydrants, valves and air valves or taps. This section "UNREPORTED FAILURES" of the model features a standardized calculation of the real loss volume stemming from failure events found through proactive leak detection programs. Unreported leaks and breaks (failure events) are defined as events that are usually hidden and are found only if a water utility has an active leakage control/leak detection program. Follow Steps 4A, 4B and 4C to calculate the real loss volume stemming from unreported leaks and breaks.

STEP 4A: UNREPORTED FAILURES ON MAINS

Instructions: Enter the total failures by main size that were detected and repaired through proactive leak detection during the audit period in cells C117 to C136. Next enter the total length of mains for each mains size group in cells D117 to D136 (Note: this information is not required for the real loss component analysis but serves to calculate failure frequencies by mains size). Next enter the average awareness duration for unreported failure events by mains size in cells I117 to I136 (If the entire distribution system is surveyed once a year the average awareness time is 365 days ÷ 2 = 182.5 days, if the system is surveyed twice a year then the average awareness time is 365 days ÷ 4 = 91.25 days and so on). Next enter the average duration of locating and containing unreported failure events by mains size in cells K117 to K136. Next select either the default average leak flow rate provided by the model in cells P117 to P136 or select and enter your own utility specific average leakage flow rates in cells Q117 to R136.

Mains by Size	Number of Failures per Year	Length of Main (miles)	Failure Frequency (number / 100miles / yr)	Average Failure Flow Rate @ 70psi (gpm)	Average Pressure (psi)	N1 (Leakage-Pressure Exponent) Value	Average Failure Duration: Average Awareness Duration (days)	Average Failure Duration: Average Duration for Location and Repair/Shutoff Failure (days)	Average Failure Duration: Total Duration (days)	Average Annual Loss per Failure (MG)	Total Annual Loss (MG)	Use Default Average Failure Flow Rate	Use Utility Specific Average Failure Flow Rate	Average Failure Flow Rate @ average system pressure (gpm)
Diameter 2"	-	-	-	13.90	77.3	0.50	-	-	-	-	-			-
Diameter 3"	-	-	-	13.90	77.3	0.50	-	-	-	-	-			-
Diameter 4"	-	-	-	22.00	77.3	0.50	-	-	-	-	-			-
Diameter 6"	1	941.8	0	46.00	77.3	0.50	150.00	1.00	151.00	10.51	10.51			-
Diameter 8"	-	-	-	46.00	77.3	0.50	-	-	-	-	-			-
Diameter 10"	-	-	-	46.00	77.3	0.50	-	-	-	-	-			-
Diameter 12"	-	-	-	111.00	77.3	0.50	-	-	-	-	-			-
Diameter 14"	-	-	-	111.00	77.3	0.50	-	-	-	-	-			-
Diameter 16"	-	-	-	111.00	77.3	0.50	-	-	-	-	-			-
Diameter 18"	-	-	-	111.00	77.3	0.50	-	-	-	-	-			-
Diameter 20"	-	-	-	111.00	77.3	0.50	-	-	-	-	-			-
Diameter 24"	-	-	-	111.00	77.3	0.50	-	-	-	-	-			-
Diameter 30"	-	-	-	111.00	77.3	0.50	-	-	-	-	-			-
Diameter 36"	-	-	-	111.00	77.3	0.50	-	-	-	-	-			-
Diameter 42"	-	-	-	111.00	77.3	0.50	-	-	-	-	-			-
Diameter 48"	-	-	-	111.00	77.3	0.50	-	-	-	-	-			-
Diameter 54"	-	-	-	111.00	77.3	0.50	-	-	-	-	-			-
Diameter 60"	-	-	-	111.00	77.3	0.50	-	-	-	-	-			-
Diameter > 60"	-	-	-	111.00	77.3	0.50	-	-	-	-	-			-
Other Diameter	-	-	-	-	77.3	0.50	-	-	-	-	-	Enter Avg Flow Rate		-
										SUB-TOTAL UNREPORTED FAILURES ON MAINS	10.51			

Step 4B: UNREPORTED FAILURES ON DISTRIBUTION SYSTEM APPURTENANCES

Instructions: Enter the total number of failures by distribution system appurtenance type that were detected and repaired through proactive leak detection during the audit period in cells C145 to C148. Next enter the total number of system appurtenances for each appurtenance type in cells D145 to D148 (Note: this information is not required for the real loss component analysis but serves to calculate failure frequencies by appurtenance type). Next enter the average awareness duration for unreported failure events by system appurtenance type in cells I145 to I148 (If the entire distribution system is surveyed once a year the average awareness time is 365 days ÷ 2 = 182.5 days, if the system is surveyed twice a year then the average awareness time is 365 days ÷ 4 = 91.25 days and so on). Next enter the average duration of locating and containing unreported failure events by system appurtenance type in cells K145 to K48. Next select either the default average leak flow rate provided by the model in cells P145 to P148 or select and enter your own utility specific average leakage flow rates in cells Q145 to R148.

System Appurtenances by Type	Number of Failures per Year	Total Number of Appurtenances	Failure Frequency Number of Failures per 1000 Appurtenances	Average Failure Flow Rate @ 70psi (gpm)	Average Pressure (psi)	N1 (Leakage-Pressure Exponent) Value	Average Leak Duration: Average Awareness Duration (days)	Average Leak Duration: Average Duration for Location and Repair/Shutoff Failure (days)	Average Leak Duration: Total Duration (days)	Average Annual Loss per Failure (MG)	Total Annual Loss (MG)	Use Default Average Failure Flow Rate	Use Utility Specific Average Failure Flow Rate	Average Failure Flow Rate @ average system pressure (gpm)
Hydrants	87	-	-	3.50	77.3	0.50	150.00	70.60	220.60	1.17	101.65			-
Valves	1	-	-	6.90	77.3	0.50	150.00	1.40	151.40	1.58	1.58			-
Meters	-	-	-	0.25	77.3	0.50	-	-	-	-	-			-
Other (e.g. Blow-offs, etc.)	39	-	-	7.00	77.3	0.50	150.00	2.00	152.00	1.53	59.75	Enter avg flow rate		7.0
										SUB-TOTAL UNREPORTED FAILURES ON SYSTEM APPURTENANCES	162.98			

Step 4C: UNREPORTED LEAKS ON SERVICE CONNECTIONS

Instructions: Enter the total number of failures by service connection size (< 1" or > = 1") that were detected and repaired through proactive leak detection during the audit period in cells C157 to C158. Next enter the total number of service connections for each service connection size group in cells D157 to D158 (Note: this information is not required for the real loss component analysis but serves to calculate failure frequencies by service connection size group). Next enter the average awareness duration for unreported failure events by service connection size group in cells I157 to I158 (If the entire distribution system is surveyed once a year the average awareness time is 365 days ÷ 2 = 182.5 days, if the system is surveyed twice a year then the average awareness time is 365 days ÷ 4 = 91.25 days and so on). Next enter the average duration of locating and containing unreported failure events by service connection size group in cells K157 to K158. Next select either the default average leak flow rate provided by the model in cells P157 to P158 or select and enter your own utility specific average leakage flow rates in cells Q157 to R158.

Service Connections by Size	Number of Failures per Year	Total Number of Service Connections	Failure Frequency Number of Failures per 1000 Service Connections	Average Failure Flow Rate @ 70psi (gpm)	Average Pressure (psi)	N1 (Leakage-Pressure Exponent) Value	Average Failure Duration: Average Awareness Duration (days)	Average Failure Duration: Average Duration for Location and Repair/Shutoff Failure (days)	Average Failure Duration: Total Duration (days)	Average Annual Loss per Failure (MG)	Total Annual Loss (MG)	Use Default Average Failure Flow Rate	Use Utility Specific Average Failure Flow Rate	Average Failure Flow Rate @ average system pressure (gpm)
Services < 1"	11	-	-	6.90	77.3	0.50	150.00	2.00	152.00	1.59	17.46			-
Services > = 1"	-	-	-	13.90	77.3	0.50	-	-	-	-	-			-
										SUB-TOTAL UNREPORTED FAILURES ON SERVICE CONNECTIONS	17.46			
										GRAND TOTAL UNREPORTED FAILURES	190.95			

Figure 4.11 Model – Real Losses Component Analysis - Step 4

Real Loss Components Chart

The Real Losses Components Chart Page (see Figure 4.12) shows the results of the real loss component analysis in a pie chart. It provides the percentage each real loss component contributes to the total system wide volume of real losses. The real losses stemming from unreported failures are further broken down into unreported failures identified through existing proactive leak detection efforts and unreported failures currently running undetected in the bar chart to the right. The example shown in Figure 4.12 is from one of the participating utilities where some proactive leak detection was carried out during the audit period.

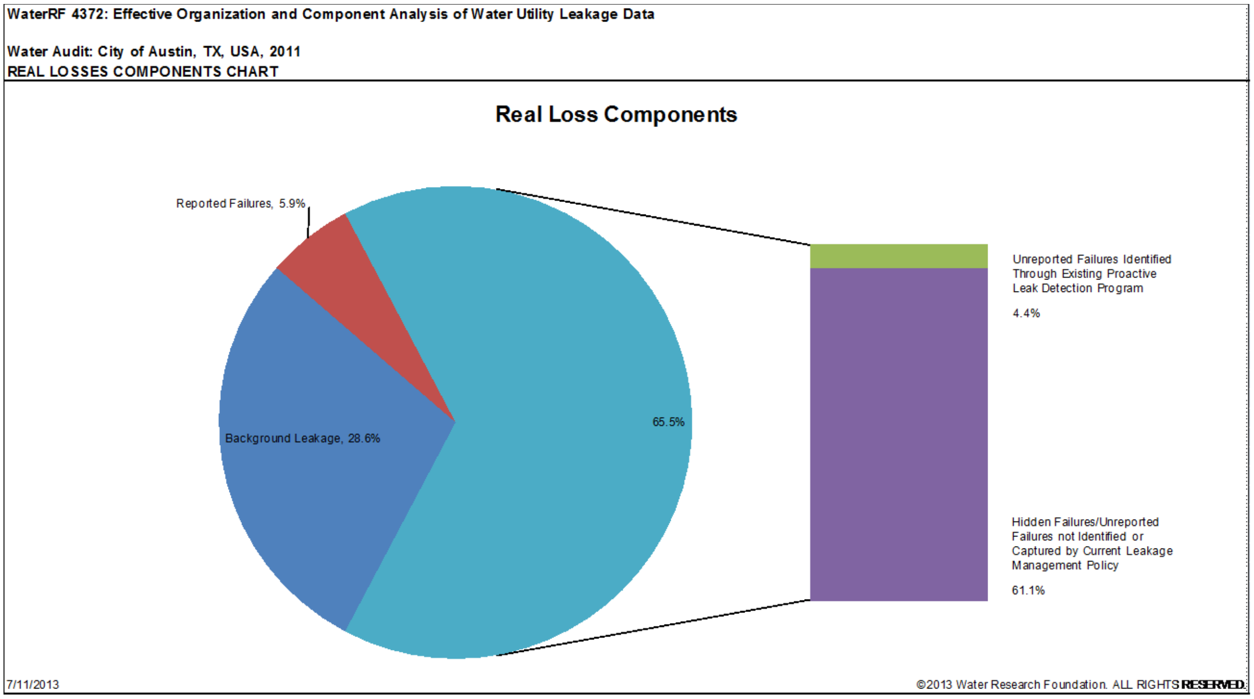

Figure 4.12 Model – Real Losses Components Chart

Failure Frequency Analysis

The Failure Frequency Analysis Page provides a comparison of the utility's mains failure frequency, based on the number of reported failures entered in the real loss component analysis page, against the research team's findings on average and optimized system mains failure frequencies. It also provides a comparison of reported service connection failures against a technical minimum service connection failure frequency (derived from the Unavoidable Annual Real Losses concept). The Model provides a warning in case the user's failure frequencies are less than what is expected for optimized systems or the technical minimum in the case of service connection failures (see Figure 4.13).

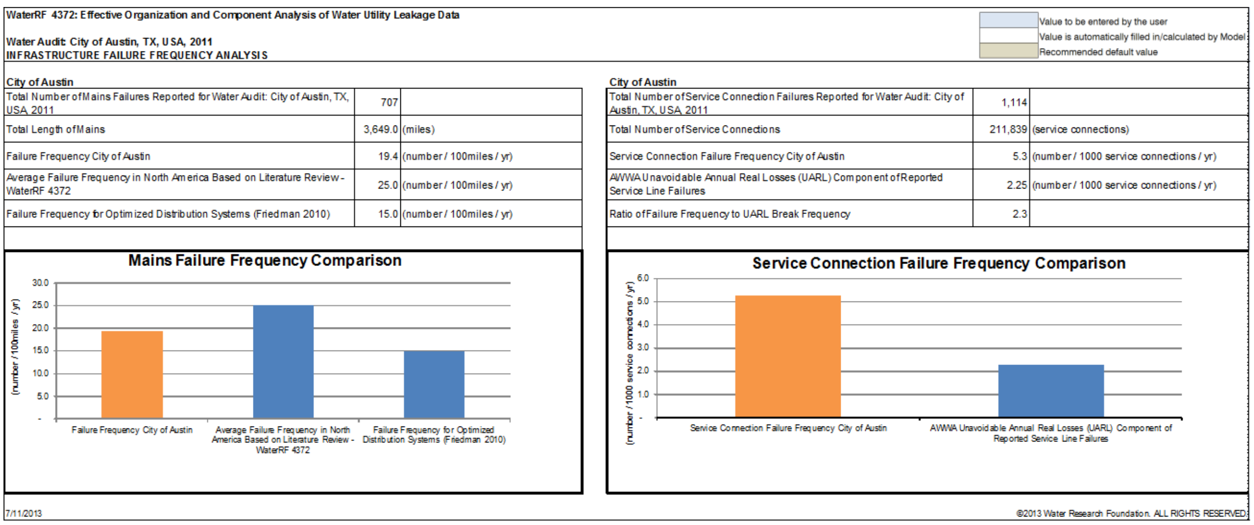

Figure 4.13 Model – Failure Frequency Analysis

A-L-R Times Options

On this tab the Model provides the user the option to evaluate one of the three short to medium term real loss intervention strategies, namely the optimization of awareness, location and repair times (A-L-R). For each component of reported and unreported failures the user sees the total number of failures, the average location and repair time, the resulting estimated real loss volume and the cost of that real loss volume. The user then can enter a theoretical reduction in location and repair time to see the resulting real loss savings and associated monetary savings. The Model component was designed to provide the user with a simple "What IF" platform to evaluate various scenarios of improved location and repair time reductions and the related real loss and monetary savings (see Figure 4.14). The user should then undertake further cost benefit analysis if this analysis has shown potentially cost effective options for leakage loss reductions by reducing the current average location and repair times.

WaterRF 4372: Effective Organization and Component Analysis of Water Utility Leakage Data

Water Audit: City of Austin, TX, USA, 2011
EVALUATION OF LOCATION AND REPAIR TIME REDUCTION OPTIONS

Value to be entered by the user
Value is automatically filled in/calculated by Model
Recommended default value

Instructions: Use What IF option in the blue highlighted cells to evaluate potential savings in real losses stemming from reducing the average location and repair time for each of the three infrastructure components for both reported and unreported failure events. Enter a target average location and repair duration (in days) and the model will calculate the resulting savings in leakage volume as well as the corresponding monetary savings. Undertake further cost benefit analysis if this analysis has shown potentially cost effective options for leakage loss reductions by reducing the current average location and repair times.

Reported and Unreported Failure Events

Failures on Mains	***Reported***	***Unreported***	
Total Number of Failures on Mains in 2011	707	1	
Average location and repair duration	1.4	1.0	days
Total Volume lost (stemming from location and repair duration)	153.9	0.1	(MG)
Total Cost of Volume lost (stemming from location and repair duration)	$ 50,785	$ 23	
What IF Location and Repair Duration is Reduced to	1	0.5	days
Percent Reduction	28%	50%	
Potential Related Savings in Leakage Volume	42.7	0.0	(MG)
Potential Related Savings in Leakage Volume Cost	$ 14,085	$ 11	

Service Line Failures	***Reported***	***Unreported***	
Total Number of Failures on Service Connections in 2011	1,114	11	
Average location and repair duration	1.4	2.0	days
Total Volume lost (stemming from location and repair duration)	16.3	0.2	(MG)
Total Cost of Volume lost (stemming from location and repair duration)	$ 5,374	$ 76	
What IF Location and Repair Duration is Reduced to	1	1	days
Percent Reduction	29%	50%	
Potential Related Savings in Leakage Volume	4.65	0.1	(MG)
Potential Related Savings in Leakage Volume Cost	$ 1,535	$ 38	

Failures on System Appurtenances	***Reported***	***Unreported***	
Total Number of Failures on System Appurtenances in 2011	1,867	127	
Average location and repair duration	17.2	49.0	days
Total Volume lost (stemming from location and repair duration)	25.2	33.4	(MG)
Total Cost of Volume lost (stemming from location and repair duration)	$ 8,323	$ 11,013	
What IF Location and Repair Duration is Reduced to	1	1	days
Percent Reduction	94%	98%	
Potential Related Savings in Leakage Volume	23.8	32.7	(MG)
Potential Related Savings in Leakage Volume Cost	$ 7,838	$ 10,788	

Total Potential Savings if Location and Repair Duration is Reduced as Simulated in the Above Sections	**182.3**	**32.9**	**(MG)**
Total Potential Cost Savings if Location and Repair Duration is Reduced as Simulated in the Above Sections	**$ 23,458**	**$ 10,837**	**Per Year**

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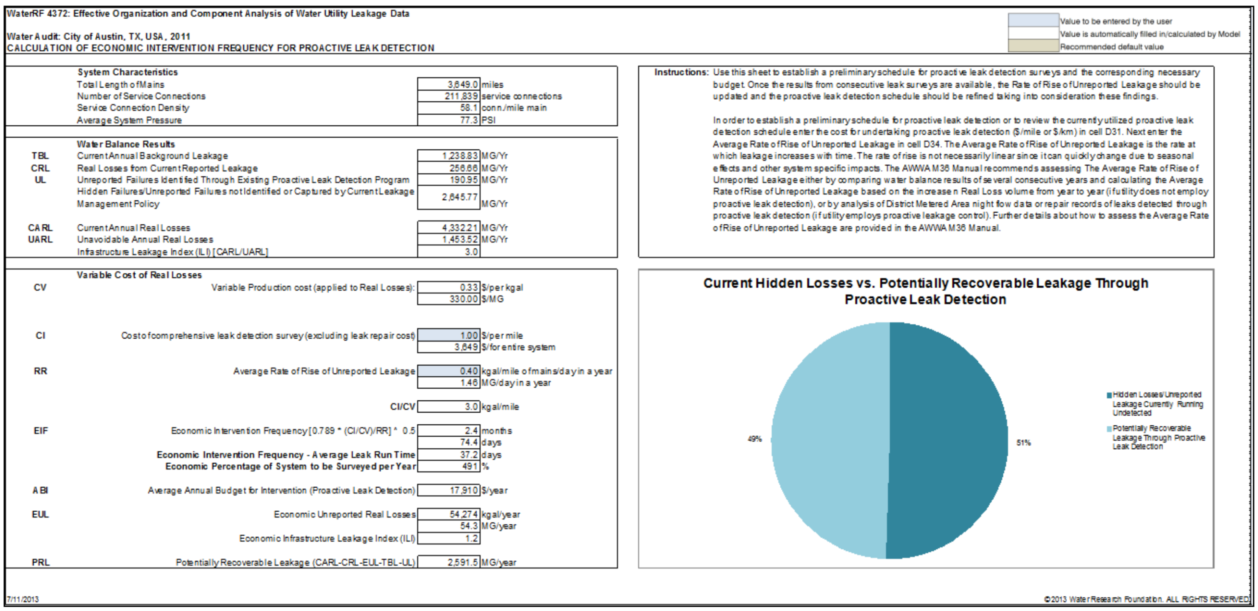
Figure 4.14 Model – A-L-R Times Option

Economic Intervention Frequency

On this tab the model provides the user the option to evaluate the economic intervention frequency for proactive leak detection. The calculation of the economic intervention frequency follows the AWWA M36 recommended approach/calculation. The user only needs to enter two parameters: the cost for undertaking proactive leak detection and the average rate of rise of unreported leakage. The Model then calculates the percentage of the system that should be surveyed each year, the required budget for proactive leak detection and estimates the volume of potentially recoverable leakage losses in case the intervention strategy is implemented. The Model also provides a graphical display of estimated recoverable leakage and the leakage volume that at current evaluation/cost is not economically recoverable (see Figure 4.15).



WaterRF 4372: Effective Organization and Component Analysis of Water Utility Leakage Data

Water Audit: City of Austin, TX, USA, 2011

CALCULATION OF ECONOMIC INTERVENTION FREQUENCY FOR PROACTIVE LEAK DETECTION

Value to be entered by the user
Value is automatically filled in/calculated by Model
Recommended default value

	System Characteristics		
	Total Length of Mains	3,649.0	miles
	Number of Service Connections	211,839	service connections
	Service Connection Density	58.1	conn./mile main
	Average System Pressure	77.3	PSI
	Water Balance Results		
TBL	Current Annual Background Leakage	1,238.83	MG/Yr
CRL	Real Losses from Current Reported Leakage	256.66	MG/Yr
UL	Unreported Failures Identified Through Existing Proactive Leak Detection Program	190.95	MG/Yr
	Hidden Failures/Unreported Failures not Identified or Captured by Current Leakage Management Policy	2,645.77	MG/Yr
CARL	Current Annual Real Losses	4,332.21	MG/Yr
UARL	Unavoidable Annual Real Losses	1,453.52	MG/Yr
	Infrastructure Leakage Index (ILI) [CARL/UARL]	3.0	
	Variable Cost of Real Losses		
CV	Variable Production cost (applied to Real Losses):	0.33	$/per kgal
		330.00	$/MG
CI	Cost of comprehensive leak detection survey (excluding leak repair cost)	1.00	$/per mile
		3,649	$/for entire system
RR	Average Rate of Rise of Unreported Leakage	0.40	kgal/mile of mains/day in a year
		1.46	MG/day in a year
	CI/CV	3.0	kgal/mile
EIF	Economic Intervention Frequency [0.789 * (CI/CV)/RR] ^ 0.5	2.4	months
		74.4	days
	Economic Intervention Frequency - Average Leak Run Time	37.2	days
	Economic Percentage of System to be Surveyed per Year	491	%
ABI	Average Annual Budget for Intervention (Proactive Leak Detection)	17,910	$/year
EUL	Economic Unreported Real Losses	54,274	kgal/year
		54.3	MG/year
	Economic Infrastructure Leakage Index (ILI)	1.2	
PRL	Potentially Recoverable Leakage (CARL-CRL-EUL-TBL-UL)	2,591.5	MG/year

Instructions: Use this sheet to establish a preliminary schedule for proactive leak detection surveys and the corresponding necessary budget. Once the results from consecutive leak surveys are available, the Rate of Rise of Unreported Leakage should be updated and the proactive leak detection schedule should be refined taking into consideration these findings.

In order to establish a preliminary schedule for proactive leak detection or to review the currently utilized proactive leak detection schedule enter the cost for undertaking proactive leak detection ($/mile or $/km) in cell D31. Next enter the Average Rate of Rise of Unreported Leakage in cell D34. The Average Rate of Rise of Unreported Leakage is the rate at which leakage increases with time. The rate of rise is not necessarily linear since it can quickly change due to seasonal effects and other system specific impacts. The AWWA M36 Manual recommends assessing The Average Rate of Rise of Unreported Leakage either by comparing water balance results of several consecutive years and calculating the Average Rate of Rise of Unreported Leakage based on the increase n Real Loss volume from year to year (if utility does not employ proactive leak detection), or by analysis of District Metered Area night flow data or repair records of leaks detected through proactive leak detection (if utility employs proactive leakage control). Further details about how to assess the Average Rate of Rise of Unreported Leakage are provided in the AWWA M36 Manual.

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Figure 4.15 Model – Economic Intervention Frequency

Pressure Management Options

The Pressure Management Options Page (see Figure 4.16) provides the user an opportunity to evaluate alternative pressure management options. The evaluation of alternative pressure management options requires the Model to apply a Fixed and Variable Area Discharges Coefficient N1, a concept that considers the relationship between pressure and distribution pipe materials when determining leakage losses. The user can either select a default N1 value of 1, or if the user has the information about the percentage of the system that is of rigid pipes and service connections (e.g. steel, cast iron, ductile iron, copper etc.), the user can enter that information (percentage rigid pipes and service connections in the system) and the Model will calculate a system specific N1 value. Next the user can enter the assumed reduction of the average system pressure and the Model will calculate the associated real leakage loss savings and the monetary value of real loss savings. Next the user can enter a best estimate for the cost to achieve the assumed reduction in average system pressure and the model will provide a simple payback period calculation for that scenario. The pressure management options section was designed so that the user can quickly evaluate various average system pressure reduction scenarios to identify the most feasible pressure reduction target. If this initial assessment of pressure management options indicates that pressure reduction could provide cost effective means of reducing and controlling real losses in the system then the Model recommends conducting a detailed pressure management study. Such a study should collect pressure data from the field, assess the presence of pressure transients, identify pressure zones with excessive pressures and prioritize pressure management in parts of the system where it's most feasible. In addition a more detailed assessment of costs for implementing the new pressure management policy should be assessed. This study should further consider the potential revenue impact a change in pressure management policy might have on residential consumption (mainly for pressure dependent outdoor consumption such as irrigation).

