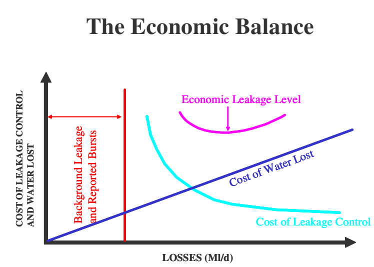
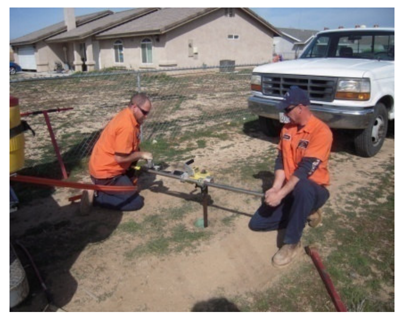
SECONDARY RESEARCH FOR WATER LEAK DETECTION PROGRAM AND WATER SYSTEM LOSS CONTROL STUDY





Final Report

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Executive Summary

The Water Leak Detection Program and Water System Loss Control Study had two components; a primary and a secondary research component. Within the primary research component detailed water audits and system water loss measurements were carried out for three water utilities in the Southern California Edison (SCE) service territory in order to accurately quantify the volume of system losses in each utility. The study team then used these results to determine the most efficient and economic intervention strategy against system water losses for each water utility.

The scope of the secondary research component was to draw on a collection of existing water leakage and system loss control studies to provide the basis for defining a range of possible water system loss control alternatives. The following documents were produced for the secondary research component:

- A whitepaper titled "How Much Water is Being Lost in California" estimating the volume of system water losses in California and the volume of economically recoverable system water losses.
- A roadmap for pursuing a system water loss and energy reduction program in the SCE service territory.
- A water loss assessment and management best practice document.
- A literature review of national and international publications discussing the link between water supply and energy consumption – with special focus on literature relevant to California.

The following sections provide short summaries of the four secondary research component documents.

Whitepaper: "How Much Water is Being Lost in California"

The vast majority of water utilities in California do not manage leakage, but instead react to it, usually after it has caused disruption like water outages or damage to property. Effective leakage management requires the water utility to be proactive in seeking and abating hidden leaks and optimizing the operation of the distribution infrastructure. In order to estimate the total volume of system water losses in California the research team collected existing water loss assessment studies carried out throughout the State of California. The results (see "How Much Water is Being Lost in California" on page 1 for more details) clearly highlighted the significant potential for water and therefore energy savings through improved system water loss management practices. Throughout California approximately 0.87 million acre-feet (MAF) of water is lost through leaking pipes. An estimated 0.35MAF of the total statewide system water loss volume is economically recoverable. To put this volume into perspective, the economically recoverable system water loss volume represents about 20 percent of Governor Schwarzenegger's plan to achieve a 20 percent reduction in per capita urban water use statewide by 2020. Additionally, the amount of water supplied to cities and suburbs in Southern California is significantly larger in volume than the amount of water supplied to cities and suburbs in Northern California. It is therefore reasonable to assume that the majority of the statewide water loss volume occurs in Southern California were the embedded energy in one unit of water is on average three times higher than in Northern California.

Roadmap for a system water loss and energy reduction program in the SCE service territory

The study team together with SCE developed a roadmap for a water loss and energy reduction program in the SCE service territory. Although much more program development will be required to create a successful water loss and energy reduction program, the roadmap outlines a concept to achieve this goal (see Roadmap for a Water Loss and Energy Reduction Program in the SCE Service Territory on page 13). Also, even though the program roadmap was developed for SCE, it is the study team's opinion that the program roadmap is also applicable to the other three investor owned energy utilities in California.

Water loss assessment and management best practice document

Another component of the secondary research study was to produce a water loss assessment and management best practice document reflecting current best industry practice (see Appendix A: Water Loss Assessment and Management Best Practice Document on page 14).

Literature review

A total of 19 national and international publications discussing the link between water supply/distribution and energy consumption (with special focus on California relevant publications) were reviewed. While only a few publications analyze the potential for energy savings through reduction of excessive distribution system water losses, these publications identify reducing system water losses as a strategy to increase energy efficiency. One study in particular discussed the energy savings of a large scale water loss assessment and reduction project carried out in the state of Tennessee. The authors of this study estimated that the program saved a total of $24.4 million per year at a total program cost of $2.7 million for 278 water utility companies in the state of Tennessee. The program achieved estimated energy savings of 21,300,338 kWh, representing an avoided cost of $1,496,860 (Note: all cost figures and savings are as of 1991).

Conclusion

The secondary research in combination with the applied component (primary research) of this study clearly indicates the significant potential for cost effective water loss reduction in California. The water saved through cost effective water loss reduction, estimated to be in the order of 0.35MAF, would be enough to provide water for 2 million people with an average daily consumption of 154 gallons per person per day. The economically recoverable system water losses would also achieve significant savings of embedded energy. Based on currently available energy proxies for California the study team estimates energy savings in the range of 1,020,125,599 KWh/year (about 26% of the 2008 California electricity system power generated by coal power plants[1]).

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[1] Source: 2008 Net System Power Report - Staff Report, Publication number CEC-200-2009-010, to be considered for adoption July 15, 2009. (PDF file, 26 pages, 650 kb).

Secondary Research Report A – The Scale of Water Losses in California and the Potential for Water Loss and Energy Reduction in California

CONTENTS

How Much Water is Being Lost in California

Background

Throughout California water losses are occurring at both the end user's plumbing (the "demand side") and the water utilities distribution network (the "supply side"). This study focuses on the water losses occurring on the water utilities supply side, namely distribution leakage losses. Every distribution network experiences leakage losses, although the amount can vary depending on the age and condition of the infrastructure, the operating pressure in the network, soil conditions, and the leakage control practices used by the utility. Even in new distribution networks there will be a small volume of unavoidable leakage loss. Water conservation in California has mainly focused on the demand side, resulting in major advances in demand side conservation over the past 20 years, but little emphasis is given to supply side conservation. The majority of California water utilities do not employ accurate assessment of leakage losses through detailed water audits. Pro-active leakage reduction as a best management practice for distribution networks is also not common.

In 2001, American Water Works Association (AWWA) published a comprehensive survey entitled "Survey of State Agency Water Loss Reporting Practices" reviewing state and regional water loss standards, policies and practices. The survey report concluded that although there are state and regional water loss policies, the targets or standards set vary widely from agency to agency. The project also confirmed that the structures in place to monitor drinking water supply efficiency are superficial in nature, of limited sophistication (in most cases "unaccounted for water" percentage is the sole performance indicator), and include scarcely any auditing or enforcement mechanism to validate the performance of drinking water utilities (Fanner et al., 2007).

The lack of standardized and meaningful water loss assessment and reporting makes it difficult to accurately quantify the volume of water lost through leaking distribution systems in California. This, however, is also the case for others states. The United States Geological Survey, 1998 (USGS) is one of the very few sources available that provides an estimate of water loss volume for the U.S.. The USGS identified a volume of 6 billion gallons per day as "public use and loss", where public use is water supplied from a public-water supply and used for such purposes as firefighting, street washing, and municipal parks and swimming pools. There is consensus among water loss control experts that it can be assumed that the losses are much greater than the public use for most systems.

Similar to what can be seen on a federal level, water loss assessment and reporting standards in California are not matching the best industry practice. The California Urban Water Conservation Council (CUWCC) is empowered to supervise and monitor the implementation of Best Management Practices (BMP) within the council's member agencies in California. BMP3 - System Water Audits, Leak Detection and Repair is one of 14 BMP which are implemented by the CUWCC in the state of California in order to reduce demand in urban water systems. It has been recognized by the CUWCC that BMP3 is out-dated in approach and under-utilized by the council's member agencies. As a result, the CUWCC has been working for the past several years on an update of the BMP3 in order to incorporate current best

industry practice in water loss assessment and management. In June 2009, the CUWCC has proposed changes to the BMP3, which will now become BMP 1.2 - Water Loss Control and will follow the current approved AWWA method for system water audits described in the AWWA manual M36. The AWWA offers a free Excel based water audit software (available for download at their site http://www.awwa.org/resources/waterwiser.cfm) and the CUWCC proposes that this will be used in acceptable BMP1.2 reports in the future. The vote on adopting the AWWA method in September 2009 was successful leading to the adoption of the new BMP 1.2 which will be used for BMP reporting starting in 2010.

The adoption of the new Water Loss Control BMP 1.2 represents a significant step forward in terms of standardized and meaningful assessment of water losses in California.

Water Loss Data Collection

Given the low level of water loss reporting described earlier, it is not feasible to obtain validated and accurate water loss data for all California water utilities. Some utilities are not members of the CUWCC and therefore do not routinely report water loss data. Also, many of the utilities that are members of CUWCC only report water loss data to the outdated BMP3 standard. Comprehensive detailed water audit data for all California water utilities is therefore not currently available.

For the purposes of this study, two data sets for a limited number of utilities were obtained. The first data set comprises water audit results from detailed and validated audits carried out by Water Systems Optimization, Inc. (WSO) for 6 California water utilities. The second data set comprises water audit data provided by the CUWCC for 26 member agencies arising out of the BMP3 revision discussed earlier. The 26 member agencies included in the data set have provided the CUWCC with more comprehensive data than the current BMP3 reporting data would provide. The CUWCC used the data to test and evaluate the applicability of the current best practice water audit methodology recommended by the AWWA for its BMP3 revision process.

The combined data set comprised water audit data from 32 water utilities.

Water Loss Data Evaluation

The first step of the data evaluation was to standardize the CUWCC data set into a standard AWWA water audit format. Once the data was entered, various standard water loss performance indicators were calculated. The water loss performance indicators were reviewed in order 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. Water losses are divided into apparent losses and real losses.

- Apparent losses are primarily associated with metering errors but do also include consumption and billing data handling errors and any form of unauthorized consumption (theft or illegal use). Apparent losses therefore represent water which has been consumed but the water utility did not receive adequate payment for.
- Real losses are associated with the real, physical loss of water from the distribution network and storage reservoirs and tanks.

This study focused on real losses since only real losses have an impact on the embedded energy of supplying water.

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.

Based on the study team's experience, it was assumed that if the audit result from one of the CUWCC data set utilities resulted in an ILI of less than 1.5, then the data should be excluded from further analysis. The rationale behind this is that very few utilities around the world have truly achieved an ILI below 1.5. Those that have achieved this low level of losses have implemented comprehensive and sophisticated leakage management practices that are currently not found in California utilities.

The data filtering described above resulted in the removal of data for 15 utilities from the original 26 CUWCC audit data set. This fact alone clearly demonstrates that better water loss assessment and reporting standards are needed for California. Although some utilities are reporting water loss data, the data is often questionable and the reported water loss volumes are often unrealistic. Many of these issues would be resolved by more thorough validation of the data, preferably by independent audit.

The final data set used for the study comprised water audit data for 17 water utilities, being 6 sets of data from water audits carried out by WSO and 11 sets of data from CUWCC member agencies.

General Characteristics of Water Utilities in the Data Set

About 59% of the 17 water utilities are from Northern California and 41% are from Southern California. The data set appears to represent adequately the various utility sizes found throughout California (see Table 1).

Table 1 Water Utility Data Set – Utility Size Characteristics of

Water Utility Size [# or service connections]	Number of Water Utilities in Each Range
< 10,000	4
10,000 to <30,000	5
30,000 to <50,000	2
50,000 to <100,000	3
>100,000	3

Other water utility characteristics were evaluated as well demonstrating that the data set provides a reasonably good representation of distribution systems found throughout California (see Table 2). The data set contains water utilities with rural characteristics (low service connection density), utilities with medium service connection density, and utilities supplying urban centers (high service connection density). The average system pressure of the data set utilities is around 81PSI. The average variable production cost for the data set is $815/AF although this varies significantly from utility to utility[2].

An estimate of the per capita consumption for each utility was also calculated. The data set did not provide population data for each utility so an average ratio of three persons per service connection was assumed for all utilities in the data set. While this is a very rough estimation the results of 226 gal/cap/day consumption appear to be within reasonable ranges for per capita consumption found throughout CA.

Table 2 Water Utility Data Set – General Utility Characteristics

	Average	Min	Max	
Service Connection Density	73	30	139	[service connections/mile of mains]
Average System Pressure	81	50	127	[PSI]
Variable Production Cost	815	53	4,099	$/AF
Billed Metered Consumption	226	63	405	gal/cap/day (assuming 3 person per service connection)

Even though the size of the data set is relatively small, the general utility characteristics indicate that the utility data set provides a good representation of California water utilities.

Water Loss Performance Indicators of Water Utilities in the Data Set

The water audit data set was used to calculate various real loss performance indicators (PI) for each water utility. For this study the three key real loss PIs evaluated were the ILI, the volume of real losses per service connection per day, and the volume of real losses as a percentage of the total volume supplied into the system (see Table 3).

ILI is the most reliable real loss PI as it takes into account the amount of underground infrastructure (both mains and service connections) and the pressure at which the infrastructure is subjected to (higher operating pressure equals higher losses in most cases). The least reliable performance indicator out of the three is real loss volume as a percentage of the total volume supplied into the system. The main reason for this is that percentage real loss is highly influenced by consumption – in any two systems with equal real loss volumes, the system with the higher consumption volume will have the lower percentage real loss volume. Percentage real loss is therefore affected by factors unrelated to

[2] Note: all utility data set averages used in this study are simple averages and not weighted averages.

real losses and because of this is considered to be unreliable as a real loss performance indicator or for purposes of target setting.

Table 3 Water Utility Data Set – Real Loss Performance Indicators

Water Loss Characteristics	Average	Min	Max	Units
Infrastructure Leakage Index	3.2	1.6	6.6	[ILI]
Real Losses	63	28	119	gal/service con/day
Real Losses as % of Volume Supplied	9%	4%	22%	%

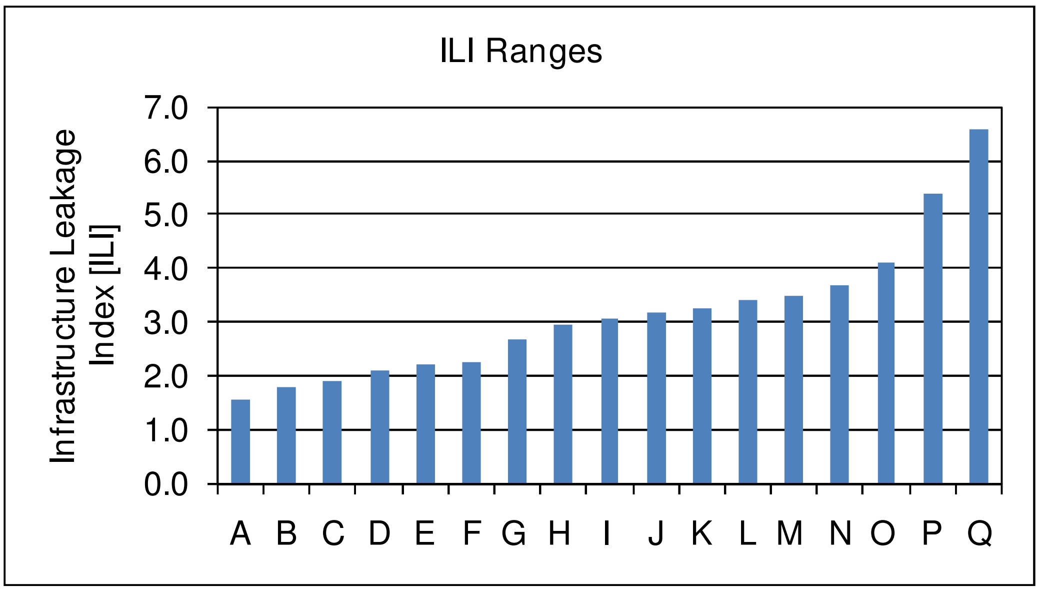

Figure 1 Water Utility Data Set – ILI Ranges

The data set shows a wide range of ILI's with about 50% of the utilities showing an ILI greater than 3. The AWWA Water Loss Control Committee has developed some general guidelines when using the ILI as a target setting tool. It is recommended that if "Available resources are greatly limited and are very difficult and/or environmentally unsound to develop" (AWWA Journal, 2003), then the ILI should be between 1 and 3. Following this general AWWA guideline, fifty percent of the utilities in the data set should improve their real loss management performance and reduce their real losses to levels that reflect the statewide water crisis.

Another useful PI for expressing real losses is to calculate the volume of real losses per service connection per day. This is calculated by dividing the total annual real loss volume by the total number of service connections and then by 365 days. Figure 2 depicts the distribution of this performance indicator among the data set utilities. The disadvantage of this PI over the ILI is that it does not take into

account the length of water main for the utility. Rural networks tend to have longer lengths of network per service connection and so have greater unit length of underground infrastructure per customer than urban networks. Rural networks will therefore tend to have higher unit rates of leakage. The AWWA recommends expressing real losses per mile of mains per day if system density is less than 32 service connections per mile of main. For that reason it was not feasible to use the real losses per service connection per day performance indicator for utility D.

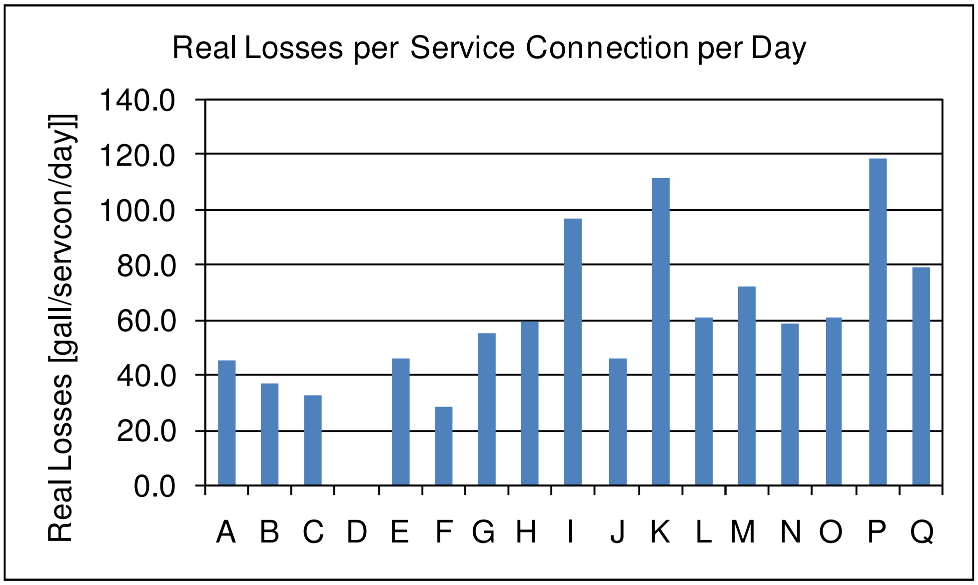

Figure 2 Water Utility Data Set – Real Losses per Service Connection per Day[3]

The final real loss PI that was analyzed is Real Loss Volume expressed as a percentage of Total Volume supplied into the network. In common with the rest of the United States, it is the PI that is most widely used to express real losses in California because it is easy to calculate. As mentioned earlier, however, this PI is highly unreliable since the percentage is unduly influenced by consumption, a factor that is unrelated to real losses. When using this PI, real losses are understated for water utilities with high per capita consumptions and or growing populations and overstated for utilities with low per capita consumption and/or contracting populations (adapted from Thornton, Sturm, and Kunkel, 2008). It is therefore important to be cautious when using the % PI to compare the water loss management performance of water utilities. Figure 3 depicts the percentage real loss for each of the data set utilities with percentages ranging between 4% and 22%.