WaterRF 4372: Effective Organization and Component Analysis of Water Utility Leakage Data

Water Audit: City of Austin, TX, USA, 2011
EVALUATION OF PRESSURE MANAGEMENT OPPORTUNITIES

	Value to be entered by the user
	Value is automatically filled in/calculated by Model
	Recommended default value

Instructions: **This sheet was designed to provide a simple way to simulate various scenarios of pressure** reduction and the resulting savings in real losses.
The calculated reductions in real losses are based on the FAVAD (Fixed and Variable Area Discharges) concept. The effect of reducing the average system pressure is assessed using data in the white cells D18 to D20 which are automatically copied from the AWWA - Water Balance Results Sheet. Next enter if default N1 value is to be used or if system specific N1 value should be calculated using the following formula N1= 1.5 - (1-0.65/ILI) * Prig/100 (Source: Thornton, J. and Lambert, A., 2005. Progress in practical prediction of pressure: leakage, pressure: burst frequency and pressure: consumption relationships. In: Leakage 2005 Conference Proceedings. Halifax, Canada), which requires entering the percentage of rigid pipes (percentage of metal vs. plastic pipe) and service connections in the system in cell D25. Next enter the targeted reduction in average system pressure in cell D29. Next the reduction in real losses and the related cost savings are calculated by the model. Next enter an initial best estimate for the cost of implementing this alternative pressure management policy in cell D35 to calculate a simple payback in years for this new pressure management policy.

Pressure Management Opportunities

	Existing Pressure Management Policy	
Current Average System Pressure	77.3	PSI
Total Annual Real Losses	4,332.2	MG/Yr
Value of Real Losses	1,429,630	$/year

FAVAD N1 Value Used for Calculation of Real Loss Reduction Due to Reduction of Average System Pressure

	○ Use Default N1	1.0
	⦿ Use System Specific N1	0.7
Enter % of rigid pipes and service connections in system	100%	
ILI	3.0	

	Alternative Pressure Management Policy	
Assumed Reduction in Average System Pressure	5.0	PSI
Assumed % Reduction in Average System Pressure	6%	
Real Loss Volume Saved Through Alternative Pressure Management Policy	203.1	MG/Yr
Value of Real Loss Volume Saved Through Alternative Pressure Management Policy	67,026	$/Year
Enter Estimated Cost of Implementing Alternative Pressure Management Policy	100,000	$
Simple Payback Period for Implementing Alternative Pressure Management Policy	1.5	Years

Note: Evaluation of Pressure Management Opportunities looks at Results of Reduced Pressure on the Volume of Real Losses. Pressure Management has additional benefits and impacts such as: reduced number of new infrastructure failures, reduced annual repair costs, extended infrastructure life, reduction in residential consumption (mainly for pressure dependent outdoor consumption such as irrigation) which are not quantified in this model. However, these additional benefits and impacts should be evaluated before implementing a new or updated pressure management policy.
If this initial assessment of pressure management options indicates that pressure reduction could provide cost effective means of reducing and controlling real losses in the system then it is recommended to conduct a detailed pressure management study. Such a study should collect pressure data from the field, assess the presence of pressure transients, identify pressure zones with excessive pressures and prioritize pressure management in parts of the system where its most feasible. In addition a more detailed assessment of costs for implementing the new pressure management policy should be assessed. This study should further consider the potential revenue impact a change in pressure management policy might have on residential consumption (mainly for pressure dependent outdoor consumption such as irrigation). Typical pressure management options include: introduction of pressure controlled areas, fixed outlet pressure control, time or demand based pressure control, transient control, altitude and level control at reservoirs and tanks etc. (see AWWA M36 for more details).

7/11/2013

Figure 4.16 Model – Pressure Management Options

Glossary

The Model also has an extensive glossary (see Figure 4.17) for all the terms used in the model. The user can click a term on any of the worksheets and will be taken directly to the associated definition in the Glossary Page.

WaterRF 4372: Effective Organization and Component Analysis of Water Utility Leakage Data

Water Audit: City of Austin, TX, USA, 2011
GLOSSARY

Term	Definition	Source
Annual Cost of Apparent Losses	The cost associated to the Apparent Losses within a distribution system Cost of Apparent Losses = (Apparent Losses Per Year) * (Customer Retail Cost of Water)	Julian Thornton, Reinhard Sturm and George Kunkel, P.E., *Water Loss Control*, (McGraw-Hill, 2008)
Annual Cost of Real Losses	The cost associated to the Real Losses within a distribution system. Annual Cost or Real Losses - (Real Losses Per Year) * (Variable Production cost of Water)	Julian Thornton, Reinhard Sturm and George Kunkel, P.E., *Water Loss Control*, (McGraw-Hill, 2008)
Apparent Losses	Losses in customer consumption attributed to inaccuracies associated with customer metering, systematic data handling error, plus unauthorized consumption (theft or illegal use of water). Apparent losses represent paper losses that result in uncaptured revenue for the water utility and distortion of customer consumption data.	*Water Audits and Loss Control Programs; M36*, (Denver: AWWA, 2009)
Apparent Losses per Service Connection per Day	Performance indicator that normalizes the apparent losses within the distribution by the number of service connections. This is considered one of the most reliable of the traditional performance indicators for apparent losses. Op24 = (Apparent Losses per Day) / (Service Connections)	Julian Thornton, Reinhard Sturm and George Kunkel, P.E., *Water Loss Control*, (McGraw-Hill, 2008)
Assumed Reduction in Average System Pressure	A theoretical value for evaluating system pressure reduction options. Based upon this assumed reduction in Average System Pressure, users will be able to estimate the associated reduction in real losses in the system.	
Authorized Consumption	= billed metered + billed unmetered + unbilled metered + unbilled unmetered The volume of water taken by registered customers, the water supplier, and others who are implicitly or explicitly authorized to do so by the water supplier, for residential, commercial, industrial, or agricultural purposes. It also includes water exported across operational boundaries. Authorized consumption also include water consumed in such activities as fire fighting and training, flushing of mains and sewers, street cleaning, watering of municipal gardens, public fountains, frost protection, building water, etc. These may be billed or unbilled, metered or unmetered.	Water Audits and Loss Control Programs; M36, (Denver: AWWA, 2009)

Figure 4.17 Model – Glossary

GUIDELINES FOR FAILURE DATA COLLECTION

Background

This research project through the literature review discussed in Chapter 2 and the data collected from the participating utilities has highlighted that the data quality of leak repair records collected by North American water utilities has still ample room for improvement. Several areas in the collection of leak repair data need to be improved in order to achieve a better and more accurate understanding of failure frequencies and accuracy of real loss component analysis.

- Terminology: the terminology used by water utilities for documenting pipe failures is highly inconsistent. The terms leak, break, and burst are all used throughout the industry and they may all have different interpretations/definitions depending on the water utility. Some utilities for example categorizes a break as a failure event of significant nature that requires immediate action and the term leak is used for smaller pipe failures where the utility does not need to respond immediately. Every failure event on the transmission system, distribution system and on service connections needs to be documented and used in the Model's leakage component analysis. The term 'failure' is used throughout this report and the model to encompass all leak/break terminology.
- Data collection and data quality assurance: infrastructure failures such as service line or distribution and transmission line failures are documented with a varying degree of accuracy and data completeness by North American water utilities. The leakage component analysis tool developed for this research project requires a certain set of information associated to each documented infrastructure failure, such as times of awareness, location and containment, plus the type and size of infrastructure the failure occurred on.

The need to provide clear guidance on failure data collection and documenting was addressed by the research team through the development of a Leak Repair Data Collection Guide in form of an unprotected MS Office Excel spreadsheet (available on WRF's Website).

Purpose

The use of spreadsheet (Leak Repair Data Collection Guide) developed for this research project for collecting data is not required for using the Model. The Leak Repair Data Collection Guide offers guidance to water utilities in the form of a standardized format to document failure events; thereby generating the appropriate data to execute a reliable leakage component analysis. The results of a leakage component analysis are used to develop effective leakage control strategies for the water utility. Utilities that carefully document all failure events have a means to define failure trends occurring in their system.

Leak Repair Data Collection Guide

Utility personnel should employ clear procedures for workers to gather data on the incidence and repair of distribution system failures in the field. The type of data to be collected is listed in the Leak Repair Data Collection Guide (see Figure 4.18) and can be collected as repair work is completed. Failures are categorized into three broad types: those failures that occur on the primary water main piping, failures on customer service connection piping, and failures on fitting and appurtenances attached to water mains; including fire hydrants, valves and air valves or taps. For each of the three broad failure types the guide provides data collection guidelines.

Failures on Water Mains - See Worksheet "Mains"	
Minimum Required Information: This information must be provided in order to compile a reliable leakage component analysis	
Failure Event Type	Reported-via complaints, or Unreported-from leak detection
Network Category of Failure	Distribution-small diameter mains, or Transmission-large diameter mains
General Location of Failure Event	List a very basic description of the failure location by street name, map number, etc.
Size information	List the size of the water main, typically by diameter in inches
Failure Event Reported	Date and Time that the failure became known
Failure Event Pinpointed	Date and Time that the source of lost water was indentified
Failure Event Contained/Valved off/Repaired	Date and Time that the flow of lost water was halted
Additional Information: Optional information that will enhance the picture of failure trends within the distribution system; however this information is not necessary to conduct the leakage component analysis.	
Detailed Failure Event Information	
Failure Event Reported by:	Pick from the dropdown list to note the person who identified the failure
Nature of Failure	Pick from the dropdown list to note the failure mode
Piping Material at Failure	Pick from the dropdown list to note the pipe material
Age of Piping at Failure Location	List the age of the piping if known
Average Pressure at Failure Location	List the typical pressure in the pipeline if known
Suspected Cause of Failure	Pick from the dropdown list to note a suspected failure cause
Detailed Location Description for Failure	
Street Address	Provide this information if it is used for a detailed description
Nearest House Number	Provide this information if it is used for a detailed description
GIS Coordinate (X)	Provide this data if a Geographic Information System is used
GIS Coordinate (Y)	Provide this data if a Geographic Information System is used
Additional Failure Event Information	
Soil Condition at Failure Location	Pick from the dropdown list to note the soil around at the failure
How was Failure Repaired?	Pick from the dropdown list to note the means of failure repair
Estimated Cost to Repair Failure	Provide an estimate of the cost to repair the failure
Comments	Include a description of any unusual aspects of the failure event
Estimated Leak Flow Rate (using AWWA M36 recommended flow rates)	For each leak enter an estimated leak flow rate using the the AWWA M36 Table 5-3 recommended flow rates
Estimated Leak Flow Rate (using utility specific estimations/measurements)	For each leak enter a leak flow rate that is based on utility specific assessments and/or measurements

Figure 4.18 Leak Repair Data Collection Guide Example for Mains Failure Data

CHAPTER 5
COMPONENT ANALYSIS MODEL CASE STUDIES

INTRODUCTION

This chapter outlines the details of using the Model. It offers two case studies: one for Eastern Municipal Water District (EMWD) and another for the Water and Wastewater Authority of Wilson County (WWAWC). For each case study, this chapter presents an examination of the data quality for each input the Model requires. These case studies outline the recommended level of data validation efforts for proper data input into the Model.

EMWD and WWAWC were selected to showcase in this chapter in order to highlight two different utility interactions with the Model. They differ most notably in size: EMWD has approximately 144,000 service connections whereas WWAWC has approximately 7,000 service connections. Further, it is instructive to highlight how each utility's proactive leak detection activity affects the use of the Model. During the audit period reviewed, EMWD did not have any leak detection program (so does not have any Unreported Leakage data entries). WWAWC has an ongoing leak detection program (so has Unreported Leakage data entries). Considering such differences, these utility examples will demonstrate how to use the Model given different circumstances and data.

EASTERN MUNICIPAL WATER DISTRICT

Eastern Municipal Water District (EMWD) is located in Western Riverside County, approximately 75 miles east of Los Angeles. As a signatory to the California Urban Water Conservation Council's Memorandum of Understanding, EMWD is required to submit annual water balances and a component analysis every four years (see Chapter 2 for details on the California regulations). Given these requirements, alongside aggressive conservation goals throughout California, EMWD was especially interested in the Model's development.

EMWD supplies water to a host of cities and unincorporated areas of Western Riverside County. EMWD serves 475,841 customers with 144,272 service connections supplied through a transmission and distribution network of 2,116.5 miles. Its service area covers 540 square miles.

The following sections outline each component of the water audit, detailing the data quality and validation efforts for Eastern Municipal Water District. The first many inputs required in the Model are directly from the AWWA Free Water Audit Software. For these volumes (outlined from pages 67 to 73), the data grading and supporting validation efforts are briefly described. The volumes required for the AWWA Free Water Audit Software addressed here include components of System Input Volume, Authorized Consumption, and Apparent Losses. The next review of data inputs for the Model examines EMWD's failure repair data (outlined from pages 72 to 81). Recommendations and next steps for improving data quality are also outlined for each data input.

System Input Volume (SIV)

Volume from Own Sources

EMWD owns and operates four treatment plants (Hemet Water Filtration Plant, Perris Water Filtration Plant, the Perris Desalter and the Menifee Desalter) and a collection of wells. For the audit period examined (FY09/10), the volume from these sources accounted for 42.88% of the total inputs. The total volume from Own Sources for the audit period was 12,684.88 MG.

Current Data Validation Efforts

For the sources EMWD owns and operates, reservoir drop tests were conducted, where possible, to determine the accuracy of the input meters. In early March 2011, WSO tested the finished water meters at two of the three EMWD Water Treatment Plants using reservoir drop test procedures.

For the groundwater well inputs, the meter installation conditions were collected and compared against installation requirements to determine whether or not those meters are installed according to the manufacturer's requirements. No regular testing of the ground water wells is currently undertaken by EMWD.

The data grading for this system input component was 8. Referring to criteria given in the AWWA Free Water Audit Software data grading matrix worksheet, a8 was assigned because the sources owned and operated by EMWD are metered, tested and calibrated annually, and less than 10% of them tested outside of the +/-6% range.

Data Validation Recommendations

EMWD should continue regular testing/calibration of finished water meters that track the water supplied into its potable water system. Two of the four finished water meters off of EMWD's treatment plants deserve regular testing and recalibration based on the relatively low confidence in their accuracy from the most recent reservoir drop tests.

Water Imported

EMWD also imports water from the Metropolitan Water District (MWD) and neighboring agencies. MWD imports supply the majority of EMWD's potable water system, providing water at three connections. Western Municipal Water District (WMWD) provides sub-agency imports as does Lake Hemet Municipal Water District and Rancho California Water District.

The total volume imported from MWD was 15,964.42 MG for the audit period; the total volume imported from sub-agencies was 928.11 MG. Overall, the total volume imported during the audit period was 16,892.53 MG.

Current Data Validation Efforts

In the spring of 2011, the research team found that the MWD meters were all installed according to the manufacturer's specifications. For the other sub-agency interties, three of the four visited meters did not have sufficient straight length to apply the manufacturer's quoted accuracy (however these meters register a comparatively very small volume so will not affect the total accuracy of Water Imported significantly).

The data grading for the water imported was an 8. Referring to the criteria outline in the AWWA Free Water Audit Software data grading matrix worksheet, an 8 was assigned.

Data Validation Recommendations

EMWD should regularly test and assess the accuracy of each sub-agency and MWD import meter. Where possible, regular cross-references should be made to compare volumes registered by EMWD meters and volumes registered by the billing party's meters.

As one of the worst performing components of the SIV, the meter that tracks the water-wheeling transaction at EM-17 (the Hancock Intertie) should also be tested regularly and upgraded if necessary.

Water Exported

The meters measuring export volumes from EMWD are located at sixteen connections, which provide water to EMWD's sub-agencies. Another component classified as Water Exported included the accounts that provided potable water where raw water is usually used. The volume exported to these sub-agencies and the raw water system during the audit period totaled 1,391.41 MG.

Current Data Validation Efforts

EMWD conducts regular testing of all export meters. The data validity score for the water exported was 7 out of 10. Referring to the AWWA Free Water Audit Software data scoring criteria table, a 7 was assigned.

Data Validation Recommendations

EMWD should continue regular testing and calibration of its export meters. Creating a system of identifying the accounts that deliver potable water to the raw water system is also recommended for consistency.

Consumption Volumes

Billed Metered Authorized Consumption (BMAC)

BMAC is the consumption volume that includes all groups of customers such as domestic, commercial, industrial or institutional. The metered consumption data was taken directly from EWMD's billing records for the water audit period.

All EMWD customers receive volume-based bills from meter reads. Almost all (97.7%) of the accounts are classified as "Domestic" (residential); another 2.2% of all accounts are classified as "Agriculture" accounts, and 0.1% are classified as "System" accounts (meters that read flow or consumption for EMWD's own purposes).

The total BMAC volume for the audit period was 26,271.92MG.

Current Data Validation Efforts

The research team examined the billing database, which included their monthly records for all 144,272 meters during the FY09-10 audit period. Each account in the billing system was classified by Service Type; however, all the accounts of one Service Type were not always included in the BMAC determination. For example, some meters classified as Service Type "E – System" withdrew water from the distribution system – qualifying as BMAC –whereas others were used to track operational flow and did not qualify as BMAC.

A protocol for proper isolation of the BMAC volume given the exceptions throughout the billing database's classification system was provided to EMWD. Consumption was also analyzed by meter size and customer type.

The data grading for BMAC was a 9. Referring to the criteria outlined in the AWWA Free Water Audit Software data grading matrix worksheet, a 9 was assigned because at least 99% of customers have volume-based billing from meter reads with at least a 95% meter reading success rate. Automatic Meter Reading trials and a meter replacement program are underway. A score of 10 was not assigned because third-party verification is not completed annually.

Data Validation Recommendations

EMWD should edit its billing database to more easily identify customer accounts that receive potable water. Currently, distinctions between Service Types (i.e. "A – Domestic", "B – Agricultural", or "E – System") do not effectively communicate whether or not the volume should be included in BMAC.

EMWD should also do a thorough cleaning of its billing database information. Blank makes and sizes make any analysis of consumption incomplete, so it is important to consistently populate and update these fields.

Other Consumption Volumes

Outside of BMAC, there are three more components of consumption to include in the water balance: billed un-metered authorized consumption, unbilled metered authorized consumption, and unbilled un-metered authorized consumption.

For billed un-metered authorized consumption, the only qualifying volume was estimated volumes of water usage for certain construction projects that do not meter their water used. The total for these estimations for FY09-10 was 0.653 MG.

A majority of metered consumption is billed in EMWD. One exception is the change in storage reservoir volume. Reservoir levels are monitored, and an overall change in storage volume from the first to last day of the audit period must be appropriately accounted for as a master meter error adjustment (if the volume of water in the reservoirs has increased) or additional system input volume (if the volume of water in the reservoirs has decreased). Between the first and last day of the audit period the reservoir storage volume increased by 0.727 MG, which was categorized as unbilled metered authorized consumption[4].

Lastly, for unbilled unmetered authorized consumption, mains flushing and firefighting water uses were identified. No estimations are taken for firefighting usage, but it was considered negligible and no volume for firefighting was included. Approximations for main flushing were provided, totaling 10.56 MG for the audit period.

Current Data Validation Efforts

For both the billed un-metered authorized consumption and the unbilled metered consumption volume, a data grading of 9 was assigned according to the criteria outlined in the AWWA Free Water Audit Software data grading matrix worksheet. For the estimated volume of unbilled unmetered consumption a data grading of an 8 was assigned according to the criteria outlined in the AWWA Free Water Audit Software data grading matrix worksheet.

Data Validation Recommendations

EMWD should isolate and record Unmetered Unbilled Authorized Consumption, recording estimations of water use for system flushing and quality checks in digital form. EMWD should also start to track firefighting volumes to add to the completeness of this component.

Apparent Losses

For EMWD, the bulk of apparent losses were from meter inaccuracies during the audit period. For the determination of unauthorized consumption, the industry standard estimate of 0.25% of the water supplied volume was applied. After an in depth review of the billing procedures at EMWD, it was determined that no data handling errors existed: no volume was allocated to the data handling error category. However, in the absence of such an extensive review, it is highly recommended for other Model users to include a reasonable estimate for data handling error.

The total under-registration for the audit period was determined to be 267.72 MG. Unauthorized consumption and data handling errors totaled 70.47 MG.

Current Data Validation Efforts

For the completion of the FY09-10 water audit, the research team requested a group of randomly selected small meters be tested for analysis of meter under-registration. The selections were informed by the consumption distribution between meter groups by make and size; meter groups/populations that registered the most volume during the audit period had a bigger test sample size. The meter accuracy test results for the small meter populations were compiled, examined, and extrapolated to the whole meter population for under-registration determination.

[4] Following AWWA M36 recommendations, this increase in reservoir storage volume should have been an adjustment to the Master Meter Error calculation. EMWD will make the appropriate adjustments for future AWWA water audits.

EMWD's large meter testing program (for meters 3" or larger) involves a recurring accuracy review for large meters that register significant volumes. Low performing meters are repaired or replaced, so the runtime for any inaccurate large meter is well controlled.

EMWD's previously completed large meter test results were compiled and examined. Average accuracies for each group of large meters (by make and size) were calculated and extrapolated to determine the total under-registration for large meter consumption.

The data grading for the meter inaccuracy volume was a 7. Referring to the criteria outlined in the AWWA Free Water Audit Software data grading matrix worksheet, a 7 was assigned because there is an ongoing meter replacement and accuracy testing program (ongoing accuracy testing only for large meters), but the selection of random meter test samples requires improvement due to the unreliability of the billing database meter information.

Data Validation Recommendations

The basic cost analysis did not show an economic incentive to repair or replace the meters beyond the programs already in place. However, to improve confidence in the test results, bigger sample sizes from each meter group (of the same make and size) should be considered. Improvements in reliability of meter make and size information should also be pursued.

It is recommended to revisit the integrity of the billing data process annually, adjusting the allocation of data handling error as necessary.

Water Audit Results and Performance Indicators

The results of the AWWA Water Audit for FY09/10 for EMWD are provided in Figure 5.1. The data validity score for the FY09/10 water audit results was calculated by the AWWA Free Water Audit Software to be 78. This is above the average data validity score for the Validated Dataset and below the 75th percentile.

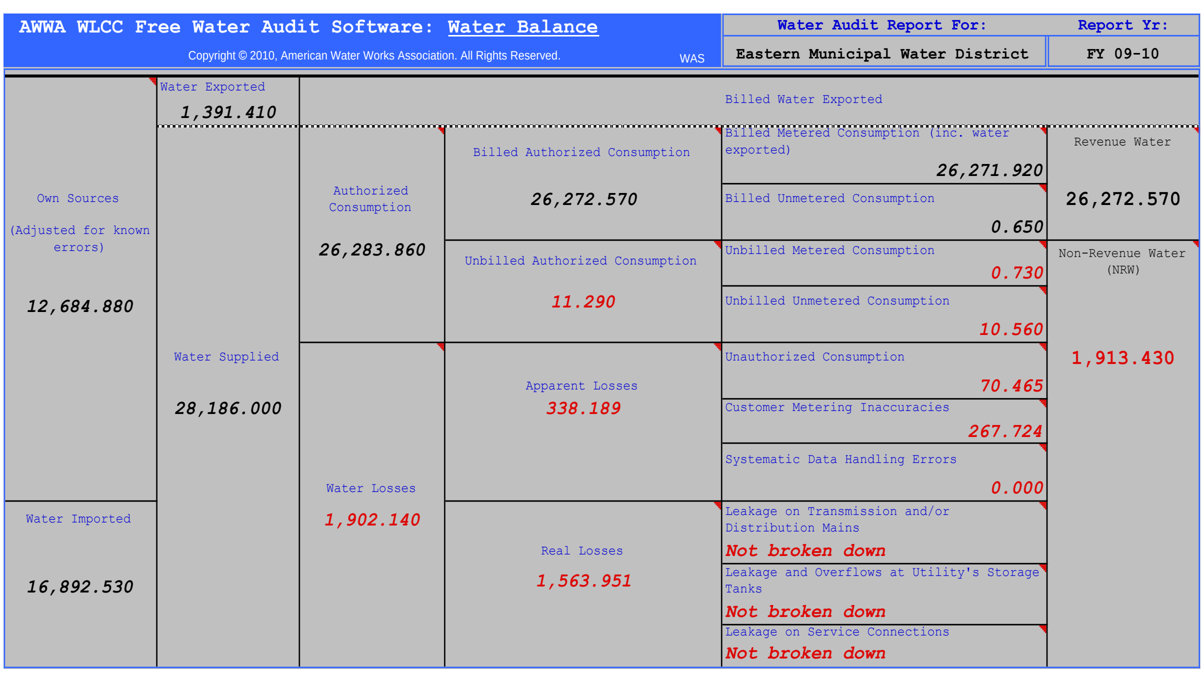

Figure 5.1 Water Audit Results for EMWD

The EMWD FY09/10 water audit data was then entered into the Model and the corresponding performance indicators as calculated by the Model are provided in Figure 5.2.

PERFORMANCE INDICATORS

Financial		
Non-revenue water as percent by volume of water supplied:	6.8%	
Non-revenue water as percent by cost of operating system:	4.1%	
Annual cost of Apparent Losses:	$669,616	
Annual cost of Real Losses:	$3,570,498	
Operational Efficiency		
Apparent Losses per service connection per day:	6.35	gal/service conn/day
Real Losses per service connection per day*:	29.34	gal/service conn/day
Real Losses per length of main per day:	N/A	gal/mi/day
Real Losses per service connection per day per PSI pressure:	0.39	gal/service conn/day/psi
Unavoidable Annual Real Losses (UARL):	913.07	MG/Yr
Current Annual Real Losses (CARL):	1,563.95	MG/Yr
Infrastructure Leakage Index (ILI) [CARL/UARL]:	1.7	
AWWA Water Audit Data Validity Score:	78	

Please enter the Data Validity Score calculated by the AWWA WLCC Free Water Audit Software

Note: If the data validity of your AWWA Water Audit is less than 51 it is recommended to improve the data validity of your AWWA Water Audit data before any of the results of the following economic analysis are considered for implementation.

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Figure 5.2 Water Audit Performance Indicators for EMWD

Leak Repair Data Collection

Water distribution system failure repair data, in the reminder of this report also referred to as failure data, was provided by EMWD directly from their work order database, run by Maximo software. The process of documenting failures (infrastructure failure) was described as follows. An initial leak work order is issued. If there is no actual failure, the work order is annotated and filed as complete. If the leak is confirmed, a new work order is issued (with a new start date and new work order identification number) and assigned to field services, which initiates the repair. Upon completion of the repair, the work order is completed with entries of failure codes and estimates of gallons lost.

EMWD did not complete any proactive leak detection during the audit period examined, so all the leak repair data submitted was exclusively for reported failures.

Current Leak Repair Data Validation Efforts

Upon analyzing an original dataset that contained leak repair work orders from 2008 through 2011, it was concluded that leak repair documentation improved in more recent years. In order to capture as many of the failures repaired as possible, the data from FY10/11 was be used for this audit as a more accurate sample, even though the water audit period was for FY 09/10. It was concluded that the FY10/11 leak repair data is representative for the FY09/10 leak repairs since EMWD does not experience significant changes in number of failures repaired from year to year. It is important to note that the leak repair work order data presented notable challenges in analysis. In the FY10-11 leak repair data alone, there were 27 duplicate work orders (out of 269 total work orders submitted). Further, to record useful time information, a work order normally includes the following sequence: date of leak starting, date of report filing, and the date of leak repair activity. However, this information was not consistently entered. For example, in 108 work orders, the report date was earlier than the failure date entry (time of estimated leak initiation), and in another 47 work orders the start date (date of repair start) was earlier than the report date. Lastly, most of the leak characteristics were found in the "LOC_DESCRIPTION" field. Size, type of leak, pressure zone and other pieces of leak information had to be manually disaggregated from one field.

Data Validation Recommendations

Better tracking and data collection location and repair time is recommended. Chapter 4 provides guidelines for the suggested failure data to collect for use in the Model. EMWD's current work order fields are numerous and detailed but do not easily describe the duration of the leak from confirmation of leakage to containment. For example, "FINISHDATE" currently describes the close of the work order, which is often unrelated to the containment of the leak. To have valuable information on estimating the run time of the leak, the time and date of exactly when the leak was contained should be entered here or in a separate field altogether. Real time field entries and staff training on when and how to enter leak relevant data are recommended.

To improve accuracy and efficiency determining the real loss volume stemming from reported failures, it is recommended that leak repair data entry follow a clear protocol. In particular, date specific data entry should be done carefully and consistently to capture an accurate idea of leak run time.

Component Analysis of Real Losses

The following sections discuss the results of the real loss component analysis.

Component Analysis of Real Losses from Reported and Unreported Failures

Utilizing the leak repair data collected for FY10/11 a real loss component analysis was carried out for EMWD by entering the failure data into the Model.

Component Analysis – Real Losses from Unreported Failures Detected Through Proactive Leak Detection

EMWD did not complete any proactive leak detection during the audit period examined, so all the leak repair data submitted was exclusively for reported failures. The volume of real losses due to unreported failures was therefore zero for the audit period.

Component Analysis – Real Losses from Reported Failures

After validation of the reported leak data (infrastructure failure data), discussed in the previous section, the reported failures were grouped by size and infrastructure type. The average awareness time was estimated to be less than 24 hours, which represents a best estimate based on discussions with EMWD. It was estimated that awareness times for reported mains failures were only a couple of hours and for mains appurtenances and service connections were between hours and a couple of days (based on discussions with EMWD).

The average location and repair time was calculated based on the data provided by EMWD's work order management system. Some of these location and repair times are unrealistically long and are a result of how the leak repair data is entered into the work order management system. Date specific data entry should be done carefully and consistently, additional data entry fields might be required, to capture an accurate idea of leak run time. EMWD is currently working on improving their data collection, following the guidelines as outlined in Chapter 4.

Table 5.1
Reported Failures Summary Table - EMWD

Infrastructure	Number of Infrastructure Failures	Average Awareness Time (days)	Average Location and Repair Time (days)
Mains 4"	7	0.5	9.28
Mains 6"	11	0.25	17.40
Mains 8"	6	0.25	7.54
Mains 12"	14	0.25	7.26
Mains 16"	1	0.10	1.0
Mains 18"	2	0.10	24.43
Mains 30"	1	0.10	5.61
Hydrants	13	3.0	25.56
Valves	23	3.0	36.11
Blowoffs	4	3.0	27.49
Service Connection <1"	163	2.0	13.51
Service Connection >=1"	19	2.0	15.63

The annual volume of water lost through reported failures was calculated by multiplying the number of reported failures, the average reported failure duration, and the average failure flow rate at the specified system pressure. The data in Table 5.1 was entered in the Model and default failure flow rates provided by the model were selected for the model to calculate the volume of real losses stemming from reported failures (see Figure 5.3).

STEP 3A: REPORTED FAILURES ON MAINS

Instructions: Enter the total number of failures by main size that were reported to and repaired by the water utility during the audit period in cells C58 to C77. Next enter the total length of mains for each mains size group in cells D58 to D77 (Note: this information is not required for the real loss component analysis but serves to calculate failure frequencies by mains size). Next enter the average awareness duration for reported failure events by mains size in cells I58 to I77 (Awareness duration is the average time from the occurrence of the failure event until the water utility becomes aware of its existence). Next enter the average duration of locating and containing reported failure events by mains size in cells K58 to K77. Next select either the default average leak flow rate provided by the model in cells P58 to P77 or select and enter your own utility specific average leakage flow rates in cells Q58 to R77.

Mains by Size	Number of Failures per Year	Length of Main (miles)	Failure Frequency (number / 100miles / yr)	Average Failure Flow Rate @ **70psi** (gpm)	Average Pressure (psi)	N1 (Leakage-Pressure Exponent) Value	Average Failure Duration: Average Awareness Duration **(days)**	Average Failure Duration: Average Duration for Location and Repair/Shutoff Failure (days)	Average Failure Duration: Total Duration (days)	Average Annual Loss per Failure (MG)	Total Annual Loss (MG)	Use Default Average Leak Failure Rate	Use Utility Specific Average Leak Flow Rate	Average Failure Flow Rate @ **average system pressure** (gpm)
Diameter 2"	-	0.8	-	13.90	75.0	0.50	-	-	-	-	-	◉	○	-
Diameter 3"	-	0.8	-	13.90	75.0	0.50	-	-	-	-	-	◉	○	-
Diameter 4"	7	66.7	11	44.00	75.0	0.50	0.50	9.28	9.78	0.64	4.49	◉	○	-
Diameter 6"	11	240.3	5	92.00	75.0	0.50	0.25	17.40	17.65	2.42	26.62	◉	○	-
Diameter 8"	6	966.1	1	92.00	75.0	0.50	0.25	7.54	7.79	1.07	6.41	◉	○	-
Diameter 10"	-	7.8	-	92.00	75.0	0.50	0.25	-	0.25	-	-	◉	○	-
Diameter 12"	14	446.4	3	222.00	75.0	0.50	0.25	7.26	7.51	2.49	34.79	◉	○	-
Diameter 14"	-	7.6	-	222.00	75.0	0.50	-	-	-	-	-	◉	○	-
Diameter 16"	1	73.0	1	222.00	75.0	0.50	0.10	1.00	1.10	0.36	0.36	◉	○	-
Diameter 18"	2	74.9	3	222.00	75.0	0.50	0.10	21.43	21.53	7.12	14.25	◉	○	-
Diameter 20"	-	-	-	222.00	75.0	0.50	-	-	-	-	-	◉	○	-
Diameter 24"	-	-	-	222.00	75.0	0.50	-	-	-	-	-	◉	○	-
Diameter 30"	-	-	-	222.00	75.0	0.50	-	-	-	-	-	◉	○	-
Diameter 36"	-	-	-	222.00	75.0	0.50	-	-	-	-	-	◉	○	-
Diameter 42"	-	-	-	222.00	75.0	0.50	-	-	-	-	-	◉	○	-
Diameter 48"	-	-	-	222.00	75.0	0.50	-	-	-	-	-	◉	○	-
Diameter 54"	-	-	-	222.00	75.0	0.50	-	-	-	-	-	◉	○	-
Diameter 60"	-	-	-	222.00	75.0	0.50	-	-	-	-	-	◉	○	-
Diameter > 60"	-	-	-	222.00	75.0	0.50	-	-	-	-	-	◉	○	-
Other Diameter	1	6.8	15	222.00	75.0	0.50	0.10	-	0.10	0.03	0.03	Enter avg flow rate		222.0
										SUB-TOTAL REPORTED FAILURES ON MAINS	86.96			

STEP 3B: REPORTED FAILURES ON DISTRIBUTION SYSTEM APPURTENANCES

Instructions: Enter the total number of failures by distribution system appurtenance type that were reported to and repaired by the water utility during the audit period in cells C86 to C89. Next enter the total number of appurtenances for each system appurtenance group in cells D86 to D89 (Note: this information is not required for the real loss component analysis but serves to calculate failure frequencies by appurtenance type). Next enter the average awareness duration for reported failure events by system appurtenance type in cells I86 to I89 (Awareness duration is the average time from the occurrence of the failure event until the water utility becomes aware of its existence). Next enter the average duration of locating and containing reported failure events by system appurtenance type in cells K86 to K89. Next select either the default average leak flow rate provided by the model in cells P86 to P89 or select and enter your own utility specific average leakage flow rates in cells Q86 to R89.

System Appurtenances by Type	Number of Failures per Year	Total Number of Appurtenances	Failure Frequency Number of Failures per 1000 Appurtenances	Average Failure Flow Rate @ **70psi** (gpm)	Average Pressure (psi)	N1 (Leakage-Pressure Exponent) Value	Average Failure Duration: Average Awareness Duration **(days)**	Average Failure Duration: Average Duration for Location and Repair/Shutoff Failure (days)	Average Failure Duration: Total Duration (days)	Average Annual Loss per Failure (MG)	Total Annual Loss (MG)	Use Default Average Leak Failure Rate	Use Utility Specific Average Failure Flow Rate	Average Failure Flow Rate @ **average system pressure** (gpm)
Hydrants	13	22,212	1	3.50	75.0	0.50	5.00	25.56	30.56	0.16	2.07	◉	○	-
Valves	23	56,788	0	6.90	75.0	0.50	5.00	36.11	41.11	0.42	9.72	◉	○	-
Meters	-	-	-	0.25	75.0	0.50	-	-	-	-	-	◉	○	-
Other (e.g. Blow-offs, etc.)	4	-	-	6.90	75.0	0.50	5.00	27.49	32.49	0.32	1.29	Enter avg flow rate		6.9
										SUB-TOTAL REPORTED LEAKS ON SYSTEM APPURTENANCES	13.09			

STEP 3C: REPORTED FAILURES ON SERVICE CONNECTIONS

Instructions: Enter the total number of failures by service connection size (< 1" or > = 1") that were reported to and repaired the water utility during the audit period in cells C98 to C99. Next enter the total number of service connections for each service connection size group in cells D98 to D99 (Note: this information is not required for the real loss component analysis but serves to calculate failure frequencies by service connection size group). Next enter the average awareness duration for reported failure events by service connection size group in cells I98 to I99 (Awareness duration is the average time from the occurrence of the failure event until the water utility becomes aware of its existence). Next enter the average duration of locating and containing reported failure events by service connection size group in cells K89 to K99. Next select either the default average leak flow rate provided by the model in cells P98 to P99 or select and enter your own utility specific average leakage flow rates in cells Q98 to R99.

Service Connections by Size	Number of Failures per Year	Total Number of Service Connections	Failure Frequency Number of Failures per 1000 Service Connections	Average Failure Flow Rate @ **70psi** (gpm)	Average Pressure (psi)	N1 (Leakage-Pressure Exponent) Value	Average Failure Duration: Average Awareness Duration **(days)**	Average Failure Duration: Average Duration for Location and Repair/Shutoff Failure (days)	Average Failure Duration: Total Duration (days)	Average Annual Loss per Failure (MG)	Total Annual Loss (MG)	Use Default Average Failure Flow Rate	Use Utility Specific Average Leak Failure Rate	Average Failure Flow Rate @ **average system pressure** (gpm)
Services < 1"	163	132,891	1	6.90	75.0	0.50	2.00	13.51	15.51	0.16	26.00	◉	○	-
Services >= 1"	19	13,134	1	13.90	75.0	0.50	2.00	15.63	17.63	0.37	6.94	◉	○	-
										SUB-TOTAL REPORTED LEAKS ON SERVICE CONNECTIONS	32.94			
										GRAND TOTAL REPORTED FAILURES	132.99			

Figure 5.3 Component Analysis for Reported Failures for EMWD

The total water lost from reported failures was estimated at132.99MG for the audit period of FY 09-10. This volume from reported failures is only a small portion of the total annual real losses (1,563.951 MG) as calculated by the water balance. As seen in most systems, the majority of real losses is caused by unreported and hidden failures that remain running continuously and undetectable background losses.

Component Analysis – Real Losses from Background Leakage

Background Leakage from the Distribution Network

Background leakage is defined as the loss of water from individual leak events for which the rate of loss is less than 2.2 gpm at 70 psi. These failures are undetectable using current leak noise detection technology. The volume of background leakage tends to increase with age of the network and is higher for systems operated at higher pressure. The type of pipe materials and jointing techniques are also contributory factors. The volume of background leakage is a function of the condition of the infrastructure, average system pressure and total length of mains and number of service connections. The AWWA theoretical minimum level of leakage for a system is known as Unavoidable Annual Real Losses (UARL) and includes values for the minimum level of background leakage from mains and service connections (see Table 5.2). For more information on Background Leakage, it is recommended to reference Chapter 5 within AWWA's Manual M36, "Water Audits and Loss Control Programs, 3rd edition".

Table 5.2
AWWA Unavoidable Background Leakage Rates

Infrastructure Component	**Background Leakage at ICF=1.0[5]**	**Units**
Mains	2.870	gallons / mile of main / day / psi of pressure
Service Connection: main to curb-stop	0.112	gallons / service connection / day / psi of pressure
Service Connection: curb-stop to meter	4.780	gallons / mile of service connection / day / psi of pressure

Source: Adapted from Lambert et al. 1999

An Infrastructure Condition Factor (ICF) of 1.2 was used based on the results of a sensitivity analysis and based on the fact that about 70% of EMWD's distribution network is less than 30 years old.

EMWD meters the customer outside of the property boundary, effectively at the curb-stop. The length of service connection between curb-stop and meter is therefore assumed to be zero. All losses on the customer's pipes after the meter are assumed to be included in authorized billed metered consumption.

By applying an ICF of 1.2 to the AWWA unavoidable background leakage rates, the annual real loss from background leakage from the distribution network was calculated by the Model to be 762.66MG (see Figure 5.4).

[5]Theoretical minimum background leakage corresponds to an Infrastructure Condition Factor (ICF) of 1.0. .

Step 2: BACKGROUND LEAKAGE ON MAINS AND SERVICES

Instructions: The background leakage volume from mains and service connections will be automatically calculated after selecting one of the default Infrastructure Condition Factors (ICF) based on infrastructure age or after a utility specific ICF has been selected and entered in cell P43. The level of background leakage tends to increase with infrastructure age and is higher for systems with higher pressure. The volume of background losses is generally a significant component of the total real loss volume, at times up to 50% of the total volume of real losses. Overestimating (ICF used in model is too high) or underestimating (ICF used in model is too low) the background leakage volume might lead to a real loss control strategy that is not truly optimized. Selecting the ICF based on general age of the distribution network should only be seen as a starting point. It is strongly recommended that over time a utility specific ICF is assessed and confirmed through field tests using one of the recommended approaches outlined in the AWWA M36 manual.

						Pressure Corrected Calculation	
System Component	Units	Quantity	Component UARL Values (g/unit/d/psi)	Infrastructure Condition Factor	Average Pressure (psi)	N1 (Leakage-Pressure Exponent)	Annual Volume (MG)
Mains	miles	2,116.5	2.87	1.2	75.0	1.5	206.55
Services - Main to Curb-Stop	number	146,025	0.112	1.2	75.0	1.5	556.11
Services - Curb-Stop to Meter	miles	-	4.78	1.2	75.0	1.5	-
						Total Background Leakage on Mains and Services	**762.66**

Select Infrastructure Condition Factor (ICF) based on age of distribution network

ICF 1 for System Age <50 years	1.0
ICF 1.5 for System Age 50 - 70 years	1.5
ICF 2.5 for System Age >70 years	2.5
OR	
Enter ICF values assessed through implementing the approaches outlined in the AWWA M36 manual	1.2

Figure 5.4 Component Analysis for Background Leakage on Mains and Service Connections EMWD

Background Leakage from Reservoirs

An additional component of background leakage exists, which comes from undetectable losses on reservoirs. There are no set minimum values for estimating losses caused by background leakage on reservoirs – the Model provides a default value of 0.25gpm/MG of reservoir volume. No study data is available for EMWD regarding background leakage from reservoirs. Therefore, the default background leakage rate provided by the model was used. The total background leakage from reservoirs was estimated to be 25.45 MG per year (see Figure 5.5).

Step 1: BACKGROUND LEAKAGE, REPORTED LEAKAGE AND UNREPORTED LEAKAGE FROM RESERVOIRS

Instructions: First enter the capacity of all distribution system reservoirs and tanks in use during the audit period. In case the system input volume is based on raw water meters located upstream of the Water Treatment Plant (WTP) then also include the capacity of the WTP reservoirs. Next select a reservoir background leakage rate - either the default value provided by the model or a utility specific flow rate. If reservoirs and tanks are well maintained and the utility does not suspect any background leakage from the reservoirs and tanks then enter zero as the utility specific flow rate. In case a reservoir or tank was reported leaking or has overflowed, enter the estimated volume in cell G27 . If a proactive investigation/inspection of the system reservoirs and tanks has discovered a leaking reservoir or tank then enter the estimated annual volume lost in cell G28.

	Capacity (MG)	Background Leakage Rate (gpm/MG)	Annual Volume (MG)
Total Reservoir/Tank Capacity	194.38	0.25	25.54
Reported Reservoir Leakage and any recorded Reservoir and Tank Overflows			0.00
Unreported Reservoir Leakage			0.00
Total Background Leakage, Reported and Unreported leakage from Reservoirs			**25.54**

Select Reservoir Background Leakage Rate

Default Value	0.25	(gpm/MG)
OR		
Utility Specific Background Leakage Rate	-	(gpm/MG)

Figure 5.5 Component Analysis for Background Leakage form Reservoirs for EMWD

Component Analysis Summary and Estimation of Unreported/Hidden Failures

The real loss component analysis calculated 788.20MG of real losses were caused by background leakage and 132.99MG were caused by reported failures repaired by EMWD. However, the sum of these two real loss components only amounts to 921.19MG, while the AWWA water audit calculated that the total volume of real losses for FY09/10 was 1,563.95MG (see Figure 5.1). Since EMWD did not undertake any proactive leak detection during the audit period it has to be assumed that the difference in real loss volume from the water audit and the real loss component analysis is due to hidden failures currently running undetected. This real loss volume caused by hidden/undetected failures is estimated to be 684.97MG and should theoretically be recoverable trough proactive leak detection (see Figure 5.6). The economic intervention frequency for leak detection will provide an initial estimate of how much of the currently hidden/undetected real loss volume is economically recoverable through proactive leak detection.

System Component	Background Losses (MG)	Reported Failures Losses (MG)	Unreported Failures Losses (MG)	Total Annual Real Losses by Component Analysis (MG)	Total Annual Real Losses by IWA/AWWA Water Audit (MG)
Reservoirs	25.54		not estimated	25.54	not estimated
Mains and Appurtenances	206.55	100.05	not estimated	306.6	not estimated
Service Connections	556.11	32.94	not estimated	589.05	not estimated
Total Annual Real Losses	788.2	132.99	not estimated	921.19	1,563.95
Total Annual Real Losses	Estimated by AWWA Water Audit (MG)			(A)	1,563.95
	Estimated by Component Analysis (MG)			(B)	921.19
	Hidden Losses (Unreported Leakage Currently Running Undetected)			= (A) - (B)	642.76

Figure 5.6 Real Loss Component Analysis Results for EMWD

Figure 5.7 provides a graphical display of the real loss component analysis results. While a certain amount of the difference between the two volumes (Real loss from AWWA Water balance and real losses from component analysis) is due to errors in the two methods of estimation, the difference is mainly due to the presence of hidden losses, i.e., the presence of detectable leaks that are not being identified. In effect, hidden losses are a backlog of failures waiting to be detected and repaired. Individually, each hidden failure may not cause a customer service problem and may not be visible at the ground surface. Collectively however, hidden losses can account for a considerable volume of real loss each year; about 41% of the total volume of real losses in the case of EMWD (see Figure 5.7).

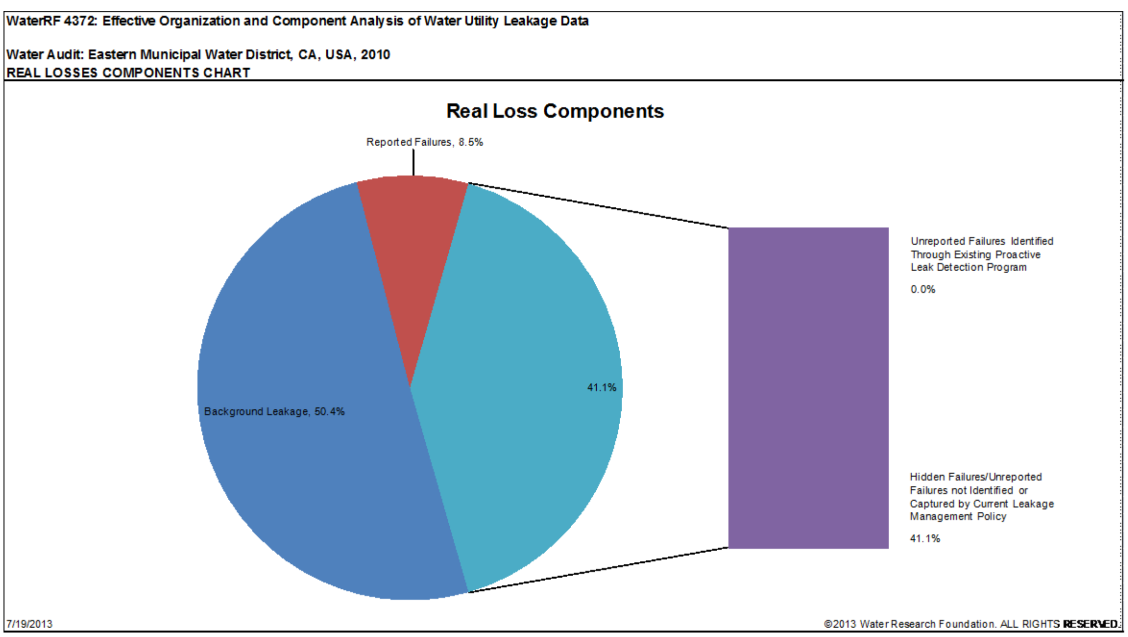

Figure 5.7 Real Loss Components Based on Real Loss Component Analaysis for EMWD

Failure Frequency Analysis for Reported Failures

The overall failure frequency of 2failures per 100 miles of main per year as calculated based on the failure data entered in the Model is significantly less than what is indicated as a failure frequency of an optimized system (15 per 100 miles per year). This may indicate that the system experiences a much lower percentage of reported failures surfacing than in other utilities. However, the low failure frequency data also clearly suggests that the leak repair database is not yet capturing all of the leaks repaired. It is important that EMWD focus on thoroughly documenting each instance of leak repair activity to properly track reported real losses.

WaterRF 4372: Effective Organization and Component Analysis of Water Utility Leakage Data

Water Audit: Eastern Municipal Water District, CA, USA, 2010
INFRASTRUCTURE FAILURE FREQUENCY ANALYSIS

Eastern Municipal Water District

Total Number of Mains Failures Reported for Water Audit: Eastern Municipal Water District, CA, USA, 2010	42	
Total Length of Mains	2,116.5	(miles)
Failure Frequency Eastern Municipal Water District	2.0	(number / 100miles / yr)
Average Failure Frequency in North America Based on Literature Review - WaterRF 4372	25.0	(number / 100miles / yr)
Failure Frequency for Optimized Distribution Systems (Friedman 2010)	15.0	(number / 100miles / yr)

Note: reported failure frequency is less than failure frequency for optimized distribution systems - check failure data

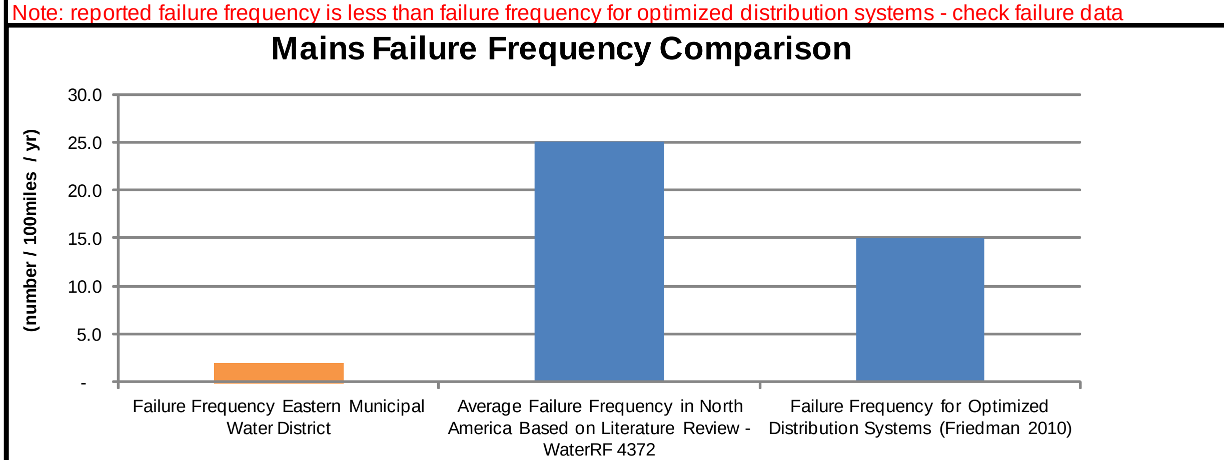

Figure 5.8 Mains Failure Frequency Analysis Results for EMWD

During FY10-11, about 80% of all leak repairs in EMWD were for service pipes 2 inches and smaller. However, the failure frequency analysis for reported service line leaks indicates that the number of reported service line repairs captured by the current work order management system does not provide a comprehensive and accurate account of all service lines repaired during FY10/11.