[3] Utility #7 has a service connection density of less than 32 connections per mile of mains which means that real losses need to be expressed in gallons per mile of main per day according to the IWA/AWWA recommendations for water loss performance indicators.

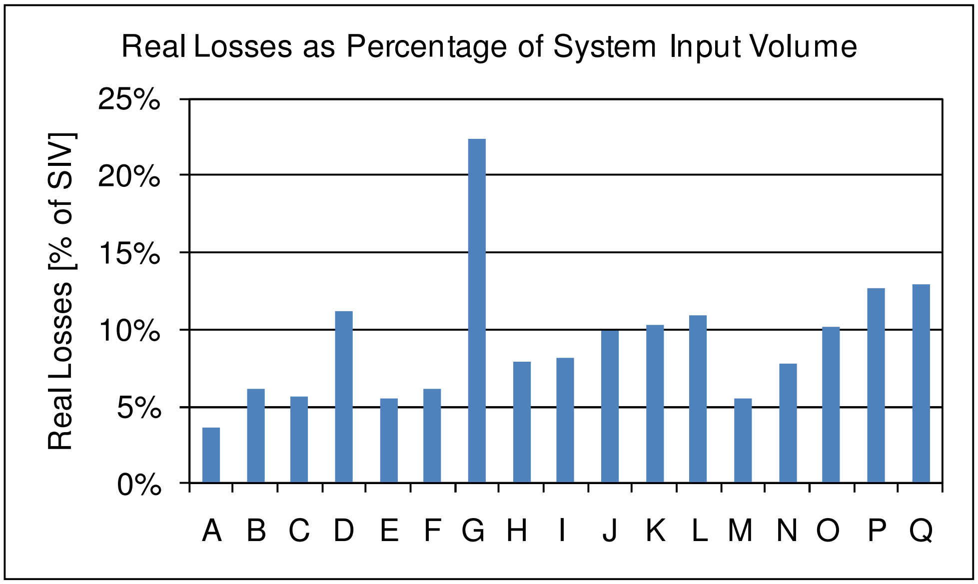

Figure 3 Water Utility Data Set – Real Losses as Percentage of Volume Supplied

Estimation of Statewide Real Loss Volumes

Relating the water loss performance indicators for the data set utilities to the state as a whole has some inherent problems. Although the data set utilities are representative of those found in the state as a whole in terms of size, connection density, operating pressure, and so on, it does not necessarily follow that the data set utilities are representative in terms of their level of real losses. It is the study team's opinion that the data set utilities represent the "better" utilities in terms of water loss management since they are utilities that actually carry out detailed water audits, and are able to use the information to manage their real loss volume. Especially the WSO data set utilities can be described as proactive utilities with better than average water loss management, actively seeking to implement the latest best industry practice. Those California utilities that do not carry out water audits are unlikely to be aware of the true level of losses in their networks and are therefore less likely to be implementing best management practices to control their real loss volumes.

Two methods have been used to estimate statewide real loss volumes; the first uses the commonly quoted threshold for acceptable real losses in California of 10% of volume supplied, the second method extrapolates the real loss indicators from the data set to the state as a whole.

The commonly quoted threshold of 10% of volume supplied appears to be supported by the data set where the average value was 9% of volume supplied. As stated earlier, however, it is thought that the 9% average of the data set utilities is not representative of the state as a whole. Using the 10% threshold value to estimate statewide real loss volumes is therefore still likely to provide a conservative estimate.

In 2000, cities and suburbs in California used about 8.7 million acre-feet (MAF) of water (California Water Plan Update, 2009). By extrapolation, applying the 10% threshold value, the total volume of real

losses for the state as a whole would be of the order of 0.87MAF/year or 283,491 million gallons (MG)/year.

Table 4 Estimation of Statewide Real Losses based on Percentage Real Loss of Volume Supplied

Description	Volume (MAF/year	Volume (MG/year)
In 2000, the urban water use for California cities and suburbs was	8.7	2,834,907
Real Losses assuming average is 10% of the total volume supplied	0.87	283,491

It is not possible to extrapolate the average ILI performance indicator from data set of utilities to the state as a whole because there is insufficient statewide data on the total length of water main, number of service connections or average operating pressure. It was therefore decided to attempt to extrapolate the real losses per service connection per day PI instead.

Although the actual number of service connections in California cities and suburbs is not known, a simple assumption can be made that every housing unit in California equals a service connection. The total number of service connections for the state as a whole is therefore estimated to be of the order of 13,530,790 [4]. This estimate is an approximation only. For instance, not every housing unit in an apartment building has an individual service connection. For the most parts there will be only one or two service connections per apartment building. A similar case will apply to mobile homes which are also included as individual housing units in the total number of California housing units. Counting each apartment and mobile home as single service connection will therefore lead to an overestimation of the number of service connections. However, the number of industrial, commercial, and institutional customers and their service connections are not included in the total number of housing units and are therefore not included in the estimate for the number of service connections. This leads to an underestimation of the total number of service connections for this group of properties. It is the study team's opinion that the overestimation of service connections based on the number of housing units is balanced by the underestimation of service connections for industrial, commercial and institutional customers.

[4] Source: California Department of Finance 2009 E-5a InternetVers- housing est CA Finance Dept.xlsx. (http://www.dof.ca.gov/research/demographic/reports/estimates/e-5/2009/documents/2009%20E-5a%20Internet%20Version.xls)

Table 5 Estimation of Statewide Real Losses based on Real Loss Volume per Service Connection per Day

Description	Volume	Units
Total number of housing units as of 2007 in California	13,530,790	Housing units/service connections
Average real losses from utilities data set (see Table 3)	63	Gall/serv conn/day
Estimated statewide real losses volume	0.95	MAF/year
Estimated statewide real losses volume	311,139	MG/year

The estimated statewide real loss volumes from both methods are of a similar order, with a slightly higher value of 0.95 MAF from the service connection method compared to 0.87 MAF from the 10% threshold method. The results are, however, very similar considering that they have been arrived at by applying different metrics to the estimated total water supplied and estimated total number of service connections. This provides a good degree of confidence in the statewide estimate of real loss volumes by extrapolation from the studied data set averages.

It should be noted that if the assumption that the studied data set utilities represent a group with better than average water loss management, then extrapolation of the results to the state as a whole will represent an estimate of statewide losses in the lower range of possible values.

The study team has decided to take a conservative approach and to use the 0.87 MAF as the final statewide real loss volume.

Estimation of Statewide Recoverable Real Loss Volumes

The total volume of real losses is made up by three basic components:

- Unavoidable Real Losses: every system experiences a certain volume of unavoidable real losses. Even newly commissioned sections of the distribution network will have some volume of real losses.
- Uneconomically recoverable real losses: it is economically not justifiable (cost prohibitive) to recover this component of the total real loss volume. The volume and characteristics of this component will vary from utility to utility.
- Economically recoverable real losses: it is economically justifiable to recover this component of the total real loss volume. The value of water recovered is equal or more than the cost to recover this volume of real losses. The volume and characteristics of this component will vary from utility to utility.

Therefore, it would be wrong to assume that the total volume of statewide real losses is economically recoverable. Each utility will have a specific economic optimum for its real loss volume based on the monetary value of its real losses. In order to estimate how much of the total statewide real loss volume is economically recoverable some assumptions need to be made.

A detailed water audit carried out by WSO for the San Francisco Public Utilities Commission (SFPUC) showed that the SFPUC is managing volumes of Real Losses effectively through reactive management process (repair of reported leaks), which is the predominant practice in California. The annual volume of Real Losses the SFPUC is experiencing is relatively small placing the SFPUC among the top four utilities in Real Loss management in a North America data set. The SFPUC is also among the top performing utilities in the California data set used for this study. An analysis of the optimum economic level of Real Losses for the SFPUC system indicated that about 40 percent of its real losses are economically recoverable if real losses are valued at retail cost. Since the SFPUC is a top performer in California and the United States, it was felt that it is a reasonable and rather conservative approach to assume that 40 percent of the statewide real losses are economically recoverable if real losses are valued at an average retail cost for water[5]. Table 6 provides the calculation of the statewide economically recoverable real losses volume.

Table 6 Estimation of Statewide Economically Recoverable Real Losses

Description	Volume	Units
Estimated statewide real losses volume	0.87	MAF/year
Economically recoverable real losses	40	%
Estimated statewide economically recoverable real losses volume	0.35	MAF/year

Out of the estimated statewide real loss volume of 0.87 MAF about 0.35MAF are assumed to be economically recoverable. The economically recoverable real loss volume would be sufficient to provide water for 2 million people with an average daily consumption of 154 gallons per person per day[6].

At an average retail unit cost of water delivered of $2 per hundred cubic-feet (based on the utility data set), which is approximately $871 per Acre-foot, the total value of the economically recoverable real losses in California is about 303 Million Dollars.

The economically recoverable real loss volume of 0.35MAF represent 20 percent of Governor Schwarzenegger's plan to achieve a 20 percent reduction in per capita urban water use statewide by 2020.

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[5] The CUWCC recommends using the avoided cost of water when analyzing the cost effectiveness of demand side conservation measures. Since the avoided cost for water varies greatly from utility to utility it was felt that the average retail cost of water is best to be used for valuing the real losses in California.

[6] Source: California Environmental Protection Agency – State Water Resources Control Board: 20x2020 Water Conservation Plan. DRAFT April 30, 2009. Target per capita use (154 gpcd) after 20 percent reduction by 2020. (http://www.swrcb.ca.gov/water_issues/hot_topics/20x2020/docs/comment043009/202020_final_report_draft.pdf)

Conclusion

This study clearly highlights the significant potential for water and therefore energy savings through improved water loss management practices. Throughout California about 0.87MAF of water are lost through leaking pipes and it is estimated that around 0.35MAF of the total statewide real loss volume are economically recoverable. This volume represents about 20 percent of Governor Schwarzenegger's plan to achieve a 20 percent reduction in per capita urban water use statewide by 2020. Not only does the economically recoverable real loss volume represent a significant water and energy conservation potential, it will also have positive impacts on the economy and job creation according to a position paper produced by the Alliance for Water Efficiency. The paper titled "Transforming Water: Water Efficiency as Stimulus and Long-Term Investment" concludes that per million dollars of investment on water loss control the output benefits are in the range of 2.8 million dollars and an employment potential in the range of 22 jobs (Alliance for Water Efficiency, 2008).

The amount of water supplied to cities and suburbs in Southern California is significantly larger in volume than the amount of water supplied to cities and suburbs in Northern California[7]. It is therefore reasonable to assume that the majority of the statewide real loss volume occurs in Southern California were the embed energy in one unit of water is on average three times higher than in Northern California[8].

This study highlights the lack of state and regional water loss policies in California. The assessment and management of water losses in California does not reflect current industry best practice. As a result good quality data on the volume of water lost by California water utilities is rare. It is therefore the study teams' recommendation to:

- support and incentivize water utilities to undertake detailed and validated water audits.
- have water audit results independently validated and reviewed.
- rank water utilities based on their current real loss volume and the related embedded energy.
- use the ranking for prioritization of real loss intervention projects.
- evaluate which real loss intervention strategy is the most appropriate for each of the prioritized water utilities.
- implement a real loss reduction program for the prioritized water utilities.

[7] Source: California Department of Water Resources, Final California Water Plan Update 2005.

[8] Source: Refining Estimates of Water Related Energy Use in CA - Dec 2006. Published by the California Energy Commission and prepared by Navigant Consulting

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Roadmap for a Water Loss and Energy Reduction Program in the SCE Service Territory

Voluntary Application Process

- For Utilities not sigantory to the CUWCC Memorandum of Understanding that are interested in participating in the program and have reliable water audit results available. Plus for CUWCC signatories who want to fast track their participation in the program .

BMP 1.2 Reports

- Review of all BMP 1.2 reports submitted by SC Edison service territory water utilities.
- First reports for FY09 and FY10 will be available December 2010.
- Can be carried out by SCE internally.

Qualifying Matix

- Import information into a ranking sheet.
- Ranking = B x C x $\sqrt{D}$

Ranking	Utility Name	(A) Infrastructure Leakage Index (ILI)	(B) Real Losses (gal/conn/day)	(C) Avoided Cost of Water ($/AF)	(D) Energy Intensity of Water Delivered (low=1, medium=2, high=3)

Component and ELL Analyses

- Conduct Component Analysis and Economic Level of Leakage Analysis to design adequate intervention strategy for top 10 (or more) water utilities of ranking sheet.
- The final number of utilities selected for component analysis and ELL depends on results of initial ranking sheet.
- This step will guarantee that only cost effective water loss intervention strategeis will be pursued.

Intervention Strategies

- Pursue individual intervention strategies:
  - Pressure Management - Has results on all three Real Loss components. Rule of thumb is 10% reduction in pressure results in 10% reduction in Real Losses. ELL will determine by how much pressure can economically and technically be reduced.
  - Proactive Leak Detection - Reduces backlog of leaks and keeps losses from unreported leaks at economic optimum. ELL will determine the economically optimum leak detection frequency.
  - Infrastructure Replacement

Offer incentive for infrastructure replacement based on assessment of direct and embedded energy savings

Pressure Management → **Savings MG/KWH**

Proactive Leak Detection → **Savings MG/KWH**

Infrastructure Replacement → **Savings MG/KWH**

Appendix A: Water Loss Assessment and Management Best Practice Document

1 Background

This best practice document provides a general overview of water loss assessment and management. The following publications, from which sections were adapted, built the main bases for this document: AWWA M36 Third Edition, AwwaRF Leakage Management Technologies, and Water Loss Control Manual Second Edition. A full list of references is provided in the reference section.

In 2000, the International Water Association (IWA) published the manual Performance Indicators for Water Supply Services (Alegre et al. 2000). This publication included a description of a water audit methodology developed during the period of 1997-2000 by the IWA Water Loss Task Force, a five-country group that included participation by the American Water Works Association (AWWA). Since it was known that a multitude of different water auditing practices existed around the world, the primary focus of the Task Force was to draw upon the best practices of the various approaches and craft them into a single, standard "best management practice" methodology that could be applied world-wide; across the spectrum of differing system characteristics and units of measure.

The IWA/AWWA method detailed in the following sections is recommended as the best management practice by the AWWA Water Loss Control Committee for drinking water utilities to utilize when conducting a water audit of their operations and was endorsed in its committee report "Applying World-wide Best Management Practices in Water Loss Control" published in the August 2003 edition of Journal AWWA (Kunkel et al. 2003). Following the acceptance of the IWA/AWWA methodology by the AWWA Water Loss Control Committee, the AWWA updated its standards adopting this methodology. In 2009, the AWWA published the third edition of the M36 – Water Audits and Loss Control Programs (AWWA 2009). This publication explains the IWA/AWWA water audit methodology and provides an overview of some of the best loss control techniques that can now be implemented for a sustainable water loss control program.

The starting point for the IWA/AWWA method is a "Top-Down" water balance to assess the volume of real and apparent losses. The top-down water balance compares all sources of water into the system against all consumption of water from the system; either from water sold to customers, water used for the operation of the system, or water lost. This step of the audit also helps to identify components that require further validation.

It is recommended as best practice by the IWA and AWWA that the assessment of real losses using a "Top Down" water balance should be complemented by the following two methodologies:

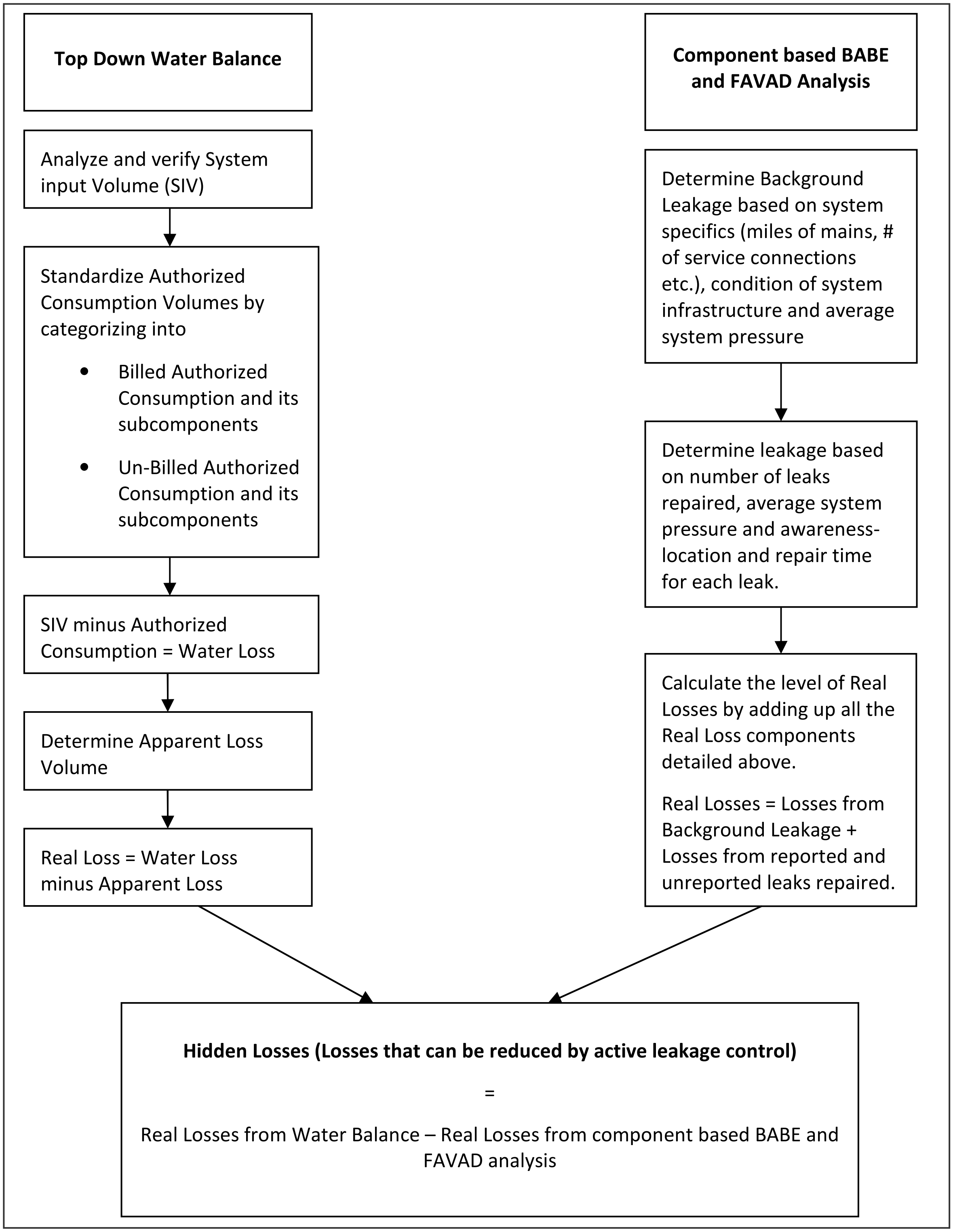
- Component analysis of real losses, a technique which models leakage volumes based upon the nature of leak occurrences and durations (see section 3 Component Analysis of Real Losses, page 22)

- “Bottom-Up” analysis of real losses using District Metered Area and Minimum Night-time Flow (MNF) analysis (see 7.1 Disaggregation of the Distribution System into District Metered Areas (DMA), page 40)

As shown in Figure 1-1, the “Top Down” water balance together with the component analysis and DMA analysis add increased refinement and confidence in the calculated volume of real losses and help identify the volume of hidden losses. Hidden losses, discussed in section 4, are made up of detectable leaks that are not being identified because of insufficient or incorrectly targeted leak detection activities.