Figure 5.9 provides a comparison of EMWD's service lines failure frequency against the minimum number of reported service line failures used in the UARL calculation. The Model again highlights that the number of service line failures appears to be too low and that the user should check the data used in the model.

Value to be entered by the user
Value is automatically filled in/calculated by Model
Recommended default value

Eastern Municipal Water District

Total Number of Service Connection Failures Reported for Water Audit: Eastern Municipal Water District, CA, USA, 2010	182	
Total Number of Service Connections	146,025	(service connections)
Service Connection Failure Frequency Eastern Municipal Water District	1.2	(number / 1000 service connections / yr)
AWWA Unavoidable Annual Real Losses (UARL) Component of Reported Service Line Failures	2.25	(number / 1000 service connections / yr)
Ratio of Failure Frequency to UARL Break Frequency	0.6	

Note: reported failure frequency is less than UARL based minimum failure frequency - check service line failure data

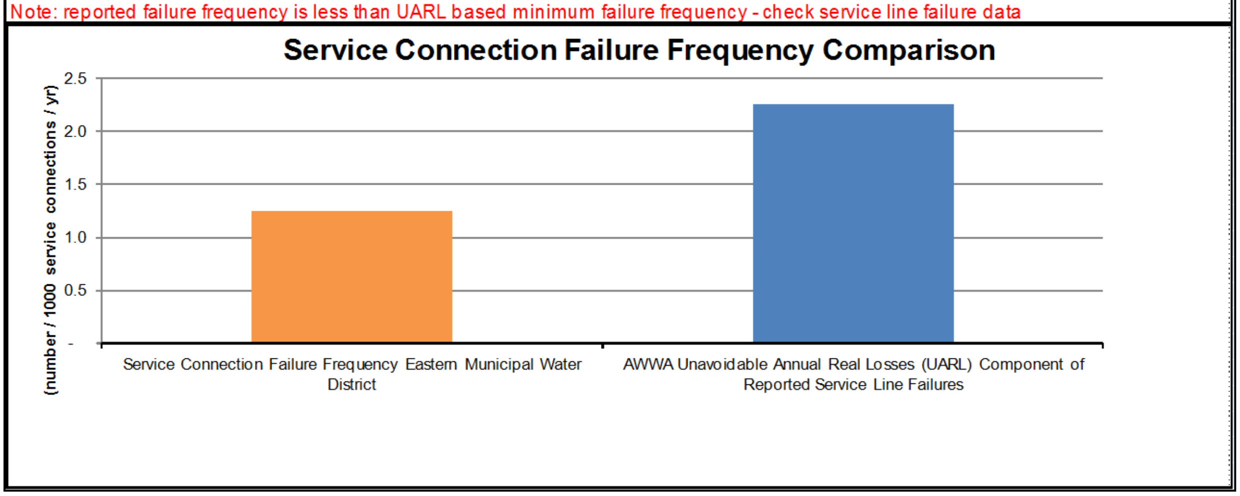

Figure 5.9 Service Connection Failure Frequency Analysis Results for EMWD

Summarizing, the failure frequency analysis has confirmed initial concerns about the completeness of the failure data collected by EMWD's work order management system.

Evaluation of Short to Medium Term Intervention Strategies

The next step in the use of the Model is to evaluate short and medium term opportunities to reduce the current real loss volume. Three intervention strategies are evaluated:

- Improved leak location and repair times,
- Economic intervention frequency for proactive leak detection, and
- Improved pressure management.

Evaluation of Location and Repair Time Reduction Options

The Model provides an opportunity to evaluate possible improvements in location and repair times for reported and unreported leaks on each of the three infrastructure components (mains, service lines and mains fittings/appurtenances). EMWD did not undertake proactive leak detection during the audit period therefore the evaluation of improved location and repair times is only applicable to reported leaks/failure events.

Based on the results of the real loss component analysis the Model provides a summary of leak/failure events for each of the three infrastructure components (mains, service lines and mains fittings/appurtenances), the average location and repair duration for each infrastructure component, the related volume of real losses, and the resulting cost of real losses due to the current average location and repair times. The Model also provides a "What IF" function to assess the potential savings in real loss volume and cost if the current average location and repair durations are reduced by a certain percentage.

EMWD's average location and repair durations are currently not very accurate for reasons discussed in previous sections. In order to demonstrate the use of this module of the model a theoretical reduction in average location and repair time from 10.6 days to 8 days for reported leaks on mains was assumed. The model calculated that EMWD could reduce the real loss volume by 21.1 MG with potential savings of about $48,000.

It was also assumed that the average location and repair duration could be reduced from 13.7 days to 7 days for reported failures on service connections and from 31.8 days to 16 days for reported failures on mains fittings. These reductions in location and repair times would result in real loss savings of 14.2MG (value of about $32,000) for reported service connection leaks and 5.7MG (value of about $13,000) for reported system appurtenances leaks (see Figure 5.10).

EMWD's next step is to evaluate the costs associated with achieving these reductions in average location and repair times in order to evaluate the cost/benefit. Since this model provides this "What IF" function, it is quite simple for EMWD to model various scenarios of reduced location and repair times and the resulting savings in real loss volume and cost once better leak repair data is available.

Reported and Unreported Failure Events			
Failures on Mains	***Reported***	***Unreported***	
Total Number of Failures on Mains in 2010	42	-	
Average location and repair duration	10.6	-	days
Total Volume lost (stemming from location and repair duration)	84.9	-	(MG)
Total Cost of Volume lost (stemming from location and repair duration)	$ 193,728	$ -	
What IF Location and Repair Duration is Reduced to	8		days
Percent Reduction	25%		
Potential Related Savings in Leakage Volume	21.1		(MG)
Potential Related Savings in Leakage Volume Cost	$ 48,139		
Service Line Failures	***Reported***	***Unreported***	
Total Number of Failures on Service Connections in 2010	182	-	
Average location and repair duration	13.7	-	days
Total Volume lost (stemming from location and repair duration)	28.8	-	(MG)
Total Cost of Volume lost (stemming from location and repair duration)	$ 65,753	$ -	
What IF Location and Repair Duration is Reduced to	7	1	days
Percent Reduction	49%		
Potential Related Savings in Leakage Volume	14.12		(MG)
Potential Related Savings in Leakage Volume Cost	$ 32,233		
Failures on System Appurtenances	***Reported***	***Unreported***	
Total Number of Failures on System Appurtenances in 2010	40	-	
Average location and repair duration	31.8	-	days
Total Volume lost (stemming from location and repair duration)	11.4	-	(MG)
Total Cost of Volume lost (stemming from location and repair duration)	$ 26,040	$ -	
What IF Location and Repair Duration is Reduced to	16		days
Percent Reduction	50%		
Potential Related Savings in Leakage Volume	5.7		(MG)
Potential Related Savings in Leakage Volume Cost	$ 12,946		
Total Potential Savings if Location and Repair Duration is Reduced as Simulated in the Above Sections	**104.6**		**(MG)**
Total Potential Cost Savings if Location and Repair Duration is Reduced as Simulated in the Above Sections	**$ 93,319**		**Per Year**

7/19/2013

Figure 5.10 Evaluation of Location and Repair Time Reduction Optionsfor EMWD

Evaluation of Economic Intervention Frequency

The WRF 4372 model also provides an opportunity to establish a preliminary schedule for proactive leak detection surveys and the corresponding necessary budget. The purpose of proactive leak detection and control is to find failures that do not surface or only surface after a long time. Therefore, by undertaking regular leak detection and repair the utility has the possibility to actively control the volume of water lost through unreported failures.

In order to reduce the level of unreported failures and make an impact into the potential 6,859 MG/Yr of Hidden Losses, it will be necessary to undertake a very comprehensive leak survey, where all fittings are sounded and an intensive ground microphone survey is undertaken.

Utilizing the rate of rise method as outlined in the AWWA M36 manual for determining the economic intervention frequency three parameters need to be assessed:

- Average rate of rise of unreported leakage (RR)
- The cost of leak detection survey intervention (CI)
- The cost of Real Losses (CV)

Once these three parameters are know it is possible to assess for any size system or subsystem:

The economic intervention frequency (EIF) to find unreported leaks using Equation 5.1

$$EIF\ (month) = \sqrt{\frac{0.789 \times \frac{CI}{CV}}{RR}} \tag{5.1}$$

The economic percentage (EP) of the system that should be inspected each year using Equation 5.2

$$EP(\%) = \frac{100 \times 12}{EIF} \tag{5.2}$$

The appropriate annual budget for intervention (ABI) costs, (excluding leak repair cost) using Equation 5.3

$$ABI(\$) = EP \times CI \tag{5.3}$$

The economic annual volume of unreported real losses (EURL), corresponding to the economic intervention frequency using Equation 5.4.

$$EURL = \frac{ABI}{CV} \tag{5.4}$$

As these parameters are calculated using square root functions, they are not very sensitive to random errors in CI, CV, and RR. Using an example discussed in a paper by Lambert and Lalonde (2005), errors of +/-10% in CV, 5% in CI and 20% in RR produced a confidence limit of +/-15% in the calculated economic intervention frequency (EIF).

Rate of Rise of Leakage (RR)

The total rate of rise of leakage may be thought of as the continuing increase in leakage that would occur in absence of any leak repairs. It is made up of two components: new leaks occurring in the network plus the growth (increase in volume) of existing leaks. Of this total rate of rise of leakage, a portion will comprise visible leaks which surface and come to the attention of the water utility, which will be promptly repaired by the water utility. It is the remaining portion which is normally used in leakage economic studies, and defines the leakage which must be overcome through proactive leak detection. The rate of rise of leakage is therefore used to define the economic effort and expenditure to manage unreported leakage at an economic level. There are three principle ways of assessing the rate of rise of leakage for a distribution system:

- Compare Real Losses from water balances several years apart.
- Use results of proactive leak detection campaign in either entire system or same subsystem.
- Use results of measured leakage night flows

Since no reliable data was available for any of the three principal ways of rate of rise of leakage estimation, it was necessary to make some basic assumptions. The Unavoidable Annual Real Losses (UARL) formula allows calculating the unavoidable annual volume of leakage due to unreported leaks for any given system. Utilizing the empiric UARL formula (see **Error! Reference source not found.**) for the EMWD distribution system the unavoidable annual real losses from unreported leaks was calculated to be around 165 MG/Year.

Table 5.3
AWWA Standard Unit Values for Calculation of UARL

Infrastructure component	Units	Background Leakage	Reported Failures	Unreported Failures	UARL Total
Mains	gal/mile/day/psi	2.87	1.75	0.77	5.39
Service Connections – main to curb-stop	gal/conn/day/psi	0.112	0.007	0.030	0.149
Service Connections – curb-stop to meter	gal/mile of conn/day/psi	4.78	0.57	2.12	7.47

Source: Adapted from Lambert et al. 1999

In order to assume a conservative value for the RR the annual rate of rise of leakage for the entire distribution system was assumed to be equal to the unavoidable annual real losses from unreported leaks of about 165 MG/Year, or 0.21thousand gallons/mile of mains/day/year.

The cost for comprehensive leak detection survey was assumed at $250/mile and the real losses are valued by EMWD at the wholesale cost of treated water imported from Metropolitan Water District (MWD) at a cost of $2,283/MG.

Using the three parameters discussed above, the Model calculates a preliminary schedule for proactive leak detection surveys and the corresponding necessary budget. The model indicates that EMWD should survey about 59% of the network every year at an annual budget for proactive leak detection of about $313,000/year. The model estimates that by implementing this proactive leak detection schedule about 505.6 MG of leakage could potentially be recovered. The pie chart provides a depiction of the potentially recoverable leakage volume in reference to the current total hidden loss volume (see Figure 5.11). Given the assumed RR, the current variable production cost and the assumed cost for a detailed leak survey the model estimates that about 137MG of hidden leakage is not economically recoverable.

Evaluation of Pressure Management Options

The final step in evaluating options for reducing the total volume of real losses in a system is the Model's sheet designed to evaluate alternative pressure management options (see Figure 5.12). Pressure management is a tool to manage system pressures to the optimum level of service, ensuring sufficient and efficient supply to legitimate users and consumers, while reducing unnecessary or excess pressures. Pressure management reduces the losses from existing leaks and research has shown that pressure management also reduces the number of new leaks and extends infrastructure lifespan. Pressure management is effective in reducing all Real Loss components: Background Leakage, Reported Leakage, Unreported Leakage and Storage overflows.

Pressure management is already being employed by EMWD through the use of reservoir/pressure zones and on some parts of the distribution system where Pressure Reducing Valve (PRV) stations are operated. The current average system pressure is 75psi, which is already a relatively modest average system pressure. EMWD currently operates 67 pressure zones, and three of these pressure zones (zones 1627, 1764 and1719) control pressure for about 50% of all service connections. Only pressure zone 1627 has an average zone pressure above 75 psi. Furthermore, 33 pressure zones have average pressures higher than 80 psi (ranging from 80 psi to 166 psi). Various improvements to the current pressure management practice were evaluated and discussed with EMWD for their implementation potential. Based on the analysis of system pressure data it was calculated that a modest reduction of average system pressure from 75 psi to 72 psi could be realistically achieved.

The model provides the opportunity to evaluate the potential savings in real loss if the average system pressure is reduced by 3 psi (see Figure 5.12). The Model used the default N1 value (N1 = 1) to calculate that the reduction in real losses would be about 63MG per year if the average system pressure were reduced by 3 psi. This would result in monetary savings of about $143,000 per year. Assuming that it would cost about $750,000 to reduce the average system pressure, the simple payback period is 5.3 years for this investment in real loss management.

WaterRF 4372: Effective Organization and Component Analysis of Water Utility Leakage Data

Water Audit: Eastern Municipal Water District, CA, USA, 2010
CALCULATION OF ECONOMIC INTERVENTION FREQUENCY FOR PROACTIVE LEAK DETECTION

Value to be entered by the user
Value is automatically filled in/calculated by Model
Recommended default value

	System Characteristics		
	Total Length of Mains	2,116.5	miles
	Number of Service Connections	146,025	service connections
	Service Connection Density	69.0	conn./mile main
	Average System Pressure	75.0	PSI
	Water Balance Results		
TBL	Current Annual Background Leakage	788.20	MG/Yr
CRL	Real Losses from Current Reported Leakage	132.99	MG/Yr
UL	Unreported Failures Identified Through Existing Proactive Leak Detection Program	-	MG/Yr
	Hidden Failures/Unreported Failures not Identified or Captured by Current Leakage Management Policy	642.76	MG/Yr
CARL	Current Annual Real Losses	1,563.95	MG/Yr
UARL	Unavoidable Annual Real Losses	913.07	MG/Yr
	Infrastructure Leakage Index (ILI) [CARL/UARL]	1.7	
	Variable Cost of Real Losses		
CV	Variable Production cost (applied to Real Losses):	2.28	$/per kgal
		2,283.00	$/MG
CI	Cost of comprehensive leak detection survey (excluding leak repair cost)	250.00	$/per mile
		529,125	$/for entire system
RR	Average Rate of Rise of Unreported Leakage	0.21	kgal/mile of mains/day in a year
		0.44	MG/day in a year
	CI/CV	109.5	kgal/mile
EIF	Economic Intervention Frequency [0.789 * (CI/CV)/RR] ^0.5	20.3	months
		617.0	days
	Economic Intervention Frequency - Average Leak Run Time	308.5	days
	Economic Percentage of System to be Surveyed per Year	59	%
ABI	Average Annual Budget for Intervention (Proactive Leak Detection)	313,036	$/year
EUL	Economic Unreported Real Losses	137,116	kgal/year
		137.1	MG/year
	Economic Infrastructure Leakage Index (ILI)	1.2	
PRL	Potentially Recoverable Leakage (CARL-CRL-EUL-TBL-UL)	505.6	MG/year

Instructions: Use this sheet to establish a preliminary schedule for proactive leak detection surveys and the corresponding necessary budget. Once the results from consecutive leak surveys are available, the Rate of Rise of Unreported Leakage should be updated and the proactive leak detection schedule should be refined taking into consideration these findings.

In order to establish a preliminary schedule for proactive leak detection or to review the currently utilized proactive leak detection schedule enter the cost for undertaking proactive leak detection ($/mile or $/km) in cell D31. Next enter the Average Rate of Rise of Unreported Leakage in cell D34. The Average Rate of Rise of Unreported Leakage is the rate at which leakage increases with time. The rate of rise is not necessarily linear since it can quickly change due to seasonal effects and other system specific impacts. The AWWA M36 Manual recommends assessing The Average Rate of Rise of Unreported Leakage either by comparing water balance results of several consecutive years and calculating the Average Rate of Rise of Unreported Leakage based on the increase n Real Loss volume from year to year (if utility does not employ proactive leak detection), or by analysis of District Metered Area night flow data or repair records of leaks detected through proactive leak detection (if utility employs proactive leakage control). Further details about how to assess the Average Rate of Rise of Unreported Leakage are provided in the AWWA M36 Manual.

Current Hidden Losses vs. Potentially Recoverable Leakage Through Proactive Leak Detection

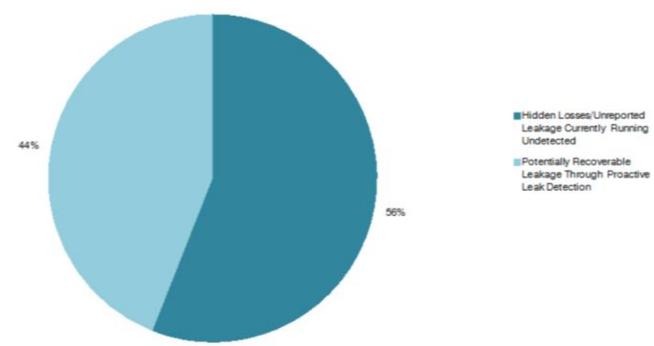

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Figure 5.11 Evaluation of Economic Intervention Frequency for Proactive Leak Detection

WaterRF 4372: Effective Organization and Component Analysis of Water Utility Leakage Data

Water Audit: Eastern Municipal Water District, CA, USA, 2010
EVALUATION OF PRESSURE MANAGEMENT OPPORTUNITIES

	Value to be entered by the user
	Value is automatically filled in/calculated by Model
	Recommended default value

Instructions: **This sheet was designed to provide a simple way to simulate various scenarios of pressure** reduction and the resulting savings in real losses.
The calculated reductions in real losses are based on the FAVAD (Fixed and Variable Area Discharges) concept. The effect of reducing the average system pressure is assessed using data in the white cells D18 to D20 which are automatically copied from the AWWA - Water Balance Results Sheet. Next enter if default N1 value is to be used or if system specific N1 value should be calculated using the following formula N1= 1.5 - (1-0.65/ILI) * Prig/100 (Source: Thornton, J. and Lambert, A., 2005. Progress in practical prediction of pressure: leakage, pressure: burst frequency and pressure: consumption relationships. In: Leakage 2005 Conference Proceedings. Halifax, Canada), which requires entering the percentage of rigid pipes (percentage of metal vs. plastic pipe) and service connections in the system in cell D25. Next enter the targeted reduction in average system pressure in cell D29. Next the reduction in real losses and the related cost savings are calculated by the model. Next enter an initial best estimate for the cost of implementing this alternative pressure management policy in cell D35 to calculate a simple payback in years for this new pressure management policy.

Pressure Management Opportunities

	Existing Pressure Management Policy	
Current Average System Pressure	75.0	PSI
Total Annual Real Losses	1,564.0	MG/Yr
Value of Real Losses	3,570,498	$/year

FAVAD N1 Value Used for Calculation of Real Loss Reduction Due to Reduction of Average System Pressure

	◉ Use Default N1	1.0
	○ **Use System Specific N1**	1.2
Enter % of rigid pipes and service connections in system	50%	
ILI	1.7	

	Alternative Pressure Management Policy	
Assumed Reduction in Average System Pressure	3.0	PSI
Assumed % Reduction in Average System Pressure	4%	
Real Loss Volume Saved Through Alternative Pressure Management Policy	62.6	MG/Yr
Value of Real Loss Volume Saved Through Alternative Pressure Management Policy	142,820	$/Year
Enter Estimated Cost of Implementing Alternative Pressure Management Policy	750,000	$
Simple Payback Period for Implementing Alternative Pressure Management Policy	5.3	Years

Note: Evaluation of Pressure Management Opportunities looks at Results of Reduced Pressure on the Volume of Real Losses. Pressure Management has additional benefits and impacts such as: reduced number of new infrastructure failures, reduced annual repair costs, extended infrastructure life, reduction in residential consumption (mainly for pressure dependent outdoor consumption such as irrigation) which are not quantified in this model. However, these additional benefits and impacts should be evaluated before implementing a new or updated pressure management policy.
If this initial assessment of pressure management options indicates that pressure reduction could provide cost effective means of reducing and controlling real losses in the system then it is recommended to conduct a detailed pressure management study. Such a study should collect pressure data from the field, assess the presence of pressure transients, identify pressure zones with excessive pressures and prioritize pressure management in parts of the system where its most feasible. In addition a more detailed assessment of costs for implementing the new pressure management policy should be assessed. This study should further consider the potential revenue impact a change in pressure management policy might have on residential consumption (mainly for pressure dependent outdoor consumption such as irrigation). Typical pressure management options include: introduction of pressure controlled areas, fixed outlet pressure control, time or demand based pressure control, transient control, altitude and level control at reservoirs and tanks etc. (see AWWA M36 for more details).

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Figure 5.12 Evaluation of Pressure Management for EMWD

Summary

After each sheet in the model is completed, a summary of the results and recommendations from the Model is available on the Summary sheet (See Figure 5.13). EMWD operates a well-managed system that is relatively young of age and therefore does not have excessive levels of real losses with an ILI of 1.7 for FY09/10. The review of leak repair data has shown that better estimates and tracking of leak repair and location time would be beneficial. EMWD is currently in the process of implementing further improvements to the tracking and record keeping of leak repair data, which includes staff training on when and how to enter leak relevant data in the work order management system.

The evaluation of real loss intervention strategies has shown that even though the current level of real losses if relatively low, given that the wholesale water purchased by EMWD is relatively expensive at $2,283/MG there are economic incentives to reduce real losses through implementation of more proactive leakage management strategies.

The currently available reported leak repair data does not allow for reliable calculation of exact leak run times. Therefore the general assessment of identifying cost effective improvements in average leak repair times need to be seen as preliminary and need to be updated once reliable leak run times are available.

Valuing real losses and respectively hidden losses at the FY2011 MWD wholesale cost of water the model indicated an economic incentive for EMWD to implement a proactive leak detection program. The recommended program would entail proactive leak detection in about 59% of the network every year at an annual budget for proactive leak detection of about \$313,000/year. The model estimates that by implementing this proactive leak detection schedule about 505.6 MG of hidden leakage could potentially be recovered. Once the results from consecutive leak surveys are available, the Rate of Rise of Unreported Leakage should be updated and the proactive leak detection schedule should be refined taking into consideration these findings.

The analysis of improved pressure management in the EMWD distribution system shows that EMWD is already successfully managing pressure at a relatively modest level of 75 psi average system pressure. The analysis has shown that there is limited room for improvement in pressure management. However, a pressure reduction of 3 psi could realistically be achieved and would yield savings of 63MG/year with a value of \$143,000/year. Assuming that it would cost about \$750,000 to reduce the average system pressure a simple payback period of 5.3 years would be the result for this investment in real loss management. The assumed implementation cost needs to be further validated and before the improved pressure management strategy is implemented.

WATER AUDIT PERFORMANCE INDICATORS		
Financial		
Non-revenue water as percent by volume of water supplied:	6.8%	
Non-revenue water as percent by cost of operating system:	4.1%	
Annual cost of Apparent Losses:	$669,616	
Annual cost of Real Losses:	$3,570,498	
Operational Efficiency		
Apparent Losses per service connection per day:	6.3	gal/service conn/day
Real Losses per service connection per day*:	29.3	gal/service conn/day
Real Losses per length of main per day:	N/A	gal/mi/day
Real Losses per service connection per day per PSI pressure:	0.4	gal/service conn/day/psi
Unavoidable Annual Real Losses (UARL):	913.07	MG/Yr
Current Annual Real Losses (CARL):	1,563.95	MG/Yr
Infrastructure Leakage Index (ILI) [CARL/UARL]:	1.7	

REAL LOSS COMPONENT ANALYSIS RESULTS				
System Component	Background Leakage	Reported Failures	Unreported Failures	Total
	(MG)	(MG)	(MG)	(MG)
Reservoirs	25.54	-	-	**25.54**
Mains and Appurtenances	206.55	100.05	-	**306.59**
Service Connections	556.11	32.94	-	**589.05**
Total Annual Real Loss	**788.20**	**132.99**	**-**	**921.19**
			Real Losses as Calculated by Water Audit	**1,563.95**
			Hidden Losses/Unreported Leakage Currently Running Undetected	**642.76**

AWARNESS, LOCATION AND REPAIR TIME REDUCTION RESULTS			
	Reported Failures	Unreported Failures	
Total Potential Savings if Location and Repair Duration is Reduced as Simulated on the A-L-R Times Options Sheet	104.6		(MG)
Total Potential Cost Savings if Location and Repair Duration is Reduced as Simulated on the A-L-R Times Options Sheet	$ 93,319		Per Year

ECONOMIC INTERVENTION FREQUENCY FOR PROACTIVE LEAK DETECTION RESULTS		
Percentage of the System to be Surveyed per Year	59	%
Average Annual Budget for Intervention (Proactive Leak Detection)	313,036	$/year
Potentially Recoverable Leakage	505.65	MG/year

ALTERNATIVE PRESSURE MANAGEMENT SCENARIO RESULTS		
User-Inputted Reduction in Average System Pressure	3.0	PSI
Assumed % Reduction in Average System Pressure	4%	
Estimated Real Loss Reduction from Pressure Management Program	62.6	MG/Yr
Financial Savings from Pressure Management Program	142,820	$/Year
User-Estimated Cost of Pressure Reduction	750,000	$
Resulting Pressure Management Program Payback Period	5.3	Years

7/19/2013

Figure 5.13 WRF 4372 Component Analysis Model Summary for EMWD

WATER & WASTEWATER AUTHORITY OF WILSON COUNTY

The Water & Wastewater Authority of Wilson County (WWAWC) is located in the central area of Tennessee. For a relatively small, rural water provider, WWAWC is especially proactive in its water loss management. Given its self-directed focus on water loss control alongside the recently adopted water loss regulations (see Chapter 2 for details), WWAWC was especially interested in the Model's development.

WWAWC supplies water to a primarily residential population with a small number of commercial customers and some industrial users, totaling 7,001 active and inactive service connections. WWAWC's distribution system consists of 322 miles of distribution piping (almost exclusively PVC).

The following sections outline each component of the water audit for the period from July 2010 to June 2011, detailing the data quality and validation efforts for WWAWC. The first many inputs required in the Model are directly from the AWWA Free Water Audit Software. For these volumes (outlined from pages 92 to 96), the data grading and supporting validation efforts are briefly described. The volumes required for the AWWA Free Water Audit Software addressed here include components of System Input Volume, Authorized Consumption, and Apparent Losses. The next review of data inputs for the Model examines WWAWC's failure repair data (outlined from pages 97 to 99). Recommendations and next steps for improving the data quality are also outlined for each input.

System Input Volume (SIV)

Volume from Own Sources

WWAWC does not own any of its water sources; it purchases all of its water.

Water Imported

WWAWC purchases all of its water supply as treated water from four different supplies (Cumberland River, Center Hill Lake, Stones River, and a groundwater supply). Fifteen meters are manually read daily to track the water supplied to WWAWC through these sources. The total volume imported from all imported sources was 395.054 MG for the audit period.

Since WWAWC does not own or operate any of its sources and purchases all of its water, the cost for its supply is relatively high. Expensive sources of water, as in the case of WWAWC, provide motivation and economic justification for reducing water losses to low levels.

Current Data Validation Efforts

The imported supply meters are operated and maintained by the water suppliers who are responsible for testing and calibration. A majority of these import meters are regularly tested every year or every 18 months. Two input meters supply small areas of the network and have not yet been tested.

The data grading for the water imported was 9. Referring to the AWWA Free Water Audit Software grading matrix worksheet a 9 was assigned.

Data Validation Recommendations

WWAWC does not own or operate its imported water meters. As such, there are limits to the validation procedures that are possible. Still, WWAWC staff reviews the reads from each of the 15 supply meters on a daily basis. Further, flows across the distribution system are regularly balanced (also taking the inflow/outflow of supply at WWAWC's five ground level water storage tanks into consideration). These supplemental efforts (beyond the suppliers' maintenance and calibration efforts) position WWAWC to catch anomalous flow readings or significant inaccuracies.

Water Exported

WWAWC does not export water to any neighboring agencies.

Consumption Volumes

Billed Metered Authorized Consumption (BMAC)

BMAC is the consumption volume that includes all groups of customers such as domestic, commercial, industrial or institutional. The metered consumption data was taken directly from WWAWC's billing records for the water audit period.

WWAWC reads customer meters on a monthly basis, reading all meters manually. It is estimated that a reliable meter reading is obtained for at least 90% of the meter reading attempts.

The total BMAC volume for the audit period was 318.918 MG.

Current Data Validation Efforts

WWAWC conducts a monthly check on billing consistency. Raw billing data by account by month for a 12-month history is pulled from the billing system. The total BMAC from these records is cross-referenced with the actual consumption billed. This comparison consistently results in a difference of less than 1%.

The data grading for BMAC was 8. Referring to the AWWA Free Water Audit Software grading matrix worksheet, an 8 was assigned because at least 97% of customers have volume-based billing from meter reads with at least 90% meter read success rate. A higher grading was not assigned because third-party verification is not completed annually and Automatic Meter Reading (AMR) trials are not yet underway.

Data Validation Recommendations

WWAWC is considering the installation of an Automatic Meter Reading system. This will ideally improve the resolution of billing data and reduce the impact of lag time.

Other Consumption Volumes

Outside of BMAC, there are three more components of consumption to include in the water balance: billed unmetered authorized consumption, unbilled metered authorized consumption, and unbilled un-metered authorized consumption.

For unbilled unmetered authorized consumption, mains flushing, firefighting, and tank cleaning water uses were identified. WWAWC tracks the water use for each of these purposes, estimating a total of 2.172 MG for the audit period.

WWAWC does not have any authorized consumption that is classified as billed unmetered or unbilled metered.

Current Data Validation Efforts

For the unbilled unmetered authorized consumption a data grading of 9 was assigned following the AWWA Free Water Audit Software grading matrix worksheet.

Data Validation Recommendations

WWAWC already tracks unmetered unbilled authorized consumption. Marginal improvements in estimation are recommended: recording an estimated flow rate and duration of use for each instance of unmetered unbilled authorized consumption will allow for the most accurate estimation of this volume.

Apparent Losses

For WWAWC, the bulk of apparent losses was from meter inaccuracies during the audit period. For the determination of unauthorized consumption, the industry standard estimate of 0.25% of the water supplied volume was applied. Data handling errors were estimated.

The total customer meter under-registration for the audit period was determined to be 5.515 MG. Unauthorized consumption and data handling errors totaled 1.008 MG.

Current Data Validation Efforts

Throughout the period from 2006 to 2010, WWAWC changed out meters (generally based on meter age and lifetime consumption) and tested 10% of those pulled. The overall accuracy determination for the meter population based on this long term testing program was 98.3%. This accuracy was used for the calculation of customer meter under-registration.

The data grading for the meter inaccuracy volume was a 7. Referring to the AWWA Free Water Audit Software grading matrix worksheet, a 7 was assigned because there is an ongoing meter replacement and accuracy testing program (ongoing only for stopped or suspect meters), but the testing program can be improved in consistency and randomness of the sample.

Data Validation Recommendations

WWAWC no longer routinely changes out meters; instead, meters are changed out only if they are stopped or suspected as damaged. The validity of customer meter under-registration determination can be improved with more regular, ongoing testing of random customer meters.

It is recommended to revisit the billing data process annually, adjusting the allocation of data handling error as necessary.

Water Audit Results and Performance Indicators

The results of the AWWA Water Audit for FY10/11 for WWAWC are provided in Figure 5.14. The data validity score for the FY10/11 water audit results was calculated by the AWWA Free Water Audit Software to be 83. This is above the average data validity score for the Validated Dataset and just below the 75th percentile.

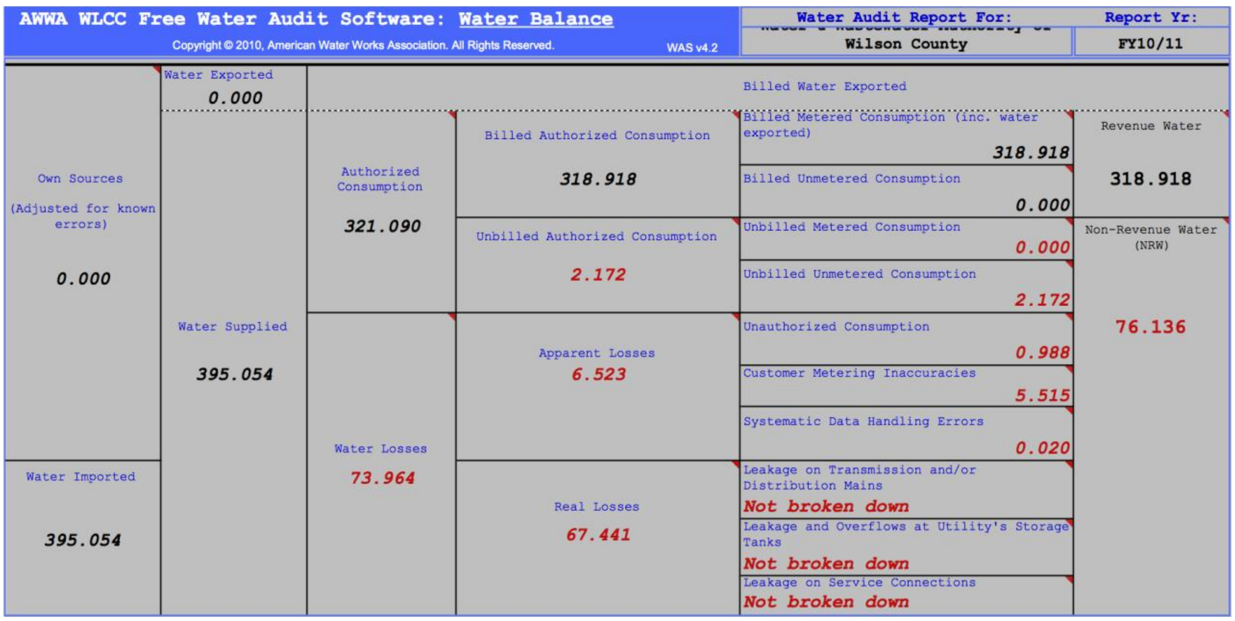


Figure 5.14 Water Audit Results for WWAWC

The WWAWC FY10/11 water audit data was then entered into the Model, and the corresponding performance indicators as calculated by the Model are provided in Figure 5.15.

PERFORMANCE INDICATORS

Financial

Non-revenue water as percent by volume of water supplied:	19.3%	
Non-revenue water as percent by cost of operating system:	6.5%	
Annual cost of Apparent Losses:	$54,638	
Annual cost of Real Losses:	$152,348	

Operational Efficiency

Apparent Losses per service connection per day:	2.55	gal/service conn/day
Real Losses per service connection per day*:	N/A	gal/service conn/day
Real Losses per length of main per day:	573.8	gal/mi/day
Real Losses per service connection per day per PSI pressure:	N/A	gal/service conn/day/psi
Unavoidable Annual Real Losses (UARL):	61.15	MG/Yr
Current Annual Real Losses (CARL):	67.44	MG/Yr
Infrastructure Leakage Index (ILI) [CARL/UARL]:	1.1	

AWWA Water Audit Data Validity Score: 83

Please enter the Data Validity Score calculated by the AWWA Free Water Audit Software

Note: If the data validity of your AWWA Water Audit is less than 51 it is recommended to improve the data validity of your AWWA Water Audit data before any of the results of the following economic analysis are considered for implementation.

5/8/2014

Figure 5.15 Water Audit Performance Indicators for WWAWC

Failure Repair Data Collection

In April 2010, WWAWC began tracking water distribution system failure data (the collection of all failure records) in MS Office Excel. As such, WWAWC was able to provide the research team with a compiled spreadsheet of all failure data from FY10/11.

This database contains both reported failures and unreported failures. WWAWC has an ongoing in-house leak detection program, wherein it employs a system of District Metered Areas (DMAs) to target and prioritize areas for leak detection (see the section on unreported failures below).

The failure dataset submitted contains all the necessary fields for a complete component analysis. Table 5.4 shows the inventory of fields featured in WWAWC's failure database, which provides a very thorough example of failure tracking. The highlighted fields were used in the Model's component analysis.

Table 5.4
Data Entry Fields for WWAWC Failure Database

FIELD	**Entry Content / Options**
Leak Number	Identifying # (6 digit date plus letter)
Street	Account Info
Address	Account Info (House Number or Intersecting Street)
Nearest Tap No.	Account Info
Abandoned Property?	Y/N
District Metered Area	District Metered Area #
Identifier	Routine Sounding, Step Tested or Telemetry, Customer, Contractor, Employee, Employee Meter Reading
Reporting Classification	Reported, Unreported
Location of Leak	Utility, Customer
Estimated Occurrence Date	Date
Date Reported	Date
Date Located	Date
Date Repaired	Date
Estimated Leak Rate	Flow Rate (GPM)
Estimation Method	Visual, Telemetry, Input meter, Hole Size/Pressure, Ultrasonic Flow Meter
Run Time	Hours (difference between date reported and date repaired)
Total Loss	Total Water Loss (gal)
Leak Appurtenance	Main, Service, Hydrant, Valve, Meter/Setter, Other
Pipe Material	Ductile Iron, Plastic, Copper, Galvanized, Cast Iron, Other, PVC
Pipe Size	Size (in)
Replacement Material Type	Ductile Iron, Plastic, Copper, Galvanized, Cast Iron, Other, PVC
Leak Type	Circumferential Failure, Corrosion, Joint Malfunction/Failure, Longitudinal Crack, Puncture, Other
Length of Failure	Length (in)
Width of Failure	Width (in)
Diameter of Failure	Diameter (in)
Cause/Comment	Comments

Current Failure Repair Data Validation Efforts

The current WWAWC protocol for failures requires that main failures are fixed immediately and service failures are repaired as soon as the scheduled work load allows. The failure database and its documentation of runtimes reflect this policy. One anomalous record stands out: a failure on an 8" main has a documented response time of 17 days. Closer examination of this record suggests a very low flow rate (of 5 gpm), so it was not prioritized.

Overall, the WWAWC failure database presents complete information on all failures – both reported and unreported – for the audit period.

Data Validation Recommendations

WWAWC's current practices and protocols include documentation of appropriate runtime data and leakage characteristics, creating a comprehensive failure database. No further data validity efforts are recommended at this time.

Component Analysis of Real Losses

Utilizing the failure repair data collected for FY10/11 a real loss component analysis was carried out for WWAWC by entering the failure data into the Model. The following sections discuss the results.

Component Analysis – Real Losses from Reported Leaks

After validation of the reported leak data (infrastructure failure data), discussed in the previous section, the reported leaks were grouped by size and infrastructure type to input into the Model. The average awareness time represents a best estimate, which was based on discussions with WWAWC and the general rule of thumb that reported infrastructure failures in urban distribution networks generally experience a short awareness time of less than 24 hours. Awareness times for reported mains failures are generally only a couple of hours and for mains appurtenances and service connections range between hours and a couple of days.

The average location and repair time was calculated based on the data provided by WWAWC's failure record database (see Table 5.5).

Table 5.5
Reported Leaks Summary Table - WWAWC

Infrastructure	Number of Infrastructure Failures	Average Awareness Time (days)	Average Location and Repair Time	Average Flow Rate (GPM)
Mains 2"	1	3.0	0.42	50.0
Mains 6"	15	0.25	0.10	187.3
Mains 8"	2	0.25	8.56	10.0
Mains 10"	1	0.25	0.08	40.0
Valves	4	5.0	0.32	230.0
Service Connection <1"	39	2.0	9.17	7.97

The annual volume of water lost through reported failures was calculated in the Model by multiplying the number of reported failures, the average reported failure duration, and the average failure flow rate. Instead of the default flow rates for a failure on a given size of main/service, the flow rates estimated by WWAWC for each record were applied. The data in Table 5.5 was entered in the Model to calculate the volume of real losses stemming from reported failures (see Figure 5.16).

STEP 3A: REPORTED FAILURES ON MAINS

Instructions: Enter the total number of failures by main size that were reported to and repaired by the water utility during the audit period in cells C58 to C77. Next enter the total length of mains for each mains size group in cells D58 to D77 (Note: this information is not required for the real loss component analysis but serves to calculate failure frequencies by mains size). Next enter the average awareness duration for reported failure events by mains size in cells I58 to I77 (Awareness duration is the average time from the occurrence of the failure event until the water utility becomes aware of its existence). Next enter the average duration of locating and containing reported failure events by mains size in cells K58 to K77. Next select either the default average leak flow rate provided by the model in cells P58 to P77 or select and enter your own utility specific average leakage flow rates in cells Q58 to R77. Average failure flow rates are based on AWWA M36 recommended flow rates and flow rates collected by the research team.

Mains by Size	Number of Leaks & Failures per Year	Length of Main (miles)	Failure Frequency (number / 100miles / yr)	Average Failure Flow Rate @ Average System Pressure (gpm)	Average Pressure (psi)	N1 (Leakage-Pressure Exponent) Value	Average Failure Duration: Average Awareness Duration (days)	Average Failure Duration: Average Duration for Location and Repair/Shutoff Failure (days)	Average Failure Duration: Total Duration (days)	Average Annual Loss per Failure (MG)	Total Annual Loss (MG)	Use Default Average Failure Flow Rate	Use Utility Specific Average Failure Flow Rate	Average Failure Flow Rate @ Average System Pressure (gpm)
Diameter 2"	1	10.0	10	50.00	60.0	1.00	3.00	0.42	3.42	0.25	0.25	○	⊙	50.0
Diameter 3"	-	-	-	13.90	60.0	1.00	0.50	-	0.50	-	-	⊙	○	-
Diameter 4"	-	6.0	-	44.00	60.0	1.00	0.50	-	0.50	-	-	⊙	○	-
Diameter 6"	15	246.0	6	187.30	60.0	1.00	0.25	0.10	0.35	0.09	1.42	○	⊙	187.3
Diameter 8"	2	50.0	4	10.00	60.0	1.00	0.25	8.56	8.81	0.13	0.25	○	⊙	10.0
Diameter 10"	1	10.0	10	40.00	60.0	1.00	0.25	0.08	0.33	0.02	0.02	○	⊙	40.0
Diameter 12"	-	-	-	222.00	60.0	1.00	-	-	-	-	-	⊙	○	-
Diameter 14"	-	-	-	222.00	60.0	1.00	-	-	-	-	-	⊙	○	-
Diameter 16"	-	-	-	222.00	60.0	1.00	-	-	-	-	-	⊙	○	-
Diameter 18"	-	-	-	222.00	60.0	1.00	-	-	-	-	-	⊙	○	-
Diameter 20"	-	-	-	222.00	60.0	1.00	-	-	-	-	-	⊙	○	-
Diameter 24"	-	-	-	222.00	60.0	1.00	-	-	-	-	-	⊙	○	-
Diameter 30"	-	-	-	222.00	60.0	1.00	-	-	-	-	-	⊙	○	-
Diameter 36"	-	-	-	222.00	60.0	1.00	-	-	-	-	-	⊙	○	-
Diameter 42"	-	-	-	222.00	60.0	1.00	-	-	-	-	-	⊙	○	-
Diameter 48"	-	-	-	222.00	60.0	1.00	-	-	-	-	-	⊙	○	-
Diameter 54"	-	-	-	222.00	60.0	1.00	-	-	-	-	-	⊙	○	-
Diameter 60"	-	-	-	222.00	60.0	1.00	-	-	-	-	-	⊙	○	-
Diameter >60"	-	-	-	222.00	60.0	1.00	-	-	-	-	-	⊙	○	-
Other Diameter	-	-	-	-	60.0	1.00	-	-	-	-	-	Enter avg flow rate		-
										SUB-TOTAL REPORTED FAILURES ON MAINS	1.93			

STEP 3B: REPORTED FAILURES ON DISTRIBUTION SYSTEM APPURTENANCES

Instructions: Enter the total number of failures by distribution system appurtenance type that were reported to and repaired by the water utility during the audit period in cells C86 to C89. Next enter the total number of appurtenances for each system appurtenance group in cells D86 to D89 (Note: this information is not required for the real loss component analysis but serves to calculate failure frequencies by appurtenance type). Next enter the average awareness duration for reported failure events by system appurtenance type in cells I86 to I89 (Awareness duration is the average time from the occurrence of the failure event until the water utility becomes aware of its existence). Next enter the average duration of locating and containing reported failure events by system appurtenance type in cells K86 to K89. Next select either the default average leak flow rate provided by the model in cells P86 to P89 or select and enter your own utility specific average leakage flow rates in cells Q86 to R89. Average failure flow rates are based on AWWA M36 recommended flow rates and flow rates collected by the research team.

System Appurtenances by Type	Number of Failures per Year	Total Number of Appurtenances	Failure Frequency Number of Failures per 1000 Appurtenances	Average Failure Flow Rate @ Average System Pressure (gpm)	Average Pressure (psi)	N1 (Leakage-Pressure Exponent) Value	Average Failure Duration: Average Awareness Duration (days)	Average Failure Duration: Average Duration for Location and Repair/Shutoff Failure (days)	Average Failure Duration: Total Duration (days)	Average Annual Loss per Failure (MG)	Total Annual Loss (MG)	Use Default Average Failure Flow Rate	Use Utility Specific Average Failure Flow Rate	Average Failure Flow Rate @ Average System Pressure (gpm)
Hydrants	-	-	-	3.50	60.0	1.00	-	-	-	-	-	⊙	○	-
Valves	4	-	-	230.00	60.0	1.00	5.00	0.32	5.32	1.76	7.05	○	⊙	230.0
Meters	-	-	-	0.25	60.0	1.00	-	-	-	-	-	⊙	○	-
Other (e.g. Blow-offs, etc.)	-	-	-	-	60.0	1.00	-	-	-	-	-	Enter avg flow rate		-
										SUB-TOTAL REPORTED LEAKS ON SYSTEM APPURTENANCES	7.05			

STEP 3C: REPORTED FAILURES ON SERVICE CONNECTIONS

Instructions: Enter the total number of failures by service connection size (<1" or >=1") that were reported to and repaired the water utility during the audit period in cells C98 to C99. Next enter the total number of service connections for each service connection size group in cells D98 to D99 (Note: this information is not required for the real loss component analysis but serves to calculate failure frequencies by service connection size group). Next enter the average awareness duration for reported failure events by service connection size group in cells I98 to I99 (Awareness duration is the average time from the occurrence of the failure event until the water utility becomes aware of its existence). Next enter the average duration of locating and containing reported failure events by service connection size group in cells K89 to K99. Next select either the default average leak flow rate provided by the model in cells P98 to P99 or select and enter your own utility specific average leakage flow rates in cells Q98 to R99. Average failure flow rates are based on AWWA M36 recommended flow rates and flow rates collected by the research team.

Service Connections by Size	Number of Failures per Year	Total Number of Service Connections	Failure Frequency Number of Failures per 1000 Service Connections	Average Failure Flow Rate @ Avergage System Presure (gpm)	Average Pressure (psi)	N1 (Leakage-Pressure Exponent) Value	Average Failure Duration: Average Awareness Duration (days)	Average Failure Duration: Average Duration for Location and Repair/Shutoff Failure (days)	Average Failure Duration: Total Duration (days)	Average Annual Loss per Failure (MG)	Total Annual Loss (MG)	Use Default Average Failure Flow Rate	Use Utility Specific Average Failure Flow Rate	Average Failure Flow Rate @ average system pressure (gpm)
Services < 1"	39	6,936	6	7.97	60.0	1.00	2.00	9.17	11.17	0.13	5.00	○	⊙	8.0
Services >= 1"	-	-	-	13.90	60.0	1.00	-	-	-	-	-	⊙	○	-
										SUB-TOTAL REPORTED LEAKS ON SERVICE CONNECTIONS	5.00			
										GRAND TOTAL REPORTED FAILURES	13.98			

Figure 5.16 Component Analysis for Reported Leaks for WWAWC

The total estimated volume of water lost from reported failures was estimated at 13.98 MG for the audit period of FY 10/11. The total annual volume of real losses stemming from reported leaks (13.98 MG/Yr) is a relatively small portion of the total annual real losses (67.44 MG/Yr) as calculated by the water balance. This indicates that a majority of real losses is usually caused by unreported and hidden failures that are left running continuously and undetectable background losses.

Component Analysis – Real Losses from Unreported Leaks Detected Through Proactive Leak Detection

WWAWC has an ongoing in-house leak detection program, wherein it employs a system of District Metered Areas (DMAs) to target and prioritize areas for leak detection. The distribution system is divided into 16 DMAs, each of which is a hydraulically discrete area with a measured input volume. Four of the DMAs account for 64% of the total system. Each of these four DMAs includes a pumping station supplying water to one or two ground level storage tanks at high elevations within the DMA. Tanks levels at these sites are measured every 30 minutes. This setup provides an opportunity to conduct Minimum Night Flow[6] analyses on a regular basis. If leakage is suspected in one of these four DMAs based on Minimum Night Flow analysis, a portable ultrasonic flow meter is installed on the main line at the storage tank to confirm a supply volume that exceeds the expected consumption for the zone. For the remaining 12 smaller DMAs, input meters are read regularly to track anomalous supply flow; if leakage is suspected in one of these DMAs, sonic leak detection methods are employed to pinpoint failures. With this program of closely tracking DMA input volume, WWAWC employs targeted and efficient leak detection efforts.

The unreported failure records were grouped by size and infrastructure type. The average awareness time represents a best estimate, which was based on the understanding that WWAWC is constantly monitoring the distribution system for suspected leakage in each of their 16 DMAs. This will reduce the awareness time for unreported failures, especially for larger infrastructure failure incidents.