Once the water audit and the component analysis of real losses are completed an economic level of leakage analysis should be carried out. The ELL analysis will provide the necessary understanding to determine how to control real losses to an economic optimum. This best practice document will discuss the ELL analysis and the four principle intervention tools against Real Losses.

Apparent loss intervention tools are not discussed in this document since apparent loss reduction will not result in energy conservation.



(Source: Thornton, Sturm, and Kunkel 2008)

Figure 1-1 Flow Chart to Determine Hidden Losses

2 Top-Down AWWA Water Balance

The top-down approach is the recommended starting point for water utilities compiling their initial water audit, and it is described in this section. The effort required to conduct a top down water audit is relatively modest depending on the availability and quality of data. The top-down audit also helps to identify components that require further validation. The AWWA has made available a Free Water Audit Software[9] to compile a basic audit of water supply and billing operations. The Free Water Audit Software is designed to allow water utilities to quickly compile a "Top-Down" water audit in the standardized IWA/AWWA methodology.

It is recommended by the IWA and AWWA to establish a water balance annually. Before establishing the water balance it is important to determine the audit period (e.g. fiscal year or calendar year) and the system boundaries. The units of the water balance components must also be chosen and standardized so that supply and customer consumption units are the same.

The water audit process discussed in this document starts at the point of supply into the distribution system. It covers the treated water transmission, storage and distribution system, but does not cover raw water transmission systems or the treatment process, since generally the losses stemming from the distribution system are dwarfing the losses occurring before the point of supply into the system.

<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>

Figure 2-1 Standard AWWA Top Down Water Balance

[9] Version 4 of the AWWA Free Water Audit Software published in April 2009 is available at http://www.awwa.org/Resources/WaterLossControl.cfm?ItemNumber=48511&navItemNumber=48158

The components of the water balance as shown in Figure 2-1 can be measured, estimated or calculated using a variety of techniques. Ideally all components of the water balance (excluding those components that are calculated by adding or subtracting other components) should be based on measurements. However, in reality estimates will need to be made especially the first time a water balance is established. Once the components needing estimation are identified it is best practice to put actions in place that allow to meter the component or to improve the estimation process. Validation of water balance components (see specific validation methods mentioned for each water balance components in the following sections) is an important integral part of conducting a water balance. Sensitivity analysis and the use of 95% confidence limits are the best tools to assess the impact individual water balance components have on the overall accuracy of the calculated volume of Non-Revenue Water and Real Losses.

2.1 Determining the System Input Volume

Definition: The annual volume input to the water supply system.

In case the entire system input is metered, the calculation of the annual system input should be a straight forward task. The regular meter records have to be collected and the annual quantities of the individual system inputs calculated. This includes own sources as well as imported water from bulk suppliers.

The accuracy of the input meters should be verified, using portable flow measuring devices or through reservoir drop/fill tests, on an annual basis. If discrepancies between meter readings and the temporary measurements are discovered, the problem has to be investigated and, if necessary, the recorded quantity has to be adjusted to reflect the real situation. It is recommended that as well as verifying the accuracy of the meters, the whole of the data recording chain from the meter to the SCADA archive is checked when testing the input meters.

If there are unmetered sources then the annual flow has to be estimated by using any (or a combination) of the following:

- temporary flow measurements using portable devices
- reservoir drop tests
- analysis of pump curves, pressures and average pumping hours

2.2 Determining Authorized Consumption

Definition: The annual volume of metered and/or unmetered water taken by registered customers, the water supplier and others who are authorized to do so.

As shown in Figure 2-1, the Authorized Consumption can be divided into Billed Authorized Consumption and Unbilled Authorized Consumption. Both categories could be either metered or unmetered. The Billed Authorized Consumption makes up the Revenue Water, while the Unbilled Authorized Consumption, along with the Water Losses (discussed in Section 2.3), make up the Non-Revenue Water.

Billed Metered Consumption

The calculation of the annual billed metered consumption goes hand in hand with the detection of possible billing and data handling errors, information later on required for the estimation of apparent losses. Consumption of the different consumer categories (e.g. domestic, commercial, industrial) have to be extracted from utility's billing system analyzed and validated. Special attention shall be paid to the group of very large consumers.

Annual billed metered consumption information taken from the billing system has to be processed for meter reading time-lag to ensure that the billed metered consumption period used in the audit is consistent with the audit period.

Billed Unmetered Consumption

Billed unmetered consumption can be obtained from the utility's billing system. In order to analyze the accuracy of the estimates, unmetered domestic customers should be identified and monitored for a certain period, either by the installation of meters on those non-metered connections or by measuring a small area with a number of unmetered customers. The latter has the advantage that the customers are not aware that they are metered and so they will not change their consumption habits. In the unlikely case that non-domestic customers are unmetered, detailed surveys have to be carried out to check the accuracy of the estimated billed consumption figures.

Unbilled Metered Consumption

The volume of unbilled metered consumption has to be established similar to that of billed metered consumption.

Unbilled Unmetered Consumption

Each type of unbilled unmetered consumption shall be identified and individually estimated by building up from individual usage events using a component based approach to develop a realistic estimate of use, for example:

- street cleaning / sewer flushing: how many trucks? volume of tank? how many fills per month? - the street cleaning and sewer flushing departments should be able to provide the necessary data.
- mains flushing: how many times per month? for how long? how much water? – the operations and construction departments should be able to provide the necessary data.
- fire fighting: number of fires during year? average volume per fire? has there been a big fire? how much water was used? – the fire department should be able to provide this data.
- fire flow tests: how many tests in year? average duration of test? flow rate? – again the fire department should be able to provide this data.

In some circumstances, it may be appropriate to meter a small sample of these events to obtain a better estimate of use per event.

2.3 Calculation of Water Losses

Definition: The difference between system input volume and authorized consumption, consisting of apparent losses plus real losses.

Water Losses are calculated by subtracting the total authorized consumption volume from the system input volume. In the subsequent process of the water balance the volume of water losses is further broken down into real and apparent losses.

2.4 Assessment of Apparent Losses

Definition: This component includes unauthorized consumption, all types of customer metering inaccuracies and data handling errors.

Unauthorized Consumption

It is difficult to provide general guidelines of how to estimate unauthorized consumption. There is a wide variation of situations and knowledge of the local situation will be most important to estimate this component. Unauthorized consumption can include:

- illegal connections
- misuse of fire hydrants and fire fighting systems - for example unauthorized construction use of hydrant water
- vandalized or bypassed consumption meters
- corrupt practices of meter readers
- open boundary valves to external distribution systems (unknown export of water)

The estimation of unauthorized consumption is always a difficult task and should at least be done in a transparent, component based way so that the assumptions can later easily be checked and/or modified.

Customer Metering Inaccuracies and Data Handling Errors

The extent of customer meters inaccuracies, namely under- or over registration, has to be established based on tests of a randomly selected representative sample of meters, which should be selected randomly (AWWA manuals M6 and M22 provide the relevant guidance). The composition of the sample shall reflect the various brands and age groups of domestic meters. Tests are done either at the utility's own test bench, or by specialized contractors. Large customer meters are usually tested on site with a test rig. Based on the results of the accuracy tests, average meter inaccuracy values (as % of metered consumption) will be established for different user groups.

In applying the accuracy test results to the whole population of different user groups of meters, it is also important to consider the issue of how quickly the utility is able to identify meters which are totally stopped by considering the utilities processes for identifying stopped meters. The average time taken to identify and replace stopped meters can have a significant impact on the overall accuracy of the meter population as a whole.

Other issues which are important to consider as a part of assessing the level of meter inaccuracies are:

- Meter size in relation to actual use patterns – is it sized correctly to maximize revenue?
- Meter type - is it the best type of meter for the operating range?
- Service line size – is it appropriate for the operating range?

Data handling errors are sometimes a very substantial component of apparent losses. Many billing systems are not up to the expectations of the utilities but problems often remain unrecognized for years. It is possible to detect data handling errors and problems within the billing system by exporting billing data (of say the last 24 months) and analyzing it using standard database software. Types of data handling errors that may be encountered and should be checked for include:

- Changes to consumption volume data when bills are adjusted for any reason other than an incorrect reading.
- Inappropriate use of estimated consumptions.
- Inappropriate determination of estimated consumptions.
- Accounts incorrectly flagged as inactive.
- Accounts missing from the database.
- Inaccurate meter data.

The detected problems have to be quantified and a best estimate of the annual volume of this component has to be calculated.

2.5 Calculation of Non-Revenue Water

Definition: The difference between system input volume and billed authorized consumption.

Non-revenue water is the portion of the water that a utility places into the distribution system that is not billed and, therefore, recovers no revenue for the utility. Non-revenue water consists of the sum of unbilled authorized consumption (metered and unmetered), apparent losses and real losses.

2.6 Calculation of Real Losses

Definition: The annual volumes lost through all types of leaks, breaks and overflows on mains, service reservoirs and service connections, up to the point of customer metering.

The volume of real losses is calculated by subtracting the volume of authorized consumption and the volume of apparent losses from the total system input volume.

3 Component Analysis of Real Losses

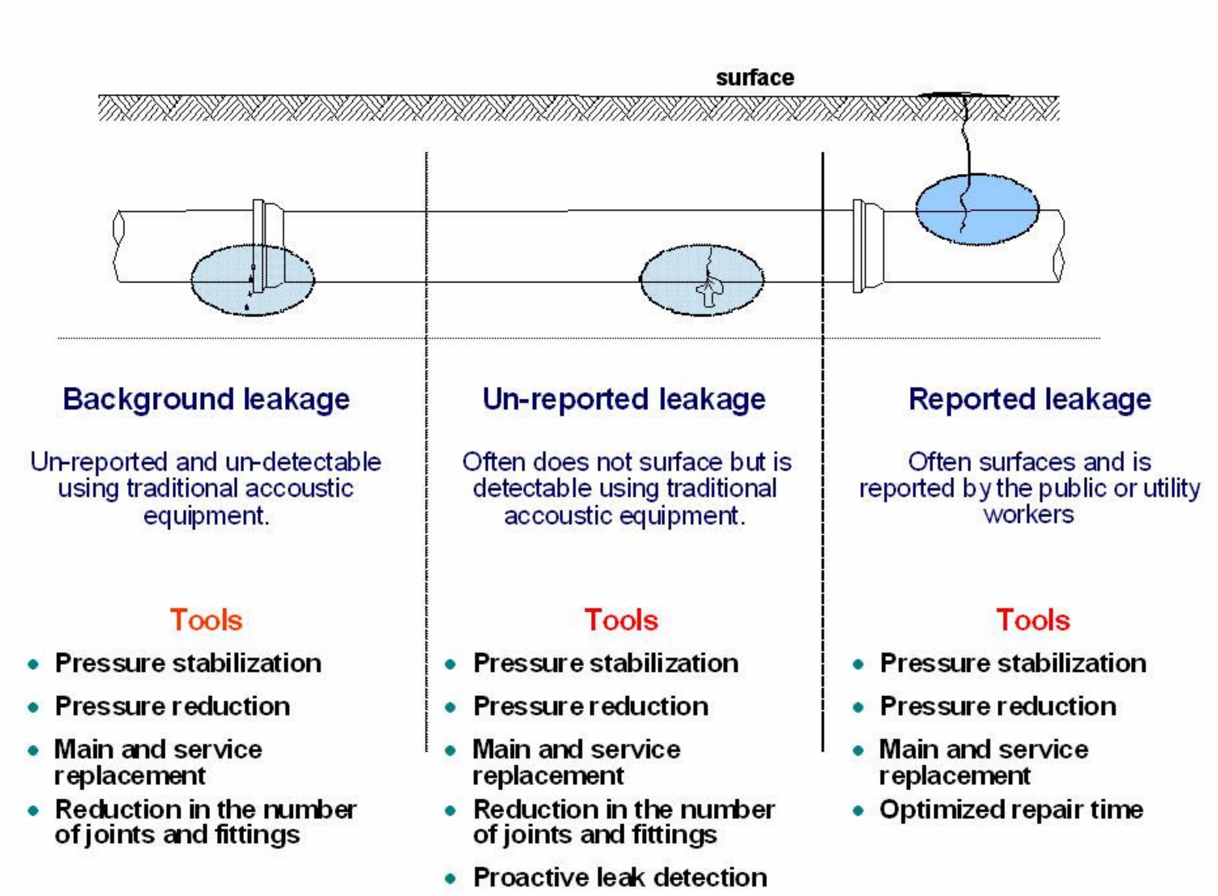
Real Losses represent the physical loss of treated, energized water from the distribution system and are comprised of breaks and leaks from water mains and customer service connection pipes, joints and fittings; from leaking reservoir walls, and from reservoir or tank overflows. Once a total volume of real losses has been determined from the top-down water audit, a component analysis should be carried out to segregate the volume of real losses.

Having a volume estimate of the individual components of real losses is a key step towards selecting the optimal leakage management strategy. Knowing the different components of the Real Loss volume, is the first step in identifying the volume of water losses from events that have already been mitigated, such as reported leaks, from the losses of ongoing events, such as hidden losses and background losses, where there is still a potential to reduce the water loss volume.

3.1 Breaks and Background Estimates Method

A systematic approach to modeling real losses was developed during the UK National Leakage Initiative between 1991 and 1993. This concept, referred to as Breaks and Background Estimates (BABE) (Lambert 1994), recognizes that the annual volume of real losses consists of numerous leakage events, where each individual loss volume is influenced by flow rate and duration of leak run time before it is repaired. The BABE component based leakage analysis breaks leakage down into three categories (see Figure 3-1):

- Background Leakage – Continuously running small leaks that are undetectable with conventional leak detection equipment.
- Unreported Leaks – Leaks with moderate flow rates that escape public knowledge and are only identified through the active leakage control work of the water utility.
- Reported Leaks – Large leaks that are reported by customers, traffic authorities, or any other outside party due to their visible and/or disruptive nature.



(Source: Tardelli 2005)

Figure 3-1 Components of Real Losses

The volume of leakage lost through each component is evaluated independently. Background leakage depends mainly on the size of the system, the average operating pressure, and the general condition of the infrastructure. For unreported and reported leaks, the volume of leakage depends mainly on the number of leaks occurring, their magnitude, operating pressure, and the total time that the leaks are permitted to run. The BABE concepts divide the length of time for which a break or leak runs into three categories: awareness, location, and repair, discussed further in section 3.4.

3.2 Effects of System Pressure on Leakage

Another concept used to determine the volume of water lost through leakage is the Fixed Area and Variable Area Discharge (FAVAD) Theory (May 1994). This theory, developed in 1994, describes the effect of pressure changes on leakage flow rates. Prior to this theory, it was believed that the amount of leakage through a fixed hole in a pipe varied in relation to the square root power of the pressure (i.e. pressure at a power of 0.5). This holds true for leaks through a fixed area, such as a pin-hole in a metal pipe, but the FAVAD Theory recognizes that some leaks occur through cracks or gaps, in which the

leakage area may change with changes in pressure. One example of a variable area discharge is a leak occurring through a crack in a plastic pipe, where the size of the crack increases with increases in pressure. In these cases, the amount of leakage through a hole varies in relation to the pressure at a power greater than 0.5 (as in fixed area leaks) and depends on the type of leak.

The exponent in the pressure-leakage relationship is known as the N1 value. The most commonly used equation to express the relationship between changes in leakage (L) due to changes in pressure (P) using the FAVAD theory is:

$$\frac{L_1}{L_0} = \left(\frac{P_1}{P_0}\right)^{N1}$$

The analyses of field tests have yielded N1 values that generally range between 0.5 and 1.5, but may reach up to 2.5 (Thornton, Sturm, and Kunkel 2008). In general, the lower N1 values occur for leaks with fixed areas that do not change with pressure, while the higher values occur in leaks where the area is more susceptible to change with pressure changes. Since many distribution systems have a variety of leakage types occurring, it is now common to assume an N1 value of 1.0 rather than 0.5 for most systems.

Field tests of systems in which all detectable losses were repaired, have generally produced N1 values of 1.5. In these cases, the leakage remaining in the systems are background leaks (undetectable leaks). Based on this, it is now generally assumed that background losses have a N1 value of 1.5 (Thornton, Sturm, and Kunkel 2008).

3.3 Real Loss Volume of Background Leakage

Background losses are the volume of water lost through small leaks and weeping joints at flow rates that are too small to be detected using current leak noise detection technology (2 gpm). They flow continuously until they are found by chance (during some other maintenance work for instance) or gradually worsen to the point they are detectable.

Background leaks typically comprise small corrosion holes (“pin-holes”) in metallic pipes and minor leaks at pipe joints and fittings. The level of Background Leakage in a water supply system will be dependent on:

- the length of pipe network,
- the number of service connections,
- the pressure at which the system is operated,
- and the condition of the infrastructure.

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.

3.3.1 Determination of the Background Leakage Volume

The background leakage in a specific system is determined from the Infrastructure Condition Factor (ICF) for that system and the Unavoidable Background Leakage (UBL). It can be calculated as follows:

$$\text{Background Leakage} = \text{ICF} \times \text{UBL}$$

More information on ICF and UBL is found in the sections that follow.

The equation above calculates the background leakage occurring in the distribution network. Additionally, the utility may also determine the background leakage volume from tanks and reservoirs. In general, underground reservoirs present higher levels of background leakage than above-ground reservoirs. However, this volume should be estimated separately by the utility.

3.3.1.1 Infrastructure Condition Factor

One of the most significant factors affecting the level of leakage in a water distribution network is the general condition of the mains and service pipes. The condition of the infrastructure in terms of its effect on the level of background leakage is referred to as the Infrastructure Condition Factor (ICF). The ICF is the ratio between the actual background leakage and the unavoidable background leakage. Every system (even newly commissioned parts of a distribution system) has a certain level of background leakage, which is unavoidable. Section 3.3.1.2 further discusses the unavoidable background leakage.

Various methods for determining the ICF are presented below.

- *ICF based on system-wide ILI*: The Infrastructure Leakage Index (ILI) is a performance indicator calculated from the top-down water balance. It is a ratio of the unavoidable annual real loss volume and the current annual real loss volume for the system. A first estimate of the system-wide ICF can be assumed to be similar to the system-wide ILI.
- *ICF based on sensitivity analysis:* Using sensitivity analysis, estimate the best case/worst case values of the ICF from component analysis, and use the average. The best case is to assume an ICF of 1, in which case the background losses for the system would be equal to the UBL, and the rest of the Real Loss volume would be recoverable losses from reported or unreported leaks. The worst case is to assume that, after deducting the known volume of reported and unreported leaks from the Real Losses, all of the remaining volume is attributable to background leakage. As an initial estimate, an average of these two values could be assumed.
- *ICF based on N1 step test:* This can only be used for systems with mostly rigid (metal) piping. In a zone or DMA supplied by a single main, when the night flow has stabilized, decrease the inlet pressure in several 30 minute steps by incrementally closing the inlet valve or pressure reducing valve. The inflow data, together with pressures measured at the Average Zone Point (AZP) can be used to calculate the ICF.
- *ICF based on removal of all detectable leaks:* Perform comprehensive leak detection and repair in a District Metered Area (DMA) to attain the lowest leakage levels possible. Using night flows at carefully selected times of year, compare the measured background leakage immediately after a 'find and fix' active leak detection with that derived from the UBL formula (discussed in

section 3.3.1.2); the ICF will be the ratio of the two values. This method requires the greatest amount of work and is therefore appropriate only for utilities that employ extensive leakage management programs. It is typically used to refine earlier estimates of the ICF.