Table 5.6
Unreported Failures Summary Table –WWAWC

Infrastructure	Number of Infrastructure Failures	Average Awareness Time (days)	Average Location and Repair Time	Average Flow Rate (GPM)
Mains 6”	3	1.0	0.89	334.33
Service Connections <1”	9	3.0	6.46	11.11

[6] A Minimum Night Flow analysis evaluates the consumption in a DMA in the middle of the night when authorized consumption is at its lowest. An allowance for Legitimate Nighttime Consumption is calculated (to account for toilet flushing and instances of irrigation) and compared to the input volume into the DMA to estimate leakage.

The data in Table 5.6 was entered in the Model to calculate the volume of real losses stemming from unreported failures. The total estimated volume of water lost from unreported failures was estimated at 4.09 MG for the audit period of FY 10/11.

Background Leakage from the Distribution Network

Background leakage is defined as the loss of water from individual leak events for which the rate of loss is less than 2.2 gpm at 70 psi. These leaks are undetectable using current leak noise detection technology. The volume of background leakage tends to increase with age of the network and is higher for systems operated at higher pressure. The type of pipe materials and jointing techniques are also contributory factors. The volume of background leakage is a function of the condition of the infrastructure, average system pressure and total length of mains and number of service connections. The AWWA theoretical minimum level of leakage for a system is known as Unavoidable Annual Real Losses (UARL) and includes values for the minimum level of background leakage from mains and service connections (see Table 5.7).

Table 5.7
AWWA Unavoidable Background Leakage Rates

Infrastructure Component	Background Leakage at ICF=1.0[7]	Units
Mains	2.870	gallons / mile of main / day / psi of pressure
Service Connection: main to curb-stop	0.112	gallons / service connection / day / psi of pressure
Service Connection: curb-stop to meter	4.780	gallons / mile of service connection / day / psi of pressure

Source: Adapted from Lambert et al. 1999

An ICF of 1.0 was used based on the results of a sensitivity analysis. The water balance suggests that WWAWC has such low levels of real losses; any larger ICF would result in background losses that would exceed the real loss determination from the water balance.

WWAWC meters are located in small meter pits in the sidewalk or at the property line of the customer, effectively at the curb-stop. The length of service connection between curb-stop and meter is therefore assumed to be zero. All losses on the customer’s pipes after the meter are assumed to be included in authorized billed metered consumption.

By applying an Infrastructure Condition Factor (ICF) of 1.0 to the AWWA unavoidable values for specific background leakage rates, the volume of annual real loss from background leakage from the distribution network was calculated by the Model to be 34.64 MG (see Figure 5.17).

[7] Theoretical minimum background leakage corresponds to an Infrastructure Condition Factor (ICF) of 1.0.

Step 2: BACKGROUND LEAKAGE ON MAINS AND SERVICES

Instructions: The background leakage volume from mains and service connections will be automatically calculated after selecting one of the default Infrastructure Condition Factors (ICF) based on infrastructure age or after a utility specific ICF has been selected and entered in cell P43. The level of background leakage tends to increase with infrastructure age and is higher for systems with higher pressure. The volume of background losses is generally a significant component of the total real loss volume, at times up to 50% of the total volume of real losses. Overestimating (ICF used in model is too high) or underestimating (ICF used in model is too low) the background leakage volume might lead to a real loss control strategy that is not truly optimized. Selecting the ICF based on general age of the distribution network should only be seen as a starting point. It is strongly recommended that over time a utility specific ICF is assessed and confirmed through field tests using one of the recommended approaches outlined in the AWWA M36 manual.

						Pressure Corrected Calculation	
System Component	Units	Quantity	Component UARL Values (g/unit/d/psi)	Infrastructure Condition Factor	Average Pressure (psi)	N1 (Leakage-Pressure Exponent)	Annual Volume (MG)
Mains	miles	322.0	2.87	1.0	60.0	1.5	18.74
Services - Main to Curb-Stop	number	7,001	0.112	1.0	60.0	1.5	15.90
Services - Curb-Stop to Meter	miles	-	4.78	1.0	60.0	1.5	-
						Total Background Leakage on Mains and Services	**34.64**

Select Infrastructure Condition Factor (ICF) based on age of distribution network

⦿ ICF 1 for System Age <50 years	1.0
○ ICF 1.5 for System Age 50 - 70 years	1.5
○ **ICF 2.5 for System Age >70 years**	2.5
OR	
○ **Enter ICF values assessed through implementing the approaches outlined in the AWWA M36 manual**	1.2

Figure 5.17 Component Analysis for Background Leakage on Mains and Service Connections WWAWC

Background Leakage from Reservoirs

An additional component of background leakage exists, which comes from undetectable losses on reservoirs. There are no set minimum values for estimating losses caused by background leakage on reservoirs – the Model provides a default value of 0.25gpm/MG of reservoir volume. No study data is available for WWAWC regarding background leakage from reservoirs. Therefore, the default background leakage rate provided by the Model was used. The total background leakage from reservoirs was estimated to be 0.18 MG per year (see Figure 5.18).

Step 1: BACKGROUND LEAKAGE, REPORTED LEAKAGE AND UNREPORTED LEAKAGE FROM RESERVOIRS

Instructions: First enter the capacity of all distribution system reservoirs and tanks in use during the audit period. In case the system input volume is based on raw water meters located upstream of the Water Treatment Plant (WTP) then also include the capacity of the WTP reservoirs. Next select a reservoir background leakage rate - either the default value provided by the model or a utility specific flow rate. If reservoirs and tanks are well maintained and the utility does not suspect any background leakage from the reservoirs and tanks then enter zero as the utility specific flow rate. In case a reservoir or tank was reported leaking or has overflowed, enter the estimated volume in cell G27 . If a proactive investigation/inspection of the system reservoirs and tanks has discovered a leaking reservoir or tank then enter the estimated annual volume lost in cell G28.

	Capacity (MG)	Background Leakage Rate (gpm/MG)	Annual Volume (MG)
Total Reservoir/Tank Capacity	1.40	0.25	0.18
Reported Reservoir Leakage and any recorded Reservoir and Tank Overflows			0.00
Unreported Reservoir Leakage			0.00
Total Background Leakage, Reported and Unreported leakage from Reservoirs			**0.18**

Select Reservoir Background Leakage Rate

⦿ Default Value	0.25	(gpm/MG)
OR		
○ **Utility Specific Background Leakage Rate**	-	(gpm/MG)

Figure 5.18 Component Analysis for Background Leakage from Reservoirs for WWAWC

Component Analysis Summary and Estimation of Unreported/Hidden Leaks

The real loss component analysis calculated 34.82 MG of real losses were caused by background leakage, 13.98 MG were caused by reported failures repaired by WWAWC, and 4.09 MG were caused by unreported failures discovered through proactive leak detection. However, the sum of these three real loss components only amounts to 52.89 MG, while the AWWA water audit calculated that the total volume of real losses for FY10/11was 67.44 MG (see Figure 5.14). The difference in real loss volume from the water audit and the real loss component analysis is due to hidden leaks currently running undetected. This real loss volume caused by hidden/undetected leaks is estimated to be 14.55 MG and should theoretically be recoverable through proactive leak detection (see Figure 5.19). The economic intervention frequency for leak detection will provide an initial estimate of how much of the currently hidden/undetected real loss volume is economically recoverable through proactive leak detection.

System Component	Background Losses (MG)	Reported Failures Losses (MG)	Unreported Failures Losses (MG)	Total Annual Real Losses by Component Analysis (MG)	Total Annual Real Losses by IWA/AWWA Water Audit (MG)
Reservoirs	0.18	-	-	0.18	not estimated
Mains and Appurtenances	18.74	8.98	2.73	30.45	not estimated
Service Connections	15.90	5.00	1.36	22.26	not estimated
Total Annual Real Losses	34.82	13.98	4.09	52.89	67.44
Total Annual Real Losses	Estimated by AWWA Water Audit (MG)			(A)	67.44
	Estimated by Component Analysis (MG)			(B)	52.89
	Hidden Losses (Unreported Leakage Currently Running Undetected)			= (A) - (B)	14.55

Figure 5.19 Real Loss Component Analysis Results for WWAWC

Figure 5.20 provides a graphical display of the real loss component analysis results. While a certain amount of the difference between the two volumes (Real loss from AWWA Water balance and real losses from component analysis) is due to errors in the two methods of estimation, the difference is mainly due to the presence of hidden losses, i.e., the presence of detectable leaks that are not being identified. In effect, hidden losses are a backlog of failures waiting to be detected and repaired. Hidden losses for WWAWC compose a relatively small portion of the total real loss volume (about 22% of total real losses). This is expected because WWAWC proactively manages its real losses on a frequent and consistent basis.

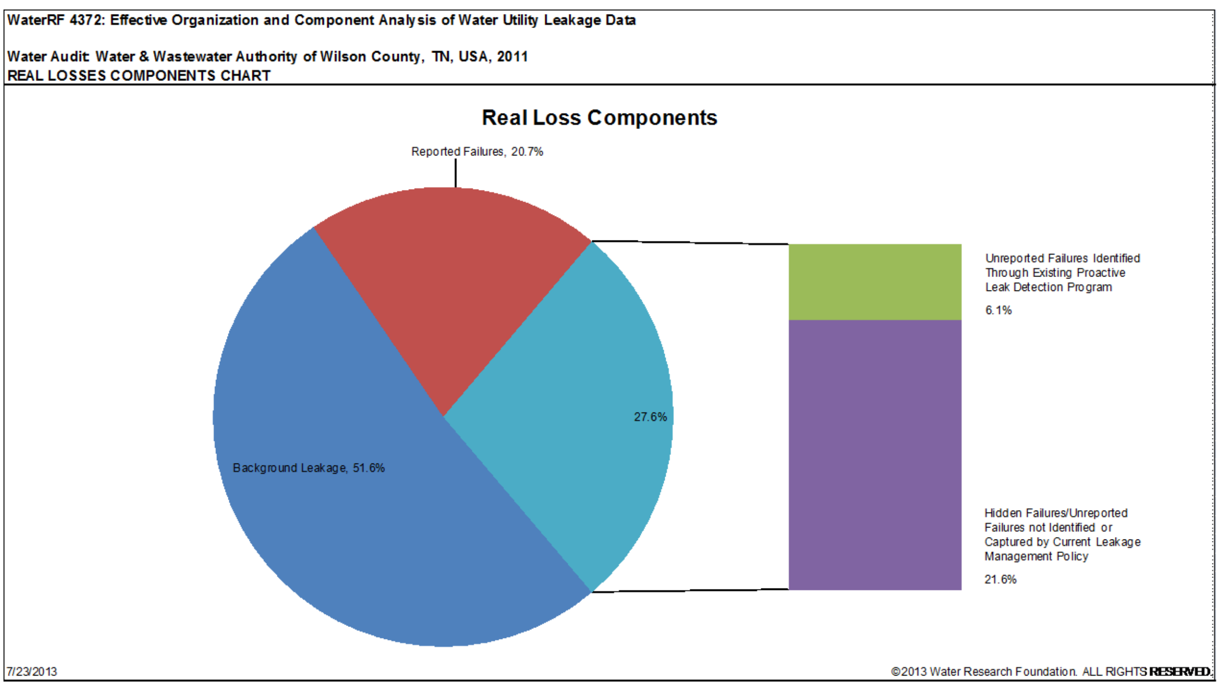


Figure 5.20 Real Loss Components Based on Real Loss Component Analysis for WWAWC

Failure Frequency Analysis for Reported Failures

The overall failure frequency of 5.9 failures per 100 miles of main per year as calculated based on the failure data entered in the Model is significantly less than what is indicated as a failure frequency of an optimized system (15 per 100 miles per year). Such a low failure frequency often suggests that the failure repair database is not yet capturing all of the failures repaired. However, in this case it is important to highlight the proactive work that WWAWC does to minimize failures and identify them early. Through the DMA work and constant monitoring of water balances by zone, it can be expected that WWAWC has an exceptionally well performing system. As shown in Figure 5.21, the Model also highlights a warning stating that the calculated failure frequency indicates that the failure data should be checked for accuracy and completeness. Though this may not apply in the case of WWAWC, it is an important check for all users of the Model.

WaterRF 4372: Effective Organization and Component Analysis of Water Utility Leakage Data

Water Audit: Water & Wastewater Authority of Wilson County, TN, USA, 2011
INFRASTRUCTURE FAILURE FREQUENCY ANALYSIS

Water & Wastewater Authority of Wilson County

Total Number of Mains Failures Reported for Water Audit: Water & Wastewater Authority of Wilson County, TN, USA, 2011	19	
Total Length of Mains	322.0	(miles)
Failure Frequency Water & Wastewater Authority of Wilson County	5.9	(number / 100miles / yr)
Average Failure Frequency in North America Based on Literature Review - WaterRF 4372	25.0	(number / 100miles / yr)
Failure Frequency for Optimized Distribution Systems (Friedman 2010)	15.0	(number / 100miles / yr)

Note: reported failure frequency is less than failure frequency for optimized distribution systems - check failure data

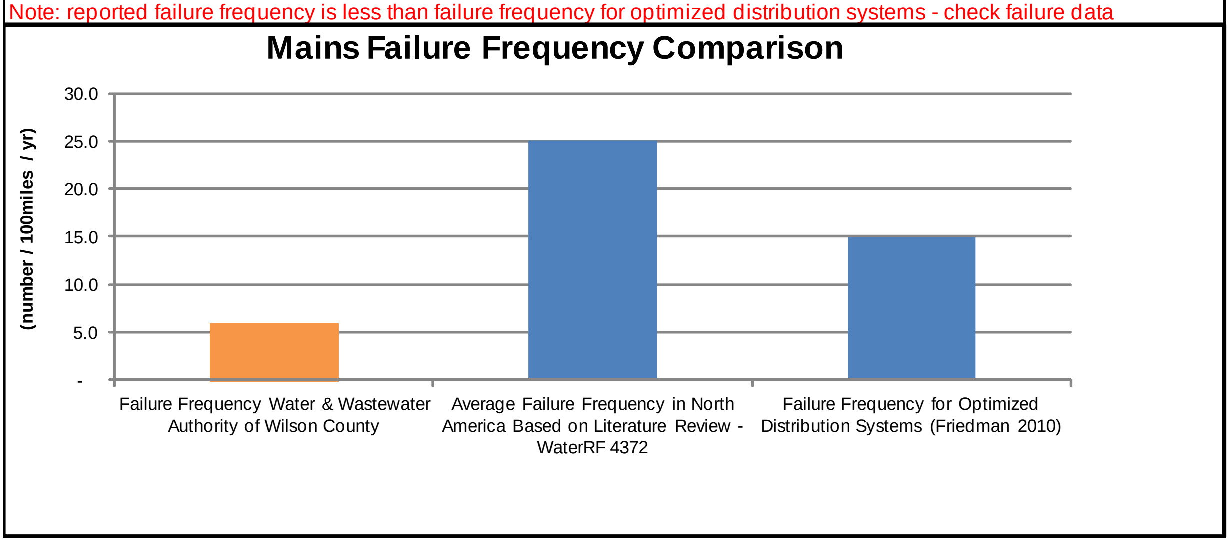


Figure 5.21 Mains Failure Frequency Analysis Results for WWAWC

During FY10/11, 39 failures were reported on service lines for WWAWC. This presents an overall failure frequency of 5.6 failures for every 1000 service connections per year. Figure 5.22 provides a comparison of WWAWC's service line failure frequency against the minimum number of reported service line failures used in the UARL calculation. WWAWC's service line failure data suggests that the system experience approximately 2.5 times the minimum number of reported service line failures used in the UARL calculation. This is within an expected range (considering the UARL formula is a standard for the absolute minimum failure frequency).

	Value to be entered by the user
	Value is automatically filled in/calculated by Model
	Recommended default value

Water & Wastewater Authority of Wilson County

Total Number of Service Connection Failures Reported for Water Audit: Water & Wastewater Authority of Wilson County, TN, USA, 2011	39	
Total Number of Service Connections	7,001	(service connections)
Service Connection Failure Frequency Water & Wastewater Authority of Wilson C	5.6	(number / 1000 service connections / yr)
AWWA Unavoidable Annual Real Losses (UARL) Component of Reported Service Line Failures	2.25	(number / 1000 service connections / yr)
Ratio of Failure Frequency to UARL Break Frequency	2.5	

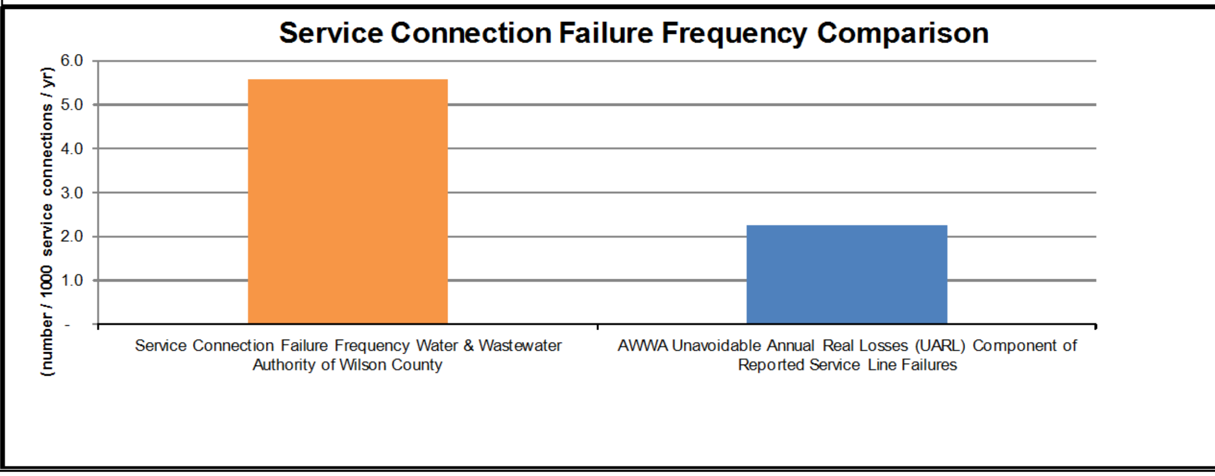


Figure 5.22 WWAWC Service Connection Failure Frequency Analysis Results

Evaluation of Short to Medium Term Intervention Strategies

The next step in the use of the Model is to evaluate short and medium term opportunities to reduce the current real loss volume. Three intervention strategies are evaluated:

- Improved failure location and repair times,
- economic intervention frequency for proactive leak detection,
- and improved pressure management.

Evaluation of Location and Repair Time Reduction Options

The Model provides an opportunity to evaluate possible improvements in location and repair times for reported and unreported leaks on each of the three infrastructure components (mains, service lines and mains fittings/appurtenances).

Based on the results of the real loss component analysis the Model provides a summary of failure events for each of the three infrastructure components (mains, service lines and mains fittings/appurtenances), the average location and repair duration for each infrastructure component, the related volume of real losses, and the resulting cost of real losses due to the current average location and repair times. The Model also provides a "What IF" function to assess the potential savings in real loss volume and cost if the current average location and repair durations are reduced by a certain percentage.

WWAWC's average location and repair durations are already relatively short. Mains failures (for both reported and unreported failures) are repaired within one day on average. To present what a marginal improvement in response times provides in water and revenue savings, a scenario with a half day response time was examined. For mains failures, reducing the response time to 0.5 days, the Model calculates that WWAWC could reduce real loss volume from reported mains failures by 0.3 MG (a value of $722) and could reduce real loss volume from unreported mains failures by 0.5 MG (a value of $1,178). The first section of Figure 5.23 outlines this scenario.

For WWAWC, there is more savings potential in the location and repair times of service connection failures. The records in the failure database for FY10/11 suggest that reported failures on service connections have a location and repair time of 9.2 days on average and unreported failures on service connections have a location and repair time of 6.5 days. For reported failures on service connections, it was assumed that the average location and repair time could be reduced from 9.2 days to 2 days. This would result in real loss savings of 2.97 MG (a value of ($6,718). For unreported failures on service connections, it was assumed that the average location and repair time could be reduced from 6.5 days to 2 days. This would results in real loss savings of 0.6 MG (a value of $1,343). The second section of Figure 5.23 outlines these scenarios.

For the failures on main appurtenances during FY10/11, a very low location and repair time of 0.3 days was documented in the failure database. As such, no improved response times were evaluated.

WWAWC's next step is to evaluate the costs associated with achieving these reductions in average location and repair times in order to evaluate the cost/benefit. Since this model provides this "What IF" function, it is quite simple for WWAWC to model various scenarios of reduced location and repair times and the resulting savings in real loss volume and cost.

Reported and Unreported Failure Events			
Failures on Mains	***Reported***	***Unreported***	
Total Number of Failures on Mains in 2011	19	3	
Average location and repair duration	1.0	0.9	days
Total Volume lost (stemming from location and repair duration)	0.6	1.2	(MG)
Total Cost of Volume lost (stemming from location and repair duration)	$ 1,434	$ 2,688	
What IF Location and Repair Duration is Reduced to	0.5	0.5	days
Percent Reduction	50%	44%	
Potential Related Savings in Leakage Volume	0.3	0.5	(MG)
Potential Related Savings in Leakage Volume Cost	$ 722	$ 1,178	
Service Line Failures	***Reported***	***Unreported***	
Total Number of Failures on Service Connections in 2011	39	9	
Average location and repair duration	9.2	6.5	days
Total Volume lost (stemming from location and repair duration)	3.8	0.9	(MG)
Total Cost of Volume lost (stemming from location and repair duration)	$ 8,584	$ 1,945	
What IF Location and Repair Duration is Reduced to	2	2	days
Percent Reduction	78%	69%	
Potential Related Savings in Leakage Volume	2.97	0.6	(MG)
Potential Related Savings in Leakage Volume Cost	$ 6,712	$ 1,343	
Failures on System Appurtenances	***Reported***	***Unreported***	
Total Number of Failures on System Appurtenances in 2011	4	-	
Average location and repair duration	0.3	-	days
Total Volume lost (stemming from location and repair duration)	0.4	-	(MG)
Total Cost of Volume lost (stemming from location and repair duration)	$ 887	$ -	
What IF Location and Repair Duration is Reduced to			days
Percent Reduction	0%	0%	
Potential Related Savings in Leakage Volume	-	-	(MG)
Potential Related Savings in Leakage Volume Cost	$ -	$ -	
Total Potential Savings if Location and Repair Duration is Reduced as Simulated in the Above Sections	**3.6**	**1.8**	**(MG)**
Total Potential Cost Savings if Location and Repair Duration is Reduced as Simulated in the Above Sections	**$ 7,434**	**$ 2,521**	**Per Year**

7/23/2013

Figure 5.23 Evaluation of Location and Repair Time Reduction Options for WWAWC

Evaluation of Economic Intervention Frequency

The Model also provides an opportunity to establish a preliminary schedule for proactive leak detection surveys and the corresponding necessary budget. The purpose of proactive leak detection and control is to find leaks that do not surface or only surface after a long time. Therefore, by undertaking regular leak detection and repair the utility has the possibility to actively control the volume of water lost through unreported leaks.

In order to reduce the level of unreported failures and make an impact into the potential 14.55 MG/Yr of Hidden Losses, it will be necessary to undertake a very comprehensive leak survey, where all fittings are sounded and an intensive ground microphone survey is undertaken.

Utilizing the rate of rise method as outlined in the AWWA M36 manual (3rd edition) for determining the economic intervention frequency three parameters need to be assessed:

- Average rate of rise of unreported leakage (RR)
- The cost of leak detection survey intervention (CI)
- The cost of Real Losses (CV)

Once these three parameters are know it is possible to assess for any size system or subsystem:

The economic intervention frequency (EIF) to find unreported leaks using Equation 5.1.

$$EIF\ (month) = \sqrt{\frac{0.789 \times \frac{CI}{CV}}{RR}} \tag{5.1}$$

The economic percentage (EP) of the system that should be inspected each year using Equation 5.2.

$$EP(\%) = \frac{100 \times 12}{EIF} \tag{5.2}$$

The appropriate annual budget for intervention (ABI) costs, (excluding leak repair cost) using Equation 5.3

$$ABI(\$) = \ EP \times CI \tag{5.3}$$

The economic annual volume of unreported real losses (EURL), corresponding to the economic intervention frequency using Equation 5.4

$$EURL = \frac{ABI}{CV} \tag{5.4}$$

As these parameters are calculated using square root functions, they are not very sensitive to random errors in CI, CV, and RR. Using an example discussed in a paper by Lambert and Lalonde (2005), errors of +/-10% in CV, 5% in CI and 20% in RR produced a confidence limit of +/-15% in the calculated economic intervention frequency (EIF).

Rate of Rise of Leakage (RR)

The total rate of rise of leakage may be thought of as the continuing increase in leakage that would occur in absence of any leak repairs. It is made up of two components: new leaks occurring in the network plus the growth (increase in volume) of existing leaks. Of this total rate of rise of leakage, a portion will comprise visible leaks which surface and come to the attention of the water utility, which will be promptly repaired by the water utility. It is the remaining portion which is normally used in leakage economic studies, and defines the leakage which must be overcome through proactive leak detection. The rate of rise of leakage is therefore used to define the economic effort and expenditure to manage unreported leakage at an economic level. There are three principle ways of assessing the rate of rise of leakage for a distribution system:

- Compare Real Losses from water balances several years apart.
- Use results of proactive leak detection campaign in either entire system or same subsystem.
- Use results of measured leakage night flows

WWAWC's leak detection work and minimum night flow analyses are targeted to examine the DMAs that have suspected new leakage and repair new leaks immediately. The minimum night flow data examined did not lend itself to assessment of the rate of rise of leakage in WWAWC's system. Instead, the Unavoidable Annual Real Losses (UARL) formula was applied, which allows calculating the unavoidable annual volume of leakage due to unreported leaks for any given system. Utilizing the empiric UARL formula (see Table 5.8) for the WWAWC distribution system the unavoidable annual real losses from unreported leaks was calculated to be around 10 MG/Year.

Table 5.8
AWWA Standard Unit Values for Calculation of UARL

Infrastructure component	Units	Background Leakage	Reported Failures	Unreported Failures	UARL Total
Mains	gal/mile/day/psi	2.87	1.75	0.77	5.39
Service Connections – main to curb-stop	gal/conn/day/psi	0.112	0.007	0.030	0.149
Service Connections – curb-stop to meter	gal/mile of conn/day/psi	4.78	0.57	2.12	7.47

Source: Adapted from Lambert et al. 1999

In order to assume a conservative value for the RR the annual rate of rise of leakage for the entire distribution system was assumed to be equal to the unavoidable annual real losses from unreported leaks of about 10 MG/Year, or 0.09 thousand gallons/mile of mains/day/year.

The cost for comprehensive leak detection survey was assumed at $250/mile and the real losses are valued by WWAWC at the wholesale cost of imported treated water at $2,259/MG.

For a utility like WWAWC, the Model's economic intervention frequency calculation only should be seen as a general check on WWAWC's current proactive leakage control efforts. WWAWC is one of only a few utilities in North America that utilizes a DMA setup, minimum night time flow analyses, and subsystem water balances to control leakage losses in its system. As a result WWAWC is being highly targeted and efficient with its deployment of leak detection efforts. Proactive leak detection resources are only deployed to DMAs/pressure zones where the minimum night-time analysis indicate the existence of unreported and not surfacing leaks. Therefore, the Model's analysis of recommended intervention frequency for proactive leak detection and estimation of economic Infrastructure Leakage Index (ILI) serves as a parallel check on the level of proactive leakage control the system warrants.

The Model indicates that an economic Infrastructure Leakage Index for WWAWC is around 1.1. The WWAWC FY10/11 water audit data calculated an ILI of 1.1 indicating that WWAWC is operating at, or very close to an economically optimized level of leakage.

Evaluation of Pressure Management Options

The final step in evaluating options for reducing the total volume of real losses in a system is the Model's sheet designed to evaluate alternative pressure management options (see Figure 5.24). Pressure management is a tool to manage system pressures to the optimum level of service, ensuring sufficient and efficient supply to legitimate users and consumers, while reducing unnecessary or excess pressures. Pressure management helps eliminating transients and faulty level controls, all of which cause the distribution system to leak unnecessarily. Pressure management reduces the losses from existing leaks and research has shown that pressure management also reduces the number of new leaks and extends infrastructure lifespan. Pressure management is effective in reducing all Real Loss components: Background Leakage, Reported Leakage, Unreported Leakage and Storage overflows.

Pressure management is already being employed by WWAWC through the use of reservoir/pressure zones and on some parts of the distribution system where Pressure Reducing Valve (PRV) stations are operated. The current average system pressure is at 60 psi, which is already a relatively modest average system pressure. WWAWC currently operates 16 pressure zones. Twelve of these pressure zones are gravity fed from the water suppliers through one or two input meters for each. The four remaining DMAs are the largest (representing 64% of the total system) and each have a pumping station that supplies water to one or two ground level storage tanks at high elevations within the DMA.

To evaluate the benefit of further pressure management, a reduction of 5 psi (reducing the average system pressure from 60 psi to 55 psi) was examined. The Model provides the opportunity to evaluate the potential savings in this pressure reduction scenario (see Figure 5.24). The Model used the default N1 value (N1 = 1) to calculate that the reduction in real losses would be about 5.6 MG per year if the average system pressure were reduced by 5 psi. This would result in monetary savings of about $17,000 per year. Assuming that it would cost about $200,000 to reduce the average system pressure, the simple payback period is 15.8 years for this investment in real loss management.

WaterRF 4372: Real Loss Component Analysis: A Tool for Economic Water Loss Control
Water Audit: WWAWC, TN, USA, 2011
EVALUATION OF PRESSURE MANAGEMENT OPPORTUNITIES

(light blue)	Value to be entered by the user
(white)	Value is automatically filled in/calculated by Model
(tan)	Recommended default value

Instructions: This sheet was designed to provide a simple way to simulate various scenarios of pressure reduction and the resulting savings in real losses.
The calculated reductions in real losses are based on the FAVAD (Fixed and Variable Area Discharges) concept. The effect of reducing the average system pressure is assessed using data in the white cells D18 to D20 which are automatically copied from the AWWA - Water Balance Results Sheet. Next enter if default N1 value is to be used or if system specific N1 value should be calculated using the following formula N1= 1.5 - (1-0.65/ILI) * Prig/100 (Source: Thornton, J. and Lambert, A., 2005. Progress in practical prediction of pressure: leakage, pressure: burst frequency and pressure: consumption relationships. In: Leakage 2005 Conference Proceedings. Halifax, Canada), which requires entering the percentage of rigid pipes (percentage of metal vs. plastic pipe) and service connections in the system in cell D25. Next enter the targeted reduction in average system pressure in cell D29. Next the reduction in real losses and the related cost savings are calculated by the model. Next enter an initial best estimate for the cost of implementing this alternative pressure management policy in cell D35 to calculate a simple payback in years for this new pressure management policy.

Pressure Management Opportunities

	Existing Pressure Management Policy	
Current Average System Pressure	60.0	PSI
Total Annual Real Losses	67.4	MG/Yr
Value of Real Losses	152,348	$/year

FAVAD N1 Value Used for Calculation of Real Loss Reduction Due to Reduction of Average System Pressure

	⦿ Use Default N1	1.0
	○ Use System Specific N1	1.5
Enter % of rigid pipes and service connections in system	0%	
ILI	1.1	

	Alternative Pressure Management Policy	
Assumed Reduction in Average System Pressure	5.0	PSI
Assumed % Reduction in Average System Pressure	8%	
Real Loss Volume Saved Through Alternative Pressure Management Policy	5.6	MG/Yr
Value of Real Loss Volume Saved Through Alternative Pressure Management Policy	12,696	$/Year
Enter Estimated Cost of Implementing Alternative Pressure Management Policy	200,000	$
Simple Payback Period for Implementing Alternative Pressure Management Policy	15.8	Years

Note: Evaluation of Pressure Management Opportunities looks at Results of Reduced Pressure on the Volume of Real Losses. Pressure Management has additional benefits and impacts such as: reduced number of new infrastructure failures, reduced annual repair costs, extended infrastructure life, reduction in residential consumption (mainly for pressure dependent outdoor consumption such as irrigation) which are not quantified in this model. However, these additional benefits and impacts should be evaluated before implementing a new or updated pressure management policy.
If this initial assessment of pressure management options indicates that pressure reduction could provide cost effective means of reducing and controlling real losses in the system then it is recommended to conduct a detailed pressure management study. Such a study should collect pressure data from the field, assess the presence of pressure transients, identify pressure zones with excessive pressures and prioritize pressure management in parts of the system where its most feasible. In addition a more detailed assessment of costs for implementing the new pressure management policy should be assessed. This study should further consider the potential revenue impact a change in pressure management policy might have on residential consumption (mainly for pressure dependent outdoor consumption such as irrigation). Typical pressure management options include: introduction of pressure controlled areas, fixed outlet pressure control, time or demand based pressure control, transient control, altitude and level control at reservoirs and tanks etc. (see AWWA M36 for more details).

5/8/2014

Figure 5.24 Evaluation of Pressure Management Options for WWAWC

Summary

WWAWC operates a very well-managed system with practices and protocols in place to track and manage water losses proactively. Therefore it has achieved very low levels of real losses with an ILI of 1.1 for FY10/11. The evaluation of real loss intervention strategies has shown that even though the current level of real losses is very low, given that WWAWC purchases all of its water, there appear to be minor economic incentives to reduce real losses through implementation of minor improvements in its proactive water loss management.

The currently available reported and unreported failure repair data shows that WWAWC responds to its infrastructure in a timely fashion. An examination of the savings potential in reducing location and repair times revealed that there is an opportunity for improvement in the location and repair time for service connection failures. For reported failures on service connections, reducing the location and repair time from 9.2 days to 2 days would result in real loss savings of 2.97 MG (a value of ($6,712). For unreported failures on service connections, reducing the average location and repair time from 6.5 days to 2 days would results in real loss savings of 0.6 MG (a value of $1,343).

WWAWC is one of only a few utilities in North America that utilizes a DMA setup, minimum night time flow analyses, and subsystem water balances to control leakage losses in its system. As a result WWAWC is being highly targeted and efficient with its deployment of leak detection efforts. Proactive leak detection resources are only deployed to DMAs/pressure zones where the minimum night-time analyses indicate the existence of an unreported and not surfacing leak. Therefore, the Model's analysis of recommended intervention frequency for proactive leak detection and estimation of economic Infrastructure Leakage Index (ILI) serves as a parallel check on the level of proactive leakage control the system warrants. The Model indicates that an economic Infrastructure Leakage Index for WWAWC is around 1.1. The WWAWC FY10/11 water audit data calculated an ILI of 1.1 indicating that WWAWC is operating at, or very close to an economically optimized level of leakage.

Lastly, the analysis of improved pressure management in the WWAWC distribution system shows that WWAWC is already successfully managing pressure and maintains it at a relatively modest level of 60 psi average system pressure. The analysis has shown that there is limited room for improvement in pressure management. A 5 psi reduction of average system pressure would yield savings of 5.6 MG/year with a value of $13,000/year. Assuming that it would cost about $200,000 to reduce the average system pressure, the simple payback period would be 15.8 years for this investment in real loss management. The assumed implementation cost needs to be further validated before the improved pressure management strategy is considered for implementation.

CHAPTER 6 CONCLUSIONS

RESULTS

The main findings and conclusions of this research project are:

Exemplary countries that pursue proactive leakage management feature freely available software tools. This statement was based on a limited international review focusing on countries (Australia, Austria, and New Zealand) where the IWA/AWWA water balance and water loss performance indicators were a recommended best practice. The review also provided an interesting prospective of water loss performance achieved or targeted in these three countries. Especially in Austria and Australia, water utilities have achieved, on average, very low levels of real losses. For example the Australian Government National Water Commission in its 2011Annual National Performance Reports reported an average real loss volume for water utilities with more than 100,000 service connections of 18.5 gallons/connection/day.

The adoption and understanding of existing AWWA Free Water Audit Software shows room for improvement. The results from the examination of state agency efforts to require and collect water audits from their member water providers was a very important exercise in understanding the extent to which water loss control software tools have been successfully adopted and properly used. The research team reviewed state agencies that exemplify proactive approaches by applying the industry's best practices in creating regulations and policies around water loss control. In general, the research team found that the data quality of water audits produced by water utilities for their reporting requirements leaves ample room for improvement. For example the water audit results received by the California Urban Water Conservation Council (CUWCC) showed that about 35% of water audits produced by the CUWCC's member agencies contained implausible results. Similar data quality issues were found when reviewing the water audit results from other state agencies. This highlights the industry wide need for further outreach, education and training in how to conduct a water audit, validate the audit data and develop water loss control strategies.

Real Loss Component Analysis is relatively new. The first step in this research project involved surveying the group of Participating Utilities to gauge general expectations for the Model in its content and complexity. Here, the research team found that a majority of the Participating Utilities selected the "Beginner" (focused on data validation and establishing benchmark performance indicators) or "Intermediate" (focused on implementing initial intervention strategies and improving an existing water loss control program) in describing their water loss control activities. This level of experience appears to be representative of the NA water industry.

The Component Analysis Model was successfully developed and employed by two utilities. The research team successfully developed the Model with significant input from the participating water utilities and the project advisory committee. The Model was designed using a standard Microsoft Office Excel software program. The Model was developed with the needs of the utility users in mind to provide a water loss analysis software tool that is accessible, user-friendly and has a reasonable level of complexity. Each of the participating utilities utilized and tested the model with the result of Eastern Municipal Water District and Water and Wastewater Authority of Wilson County being discussed in this report. For both water utilities the Model helped breaking down their real loss volume, as determined through the AWWA Free Water Audit, into its components, assess the volume of hidden leakage (detectable leaks currently running undetected), and evaluate least cost real loss reduction strategies.

There is ample room for improvement in the data quality of failure records collected by NA water utilities. The research team's failure frequency literature review revealed that that the failure repair records collected by North American water utilities are often incomplete (a finding that was supported by the Participating Utility's dataset). In light of this, the average failure frequencies as assessed by various industry studies are only best estimates reflecting the quality of available failure data. A majority of the documented failure frequencies in the reviewed literature do not have well characterized source data. In other words, the failure frequencies are reported in aggregate without much detail on the original data or the quality assurance measures taken to calculate the aggregate failure frequency. In this context, it is difficult to distinguish between the failure frequencies on the basis of data source, confidence and reliability. Several areas in the collection of leak repair data need to be improved in order to achieve a better and more accurate understanding of failure frequencies.

Terminology for documenting pipe failures needs to be consistent. The terminology used by water utilities for documenting pipe failures is highly inconsistent. The terms leak, break, and burst are all used throughout the industry and they may all have different interpretations/definitions depending on the water utility. Some utilities for example categorize a break as a failure event of significant nature that requires immediate action and the term leak is used for smaller pipe failures, which do not require immediate response. Therefore, it was important to feature clear definitions for the failure data inputs needed for the Model developed for this research project. Every failure event on the transmission system, distribution system and on service connections needs to be documented and used in the Model's leakage component analysis. The term 'failure' is used throughout this report and the model to encompass all leak/break terminology.

A Leak Repair Data Collection Guide was developed. The need to provide clear guidance on failure data collection and documenting was addressed by the research team through the development of a Leak Repair Data Collection Guide in form of an open source MS Office Excel spreadsheet.

Failure frequency benchmarks were identified during the literature review. The goal of the failure frequency literature review (see Figure ES.2) was to isolate two failure frequency benchmarks that can be used in the Model for comparison to typical North American distribution system or to a suggested target for an optimized distribution system. The following failure frequency benchmarks were assessed:

- Aggregate North American failure frequencies based on the data in six studies in the literature review: approximately 25 failures / 100 miles / year.

- Failure frequency goal for an optimized distribution system: 15 failures / 100 miles / year (taken from Friedman et al. 2010).

APPLICATIONS/RECOMMENDATIONS

The Component Analysis Model (the Model) was developed to provide the water industry with a computer-based model for leakage component analysis, failure frequency analysis, economic leakage control intervention strategy evaluation, and display of key water loss performance indicators. The Model is a complementary analysis tool to the AWWA Free Water Audit Software and was designed using a standard Microsoft Office Excel software program. The Model was developed with the needs of the utility users in mind to provide a water loss analysis software tool that is accessible, user-friendly and has a reasonable level of complexity.

The research team is careful to acknowledge that the Model is only as useful and instructive as the quality of the user's inputs. Throughout the instructions provided in the Model (and throughout this report), there is particular emphasis on the importance of data quality and validation. In making the Model freely available and encouraging its adoption, the research team will continue to highlight the importance of data quality.

Furthermore it is important to highlight that the Model requires a significant amount of validated data and its "outputs" are meant to provide opportunities to test scenarios but do not represent concrete goals or hard and fast targets. The Model is a dynamic tool meant for guidance and not a mechanism for direct reporting like the AWWA software or regulatory target setting.

In addition to the model the research team developed a Leak Repair Data Collection Guide in form of an open source MS Office Excel spreadsheet to aid the industry in collecting consistent failure data. This tool offers guidance to water utilities in the form of a standardized format to document failure events; thereby generating the appropriate data to execute a reliable leakage component analysis. Utilities that carefully document all failure events have a means to define failure trends occurring in their system.

APPENDIX A
REVIEW OF NA & INTERNATIONAL FAILURE FREQUENCIES

LAYOUT OF REVIEW

The literature review that follows highlights the following points from each report.

i. Overview of subject material
ii. Description of Failure Frequency Given
iii. Applicability to the Model comparison

In the Failure Frequencies Review for Model Comparison of this report, Table 2.14summarizes the failure frequencies from a selection of the most relevant literature, and the section summarizes the general findings and conclusions from the literature review whereas this Appendix looks at each source individually.

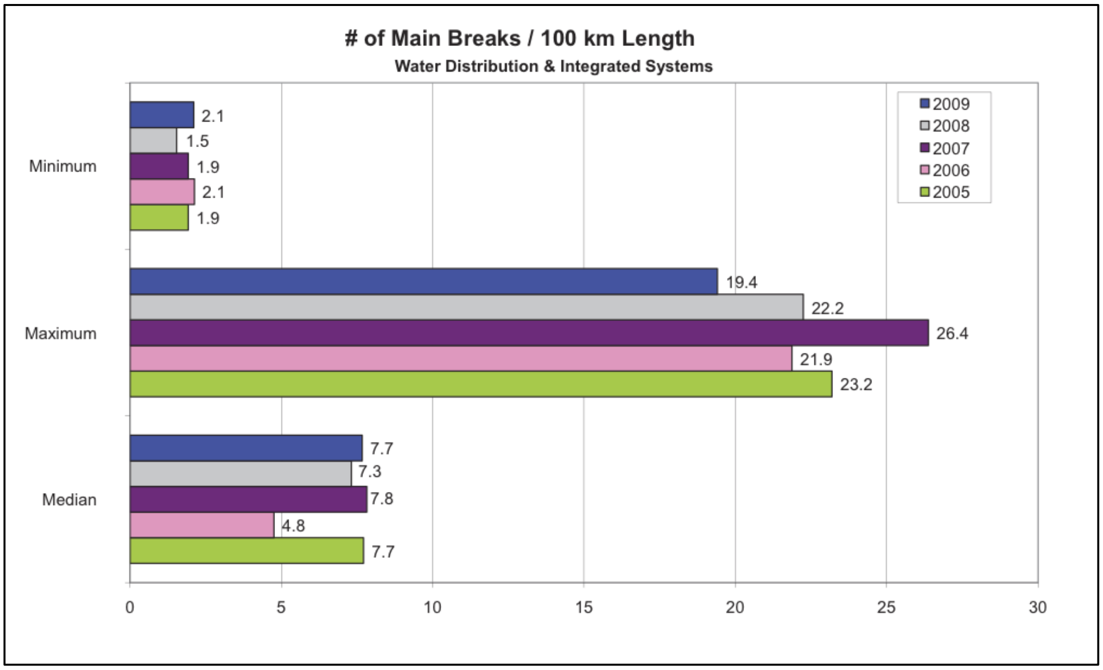
FAILURE FREQUENCY LITERATURE REVIEW

AECOM. 2011. *2011 Public Report*. Vancouver, British Columbia, Canada: National Water and Wastewater Benchmarking Initiative.

Overview

Established in 1997, the National Water and Wastewater Benchmarking Initiative began compiling performance indicators for Canadian utilities. The goal of the organization is to "measure, track and report on their utility performance" (AECOM 2011). Further, it aims to aid utility managers in monitoring trends, analyzing standards, setting goals and implementing action plans.

This particular report highlights the most recent collection of data, which includes a survey (conducted in 2009) of 34 water utilities (in addition to 39 wastewater utilities and 16 storm water management plans). This report does not detail the size or the operational practices of the surveyed utilities. Instead, the report features graphs of the minimum, maximum, and median results for the performance metrics collected over five years. Figure A.1 shows the failure frequency data collected.



Source: AECOM 2011.

Figure A.1 National Water and Wastewater Benchmarking Initiative's failure frequency performance indicator results.

Failure Frequency

- Median in 2009: 7.7 failures/100km/yr (12.4 failures/100miles/yr)
- Average over 5 Years: 7.06 failures/100km/yr (11.36 failures/100miles/yr)

Applicability to Model Comparison

This report contains good examples of the lower threshold of failure frequencies found in this literature review. It is useful in highlighting examples of low failure frequencies that are attainable.

American Water Works Association. 1996. *Water:\STATS 1995 Distribution Survey.* Denver, Colo.: AWWA.

Overview

The research team was unable to access the AWWA Water:\STATS Database from 1996 (it is no longer available through the AWWA Bookstore). Deb et al. (2002) gives a brief review of the 1996 Water:/STATS Database, outlined here.

A number of different distribution system statistics were compiled in the AWWA Distribution Survey. These included length of pipe, length of pipe replaced in the year prior, and length of pipe extended in the year prior. Findings on materials of pipe were also summarized: in the US, 48% of the total pipe length is cast iron and 19% is ductile iron (in Canada the distribution is 44% and 25% respectively).

As for failure frequency data, of the 898 utilities that responded to the survey, 702 of them provided information on distribution main failures experienced in 1995. The whole dataset contains 90,952 failures for the year, equivalent to 23 failures per 100 miles per year. No more detail on this data was available.

Failure Frequency

- Average for 702 North American utilities: 23 failures / 100 miles / yr

Applicability to Model Comparison

This database provides very relevant context to the Model, especially because it features data from such a large number of utilities. Unfortunately, not much context can be given to this failure frequency due to the lack of information on the sizes of utilities participating in the survey and the types or size of failures.

American Water Works Association. 2003. *Water:\STATS 2002 Distribution Survey.* Denver, Colo.: AWWA.

Overview

Another distribution system survey was sent to 3,000 utilities in the summer of 2002. Over the next year, AWWA collected responses from 337 utilities, which represented a total of 59,389,902 in population served, 14,339,261 customer service lines, and 146,435 wholesale connections (AWWA 2007b). This survey mainly took inventory of utility infrastructure and assets (i.e. length of pipes, number of valves and fire hydrants, storage capacity, etc.).

AWWA (2007b) notes that the information gathered in this survey needs more analysis to distinguish between wholesale and retail customers in order to allow for better year-to-year comparisons and per capita metrics.

Grigg (2007) looked at the full dataset, “removing obvious errors and outliers” to calculate the average main failure frequency to be 21 failures per 100 miles per year. He qualifies this failure value with a critique of the survey’s clarity: “The questions were simple and did not explain to the utilities how to define a failure.”

The research team also analyzed a subset of the 2002 Distribution Survey that included all utilities surveyed that served more than 100,000 people. Excluding all zero values and the outlier failure frequencies that fell outside two standard deviations from the mean, the research team confirmed an average of 21 failures / 100 miles / year.

Failure Frequency

- 21 failures / 100 miles / yr

Applicability to Model Comparison*:*

This database provides very relevant context to the Model. It represents a good number of utilities from a geographically diverse area. Little information is available on the quality of the failure data received, the types of utilities involved, and the types of failures encountered, but it remains a useful reference.

American Water Works Association. 2007a. *Benchmarking Performance Indicators for Water and Wastewater Utilities: 2007 Annual Survey Data and Analysis Report.* Denver, Colo.: AWWA.

Overview

In 2007, AWWA conducted another survey with the aim of collecting data to establish benchmarks and inform performance indicator goals for the industry. As a performance indicator that characterizes infrastructure integrity, failure frequencies from 150 utilities were collected.

Friedman et al. (2010) uses this data to inform its determination of utility performance indicator goals, citing that the top quartile of the dataset included a range between 14.9 and 21.7 failures / 100 miles / yr.

The research team was unable to access a hard copy of this report, so no further analysis of its failure frequency data was possible.

Failure Frequency

- Top quartile performance: 14.9 – 21.7 failures / 100 miles / yr

Applicability to Model Comparison

The top quartile of the failure frequency dataset will provide a very useful benchmark for use in the Model. As Friedman et al. (2010) explains more thoroughly, 15 failures/100miles/year is a reasonable goal for utilities to aim for in an optimized distribution system that proactively managements its infrastructure.

American Water Works Association. 2007b. *Distribution System Inventory, Integrity and Water Quality.* Office of Ground Water and Drinking Water Total Coliform Rule Issue Paper. Denver, Colo.: AWWA.

Overview

This report was prepared by AWWA for the Environmental Protection Agency (EPA) in 2007, and it provides an overview of distribution system infrastructure studies. In particular, it details the Water:/STATS Database work and other AwwaRF projects.

No new data is collected here: the failure frequencies listed are drawn from other sources, all of which are detailed throughout this literature review.

Failure Frequency

- None given.

Applicability to Model Comparison

Without any new reporting of failure frequency data, this report will not directly inform the comparison made within the Model. However, it is very helpful in contextualizing the development of failure frequency research overall.

Australian Government National Water Commission. 2011. *National Performance Report 2009-10: Urban Water Utilities.* Canberra, Australia: National Water Commission.

Overview

This report – published in 2011 – is the latest in a series of annual National Performance Reports. These reports provide a public and independent review of the performance of Australian Water Utilities. The report summarizes and describes results from a database of 117 performance indicators collected each year.

For this year's review, 79 utilities, serving a total of 18.3 million Australians, participated. Table A.1 shows the results, organized by utility size. The report highlights that the failure frequency increases with size: the larger the utility, the more failures it experiences.

Table A.1
Australian water utility main failure data, organized by utility size

	Water main breaks (per 100 miles of water main)		
Size group	High	Average	Low
100,000+ connected properties	84	43	21
50,000 to 100,000 connected properties	95	39	10
20,000 to 50,000 connected properties	93	27	3
10,000 to 20,000 connected properties	93	26	5

Source: Australian Government National Water Commission 2011a.

Failure Frequency

- Average for 100,000+ service connections: 43 failures/100 miles/yr
- Average for 50,00 to 100,000 service connections: 39 failures/100 miles/yr
- Average for 20,000 to 50,000 service connections: 27 failures/100 miles/yr
- Average for 10,000 to 20,000 service connections: 26 failures/100 miles/yr

Applicability to Model Comparison

This is a very relevant and useful reference for the Model. It is important to include international standards in contextualizing the Model's results.

Notably, these averages are on the higher end of the aggregate failure data reviewed here. At the same time, Australia's water loss control policies are regarded as very progressive. The water loss metrics highlighted in the same reported range from 18 to 31 gallons per connection per day on average (depending on utility size). Australia proves that failure frequency does not have to equate to large water system losses if response time and repairs are managed efficiently and executed well.