Additional methods for estimating the ICF can be found in the third edition of the AWWA M36 manual.

3.3.1.2 Unavoidable Background Leakage

Table 3-1 presents the standard flow rates for calculating the Unavoidable Background Leakage (UBL). These values are based on international data from analysis of night flows after all detectable leaks and breaks were located and repaired. The UBL obtained from these values represent the minimum background leakage expected in a normal distribution system in good condition and is assigned an ICF of 1.

Table 3-1 Unavoidable Background Leakage Rates

Infrastructure Component	**Background Leakage at ICF=1.0**	**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

Infrastructure data specific to the utility, such as total miles of mains, average system pressure, number of service connections, and average length of service line from the curb stop to the meter or property boundary, must be available to calculate the UBL.

The UBL calculated from the table above corresponds to an N1 value of 1. Since background leakage has been found to vary with pressure to the power 1.5 (see section 3.2), the UBL has to be corrected for pressure using an N1 value of 1.5.

3.4 Real Loss Volume of Reported and Unreported Leaks and Breaks

As mentioned previously, the volume of water lost through unreported and reported leaks depends upon the number of leaks occurring, their magnitude, operating pressure and the total time that the leaks are permitted to run. The BABE concepts divide the length of time for which a break or leak runs into three categories:

- Awareness time is the time needed for the operator to become aware that a leak exists; a parameter strongly influenced by the presence or absence of an active leakage control program.
    - For reported breaks, the awareness time is generally very short. In most cases, in urban areas it will not take more than 24 hours until the break is reported.
    - For unreported breaks, since these are found by definition through active leak detection, the awareness time depends on the utility's intervention policy. If, for example, regular sounding is done on the entire system once a year, the awareness duration for the unreported break will be 183 days. If the entire system is surveyed twice a year, the awareness duration will be 90 days.
- Location time is the time taken to pinpoint the source of the leak once the operator is aware of its existence.
    - For reported breaks, the location time is generally short since most are visible.
    - For unreported breaks, the location time depends on the intervention method. If regular sounding is done, location duration is zero, since the inspector locates the leak when becoming aware of it. If regular night flow monitoring is done, the utility might be aware of the new leak in a general area, but might take additional time to locate its exact location.
- Repair time is the time to affect a repair that halts the leakage flow, once the leak position has been identified.

The total run time of a leak has been found to be a crucial factor influencing the volume of water lost to leakage. As shown in Figure 3-2, smaller leaks are more often left to run for long periods of time accounting for the greatest volume of leakage losses in a water distribution system. While large breaks, despite having higher flow rates, prompt a quick response by the water utility and a relatively speedy shutdown of the broken section of pipe. Since the run time of the break is often limited to a period of hours, the total volume of lost water from the event is contained.

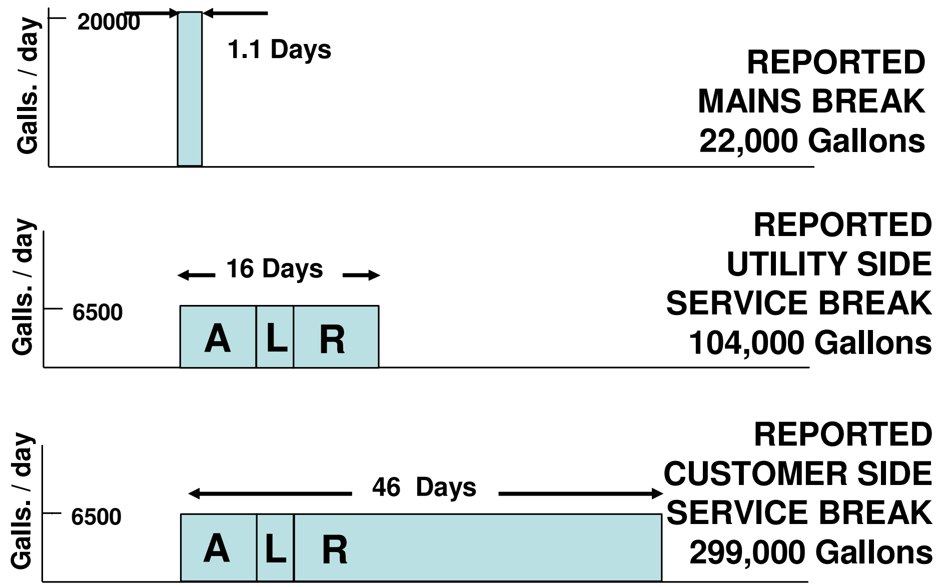


Figure 3-2 Influence of Run Time on the Leak Loss Volume

The volume of water lost through breaks on an annual basis is then calculated from:

1. The number of breaks of each component type that occurs each year
2. The total amount of time each leak ran
3. The flow rate associated with the type of break

In 2001, WSO conducted an evaluation of leak flow rate data for different types of leakage events from utilities in the US, UK, Canada, Brazil, and Germany. Table **3**-**2** presents the recommended typical flow rate values for leaks and breaks at 70 psi that was developed from this evaluation. The leakage flow rates ultimately used by a utility should be corrected according the average system pressure.

Table 3-2. Typical Flow Rates for Leaks and Breaks

Leak/Break Location	Unreported Leaks and Breaks (gpm)	Reported Leaks and Breaks (gpm)
Main Line		
Less than 4 inch	13.9	13.9
4 inch	22	44
6 inch	46	92
8 inch	46	92
10 inch	46	92
12 inch	111	222
Greater than 12 inch	111	222
Service Lines		
1 inch and smaller	6.9	6.9
Greater than 1 inch	13.9	13.9
Fire Hydrants	3.5	3.5
Valves	6.9	6.9

Any water losses occurring from tank leaks or tank overflows should also be considered and included as a component of Real Losses. The Real Loss volume from this component should be determined on a case by case basis by the utility.

For utilities that do not carry out any active leak detection, the volume of Real Losses assigned to the component of unreported leaks and breaks is zero. This does not mean that the utility does not have any unreported leaks; it does mean however that none of the unreported leaks have been fixed, and hence, they are still causing water losses in the system. These are considered hidden losses (see section 4). Most likely, some portion of those losses is economically recoverable. Additional information on determining the economic level of unreported leakage is presented in section 0.

4 Calculation of Hidden Losses

Hidden Losses are the volume of Real Losses that has not been identified in the component analysis described above. This volume represents water that is lost through leaks that have not been detected or repaired.

The hidden losses are calculated as follows:

Hidden Losses = Real Losses from Top-Down Water Balance – Real Losses from Component Analysis

While a certain amount of the difference between the two Real Loss volumes is due to errors in the two methods of estimation, the difference is mainly due to the presence of Hidden Losses. In effect, Hidden Losses are a backlog of leaks and breaks waiting to be detected and repaired. Individually, each hidden leak 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.

5 Performance Indicators

As part of the water audit process, utilities can determine water loss Performance Indicators (PI) to gain an understanding of how well losses are being managed and evaluate the level of effort that should be taken to control losses. Because conditions and sizes of water utilities can vary greatly, effective performance indicators take into account those differences. Some of the key local factors that have been found to impact real losses in a system include (Lambert et al. 1999):

- Length of mains
- Number of service connections
- Location of customer meter on service connection
- Average operating pressure
- Continuity of supply
- Soil or ground conditions

The commonly used value percentage of losses over the system input volume has been found to be a poor indicator of a utility's operational performance controlling water losses (Lambert et al. 1999). One reason is that this value does not account for the wide range of conditions that can be found in utilities. Another, perhaps more consequential reason, is that the average rate of consumption or the system input volume may markedly impact the final value, causing utilities with lower per capita consumption or smaller supply volumes to obtain less favorable numbers. This gives a false impression of true performance when comparing a large utility with a smaller utility. It may even be misleading to one utility comparing records for different audit periods, before and after implementing consumption reduction measures.

The IWA has published a list of PI for Water Supply Services (Alegre et al. 2000), also endorsed by the AWWA. The PI for Non-Revenue Water and Water Losses are summarized in Table **5**-**1**.

Table 5-1 Performance Indicators for Non-Revenue Water and Water Losses

Indicator	Type	Recommended Units	Comments
Inefficiency of use of water resources	*Water Resources*	Real Losses as % of System Input Volume	Unsuitable for assessing the efficiency of management of distribution system and can be unduly influenced by consumption.
Water losses	*Operational*	gallons/service connection/year[10]	Same units as Authorized Consumption. Of limited use when Water Losses can be readily expressed in its constituent components of Apparent Losses and Real Losses.
Apparent losses	*Operational*	gallons/service connection/year	Same units as Authorized Consumption.
Real Losses	*Operational*	gallons/service connection/day when system is pressurized	Allows for intermittent supply situations.
Infrastructure Leakage Index (ILI)	*Operational*	Ratio of Real Losses to technical achievable low-level annual Real Losses	Technical achievable low-level annual Real Losses are equal to the best estimate of Unavoidable Average Real Losses, UARL. They include system-specific allowance for connection density, customer meter location on service, and current average system pressure.
Non-Revenue Water by volume	*Financial*	Volume of Non-Revenue Water as % of System Input Volume	Can be calculated from simple Water Balance.
Non-Revenue Water by cost	*Financial*	Value of Non-Revenue Water as % of annual cost of running system	Allows different unit costs for each component of Non-Revenue Water, e.g. Apparent Loss due to under-registration valued at water sales cost; Real Losses valued at marginal operating cost.

[10] Where service connection density is less than 32 per mile of mains, use gallons/mile of main/year.

It is important to point out from Table **5**-**1** regarding the use of the IWA PI that:

- Inefficiency of use of water resources (percentage of real losses over system input volume) is a water resources PI and not an operational PI.
- Non-Revenue Water, as a percentage of System Input Volume, is a financial PI not an operational PI.
- The financial PI, NRW as a percentage of annual running cost, is a development of an approach proposed by the recommendation of the AWWA Leak Detection and Water Accountability Committee in 1996 (AWWA Leak Detection and Accountability Committee 1996).

5.1 Real Losses as Percent of System Input Volume

This PI can be unduly influenced by consumption. Increases in the annual volume of consumption lead to an increase in the total System Input Volume. The volume of Non-Revenue Water, however, remains constant. This causes Non-Revenue Water as a percent of the total System Input Volume to decrease. It is important not to misinterpret this decrease as a reduction in Non-Revenue Water.

5.2 Apparent Losses in gallons/service connection/day

This PI is useful for comparison with average annual consumption per customer and for quick estimation of the value of Apparent Loss when multiplied by an average sales cost for water.

5.3 Real Losses in gallons/service connection/day

This is the preferred basic operational PI for comparing leakage management performance and one of the most reliable when used in urban networks with service connection density greater than 32 connections per mile. This PI does, however, have the distinct disadvantage, that three of the key factors which affect the level of leakage in any system are not considered:

- Density of service connections;
- Location of customer meter on service connections; and
- Average system pressure

The last factor is particularly relevant when comparing Real Loss rates for small sections of the network, e.g. in a District Metered Area (DMA), where the average system pressure may vary widely. The disadvantage can be overcome by use of a modified version of the PI where Real Losses are first converted into gallons/service connection/day/psi of pressure using the average system pressure for the DMA and then converted back into gallons/service connection/day using the average system pressure for the entire network.

5.4 Infrastructure Leakage Index (ILI)

The Infrastructure Leakage Index is calculated by comparing the annual volume of Real Losses for the system against an internationally derived standard that relates to the best that can be technically achieved for that system. The methodology takes into account all the factors that affect the annual volume of Real Losses.

A committee report published by the AWWA Water Loss Control Committee in 2003 (Kunkel et al. 2003) recommends that "…Water suppliers should make use of the performance indicators included in the international methodology, particularly the ILI…".

The theoretical technically achievable minimum level of Real Losses is known as Unavoidable Annual Real Losses (UARL). The standard unit values used for the calculation of UARL are summarized in Table **5**-**2**.

Table 5-2 Components of UARL

Infrastructure component	**Units**	**Background Leakage**	**Reported Leaks and Breaks**	**Unreported Leaks and Breaks**	**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	gal/mile of conn/day/psi	4.78	0.57	2.12	7.47

(Source: Lambert, Huntington, and Brown 2000)

The 2003 AWWA committee report also recommended general guidelines for target levels of ILI in the absence of a system-specific economic level of leakage (ELL). (ELL is discussed in section 0.) These guidelines are summarized in Table **5**-**3**.

Table 5-3 AWWA General Guidelines for Target Level ILI

Target ILI Range	Water Resources Consideration	Operational Consideration	Financial Consideration
1.0 – 3.0	Available resources are greatly limited and are very difficult and/or environmentally unsound to develop	Operating with system leakage above this level would require expansion of existing infrastructure and/or additional water resources to meet the demand.	Water resources are costly to develop or purchase; ability to increase revenue via water rates is greatly limited because of regulation or low ratepayer affordability
3.0 – 5.0	Water resources are believed to be sufficient to meet long-term needs, but demand management interventions (leakage management and/or water conservation) are included in the long-term planning.	Existing water supply infrastructure capability is sufficient to meet long-term demand as long as reasonable leakage management controls are in place.	Water resources can be developed or purchased at reasonable expense; periodic water rate increases can feasibly be imposed and are tolerated by the customer.
5.0 – 8.0	Water resources are plentiful, reliable and easily abstracted.	Superior reliability, capacity and integrity of the water supply infrastructure make it relatively immune to supply shortages.	Cost to purchase or obtain/treat water is low, as are rates charges to customers.
> 8.0	Although operational and financial considerations may allow a long-term ILI greater than 8.0, such a level of leakage is not an effective utilization of water as a resource. Setting a target level ILI greater than 8.0 – other than as an incremental goal to a smaller long-term target – is discouraged.		

6 Economic Level of Leakage

Once a detailed assessment of all real loss components was completed the utility needs to determine which of the four leakage management options as depicted in Figure **6**-**1** are the most appropriate. In order to answer this question, it is necessary to undertake an analysis of the Economic Level of Leakage (ELL). Even if it were technically possible, eliminating leakage altogether would be a wasteful use of resources. The cost of doing so would far exceed the cost of balancing water supply and demand by other means, and that would mean higher bills for customers. The ELL represents the most cost effective level of leakage given the current valuation of water lost. Determining the ELL is crucial since it enable a utility to improve operational efficiency by reducing unnecessary operating expenditure.

The ELL analysis entails assessing the costs and benefits of implementing alternative appropriate leakage management options, and thereby determine the most cost effective, or optimal leakage management strategy for the utility. The ELL analysis should be a holistic analysis of each of the alternative strategies to reducing real losses, and it should consider all four of the IWA four arrows of basic strategies that can be used to reduce losses (see Figure **6**-**1**). Strategies that do not entail investment, such as active leakage control and improving the speed and quality of repairs should be considered in the economic short run, but strategies that entail significant investment, such as pressure management, the development of DMAs and infrastructure rehabilitation / renewal should be considered in the economic long run. Each of the four basic strategies for reducing real losses should be evaluated individually and each of these strategies will have a break-even point, beyond which the value of the water saved, based on the based on the valuation of one unit if water lost, does not justify further expenditure. The ELL will not have been achieved until all four strategies have been implemented to their economically optimal level. If a utility has no supply demand problems and no plans to develop new resources, the ELL determined through this process would be the final answer. However, if the utility has a tight supply/demand balance, after it has achieved this level of leakage, and is considering developing additional water resource schemes, it then has to decide whether to undertake further real loss reductions or other water conservation programs to defer construction of the new resource, or whether to proceed with construction (Fanner et al. 2007).

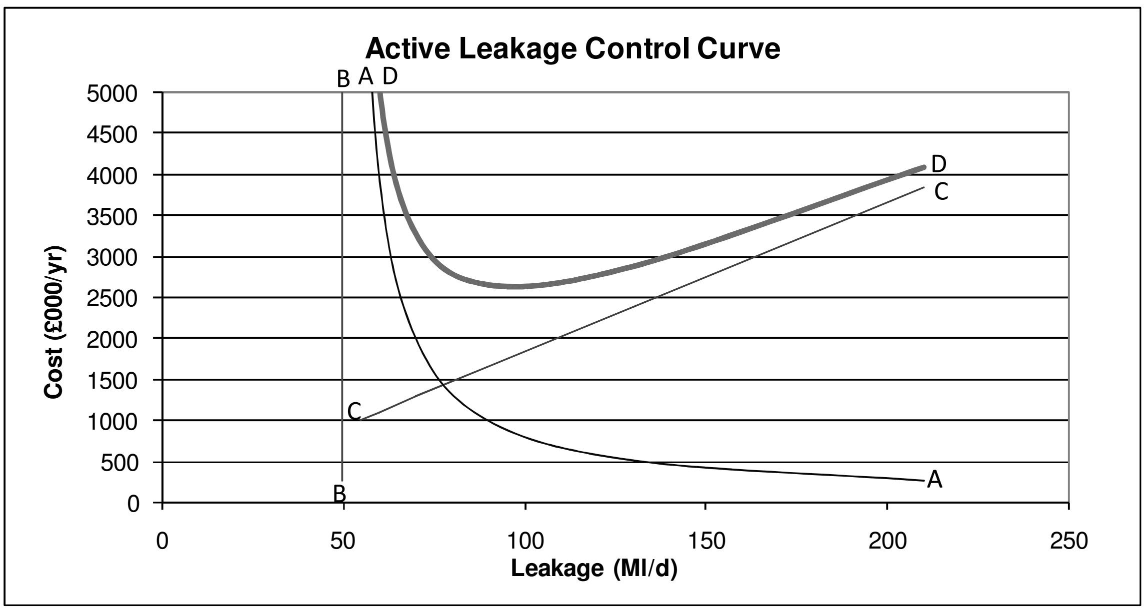
The following subsections were adapted from the Water Loss Control Manual 2nd Edition.

6.1 SHORT-RUN ELL

6.1.1 Active Leakage Control

The purpose of active leakage control (ALC) is to find leaks that do not surface or otherwise come to the attention of the operating company through customer contact e.g. poor supply, loss of water etc., (which are known as reported leaks). The process of active leakage control involves teams of leakage detection staff sweeping an area to find leaks generally using sounding techniques or similar. This may be in response to an increase in a nightline if the area is sectorized, an increase in the output from a treatment works or service reservoir/tank or simply as a result of a regular sounding program at an agreed interval.

This ALC activity will locate unreported leaks, which will then be repaired, and leakage levels will be maintained. If sweeping is carried out at more frequent intervals then leakage will be maintained at a lower level. Thus, there is a relationship between average leakage level and the time between surveys. This is shown as curve A-A in Figure **6-1** and is referred to as the Active Leakage Control Curve. The vertical axis is usually expressed in cost terms and is simply the annual cost of the leakage detection resources. The horizontal axis is the average leakage level, over the same period (usually a year). On the assumption that some leaks would never come to the attention of the operating company if they did not come to the surface (e.g. if they break through to a sewer) and would therefore accumulate on the system, then the curve will asymptote to the horizontal axis. The curve will also asymptote to a line parallel to the vertical axis. This line, B-B, will be equivalent to the level of leakage that would result if infinite resources were deployed on leakage control activity. This minimum level of leakage would equate to background leakage, i.e. leakage below the level of detection, plus the leakage from reported leaks plus the leakage from unreported leaks during the period they run between detection and repair, resulting from any given leakage control policy. This is sometimes referred to as the policy minimum level of leakage.



(Source: Thornton, Sturm and Kunkel 2008)

Figure 6-1 - Active Leakage Control (ALC) cost curve

There has been much debate about the shape of the curve between these asymptotes. In the most simplistic model of regular sounding the curve will be hyperbolic. This is based on the fact that the curve will be defined by the leakage during the period which unreported leaks run until they are detected. This will be directly related to the length of time they run before being detected and hence the intervention interval. As the intervention interval will be inversely related to the resources (doubling the resources will half the intervention interval) then leakage will be inversely proportional (i.e. a

hyperbole) to the level of resources and hence the ALC cost. If the area is sectorized, or if other forms of flow measurement are used to direct resources more efficiently compared to simple regular sounding, the curve will be flatter than a pure hyperbole.

If the cost of the water lost at different levels of leakage is plotted on the same graph this would be represented by the line C-C. The cost will be the simple difference in cost in producing or purchasing one more or less unit of water. Following recommendations by the California Urban Water Conservation Council water efficiency programs should value one unit of water saved at the avoided cost of water. However, depending on the utilities supply/demand balance one unit of water can even be valued at retail cost since every unit of water saved through optimized leakage management could potentially be sold to new customers or mitigate the need for demand side restrictions. The slope of this line is referred to as the marginal cost of water. If the marginal cost of water is constant, line C-C will be a straight line. If the marginal cost of water production is not constant, then line C-C will be made up of a number of straight lines; usually increasing in slope with higher leakage as more expensive water is used. Curve D-D is the total cost of operation i.e. cost of leakage control plus cost of water production. As can be seen, the curve will be high initially due to the high cost of leakage detection required to achieve very low levels of leakage. The total cost then reduces before increasing again as the cost of water production increases with increasing levels of leakage. The point at which the total cost is lowest will be the short run economic level of leakage. At this point, the marginal cost of leakage detection activity will be equal to the marginal cost of water. This point will also define the economic level of resources to be deployed on leakage detection and the economic period between interventions.

6.1.2 Leak Repair Time

A similar methodology to that for ALC can be applied to developing the economic level of speed of repair. Very short repair times can be achieved but at the cost of possible overtime for weekend and evening working for the repair teams. This may or may not be economic. Leakage level will be related to the average repair time, and so a similar curve to the ALC curve can be produced. The benefit from reducing repair times can be estimated using a component loss model.

6.2 LONG-RUN ELL

Some leakage control activities will involve an investment decision, and hence a payback longer than the short-run period. This will typically apply to options such as pressure management and mains rehabilitation. In these cases, it will be economic to make an investment on pressure management or rehabilitation to reduce leakage if the cost of water saved over the investment period would pay for the cost of carrying out the works. Once the investment has been made, there will be a new (lower) short-run economic level of leakage, which has to be re-calculated using the method discussed in the previous sections.

6.2.1 Pressure Management

Leakage will reduce as a result of pressure reduction due to two factors namely:

- Both background and leak flow rates will reduce, as leakage flow is directly related to pressure by a factor called the N1 relationship
- Burst frequency rates will reduce, due to reduced stress on the pipe network, the so called N2 relationship

Bursts and leaks can be caused by surges on the network. These surges can be caused by defective operator or customer equipment or the lack of surge suppression equipment on pumped systems.

In the case of pressure reduction, the investment costs will include the one-off cost of construction of the chambers, the cost of purchasing the pressure reducing valves (PRVs) and their replacement as well as ongoing maintenance costs. As pressure management is deployed in an area, the average pressure will reduce. Schemes will be deployed on the basis of those which give most benefit first and therefore as more and more schemes are installed, the marginal benefit of each scheme on the average pressure for the system as a whole will reduce. As leakage is proportional to pressure, there will be a break-even point at which the additional cost of scheme deployment equals the marginal cost of water losses.

6.2.2 Sectorization (DMA)

It is common practice in some parts of the world to split the water network into sectors (DMA) and monitor flows into and out of these sectors at night. Data about the flows into DMA provides information to be able to locate leaks faster and therefore improve leakage detection efficiency. However the introduction of sectorization involves costs in the following areas:-

- One off cost of construction of meter chambers
- Cost of meter and replacements and/or refurbishment
- Cost of data logging equipment
- Ongoing cost of data retrieval (either manual or by telemetry)

The benefit of introducing sectorization in terms of leakage will be a function of the natural rate of rise of leakage in the sector. Not all sectors will have the same rate of rise, and so again there will be a curve showing diminishing returns. Other factors affecting costs will be the environment, the complexity of the network and the degree to which sectorization has already been established. The calculations are similar to the ones described above for pressure management. They can be carried out to establish an economic breakpoint that would give the economic level of sectorization and the optimum size of sectors.

6.2.3 Network Rehabilitation

Network rehabilitation (both mains and service pipes) will reduce the rate at which leaks break out on the network. This will reduce leakage, as well as reducing costs associated with inspections and active

leakage control activity highlighted above. In each system there is a distribution of the frequency at which pipes burst on the network. A small proportion will burst at a high frequency, whilst other parts of the network will burst at a much lower frequency. In order to have the greatest impact on leakage one would try to identify those pipes with a high frequency of failure and replace these first. The benefit of replacing further sections of pipe will then be less. Again the law of diminishing return applies, and a point will be reached when it is not economic to replace pipes.

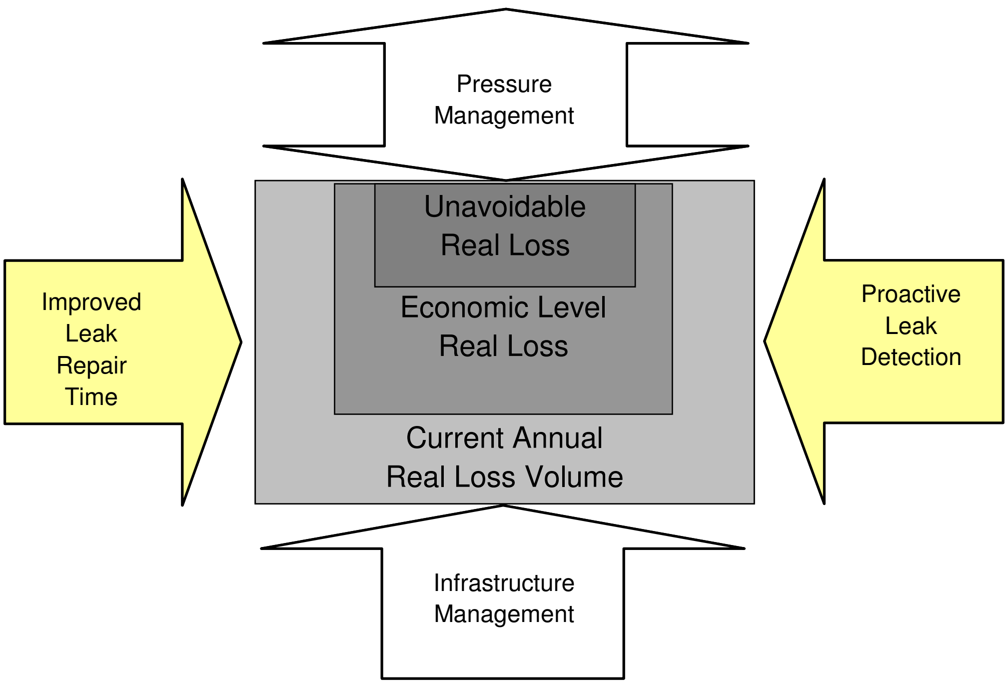
6.2.4 Combination of Activities

The methodologies described above all require the assessment of the benefit in leakage terms from the proposed activity. Each case has been considered independently – i.e. the assessment of the economic level of pressure management or rehabilitation. However, the implementation of one option will affect the economics of the implementation of the other i.e. the benefits from rehabilitation will be reduced if average pressures have already been reduced due to pressure management. In practice, an operating company will want to develop a strategy that looks to establish the economic balance between all activities i.e. active leakage control, leakage repair, mains rehabilitation, service pipe replacement, sectorization and pressure management.

7 Real Loss Intervention Strategies

7.1 Disaggregation of the Distribution System into District Metered Areas (DMA)

This section discusses the use of DMA for leakage management purposes. DMA have the benefit of combining two of the four tools against real losses (see Figure **7-1**). DMA help reduce leak repair times by identifying newly occurred leaks through minimum night-time flow analysis. DMA also improve proactive leak detection efforts though prioritization of leak detection efforts to areas where DMA analysis have shown that leakage levels are highest.



(Source: Water Loss Task Force)

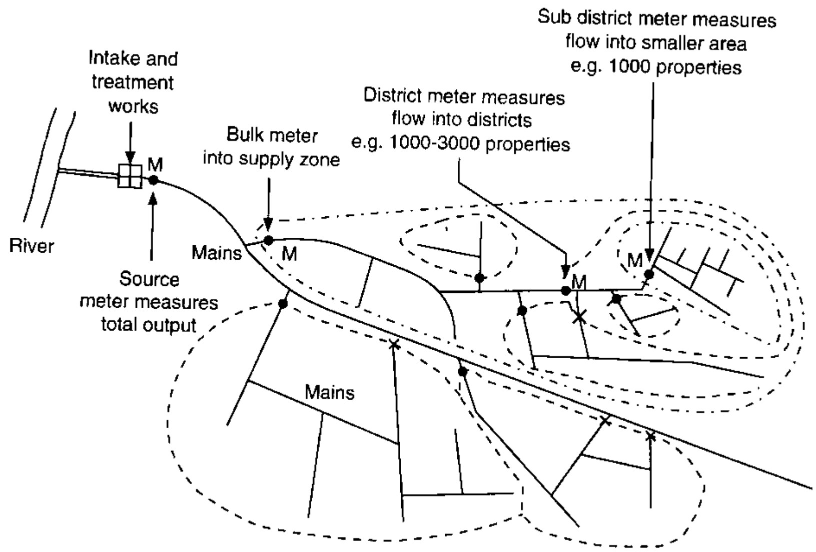
Figure 7-1 - Four components of a proactive real loss management program

DMA can be used on a temporary or permanent basis. Nevertheless, the general DMA principles are the same for both operational modes. The following subsections discuss the installation and operation of permanent DMA.

7.1.1 DMA Overview

A DMA is a hydraulically discreet part of the distribution network, ideally with one but sometimes with two or more inflow points equipped with flow meters (Fanner et al. 2007). The primary concept and advantage of DMA monitoring is to isolate and monitor a small area of the distribution system with supply flows into the DMA of sufficient scale that flows can be analyzed to distinguish components of normal consumption from leakage rates. While flow monitoring in DMA does not provide the ability to

pinpoint individual leaks, it gives the important capability of obtaining a quantity of the collective leakage occurring within the DMA and it allows the measure of background leakage to be distinguished from unreported leaks. Well managed DMA also serve as "early warning systems" of newly rising leakage and can alert the operator when to optimally schedule leak detection crews (AWWA M36 2009).



(Source: AWWA M36 Third Edition)

Figure 7-2 Conceptual Diagram of a District Metered Area

The technique of flow measurement to infer leakage volumes requires metering and tracking the flows supplying sections of the water distribution system. As presented in the third edition of the AWWA M36 manual, the design of such a leakage monitoring system for active leakage control has two aims:

- To divide the distribution network into a number of zones or DMA, each with a defined and permanent boundary, and appropriately sized so that flows can be regularly monitored, and the presence of unreported leaks can be distinguished from levels of normal consumption; by analyzing flow patterns during minimum consumption periods of the day.
- To manage pressure in each district or group of districts so that the network is operated at the optimum level of pressure; thus inhibiting the rise of new leaks and eliminating pressure transients that cause pipe failures.

It therefore follows that a leakage monitoring system will comprise a number of districts where flow is measured by permanently installed flow meters. In some cases the flow meter installation will also be accompanied with a pressure reducing valve (PRV) in series on the supply main.

Depending on the characteristics of the water distribution system, a DMA will be:

- Supplied via a single supply main, or multiple feeds to provide emergency supply

- A discrete area (i.e. no flow into adjacent DMA), or
- An area which cascades into an adjacent DMA

DMA enable a water utility to quantify the current level of leakage in a discrete area and to consequently prioritize their leak detection activities, sending leak detection crews into those DMA when leakage rates rise appreciably, and deferring crew action as long as leakage rates remain contained. By regularly monitoring DMA inflows into a well managed grid, the operator can identify the occurrence of new leaks and breaks by the rise in flow during the minimum hours of consumption. This information enables a utility to intervene and repair the leaks once the action level of leakage is reached, and avoids expending leak detection crew time when the presence of excessive leakage is not indicated.

7.1.2 DMA Planning Considerations

A number of factors should be taken into account when planning a DMA (AWWA M36 2009), including:

- The target volume and cost of leakage to be reduced. Does the preliminary target or Economic Level of Leakage calculation indicate that a sufficient return on recovered leakage will exist to justify the expense to establish the DMA? Preliminary measurements can be gathered using temporarily installed flow meters to determine which areas indicate high leakage levels. A pilot DMA employing permanent metering can be implemented at reasonable cost to give a better indication of the feasibility of using DMA on a wider scale across the distribution system.
- Size, by geographical area and number of properties - The DMA size is typically expressed in number of properties or service connections. The size of a typical DMA in urban areas varies between 500 and 3,000 properties. The size of an individual DMA will vary, depending on a number of local factors and system characteristics, such as:
    - The estimated level of economic leakage reduction in the region of the system
    - Geographic/demographic factors (e.g. urban or rural, industrial areas)
    - Previous leakage control technique (e.g. former flow measurement areas)
    - Individual water utility preference (e.g. discrimination of service pipe breaks, ease of leak survey deployment)
    - Hydraulic conditions (e.g. limitations in closing valves, low pressures, local standards of service)
    - Minimum flow and pressure, as well as fire flow requirements
    - Ability to maintain adequate water quality when employing additional closed valves

DMA in dense urban areas, e.g. inner cities, may be larger than 3,000 properties, because of high housing density. The number of DMA service connections may vary in rural areas, as rural DMA may consist of a single village, or may encompass a cluster of villages (small number of properties but large geographical areas). If a DMA is larger than 5,000 properties, it becomes difficult to discriminate small leaks (e.g. service pipe leaks) from minimum consumption hour flow data, and location takes longer, therefore the DMA is less effective.

As a general guide line DMA can be grouped according to size in three categories:

- Small: < 1,000 properties

- Medium: 1,000 – 3,000 properties
- Large: 3,000 – 5,000 properties

Ultimately the configuration of the distribution system will play the largest role in determining the size of the DMA, based upon factors including:

- Type of consumers (industrial, multi family, single family, commercial etc)
- Variation in ground level
- Targeted final leakage level
- Minimum flow and pressure requirements for fire flow, insurance, meeting standards of service
- Looping and redundancy considerations of the piping grid
- The location of service connections serving large or special-needs customers – buildings such as hospitals, schools, etc. – should be examined for any special hydraulic considerations. If the proposed DMA includes several large and sensitive customers it is necessary to pay special attention when selecting the inflow location. If it is not possible to meet flow and pressure requirements when supplying through only one inflow, it is necessary to identify a second metered inflow water main into the configuration of the DMA.
- Water quality considerations - Creating a DMA involves closing valves to form a boundary. This creates more dead-ends than would normally be found in a fully open system. Consequently the potential for water quality degradation from flow disturbance (initially) and stagnation (eventually) may occur. The greater the number of closed valves in a DMA, the greater the care that should be exerted in designing water quality safeguards. Conversely, the creation of a DMA allows the water utility to focus more specifically on valves, fire hydrants, pressure levels and water quality than in a typical open system. Although the evaluation of water quality in DMA by various utilities have not shown any significant impact on this issue (Fanner et al. 2007), water quality sampling and assessment should be conducted during the planning and implementation phases of the DMA, as well as routinely during the DMA operation. This will give the utility operator the opportunity to proactively build any needed water quality controls into the design of the DMA. Good water quality can be maintained by proper configuring the boundary or performing periodic flushing.

The planning phase aims to configure portions or all of the distribution system into suitably sized DMA. As a first pass, use small scale distribution mains maps to outline provisional DMA boundaries using local knowledge of the distribution grid and hydraulic data (pressure and flow) to obtain the desired flow monitoring capability and identify potential trouble spots to be managed in the DMA design.

7.1.3 DMA Installation and Testing

In order to isolate the DMA, it is necessary to inspect all boundary valves and insure that they are functional and provide a water tight shut. Defective valves, or those that “pass” water should be repaired or replaced, or the boundary of the DMA moved to the next nearest operational valve. The operator should install pressure loggers at the critical and average zone pressure points and collect data for several days before closing the boundary valves. Loggers should also be installed near any critical customers in the DMA. Comparing this data with the pressure values recorded after the DMA is isolated gives a profile of pressure changes to be encountered in operating the DMA and helps to identify any

problem locations. If an unacceptable pressure reduction occurs in operating the DMA, it may be necessary to revise the DMA design to provide sufficient pressure within the DMA.

Once boundary valves are closed a "pressure drop test" should be conducted to ensure that the DMA is hydraulically tight. During this test the pressure is dropped within the DMA in various steps by operating the valve controlling the inflow to the future DMA. In order to avoid a disruption of service, such tests can be conducted during the minimum consumption period. The minimum consumption period occurs during the nighttime hours between 2 AM and 4 AM in many communities. However, the growing use of irrigation systems operating at night by timer control means that the minimum consumption may not always occur during the night hours. This period needs to be adjusted to take into account any local differences in demand patterns. The steps in pressure reduction should be in the range of 10 – 15 PSI down to the pressure level where the minimum required pressure at the critical zone pressure point is set. In order to monitor if the DMA is hydraulically discrete or not, several pressure loggers should be installed outside the DMA boundaries prior to the test. These boundary loggers will record any change in pressure related to pressure drops created within the DMA in case the DMA is not hydraulically discrete. During the pressure drop test, pressure inside the DMA should drop as the supply is reduced. If the inflow supply is reduced and the DMA pressure fails to drop, it is likely that one or more boundary valves are not holding tightly and are allowing flow from the neighboring grid to pass back into the DMA. Again, such valves must be addressed and the DMA confirmed to be hydraulically tight, before continuing with the DMA work.

After determining that the DMA boundary is hydraulically intact, the operator should confirm that the DMA supply can meet peak demands. High flow conditions can be created by opening a boundary valve to a neighboring lower pressure zone or DMA thereby creating an additional flow demand through the subject DMA. Alternatively, one or more fire hydrants can be opened to simulate fire fighting conditions. The utility should log or monitor pressures at the critical point and any sensitive customer locations. If the pressure drops incurred during the peak flow conditions are unacceptable, then the DMA design should be revised, with one or more additional inflow mains created to adequately supply peak level flows.

After the successful completion of these initial tests the total inflow to the DMA has to be monitored over several days under normal operation. The inflow data is needed to determine the selection of an appropriate flow meter. Several key issues related to DMA metering that should be considered are the sizing of the meter, the ability to record accurately at maximum and minimum flow rates, and the necessity to meet peak demand and fire flow requirements.