Cook, Dominic, B. McAndrew, and G. Shuker. 2009. *Large Diameter Trunk Failures*. London, U.K.: UK Water Industry Research Limited.

United Kingdom Water Industry Research Limited (UKWIR) published this report on historic failure data and predictive software modeling in 2009. Thirteen UK utility datasets were compiled and analyzed to shed light on large diameter failure trends and inform their software modeling development.

This report stands out among those reviewed in this literature review because it includes a great deal of detail on the analysis and content of the datasets collected. The first component of the report highlights the utility data sets' levels of completeness (as shown in Figure A.2).

	Company													
Burst Attribute	**E**	**D**	**A**	**F**	**M**	**G**	**J**	**C**	**B**	**I**	**L**	**H**	**K**	Coverage
Diameter														76.9%
Pipe material														71.2%
Mode of failure														30.8%
Accurate grid reference														65.4%
Time to restore supplies														34.6%
No. of properties affected														26.9%
Consequence of failure														3.8%
Cause of failure														26.9%
Unique asset ID (link to GIS)														28.8%
"Coverage"	31%	53%	66%	9%	19%	47%	44%	41%	75%	41%	50%	41%	31%	
Nr of bursts per annum	39	5.4	10.2	233	17.4	9.6	73.3	7.4	12.5	213	88.4	75.7	465	
Nr of years recorded data	6	13	7	3	11	17	10	18	36	12	7	5	9	

Source: Cook et al. 2009.

Figure A.2 Attribute matrix for work management records

The report summarizes: “The table above shows that there is good coverage across all companies for the ‘basic’ attributes (diameter, material, grid reference) required to investigate burst rate trends. Coverage of the more ‘advanced’ attributes which would support detailed analysis of consequence of failure is more sparse” (Cook et al. 2009). As the aim of this literature review is to isolate failure frequencies, the ‘basic’ attributes collected here are sufficient. For the more advanced endeavors of replacement program development, the ‘advanced attributes’ will be critical for populating predictive models.

Table A.2 summarizes the results of the failure frequency analysis. It is important to note that only failures on pipes 12” or larger were included in the analysis. The report later summarizes that the average failure frequency was approximately 6.11 failures / 100 miles / year.

Table A.2
Utility failure frequency data for mains 12” or larger

Utility	K	H	J	B	F	I	L	C	G	E	D	M	A
Breaks	1525	152	700	392	378	1626	630	129	92	222	57	406	57
Breaks / 100 miles / year	14.3	7.7	7.5	7.1	6.4	5.9	4.4	3.3	2.7	2.6	1.8	1.3	0.6

Source: Cook et al. 2009

Cook et al. (2009) goes on to detail failure frequency trends for size, material, age, and soil condition factors. In summary, the report concludes: “The results tend to show frequency of failure increasing with age, reducing as diameter increases and for certain materials increasing with increased soil corrosivity” (Cook et al. 2009).

Failure Frequency

- Average from 13 UK Utilities for failures on 12” or larger pipes: 6.11 failures / 100 miles / year

Applicability to Model Comparison

This is a relevant and useful reference for the Model in providing background on data availability and an international comparison. However, without any other sources that offer size-specific failure rates, the Model can only feature an average failure rate comparison.

Deb, Arun K., F.M. Grablutz, Y.J. Hasit, et al. 2002. *Prioritizing Water Main Replacement and Rehabilitation.* Denver, Colo.: AwwaRF.

Overview

This report thoroughly reviews different approaches to main repair and replacement programs. Assessing the condition of a utility's pipe infrastructure is crucial to any such program, so a review and compilation of failure frequency data is included. The objectives of this report include: highlighting a protocol of data collection on failure events, outlining a procedure around analyzing that data, outlining how that analysis can inform rehabilitation efforts, and drafting a model to predict and prioritize repair or replacement.

The most relevant part of this report for the purposes of this literature review is Chapter 2: "Current Information", which highlights failure frequencies (via a questionnaire they conducted and the AWWA Water:\Stats Database (AWWA, 2003)). This section highlights differences between aggregated failure frequencies for NA and Europe. It also reviews the failure databases of six utilities. The authors conducted two questionnaires. First, data was collected from 37 North American utilities (32 served more than 100,000 people and 5 served less than 100,000). This dataset revealed that the average failure frequency for these utilities between 1993 and 1997 was between 21 and 25 failures per 100 miles per year. The second survey was given to European utilities. Twenty-eight utilities responded, totaling a higher average failure frequency of 50 failures / 100mi /yr.

It is important to note here that despite having a higher average failure frequency, the report describes more proactive management of main maintenance in European utilities. In concluding the section on the questionnaires Deb et al. (2002) states: “Less than half of the North American utilities reported that they have a formal program in place for controlling main failures, while 80% of the European utilities have such programs. While all European utilities have water main inventories, 11% of Northern utilities did not have them.”

The report continues to detail the importance of data collection when repairing a main failure, and it reviews applications of this failure data in predictive modeling and planning. It also includes template for failure data collection (and term definitions), thorough description of pipe material and soil testing procedures, and a mechanistic model application case study.

Failure Frequency

- Average from 37 North American utilities surveyed from the period 1993 to 1997: between 21 and 25 failures / 100 miles / year
- Average from 28 European utilities: 50 failures / 100 miles / year

Applicability to Model Comparison

This report is relevant and useful for the Model comparison. Though the specifics of the data validation around the failure data aggregations are not explained, this paper is widely cited in regards to failure rates.

Deb, Arun K., Y.J. Hasit, and F.M. Grablutz 1998. *Quantifying Future Rehabilitation and Replacement Needs of Water Mains.* Denver, Colo.: AwwaRF.

Overview

This report describes an AwwaRF project that aimed to develop a predictive distribution assessment model for North American utilities. The report reviews the projects main objectives, which included developing the model to provide long range replacement and rehabilitation strategies, testing of the model, developing a user’s manual, and describing the condition of North America’s infrastructure through the results of the predictive model’s replacement and rehabilitation recommendations.

The model was inspired by European utility success with the German Karlsruhe Model ("KAMODEL"), and the research team for the project engaged with five utilities for testing. Data from the Los Angeles Department of Water and Power, the Philadelphia Water Department, the Boston Water and Sewer Commission, the Fort Worth Water Department, and Severn Trent Water Limited was used to test the model.

The case studies and background research reviewed in this project did not include any failure frequency specific data. System attributes like mileage of pipe and material breakdowns were included, but no failure data was featured.

One of the recommendations of the report does highlight a relevant finding for this work in emphasizing the need for more thorough documentation of infrastructure characteristics and events. It states: "North American water utilities should develop better database management systems for existing distribution system inventories and for capturing historical water main rehabilitation and replacement data" (Deb et al. 1998).

Failure Frequency

- None given.

Applicability to Model Comparison

This report does not provide relevant data for use in the Model's comparison of failure frequency results.

Deb, Arun K., Y.J. Hasit, and F.M. Grablutz 1995. *Distribution System Performance Evaluation.* Denver, Colo.: AwwaRF.

Overview

This report offers a comprehensive review of distribution performance indicators and provides utility managers with the methodologies necessary to evaluate and analyze their own system performance. Toward this end, the study featured a review of state-level standards and regulations, receiving 38 questionnaires from members of the Association of State Water Administrators. An expert workshop was also help to discuss performance requirements and appropriate approaches with utility leaders.

Failure rates were not included in the data collection process for this study. However, in the discussion of performance goals (see the section on "Service Dependability" and "Recommendations"), a range of 20 to 30 failures per 100 miles per year is recommended.

Failure Frequency

- Recommended Failure Frequency Range: 20-30 failures/100 miles/year

Applicability to Model Comparison

This report features a relevant failure frequency range. However, more recent studies on performance goals will be used for the Model comparison.

Friedman, M., G. Kirmeyer, and J. Lemieux. 2010. *Criteria for Optimized Distribution Systems*. Denver, Colo.: Water Research Foundation.

Overview

This study aims to develop "consensus-based criteria and assessments useful for distribution system optimization" (Friedman et al. 2010). It isolates three areas of importance in evaluating a system's performance: water quality integrity, hydraulic integrity and infrastructure integrity.

Notably, the metric chosen to evaluate infrastructure integrity in this report is failure rate. The study also considers leakage run time and failure costs as other infrastructure integrity parameters, but it concludes that neither could be sufficiently supported with readily available data. Utilities more consistently track number of events than they do the running time or costs.

For a specific failure frequency goal for an optimized system, the report recommends "no more than 15 reported failures per 100 miles of utility-controlled distribution and transmission piping per year" (Friedman et al. 2010). The report continues to detail, "This includes failures and leaks on appurtenances such as valves, hydrants, blow-offs, fittings, tapping sleeves/saddles and the connected tapping valves/corporation stops. It does *not* include service lines and appurtenances beyond the connecting point at the main, regardless of whether utility-owned/controlled or customer owned/controlled. Reported failures include both emergency events (i.e., needing immediate response and repair) and non-emergency events (i.e., addressed during normally schedule work hours)" (Friedman et al. 2010). The selection of 15 failures per 100 miles per year was derived from the lower end of the top performance quartile of AWWA's benchmarking report (AWWA 2007a).

The report also included an analysis tool that accepts number of failures and miles of main to calculate failure frequency. The tool then compares it to the performance goal described above.

Failure Frequency

- Given as a goal for optimized systems (and does not include service line failures): 15 failures / 100 miles / year

Applicability to Model Comparison

This report will definitely contribute to the Model comparison. Its determination of 15 failures per 100 miles per year will be a fitting benchmark, and comparing the user utility's results with this goal will be useful in contextualizing the utility's infrastructure condition and illustrating its improvement potential.

It is notable that the results of this report provided the basis for AWWA's Distribution System Optimization Program within their Partnership for Safe Water Program. As such, many water utilities are now collecting break data to inform the distribution system optimization goals. This will be beneficial to any user of the Model because their break data will be readily available.

Grigg, Neil S. 2004.*Assessment and Renewal of Water Distribution Systems.* Denver, Colo.: AwwaRF.

This report reviews and details water distribution system capital management. It specifically describes the tasks of locating, assessing, planning, repairing, and renewing water distribution systems. It provides a good summary reference for condition assessment methodologies and renewal/rehabilitation strategy planning.

Most of the study is devoted to reviewing different technologies and methodologies that would aid a utility manager in infrastructure maintenance. Failure frequencies are only specified in the section that reviews current distribution systems conditions, "Chapter 2: Distribution System Issues and Statistics". Here the frequencies originally reported in Kirmeyer et al. (1994) and AWWA (1996) are reviewed.

Failure Frequency

- As reported in Kirmeyer et al. (1994): 27 failures / 100 miles / year
- As reported in AWWA (1996): 23 failures / 100 miles / year

Applicability to Model Comparison

As this report only references failure frequencies from other data collection efforts, it serves as confirmation of the validity and acceptance of the failure rates mentioned.

Grigg, Neil S. 2007. *Main Break Prediction, Prevention and Control.* Denver, Colo.: AwwaRF.

Overview

Grigg (2007) includes literature review on factors that cause main failures, failure consequences, and predictive failure models. This report provides a great summary of renewal programs and predictive models developed to date. It concludes that most available models require serious calibration and are not easily used with the level of data utilities often have accessible currently: "The limits of model capabilities are not in mathematics or statistical analysis methods, but in lack of accurate and consistent data and in the complexity of analysis" (Grigg 2007).

The report also included a survey that requested information on infrastructure characteristics, data availability, failure frequencies, and failure replacement policies (Chapter 3 presents details). Though published in 2007, the data collected from 47 survey respondents featured failure information from 1998. The report presents that the average of this data is 25 failures per 100 miles for that year.

Further, six utility failure databases were collected and analyzed. Though no data validation was applied to these datasets, the ranges of failure frequencies from this sample of utilities is reported between 14 and 24 failures/100 miles/year (excluding an outlier of 281 failures/100 miles/year).

Failure Frequency

- Average from 47 utilities, failure main data from 1998: 25 failures / 100 miles / year
- Range from six utilities studied in more detail: between 14 and 24 failures / 100 miles / year

Applicability to Model Comparison

The specific failure frequencies given in this report are relevant and will be useful in the Model comparison. However, there is little background information on data validation or specifics on survey content. As the data was collected from 1998, this is not the most recent averaged failure rate information evaluated in this literature review.

Kirmeyer, G.J., W. Richards, and C.D. Smith. 1994. *An Assessment of Water Distribution Systems and Associated Research Needs.* Denver, Colo.: AwwaRF.

Overview

One purpose of this report was to compile data on distribution systems and establish research goals for AwwaRF around water distribution systems. It outlines objectives for the AwwaRF research category focused on Water Distribution System Infrastructure. The study highlights the need for developing and demonstrating effective test methods for condition assessment that will better inform rehabilitation and replacement programs. The report includes a literature review, comprehensive assessment of AwwaRF studies to date, expert workshops, a review of the Water Industry Data Base, and a new survey.

Both the WIDB review and the survey provide failure frequency values. Kirmeyer et al. (1994) describes the details of the WIDB data collection effort in 1992. It describes how two surveys (identical in questioning) were administered to two different groups of utilities. The first – in 1990 – was given to 600 large systems (500,000+ in population served), and the second – in 1991 to 1992 – was given to medium systems (10,000 to 50,000 in population served). The total count of respondents came to 1097 utilities, representing 112 million people and approximately 2% of the community water systems in the United States.

Kirmeyer et al. (1994) summarizes the relevant WIDB findings in reporting that the average failure frequency for the dataset was 27 failures per 100 miles per year (for more specifics see AWWA (2007b)). The survey conducted by Kirmeyer et al. (1994) featured 20 carefully selected utilities. The study aimed to select a sample that represented a range of North American utilities (varying in population served, water source, public/private, geographic location, and age of system). The failure data collected from this survey presents an average failure frequency of 21 failures per 100 miles per year.

Failure Frequency

- WIDB survey in 1992 (1092 participating utilities): 27 failures / 100 miles / year
- Survey of 20 utilities: 21 failures / 100 miles / year

Applicability to Model Comparison

This survey is very relevant and useful for the Model comparison. Though the data is not as recent as other surveys, one of the primary purposes of this report was to investigate statistics of infrastructure integrity. As AWWA (2007b) summarizes: "While more recent survey data is available, the Kirmeyer et al. (1994) report for AWWARF offers a comprehensive view and useful statistics because a main activity of the study was to process and analyze the available AWWA and utility data about distribution system infrastructure, whereas data from more recent AWWA surveys requires further analysis to determine trends and conclusions."

Kleiner, Yehuda, and B. Rajani. 2010. *Dynamic Influences on the Deterioration of Individual Water Mains (I-WARP)*. Denver, Colo.: Water Research Foundation.

Reviews approaches to statistically determine failure frequencies for individual pipes, considering both static characteristics (e.g., pipe material, size, age, soil type) and dynamic characteristics (e.g., climate cathodic protection, pressure zone changes). Chapter 4 of the report reviews the data used to test the model, and Appendix A provides data for each of 4 utilities. Pipe length and numbers of failures (going back 30+ years) are provided for the following cities' utilities: Ottawa, Calgary, Scarborough, and Cleveland.

The research team extracted this data and converted the number of failures and pipe lengths – given by year – into failure frequencies (# of failures/100 miles/year), as outlined in Table A.3.

Table A.3
Utility data used for testing in Kleiner and Rajani (2010)

City	Dataset Size	Latest Pipe Mileage	Max Break Freq	Min Break Freq	Average Break Freq.
	(# of years)	(miles)	breaks/ 100miles/yr	breaks/ 100miles/yr	breaks/ 100miles/yr
Ottawa	36	1,670.22	26.23	8.21	16.49
Scarborough	43	717.97	75.85	0.14	48.47
Calgary	52	2,818.65	38.15	1.99	13.99
Cleveland	13	1,492.29	73.65	43.76	61.12

Failure Frequency

- Ottawa, Canada average over 36 years of failure data: 16.5 failures / 100 miles / year
- Scarborough, Canada average over 43 years of failure data: 48.5 failures / 100 miles / year
- Calgary, Canada average over 52 years of failure data: 14.0 failures / 100 miles / year
- Cleveland, OH, USA average over 13 years of failure data: 61.1 failures / 100 miles / year
- Mileage weighted average for 4 cities studied: 28.8 failures / 100 miles / year

Applicability to Model Comparison

This report is relevant to the Model comparison in that it isolates historical data of failure frequencies for four utilities. The range of failure frequencies in this study (from 16.5 to 61.1 failures / 100 miles / year) provides an important reminder of how widely failure frequencies can vary from one utility to the next. However, without a bigger sample size and more data validation efforts, the actual failure frequencies values will not be used in the Model comparison.

Kleiner, Yehuda, B. Rajani, and R. Sadiq. 2005. Risk Management of Large-Diameter Water Transmission Mains. Denver, Colo.: AwwaRF.

Overview

This study outlines a model for large main failure prediction and renewal program planning that involves assessment of pipe condition and comparison to "maximum risk tolerance". The research produced "T-WARP: Transmission - Water Mains Renewal Planner) computer model. This methodology only applies to concrete and iron pipes over 16 inches.

Failure Frequency

- None Given.

Applicability to Model Comparison

This research and report are not relevant to the Model comparison of failure frequencies. Instead of supplying aggregate data on the current condition of infrastructure, this research provides utilities with a predictive tool to inform their rehabilitation and replacement programs.

Laven, K and A.O. Lambert. 2012. *What Do We Know About Real Losses on Transmission Mains?* IWA Water Loss Conference, Manila, Phillipines, February 22 – 26, 2012.

Overview

This paper examines the frequency and flow rates of leakage in transmission mains. It looks at how the BABE (Bursts and Background Estimates) concepts used for component analysis of distribution system real losses compare to a collection of data from extensive leak detection efforts on transmission mains. The analysis shows that the empirical data presents higher unreported failure frequencies than the assumptions used in the BABE analysis.

The BABE analysis assumes that the unreported component of Unavoidable Annual Real Losses (UARL) is 1.04 bursts per 100 miles per year (as developed for distribution systems). This is based on the assumption that 5% of all failures (at 20.92 failures/100 miles per year) do not surface. Calibrating this failure frequency for the higher pressures typical of transmission mains results in an unreported failure frequency of 1.67 bursts/100 miles/ year.

However, the data collected from leak detection efforts on over 1800 miles of transmission main suggest a higher rate of unreported leakage. Using main age information to analyze the rate of rise and estimate the average unreported failure frequency, this report presents the average unreported failure frequency of 2.51 failures/100 miles/ year. This data suggests that the UARL formula values used in the BABE analysis underestimate unreported leakage on transmission mains. Thus, the paper concludes that "unreported leaks [for transmission mains] may be accumulating with time, rather than maturing into reported leaks and reaching a 'steady state' frequency" (Laven and Lambert 2012).

Though not the focus of its examination, this paper also mentions a reported failure frequency of 8 bursts/100 miles/ year for transmission mains (Laven 2010).

Failure Frequencies

- 2.51 unreported failures / 100 miles / year for transmission mains
- 8 bursts / 100 miles / year for transmission mains

Applicability to Model Comparison

These failure frequencies will be important to weigh in the development of the Model, as they demonstrate the distinctions in component analysis approaches for distribution and transmission systems. The inclusion of these findings will be dependent on the complexity of the Model. The values will not be included in the Model's comparison of failure frequencies because a breakdown by size will not be provided.

MacKellar, Steve. UKWIR National Mains Failure Database. Presented at *The International Conference of Plastics Pipes XIII, 2006, Washington DC.* London, U.K.: UK Water Industry Research Limited.

Overview

In this report, failure inventories were collected from 21 of the 23 UK Water companies, creating an ongoing database ("National Mains Failure Database"). The authors emphasize that the dataset has become useful as an asset management resource, and they aim for the dataset to evolve in order to meet the needs of asset management models and tools.

Table A.4 shows failure rates for five different pipe materials are given for each year between 1995 and 2003.

Table A.4
Break frequencies as reported in UKWIR National Mains Failure Database (MacKellar 2006)

FAILURES by PIPE MATERIAL*
(breaks/100km/yr)

YEAR	IRON	ASBESTOS CEMENT	PVC	DUCTILE IRON	PE	AVERAGE (weighted by % composition)
% of SYSTEM by material**	**47.5%**	**11.0%**	**16.5%**	**9.5%**	**15.5%**	
1995	33.0	19.0	10.0	5.0	3.5	20.4
1996	37.0	18.0	10.0	6.0	4.0	22.4
1997	30.3	22.0	11.0	7.0	5.0	20.0
1998	29.0	18.0	8.0	7.5	4.5	18.5
1999	29.0	19.5	7.5	7.3	4.0	18.5
2000	22.5	15.0	5.5	7.0	5.0	14.7
2001	26.5	10.5	6.0	5.5	3.5	15.8
2002	25.0	9.5	10.5	7.0	3.5	15.9
2003	32.5	14.5	12.5	14.0	4.0	21.0
AVERAGE	**29.4**	**16.2**	**9.0**	**7.4**	**4.1**	**18.6**
in breaks/100mi/yr	**47.4**	**26.1**	**14.5**	**11.9**	**6.6**	**29.9**

* Derived from Figure 5 in MacKellar (2006)
** Derived from Figure 1 in MacKellar (2006)

Break Frequency

- Average failure frequency (for all materials) for 21 UK utilities from 9 years of data: 29.9 failures / 100 miles / year

Applicability to Model Comparison

This report is very relevant and applicable for the Model comparison. The dataset is reliable with a large number of utilities and many years of data. It will be instructive to include a European failure rate values alongside the North American benchmarks.

Rajani, Balvant, and S. McDonald. 1995. *Water Mains Break Data on Different Pipe Materials for 1992 and 1993*. Ottawa, Canada: National Research Council Canada.

Overview

This report compiles the survey responses from 21 Canadian utilities survey, collecting 1992 and 1993 data on failures by pipe material. Failure frequencies for cast iron, ductile iron, asbestos-cement, and PVC are reported. Types of failures are also included in the analysis.

Break Frequency

- Cast Iron: 57.8 breaks/100 miles/yr
- Ductile Iron: 15.4 breaks/100 miles/yr
- Asbestos Cement: 9.3 breaks/100 miles/yr
- PVC: 1.1 breaks/100miles/yr

Applicability to Model Comparison

These break frequencies are relevant to the Model comparison, but more recent and applicable data is available.

Wood, Andrew, and B. Lence. 2006. Assessment of Water Main Break Data for Asset Management. *Jour.* AWWA, 98(7):76-86.

Overview

This study replicates the survey conducted in Deb et al. (2002). Fifty-nine more responses on quantity and quality of break data we compiled. Wood and Lence (2006) describes its featured survey: "The survey included questions about the amount and type of data collected by water utilities, the level of comfort with the amount of data collected, and the availability of data elsewhere within the utility."

The information gathered indicated only whether or not particular types of data were part of the utility's inventorying protocol. The survey confirmed whether or not the utility collected location data, physical data on the pipe, data on the type of failure and environmental data, but it did not compile the content of these fields.

Noteworthy results include that all of the respondents reported that they record the date and time a break is reported, however fewer do any documentation of the cost of the break: "70% of respondents record labor, materials, and equipment costs, and fewer than 30% record the cost of property damage or the effect of the break on customers" (Wood and Lence2006).

Break Frequency

- None Given.

Applicability to Model Comparison

As no break frequencies are given, this report will not directly inform the Model comparison. However, it is useful to note the level of data availability from this sample of respondents. This report reiterates the critical issue of establishing more comprehensive break inventorying protocols.

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ABBREVIATIONS

ABI	annual budget for intervention
AMR	automatic meter reading
ANWBS	Australian National Water Balance Software
AUMA	Alberta Urban Municipalities Association
AWE	Alliance for Water Efficiency
AWWA	American Water Works Association
BABE	burst and background estimate
BMAC	billed meter authorized consumption
BMP	best management practices
CARL	current annual loss
CEP	conservation, efficiency and productivity
CI	cost of leak detection survey intervention
CPUC	California Public Utilities Commission
CUWCC	California Urban Water Conservation Council
CV	cost of real losses
DERM	Department of Environment and Resource Management
DMA	district metered area
DNR	Department of Natural Resources
DRBC	Delaware River Basin Commission
EIF	economic intervention frequency
ELL	economic level of leakage
EMWD	Eastern Municipal Water District
EP	economic percentage
EPD	Environmental Protection Division
EURL	economic annual volume of unreported real losses
GAWP	Georgia Association of Water Professionals
GEFA	Georgia Environmental Finance Authority
GRWA	Georgia Rural Water Association
GSB	Georgia Senate Bill
GWSA	Georgia Water Stewardship Act
ICF	infrastructure condition factor
ILI	infrastructure leakage index
IWA	International Water Association
MWD	Metropolitan Water District

NA	North American
NRW	non-revenue water
NWI	National Water Initiative
OP24	operational performance indicator
OSM	New Mexico Office of the State Engineer
OVGW	Austrian Association of Gas and Water
PA PUC	Pennsylvania Public Utility Commission
PRV	pressure reducing valve
PSC	Wisconsin Public Service Commission
RR	rate of rise
SCE	Southern California Edison
SIV	system input volume
SLMP	system leakage management plan
TAUD	Tennessee Association of Utility Districts
TSG	technical support group
TWDB	Texas Water Development Board
UARL	unavoidable annual real loss
UFW	“unaccounted for water”
UKWIR	UK Water Industry Research
UMRB	Utility Management Review Board
WADOH	Washington State Department of Health
WAC	Washington Administrative Code
WLCC	Water Loss Control Committee
WRC	Water Research Commission
WRF	Water Research Foundation
WSAA	Water Services Association of Australia
WSO	Water Systems Optimization
WWAWC	Water and Wastewater Authority of Wilson County
WWFB	Water and Wastewater Financing Board