7.1.4 DMA Flow Data Analysis

The concept of DMA monitoring is to measure flow into a discrete area with a defined boundary and observe typical variations in flow. The flow into the DMA can then be segregated into legitimate consumption and real losses from background leakage and bursts or breaks, as shown in Figure 7-3.

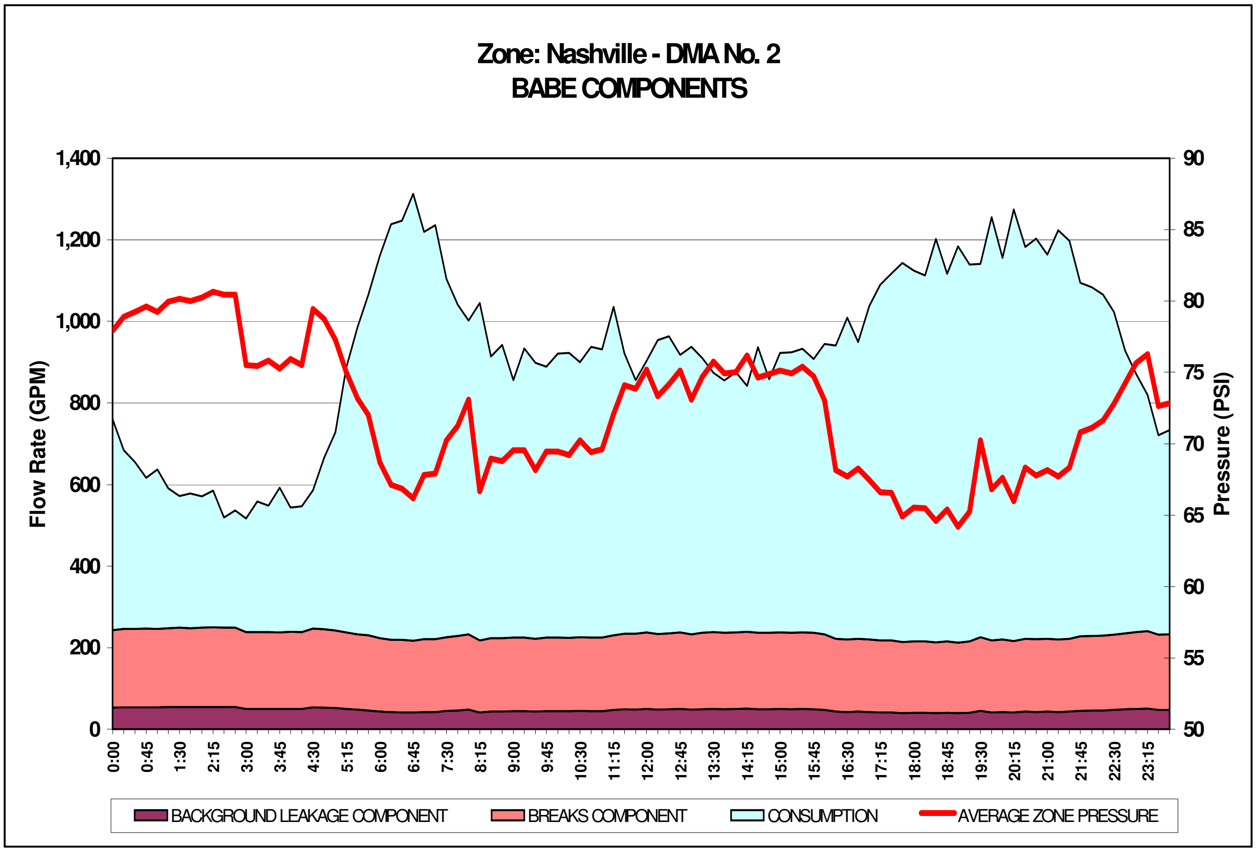


Figure 7-3 Analysis of Real Losses in DMA

The estimation of the real loss component can be done via a minimum night flow analysis. The minimum nighttime flow in urban areas usually occurs between 2 AM and 4 AM. This flow value is the most meaningful data used in determining the leakage rate in the DMA because during this period, authorized consumption is at a minimum and, therefore, leakage is at its maximum percentage of the total inflow. However, in regions where customer landscape irrigation makes up a significant part of the demand during the minimum nighttime flow period, the accuracy and the confidence in the calculated real loss figures will diminish.

The real losses in the DMA are determined by subtracting an assessed or measured volume of legitimate night consumption for each of the customers connected to the water mains in the DMA from the inflow. The result obtained is known as the net night flow (NNF) and provides an estimation of the volume of real losses during the MNF period. The leakage volume can be modulated over the whole 24-hour period using the FAVAD concept. The NNF is mostly composed of real losses from the distribution network and the service connection piping between the water main and the customer meter. However, it may also include leakage on the customer side of the meter and consumption through unauthorized connections.

7.1.5 Prioritizing DMA Leak Detection Effort

DMA allow assessment of leakage volumes in a hydraulically discrete zone. If multiple DMA are established in the service area, leakage volumes can be assessed for each of the DMA on a regular basis. The results gained from the DMA measurements allow a utility to prioritize its leak detection efforts, targeting the DMA with the highest leakage volume, where the leak detection efforts bring the best results in real loss reduction in relation to the work effort required. Consequentially, targets can be set to decide which DMA needs to be addressed and in what order by the leak detection team. Ideally, targets or thresholds for leak detection intervention are set based on analysis of the economic optimum volume of leakage in each DMA.

7.2 Pressure management

7.2.1 What Do We Mean by Pressure Management[11]?

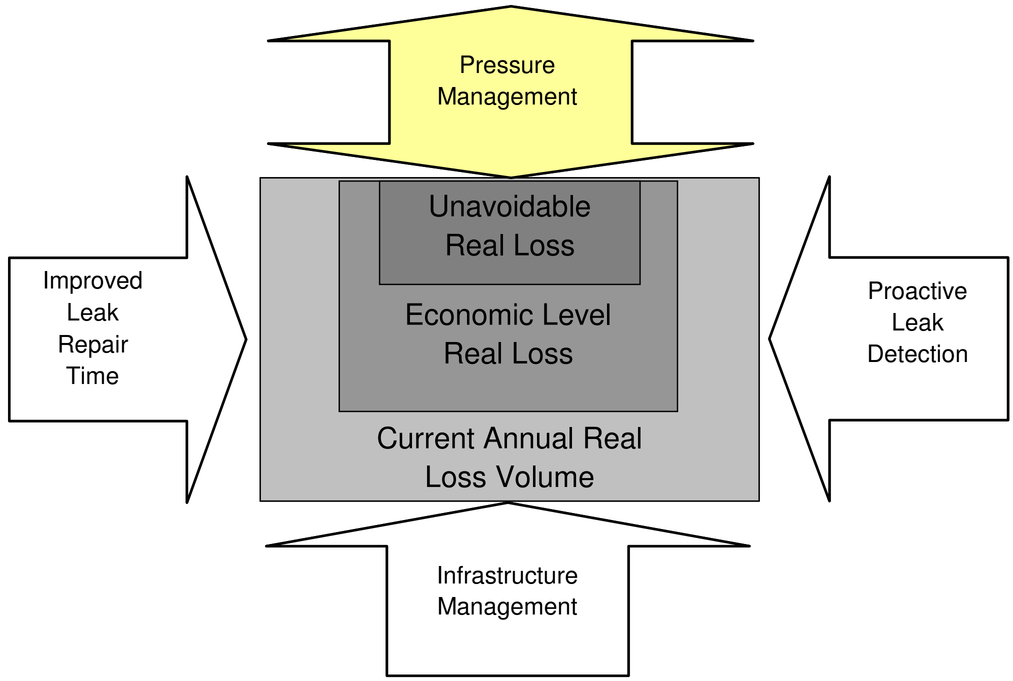
Pressure management can be defined as "The practice of managing system pressures to an optimum level of service ensuring sufficient and efficient supply to legitimate uses and consumers, while eliminating or reducing pressure transients and variations, faulty level controls and reducing unnecessary or excess pressures, all of which cause the distribution system to leak and break unnecessarily".

Most water systems in North America perform basic methods of pressure management through the use of booster stations, level controls, and pressure zones. Refining their pressure management may not be a great additional step for many of these utilities as they already employ basic controls. However, many of the same utilities likely do not have a full understanding of the dramatic leakage control potential that exists for them in employing optimized pressure management.

7.2.2 Why Manage Pressure?

The diagram below in Figure 7-4 shows the current annual real loss volume as defined by the annual water balance as explained in the first section (Developing the IWA Water Balance) of this best practice water loss control document. Figure 7-4 shows that this volume can be reduced to an unavoidable real loss volume by using one or several of four key tools of which pressure management is one.

[11] "Managing pressures to reduce new breaks" Thornton J, Lambert A, IWA Publishing Water 21 Magazine ISSN 1561-9508, December 2006



(Source: Water Loss Task Force)

Figure 7-4 - Four components of a proactive real loss management program

The two primary objectives of pressure management for leakage control and infrastructure sustainability are:

- Reduction in the frequency of new breaks occurring within a water distribution system
- Reduction in the flow rates of those breaks and background leakage that cannot be avoided

Other possible benefits of pressure management include (Thornton, Sturm, Kunkel 2008):

- Water conservation – In direct pressure uses, pressure reduction can be an effective way of controlling demand. Some examples of these uses include showers, faucets, and sprinkler systems. However, pressure reduction does not reduce demands in volume controlled uses such as toilets, clothes washing machines, or properties with reservoirs (see more on section 7.2.2.2 and 7.2.3.2).
- Efficient distribution of water – Many water distribution systems have problems supplying some customers, while others enjoy a constant source of water. Pressure management using not only pressure reducing techniques, but also pressure sustaining techniques, boosters or flow control, can ensure that the system distributes its resources as evenly as possible, ensuring required volumes for a majority of the customers.
- Guaranteed storage – The implementation of pressure management schemes can assist the utility operator in ensuring that reservoirs and storage tanks remain at realistic levels to meet demands. This may be done by a mixture of pressure-reducing, pressure-sustaining, and flow-control valves. Level controls in tanks also ensures that storage is not allowed to overflow

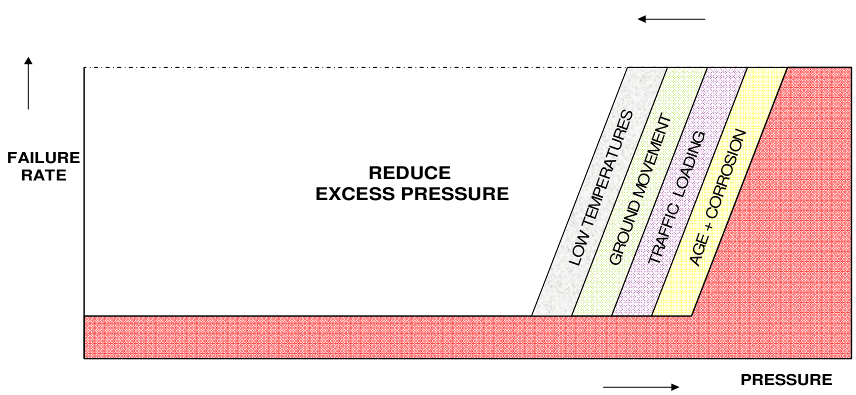
during off peak hours when system demand and head loss are low and pressures are at the highest level.

7.2.2.1 Reduction in the Frequency of New Breaks

The International Water Association (IWA) Water Loss Task Force (WLTF) Pressure Management Team published results from evaluations of break frequencies in distribution systems before and after the implementation of pressure management (Thornton and Lambert 2006). These case studies showed that pressure management produced immediate, significant and sustained reductions in new break frequencies.

One of the most important factors investigated was the relationship between pressure and water main break and service connection leak frequency. In many water distribution systems, the presence or absence of pressure surges, or pressure transients, is a major factor in the frequency of occurrence of water main breaks. These brief but dramatic increases in pressure can be caused by pump activation and deactivation, control valves opening or closing too quickly, tank filling operations, or sudden large water demands from industrial consumers, wholesale water utilities or other large draws. Because they are usually very brief in nature, pressure transients can only be measured over very short time periods, of the order of one second or less, using very precise data-logging instruments. In developing the leakage management strategy, some consideration should be given to launching an evaluation of the function of pumps, control valves, tanks and important hydraulic controls to determine if opportunity for harmful transients exists, and if cost-effective controls can be incorporated into the strategy.

Most breaks and leaks on water mains and service connections occur because of a combination of factors, rather than any single influence. Figure **7**-**5** shows, conceptually, the relationship between water pressure, main break frequency and other contributory factors.



(Source: AWWA M36 Third Edition)

Figure 7-5 Failure Rate Relationship with Pressure

As water pipes deteriorate over time due to corrosion, traffic loadings, pressure transients, and other local and seasonal factors, the pressure at which failure occurs gradually reduces until at some point in

time, break frequency starts to increase significantly. Pressure management rationale suggests that surges and excess pressures should be removed where possible in order to keep the operating pressure away from that point where the failure rate increases significantly, thus extending the life of the individual infrastructure components.

7.2.2.2 Reduction in the Flow Rates of Breaks and Background Leakage

Section 3.2 explains the influence of pressure on leakage flow rates, based on the FAVAD principles. The reduction of pressure in a zone results in a reduction in the flow rate of a leak through breaks, cracks, joints, or fittings in that zone. The N1 value for small systems, zones or DMA, which can be calculated via a pressure step test in the field, could then be used to estimate the reduction in leakage from a reduction in pressure.

Some components of consumption also vary with pressure, and can be represented using an exponent N3 in the FAVAD equations. N3 exponent values range from 0 (pressure independent for example after a storage tank) to 0.5 (open tap) or 0.75 (for sprinkler systems with numerous small orifices). The FAVAD concept can be used to predict the effect of pressure management (at different times of day) on different elements of consumption. The higher the N3 value, the greater the potential for controlling some elements of consumption via proactive pressure management.

7.2.3 Potential Concerns with Pressure Management

Designing pressure managed areas, within a DMA configuration or otherwise, is a new concept to most North American water utilities. While the impacts of excessive pressure levels and transients are intuitively clear to utility operators, it is common for the same operators to be apprehensive about reducing pressure; fearing that pressures might become so low as to generate customer complaints or impair fire fighting capability.

The primary concerns for water utilities in maintaining minimal water pressures are to satisfactorily meet customers' varying water demands, provide sufficient pressure for fire fighting flows, and to minimize the possibility of backsiphonage of contaminants. The pressure level determined to be the minimally designated service level requirement is ultimately determined in a case-by-case manner in individual distribution systems. By carefully assessing the above three design factors, it is possible to define the low limits of the pressure reduction, below which system operation may be negatively impacted in some way. Some of the typical concerns for water utility managers when assessing pressure management are presented in the following sections.

7.2.3.1 Adequate Fire Flow Capability

The design process should include a careful review of the types of buildings and potential fire risks existing in the area, as well as a review of prevailing national fire guidelines, such as those from the National Fire Protection Association (NFPA), and any state, provincial or local building or fire safety codes that apply. There are various alternatives to maintain the required pressures in a system with a

pressure management scheme. One alternative is to have multiple feeds into a sector, controlled by pressure reducing valves (PRV) with flow modulated capacity. This will provide the sector with sufficient hydraulic capacity to maintain pressures and flows for fire protection as required. If there is a fire, the valves will automatically regulate pressure as determined by the demand requirements and the operating limits. For systems that do not have flow-modulated valves, they may have a large sleeper valve either in parallel with the main operational valve or at a different strategic entrance to the sector. This larger valve will open when the system pressure drops due to additional head loss created by the fire flow.

7.2.3.2 Reduced Revenue from Reduced Consumption

First, it is important to understand consumption-pressure relationships. Secondly, if water conservation is an objective of the water utility, pressure management can be tailored to assist this goal. Discussion on these two points follows.

In residential buildings over one half of consumption occurs from uses that are volumetric; meaning water fills a tank or basin of a fixed volume so that the same amount of water is consumed, regardless of the system pressure. Toilets, washing machines, bathtubs and other basins are common volumetric uses. Hence reductions in customer consumption from reduced pressure levels are usually not nearly as significant as perceived.

Where outdoor water use for irrigation is a significant part of consumption, pressure reduction may have some impact on revenue. However, utilities with high levels of outdoor consumption are often located in areas where water is not a plentiful resource and reductions in irrigation use might be considered a desired conservation measure that is being matched with an appropriate water rate structure to moderate impacts on the revenue stream.

Many North American water utilities are undertaking water conservation programs, and frequently tailor specific water rates as part of the effort. The cost of these programs incorporates the cost of lost revenue which is usually less than the cost of development of new water resources and supply infrastructure. Pressure management can clearly assist a water conservation program by reducing distribution side losses and direct pressure water use. For water utilities with constrained water resources and water conservation programs, pressure management can serve as an effective tool in assisting the reduction of water demands.

Systems with high leakage volumes will almost always see a positive benefit from pressure management – even when stacked against a potential loss of revenue – due to reduction of delivery pressure for metered consumption. This is also true for systems with lower losses and high costs to produce or purchase water. The tradeoff in leakage reduction benefits gained vs. any reduction of revenue can be estimated and taken in account in the cost-benefit analysis of the leakage management strategy.

In situations where a revenue loss is predicted and cannot be tolerated, pressure reduction can be limited to minimum consumption hours, when legitimate consumption is at the lowest level and system pressures are likely to be at the highest level of the day.

7.2.3.3 Reduced Hydraulic Reliability

If good reliability exists in an "open" area of a water distribution system, then adequate reliability can be designed into the pressure managed configuration. Typically a primary supply feed providing routine flows coupled with a larger emergency feed, should be adequate in most applications. A second emergency feed (three feeds in total) can be added if circumstances dictate. Additional emergency feeds can be added in like manner if needed, but if managing a DMA, each additional feed brings forth the need for an additional flow meter, PRV and increased complexity in the design.

If it appears that many feeds are needed to adequately supply a particular area, perhaps the proposed size of the area is too large and the area can be segmented into two or more areas. Pressure management or pressure reduction should be carefully designed when applied to large zones which may include storage tanks or reservoirs, or transmission mains which are responsible for transporting water from one part of the system to another. If available, a calibrated hydraulic model may be used to model the effects of pressure reduction on the system's ability to transport water from one point to another and to fill storage. Hydraulic models can be used to predict the function of any area before it is put into use.

7.2.4 Approaches to Optimized Pressure Management

A number of different approaches exist to incorporate optimized pressure management into water distribution operations such as pressure zones, pump controls, and pressure reducing valves.

Other means also exist to maintain good pressure management in a water distribution system. However, the above represent the most basic and common means in use and these approaches should be carefully considered if they are not already in use in the water utility.

7.2.4.1 Pressure Zones

Due to variations in topography, pumped pressure zones are established to ensure minimum pressures can be provided to critical areas, particularly to sections of the water distribution grid at higher elevations. Pressure zones represent the broadest level of sectorization, with DMA the finest level of sectorization, in many water utilities throughout the world. Pressure zones represent the most basic method of configuring the water distribution system for efficient pressure management, and are in common use in many North American water utilities. Sub-sectors within pressure zones, such as DMA, are divided either naturally or by physical valving. Pressure zones are usually quite large in medium- to large-sized water utilities and often have multiple supply feeds; therefore they do not usually develop localized hydraulic problems because of valve closures. Systems with gravity feeds are usually configured based upon ground elevations and systems with pumped feeds configured depending on the level of elevated tanks or storage reservoirs. The boundaries of existing pressure zones, and the typical pressure variations within them, should be well understood in the planning of a pressure management strategy.

7.2.4.2 Pump Controls

Pumps are common in almost all water distribution systems, and are typically activated and de-activated depending upon system water demand. Good pump control schemes incorporate a slowly starting, and slowly stopping valve on the discharge side of the pump which inhibits the creation of transients in the distribution system, thereby minimizing risks of resultant leaks and breaks on system piping. Pumping systems employing variable frequency drives (VFD) can often meet widely varying water demands with fewer pump changes than systems without VFDs. Improvements in hydraulic efficiency, such as use of VFDs, might also be accompanied by improved energy efficiency. It is likely that many water distribution systems encounter a number of pump-related surges each day, and an opportunity for cost-effective refinement of pump operations exists in these systems.

7.2.4.3 Pressure Reducing Valves

Pressure reducing valves (PRV) are commonly used in water distribution systems and other hydraulic applications. PRVs are designed to automatically reduce an inlet pressure to a designated lower outlet pressure, and maintain the constant outlet pressure despite varying flows. This type of control is known as fixed outlet control. Separate electronic controllers can be connected to PRVs to provide a range of additional control capabilities. Since topography can present great challenges in providing consistent pressures in many water distribution systems, PRVs are highly effective in reducing excessive pressures in certain sections of a distribution grid subject to widely varying pressure.

7.2.4.3.1 Mechanisms for Pressure Reduction Control Using PRVs

Pressure reduction can be employed in various manners, each with advantages for certain applications. The level of sophistication usually depends on the distribution system condition, the components of loss and the ability of the utility to maintain the equipment. Care should be taken when sizing a PRV or other control valve, to check the potential head-loss through the valve assembly (gate-valves, filter, meter, control-valve and pipe fittings), especially when the pressure during the peak hours is already low (as is often the case in systems with weak hydraulic capacity or small or corroded pipes) and modulated control is only desired during off peak times. If care is not taken, supply may be constrained during peak hours resulting in no water or low pressure complaints. Common pressure reduction control methods are listed below:

- **Fixed outlet control** – is the traditional method of control, typically using a hydraulically operated PRV or similar control valve. This method is effective in areas of uniform supply characteristics, pipelines with good flow carrying capacity and low head losses, and water demands that do not vary greatly due to seasonal changes. This type of control is common in North American utilities, however, in many of the applications, systems tends to be over pressurized at off peak times
- **Time based modulation** – the pressure regulating capabilities of a PRV can be modified by using a separate electronic controller with an internal timer, connected to the PRV. Control is affected in time-bands in accordance with demand profiles. This methodology is very effective for areas with stable demand profiles and moderate pipeline head-losses, and is usually used

where project cost containment is important, but advanced pressure management is desired. Time based modulation controllers can be supplied with or without data loggers or remote communication links to SCADA or central control centers. Some manufacturers connect the controller to the pilot valve of the PRV and alter the set point of the pilot valve by introducing a force against the existing force of the pilot spring. Other manufacturers use a timer and a solenoid valve to re-route control through preset pilots. This type of control is not recommended for use as a sole means of advanced pressure control in North America as the timer will not respond to increased needs for high flows in an emergency such as a sudden high fire flow demand. The use of a time based controller to control the second valve in a two valve supply ensures that pressure can be dropped below that of the fixed outlet pressure. In this case the main valve, if it is on a flow based modulation, ensures additional supply can be made available for emergency demands as required.

- **Flow based dynamic modulation** – this is a more efficient type of control for areas with changing conditions, pipelines with poor flow carrying capacity and notable head-loss, considerable fire flow requirements, and the need for advanced proactive pressure management to reduce leakage losses. This type of control is implemented by controlling outlet pressure in relation to demand, by connecting a separate electronic controller device to a metered signal output from a flow meter measuring the water supply input to a zone or DMA. As water demand increases, the controller increases outlet pressure; and as water demand decreases the controller reduces outlet pressure. Modulation of outlet pressure (within predetermined maximum and minimum settings) is achieved by altering the force against the regular hydraulic pilot spring ensuring that, if the controller fails, the hydraulic pilot on the PRV will return the PRV to its highest hydraulic outlet pressure setting, thus providing a failsafe feature. The controller is normally supplied with a local data logger and optional remote communications. Flow based pressure modulation combats the effect of head-loss in the system ensuring that critical points where pipe diameters are often smaller, and therefore mechanically weaker, receive a smooth constant lower pressure.
- **Remote node control** – is affected by controlling the outlet pressure of the valve in conjunction with the pressure at a remote location or "node" in the area. The critical point is often selected as the node. This method requires the use of a communication link to continuously relay the pressure reading at the node or critical point to the PRV site. This can be done via a SCADA System, GSM telephone technology or similar communication mechanism to pass the critical point pressure signal to the PRV or electronic controller. This type of control is often affected with non-hydraulic electrically actuated valves of larger diameter.

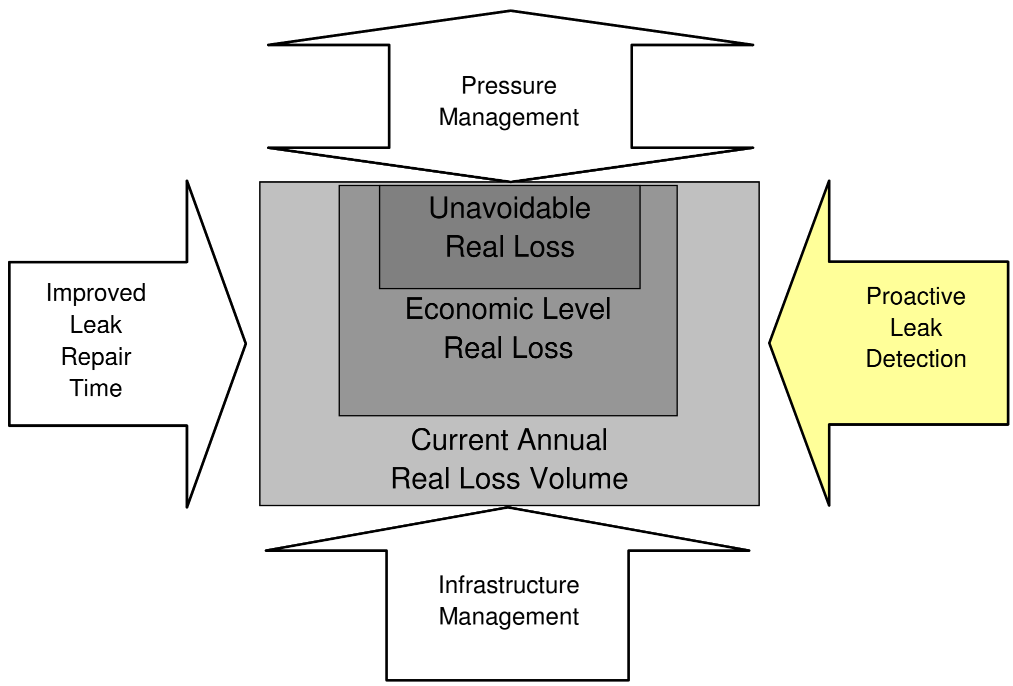
Component analysis shows that in many cases the smaller diameter mains and services which are often found at the extremities of the system - which are often also the critical points - have a higher break frequency than the larger diameter mains found at the entrance to most districts. In cases of very high break frequencies in small extremity mains, both the flow based pressure modulation mode and remote node based pressure modulation mode have the effect of reducing volumes of real loss and frequencies of new leaks.

7.3 Proactive Leak Detection

Leak Detection is the technique of pinpointing the location of distribution system leaks. Water utilities usually practice leak detection in one of the two approaches below:

- Proactive Leak Detection – In this approach, utilities deploy resources and equipment in order to actively detect leaks that are currently running undetected.
- Reactive Leak Detection – Under this approach, practiced by most utilities in the US, the utility does not seek to actively identify leaks that are not visible or causing supply problems. Instead, utilities respond to leaks only when they are brought to the attention of the water utility. This typically occurs when they become visible on the surface or when they cause a drop in pressure to a customer.

Proactive leak detection, discussed in this section, is one of the four tools against real losses (see Figure **7**-**6**) and an essential part of an effective active leakage control program. As mentioned in section 7.1, proactive leak detection could be optimized when used in conjunction with DMA.



(Source: Water Loss Task Force)

Figure 7-6 - Four components of a proactive real loss management program

All drinking water utilities should employ some form of regular leak detection; either provided by their own staff or contracted services. It is best to have leak detection capabilities on an ongoing basis; leak detection that only covers portions of the distribution system every several years ensures that a backlog of unreported leaks will grow and run at length, causing unnecessary real losses.

Some of the many benefits of a proactive leak detection program include:

- Reducing leakage reduces the production costs to treat and energize the water that is being lost.

- Reducing leakage may help to avoid or defer capital expenditure needed to develop new resources for water supply to meet the needs of a growing service area.
- Helps prevent damage to the infrastructure if leaks are found and repaired before they can cause a catastrophic failure.
- May reduce the amount of treated water that is entering the sewer system – adding unnecessary loading to the wastewater treatment process.
- Reduces the liability to the utility.
- Increased supply standards and reliability.
- Has a positive impact on the public perception of the water utility.

7.3.1 Leak Detection Equipment

Leak detection equipment is available in a wide range of technologies, capabilities, and prices. Hence a good understanding of the nature and occurrence of real leakage losses enables the water utility operator to select the most appropriate technology.

The most commonly used equipment for detecting leaks are based on acoustic principles, detecting noise generated by leaks. Leak sounds vary depending on the type of leak, type of pipe, backfill material, and whether a water-filled cavity has formed around the leak. In general leaks produce the following sounds:

- Friction sound – The sound created by water forcing its way through the pipe wall and making vibrations along the pipe.
- Fountain sound – The sound of water circulating around the leak site.
- Impact sound – The sound of a leak impacting on the walls of the hole around the leak and the sound of the impact of rocks, which are often thrown around the leak.

The noise generated by a leak will be influenced by pressure, pipe material and size, type of leak, the surface covering the pipe, and soil moisture. In general, higher pressures generate higher quality noise and vice versa. Therefore, the most effective time for sounding in densely populated areas is usually between the hours of 2 AM and 4 AM when system pressure is usually at its highest levels and other noise sources are at its minimum level. Metallic pipe materials, such as cast iron, steel and copper, are better for leak noise detection than plastic pipes and internally lined or externally wrapped pipes.

Several commonly used acoustic leak detection equipment are discussed in the following section. Non-acoustic leak detection techniques, such as tracer gas and ground penetrating radar (GPR), may also be used for leak detection.

7.3.1.1 Acoustic Leak Detection Equipment

7.3.1.1.1 Mechanical and Electronic Listening Stick

The listening stick, probe rod, or similar name describes a traditional instrument used to systematically sound all mains fittings and service connection pipes. There are various designs, the most common

having an earpiece attached to a steel shaft. The listening stick is used by placing it on a fitting, whereby any leak noise is transferred from the pipe, through the steel shaft and is heard at the earpiece.

The electronic listening stick is used in the same way as the mechanical version, but has a battery powered sound amplifier attached so that the leak noise is enhanced and then heard through headphones. The electronic listening stick is utilized in areas of low pressure, where leak noise is weak and requires amplification. It is also useful for direct sounding in areas where there may be high noise interference from passing traffic.

7.3.1.1.2 Ground Microphone

Ground microphones (geophones) are listening devices mostly used to listen for leaks from the surface where contact points such as valves, hydrants, service connections, and the like are far apart. Ground microphones are also used to pinpoint the exact location of a leak. Ground microphones are usually used in conjunction with other leak detection equipment, although it can be used alone, especially in areas with few fittings and predominantly plastic pipe.

7.3.1.1.3 Leak Noise Correlator

A leak noise correlator finds leaks the same way as traditional sonic equipment, detecting the sound generated by the leak. However, they are used to pinpoint the exact location of a leak, not just to detect a leak in a general area.

It typically consists of a receiver and processor unit and two sensors equipped with a radio transmitter. The two sensors are placed on valves or hydrants on each side of a suspected leak. The leak noise detected by the sensors is converted into electrical signals and then transmitted via the radio transmitters to the correlator unit. Leak sound travels along the pipe with a constant velocity depending on the pipe diameter and pipe material. The leak noise will first arrive at the censor closer to the leak. The correlator uses the time difference between the two arrival times, information about the pipe material and size, and the distance between the two sensors to calculate the location of the leak.

7.3.1.1.4 Leak Noise Loggers

Noise loggers are installed at fittings and programmed to automatically monitor system noise and listen for signs of leakage at night. The usual logging period is between 2 AM and 4 AM. Nighttime logging has the dual benefits of increased intensity of leak noise due to higher pressures and the absence of interfering ambient or consumption sound. It is important to point out that nighttime irrigation will affect the results generated by the leak noise loggers. Leak noise loggers can be installed permanently or be moved from location to location depending on the need.

Leak noise loggers do not pinpoint the location of the leak; they give an indication that there is a leak present within the vicinity of the logger. Hence, the leak pinpointing needs to be carried out by an operator using any of the equipment presented in the previous sections.

7.3.1.1.5 Digital Correlating Leak Noise Logger

Digitally correlating leak noise loggers combine acoustic noise logging and leak noise correlation. This technology has the advantage of reducing the time span between identification of leak noise and localization of a leak. Nevertheless, it is still highly recommended that the exact location of the leak be verified by a trained leak detection specialist before excavation for the leak repair.

7.3.1.2 Leak Detection Equipment for Transmission Mains

Transmission mains present difficulties when using the acoustic methods mentioned above for detecting leaks. The main reason is the long distance between fittings that can be used as sounding contact points and the fact that leak sound decreases with increasing pipe diameters and increasing distance from the leak. Leak detection equipment better suited for mains is presented in the following sections.

7.3.1.2.1 Sensors Inserted into the Transmission Main

This technology uses the principle of a sensor being inserted in the transmission main, which then travels along with the flow in the pipe picking up any noise generated by a leak. The use of inline transmission main leak detection service is proving to be very accurate, as it has a well established history in the United Kingdom.

7.3.1.2.2 Fiber Optics

Acoustic fiber optics is used for managing and monitoring large diameter mains. A continuous fiber optic cable is installed in the pipeline and the fiber optic cable is then connected to a data acquisition system that allows permanent real-time acoustic monitoring.

7.3.1.2.3 Infrared Technology

Infrared thermography can be used as a method of testing for leaks which do not surface. The underlying principle of this technology is that the water escaping from a leak is of a different temperature than the surrounding ground and can therefore be detected by a thermographic camera. The method has been used successfully for testing transmission mains in rural areas, but is not practical for dense urban areas, where interferences from other underground utilities, such as sewers, would complicate the process. Some operators are also using the method to detect reservoir leakage.

7.3.2 Leak Detection Techniques

The leak detection technique or combination of techniques used by a water utility will most likely depend on the monetary value of water lost through leaks. When deciding on the right techniques it is also important to consider age, condition, and material of the distribution system.

7.3.2.1 Visual Survey

The most basic form of leak detection is the visual survey. A visual survey consists of walking the pipeline routes looking for either leaks which appear above the ground, or in very dry regions, areas that have suspicious green growth patches above the water lines. Leaks on system appurtenances, such as valves, hydrants, and meters, may also be found through visual surveys.

While the visual survey is not the most sophisticated technique, it may still be a useful method to detect leaks, particularly for utilities which have suffered from a lack of good and frequent maintenance.

7.3.2.2 Acoustic Leak Detection Survey

The acoustic leak detection survey is probably the most common and familiar leak detection methodology. Different types of acoustic sounding equipment (discussed in section 7.3.1.1) are used in two different levels of detail, general survey or comprehensive survey.

In a general survey, often referred to as a hydrant survey in the US and Canada, listening devices are used to survey fire hydrants and valves on distribution systems to detect any leak sounds. Fire hydrants can be found at more or less constant distances providing a good coverage in most areas. However, one shortfall is that service connection leaks often go undetected since service connections are not surveyed.

In a comprehensive survey, listening devices are used to all available fittings on mains and service connections. Geophones are used to sound above the mains in case contact points are far apart. Once a leak sound is detected, geophones and leak noise correlators may be used for pinpointing the exact location of the leak.

7.3.2.3 Step Testing

Step testing involves isolating sections of the water distribution system into small zones and measuring the supply to the zone. This is often done on a temporary basis during the minimum nighttime flow period and portable flow meters are used to measure flow into the zone. Every time a section with a leak is isolated, a marked drop on the flow will be seen. This drop represents the leak volume; a valuable information for cost-benefit calculations and program tracking. This method also saves time by directing leak pinpointing crews only to those sections of the water main where leakage has been proven to be occurring.

However, there is a fundamental problem with the step testing that should be mentioned. In theory, when one section of the test area is isolated, if there was leakage in that section, the flow into the test area will decrease by the amount of leakage in the isolated section. But, this will also increase the pressure in the areas not yet isolated which will also increase the leakage in those areas. The increased leakage in the areas not isolated may cause for the leakage in the isolated area to be underestimated or, in the worst case to be completely masked. This scenario is common in zones where several leaks are present. Therefore, it is necessary to carefully evaluate if a step-test is the appropriate method to be used.

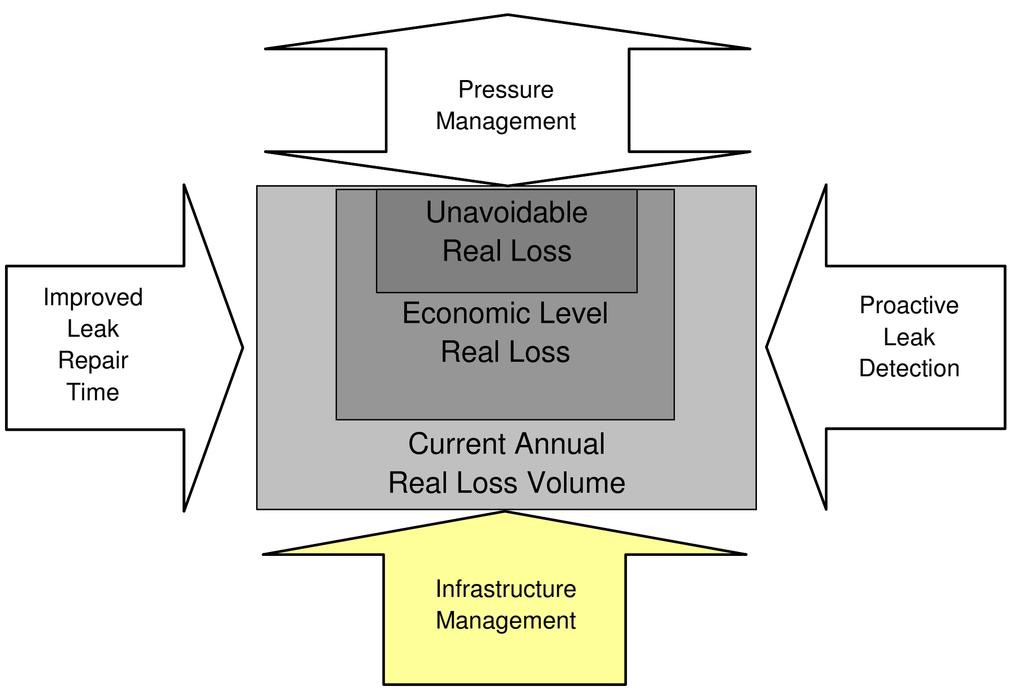
7.3.2.4 Leak Noise Logger Survey

Noise loggers are installed on pipe fittings such as valves and hydrants. They are programmed to listen for noise generate by leaks, typically recording at 1 second intervals during the night when background noise is likely to be lower. By recording and analyzing the intensity and consistency of noise, each logger indicates the likely presence or absence of a leak. They can be installed permanently or temporarily in the distribution network.

8 Infrastructure Management

Even the best-maintained water distribution piping and infrastructure eventually serves its useful life and requires rehabilitation or replacement if it is to continue to provide reliable service. In managing water losses and maintaining infrastructure, water utility managers can strive to ensure that infrastructure assets are maintained to attain their maximum life. Only then is the asset lifecycle optimized. Providing the appropriate balance of effective water loss control functions of active leakage control, pressure management and optimized repairs will extend the life of piping assets to their ultimate range.

Infrastructure management forms one of the four pillars to the successful control of real losses in water utilities (see Figure **8**-**1**), and it is essential that water utilities have a program to renew their infrastructure as it reaches the end its service life.



(Source: Water Loss Task Force)

Figure 8-1 - Four components of a proactive real loss management program

8.1.1 When to Replace or Rehabilitate

Rehabilitation and replacement create new pipeline assets. While this is ultimately necessary for all pipeline assets, it is also the most comprehensive, costly and involved of all of the pipeline management options. Therefore, every effort should be made to extend the service life of piping to the ultimate level, before renewing it.

Some common reasons to replace or rehabilitate pipelines include:

- High break or leakage rate
- High occurrence of joint leaks
- Encrustation or corrosion (internal or external)
- Hydraulic carrying capacity
- Structural reinforcement
- Threat to life or property

From a water loss reduction perspective the decision to replace or rehabilitate a pipeline should be based on a cost to benefit analysis. The cost to replace or rehabilitate the pipeline in question and the life span of the proposed intervention should be compared to the cost of not carrying out the proposed intervention. When considering the costs of not replacing or rehabilitating the pipe, the following components may be considered:

- Average historic break frequency
- Cost of volume of lost water
- Cost of damage caused by breaks
- Cost to repair the pipeline
- Cost to reinstate the surrounding area.

Other factors that might also influence the decision on whether to replace or rehabilitate a pipeline include:

- Environmental considerations
- Health concerns
- Structural problems
- Emergency hazards
- Demand growth
- Reduced hydraulic capacity
- Lack of alternative supplies

8.1.2 Pipe Replacement and Rehabilitation Methods

Many options exist for rehabilitation and renewal of water distribution system assets. A brief discussion some of these methods is presented in this document. More information on these methods could be found in a variety of AWWA publications in its Manual of Practice series:

- Concrete Pressure Pipe (M9)
- Steel Water Pipe – A Guide for Design and Installation (M11)
- PVC Pipe – Design and Installation (M23)
- External Corrosion: Introduction to Chemistry and Control (27)
- Rehabilitation of Water Mains (M28)
- Ductile Iron Pipe and Fittings (M41)
- Fiberglass Pipe Design (M45)
    - PE Pipe – Design and Installation (M55)

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Secondary Research Report B – Literature Review
Link between Water Supply and Energy Consumption

CONTENTS

Literature Review Summary

Background

As part of the secondary research component of the "Water Leak Detection Program and Water System Loss Control Study" an extensive literature review was undertaken with a special focus on publications discussing the link between water supply and energy consumption. A total of 17 national and international publications were reviewed. The following sections summarize the findings of the literature review.

Water Supply Schemes in California

Water is an energy intensive resource in California mainly because natural sources of water are located far from major urban and agricultural centers. This situation has created the need for large infrastructure projects to capture and store water where it is available; and to convey water to where it is needed.

The main sources of water in California are located in the northern and eastern mountainous parts of the state; while the major urban centers are in the western coastal areas of the North Bay and Southern California, and the major agricultural lands are in the Central Valley. Water supply and demand in the state are balanced by transferring water from sources in the northern and eastern regions to the areas of need in the rest of the state. These interbasin water transfers are delivered through complex aqueduct systems that include numerous reservoirs, thousands of miles of canals, and pump stations, among other facilities. Some of the major conveyance systems in California are the Central Valley Project (CVP), the State Water Project (SWP), the Colorado River Aqueduct, the Hetch Hetchy Regional Water System, the Los Angeles Aqueduct, and the Mokelumne Aqueduct. These facilities deliver approximately 11.4 MAF a year (Cohen, Nelson, and Wolff 2004).

Energy, mostly for pumping, is required by the aqueducts to deliver water across the state. The amount of energy required depends on the source of water and the delivery location. Water from Northern California delivered to Southern California requires more energy than the same water delivered to the Central Valley. Some of the conveyance systems, such as the CVP and the Hetch Hetchy Regional Water System, produce more energy than they require through hydroelectric generation plants along the system. However, other conveyance systems do not produce energy and require more energy than the amount they can produce. The SWP is still the largest single user of energy in California, accounting for 2 to 3 percent of all electricity consumed in the state (Anderson 1999).

Energy intensity is defined as the amount of energy required to use one unit of water in a specific location. This quantity includes the energy requirements of all the steps in the water supply chain: supply and conveyance, water treatment, distribution, end use, and wastewater treatment. Typical units for energy intensity are kilowatt hour per acre foot (kWh/AF) or

kilowatt hour per million gallons (kWh/MG). The energy intensity of water in California is highly variable since it depends on many factors, such as the original source of the water, the conveyance distance and method, the type of water treatment, and the point of delivery, among others.

Supply and Conveyance

Energy for the supply and conveyance of water contributes significantly to the energy intensity of water in California. Energy in the supply and conveyance step is required to extract water from the source and convey the water to the next step in the water supply chain. Depending on the source, the extraction may require significant amounts of energy, like deep groundwater wells, or may generate energy, like some aqueduct systems with hydroelectric plants. The energy intensity for conveyance will also depend on the location of the next step. For example, the energy intensity of water delivered from the SWP may range from 676 kWh/AF to 3,236 kWh/AF depending on the delivery location (Kline et al. 2005).

The next step in the water supply chain depends on the end use for the water. Water for agriculture usually does not require additional treatment and is therefore delivered to the end user. On the other hand, water for urban uses is typically conveyed to a water treatment facility.

Potable Water Treatment

Water treatment facilities use energy to pump and process water. From a survey of more than 30,000 public supply systems in the United States, the Electric Power Research Institute estimates the average energy intensity of water treatment facilities with a capacity of at least 1 million gallons per day (MGD) to be 1,422 kWh/MG, equivalent to 463 kWh/AF (Klein et al. 2005). Nevertheless, the amount of energy required for treatment depends on many factors, such as source-water quality and specific treatment processes within the facility. High quality groundwater may require little treatment; surface water taken from rivers that have upstream discharges of wastewater may require significant treatment. Conventional water treatment processes are generally not energy intense, relying mostly on gravity and chemicals for sedimentation and filtration processes. However, future changes in water quality regulations may require more energy-intensive water treatment technologies such as membranes, ultraviolet disinfection and ozonation. Desalination processes, which are mostly based on either thermal distillation or membrane filtration technologies, are also very energy intensive.

Distribution of Water

Energy use for the water distribution step is primarily for pumping water to the end user and maintaining sufficient pipe pressure in the distribution system. The amount of energy required for distribution depends on the topography and size of the service area as well as on the age of the system. The California Energy Commission (CEC) has adopted an energy intensity of 1,272 kWh/MG (414 kWh/AF) for the prototypical water distribution system (Navigant Consulting, Inc. 2006), although it suggests the development of estimates of energy intensity for different

topographies and distances. Gravity pressurization and distribution may also be possible when reservoirs are sufficiently higher than the end users, reducing the need for electric energy or shifting the energy demand to off-peak hours. Nevertheless, some distribution systems are maintained at excessively high pressures. Excess pressure relates to excess friction losses in the distribution network which destroy energy (Cabrera et al. 2009). Excessive pressures in a distribution system are also likely to cause more frequent line breaks and increase the volume of leakage from the system. Reducing the pressure in distribution systems reduces the energy intensity of water directly by reducing the amount of energy used for pumping in the system and indirectly by reducing the leakage volume lost in the system.

End Use

Water users consume energy by further treating water, with softeners or filters; circulating and pressurizing it; and, heating and cooling it. An analysis on the energy intensity of various water supply alternatives for San Diego County Water Authority (SDCWA) by the Natural Resources Defense Council concludes that the end use constitutes the largest component of energy embedded in the urban water-use cycle of that area (Cohen, Nelson, and Wolff 2004). This was an unexpected outcome considering that San Diego County imports most of its water from long distances, requiring large amounts of energy for conveyance. The total energy intensity for the current sources of water in SDCWA was estimated at 6,900 kWh/AF, with 56% percent of that amount for end uses compared to 30% for source and conveyance.

Wastewater Treatment

The energy requirements of wastewater collection and treatment depend primarily on the characteristics of the waste water, the level of treatment, and the distance and elevation of the wastewater treatment plant in relation to the wastewater sources. Electric loads at wastewater treatment plants consist mainly of pump motors, air blowers, injection equipment, controls, sludge handling systems, and in some cases ultraviolet light disinfection and ozonation.

Summary of Current Water-Energy Proxies in California

The CEC published a report estimating prototypical intensities of water-related energy consumption in California by each step of the water-use cycle (Navigant Consulting, Inc. 2006). These values are presented in the following table. Energy intensity in end uses was excluded from these values because the primary objective of the proxies is estimating the energy embedded in water saved.

Table 1. Recommended Water-Energy Proxies

	Indoor Uses		Outdoor Uses	
	Northern California (kWh/MG)	**Southern California (kWh/MG)**	**Northern California (kWh/MG)**	**Southern California (kWh/MG)**
Water Supply and Conveyance	2,117	9,727	2,117	9,727
Water Treatment	111	111	111	111
Water Distribution	1,272	1,272	1,272	1,272
Wastewater Treatment	1,911	1,911	0	0
Regional Total	5,411	13,022	3,500	11,111

Source: *Refining Estimates of Water-Related Energy Use in California*, Navigant Consulting, Inc.

The estimates presented above were adjusted to account for losses of water throughout the water supply steps. The assumed losses are: 5% for conveyance, 5% for water treatment, and 6% for water distribution. Reducing system losses is identified as a strategy to increase energy efficiency. Reducing the amount of water lost in traveling from the source of supply to the retail customer in turn reduces the amount of water that needs to be moved and treated to meet end-use requirements, resulting in energy savings equal to the amount of energy required to move and treat the reduced amount of lost water. In 1991, a program to identify energy and water losses in the state of Tennessee estimated savings of $24.4 million per year at a cost of $2.7 million for 278 water utility (Thornton 2002). Included in the avoidable cost is 72,698,052,000 avoidable Btu's, representing $1,496,860 of energy savings.

Water conservation at the end user has also been identified as an important step for energy conservation. For instance, the water conservation program developed by the Santa Clara Valley Water District (SCVWD) has saved approximately 300,000 acre feet (AF) since the program began in 1992, while the water recycling program has saved 68,200 AF of water since the program began in 1998 (Larabee and Ashktorab 2007). The SCVWD estimates the total energy savings of both programs to be approximately 1.42 billion kWh.

California urban water use in 2000 was estimated at 8.7 million acre feet (MAF) (DWR 2005). The California Department of Water Resources (2005) has estimated that by 2030 urban water needs may be between 10.2 MAF and 14.7 MAF, depending on assumptions of population growth, development patterns, industrial production, and water conservation, among other factors. However, an investigation by The Pacific Institute (Gleick, Cooley, and Groves 2005) estimates that urban water needs could be reduced to 8.4 MAF by 2030, representing a 6% reduction from current urban water use. The Pacific Institute's scenario is based on widespread adoption of existing water-efficiency technologies, not on the invention of new efficiency options, and on different estimates of water prices and trends.

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Energy Down the Drain- The Hidden Costs of California's Water Supply

August 2004

By Natural Resources Defense Council (NRDC)

Overview

Water use and energy use are closely linked, but are rarely integrated in policy or planning activities. This report explores the energy implications of water use and presents a methodology for incorporating energy impacts into water resource decisions. This methodology includes a model for how policymakers can calculate the amount of energy consumed in water use. The report also discusses policies, such as subsidies for water, energy, and farming, which contribute to energy intensive water projects. Points out that current water planning practices do not take into account energy considerations.

A key concept of the water-energy connection is the energy intensity of water. This is defined as: "The total amount of energy required to use a specific amount of water in a specific location. Energy intensity takes into account each site-specific step in the water supply-use-disposal cycle: source and conveyance, treatment, distribution, end use, and wastewater treatment."

This report describes the link between energy and water use at all the stages of the water supply chain: source and conveyance, treatment, distribution, end use, and wastewater treatment. For each of the stages it provides the energy requirements or energy intensities of specific facilities, but does not provide general figures of intensity at a state level. As an example of energy intensity in the source and conveyance stage, the report presents that on average, pumping one acre-foot of State Water Project water to Southern California requires approximately 3,000 kWh (this is an average net energy use figure; actual energy use varies for different Southern California communities).

End uses are identified as the largest consumer of energy in the water-supply-use chain. Once a customer receives water, additional energy may be needed to heat, cool, purify, or pump that water in preparation for its intended use. As a result, they conclude that water conservation programs hold enormous energy conservation potential. The report presents the energy (in kilowatt hour per year) and cost savings of various conservation measures at the end users (efficient shower heads, faucets, appliances, etc.).

The only mention of water losses in the distribution system is presented below:

"Many urban water distribution systems were placed underground more than 50 years ago, and leaks caused by corrosion of pipe material or other problems can lead to the loss of significant amounts of potable water. Distribution system losses increase the energy intensity of water supply by requiring utilities to treat and convey water that will be lost. Losses vary significantly among urban suppliers: typically from 6 to 15 percent, but as high as 30 percent. Approximately

2 percent of this lost water goes to unmetered use for firefighting, construction, and flushing drains and hydrants."

The report provides three case studies on how taking energy consumption into consideration can affect the outcome of an analysis of water source alternatives. One case study is for increasing water supply for San Diego County Water Authority (SDCWA) and two case studies for water for agricultural uses.

The SDCWA is attempting to find additional water sources to meet its current and projected water demands. Efforts to develop these supplies are well under way and are specifically targeting seawater desalination as the preferred alternative. However, the preliminary results of the analysis indicate that conservation and recycling appear to be the most energy efficient sources of water if local surface supplies are not available.

The next case study evaluates three alternatives for the disposition of the water formerly used to irrigate retired lands in the Westlands Water District: the water could be used to enhance environmental flows in the delta; it could be used on other land within the district; or it could be transferred to other agricultural or urban uses. The analysis indicates that dedicating water from retired lands to environmental flows in the delta would have the greatest energy benefits. Transferring water from Westlands to urban locations would significantly increase energy use. As an example, the data from the San Diego case study is used to estimate the energy use that would result if the water conserved were transferred to San Diego. Total energy use would increase by more than eight times the energy use in the status quo: more than 1.2 billion kWh/yr.

Applicability to Water-Energy nexus

The whole document is about the water-energy nexus. Presents a model to quantify the energy intensity of water for specific conditions.

Provides data on energy savings due to reduced water consumption

Provides data of energy reduction by reduction in the end-use stage of water (shower heads, toilets, appliances, etc.). Provides examples of energy savings for specific utilities.

Provides data or information on link between distribution network efficiency improvements and energy savings

Mentions the example of Fresno, where they used SCADA and more efficient pumping to reduce their operational costs and provide better control of water-line pressure, which reduces leakage. However, they don't provide more detail or any raw data.

Provides data or information on energy use by water systems

Provides examples of energy use by water systems at all stages of the supply chain throughout the document.

Better than the Sum of their Parts: Taking Advantage of the Water-Energy Nexus to Create Dual-Funded Partnership Programs

2008 ACEEE Summer Study on Energy Efficiency in Buildings

Mikhail Haramati, California Public Utilities Commission

Overview

Partnerships between water and energy agencies are becoming a valuable tool to enhance funding for resource conservation programs. This paper presents a series of steps partner agencies can use to determine what level of program co-funding is appropriate, how benefits should be calculated for each agency, and the nature of partnerships most likely to succeed. The paper focuses on programs which are not cost-effective for one agency to fund exclusively, but that may be cost-effective if funded by other entities who would also receive benefits.

The paper proposes allocating the costs of the programs between the agencies in the same proportion as the benefits received by each agency. The Embedded Energy in Water Calculator produced by the California Public Utilities Commission (CPUC) was used to quantify the likely energy benefits and costs of the proposed program. The main drawback of the calculator is that it only calculates the benefit from energy conservation without attempting to determine the benefit from water conservation. Determination of water conservation benefits requires the development of water agency specific avoided water costs.

The energy benefits are calculated based upon the annual water use reduction attributed to each measure and converted to annual electricity and gas use reduction. The conversion of water use reduction to energy use reduction is calculated based on the water savings and the supplying water agency energy use related to water treatment and distribution.

These calculations include only the “embedded” energy from the water agency side of the water meter. Many hot water use reduction measures have already proved cost-effective in energy efficiency programs. Consequently, this effort focuses on cold water use reduction. However, the calculator does not include energy use by the California Department of Water Resources (operator of the State Water Project) or the Western Area Power Administration.

Applicability to Water-Energy nexus

Method for calculating the cost and benefit of water conservation measures for energy and water agencies in a partnership.

Provides data on energy savings due to reduced water consumption

Provides a method for determining the avoided energy costs for water conservation measures.

Provides data or information on link between distribution network efficiency improvements and energy savings

It does not provide data on the link between distribution network efficiency improvements and energy savings.

Provides data or information on energy use by water systems

It does not provide data on energy use by water systems.

From Watts to Water – Climate Change Response through Saving Water, Saving Energy, and Reducing Air Pollution

June 2007

Santa Clara Valley Water District

Overview

This report describes the water conservation and water recycling program developed by the Santa Clara Valley Water District (SCVWD). The Water to Air model was used to estimate the energy savings and air emission reductions from their water conservation and water recycling programs.

The residential water conservation programs provides a trained water use efficiency expert to inspect all indoor and outdoor water-using devices, install low flow showerheads, install faucet aerators, replace leaking toilet flappers, and suggest other/ additional ways to improve residential water use efficiency, including improved irrigation system water use efficiency. The residential water conservation program also includes rebate programs for high efficiency clothes washer, high efficiency toilets, and high efficiency water softener. The commercial, industrial, and institutional (CII) water conservation programs offers rebates for any process, technological, or equipment change that conserves water. The SCVWD also offers rebates and technical assistance as part of the landscape water conservation program for the urban sector and the agricultural sector.

Since the District's water conservation programs began in FY 92-93, these programs have cumulatively saved approximately 300,000 AF of water while the District's water recycling programs, in place since FY 98-99, have cumulatively saved approximately 68,200 AF of water. Energy savings resulting from the District's water conservation and water recycling programs were estimated to be approximately 1.42 billion kWh for FY 92-93 through FY 05-06.

Energy savings are estimated for source and conveyance, treatment, distribution, and wastewater treatment steps of the water supply chain. They do not include energy savings from the end uses.

This report assumes water losses of 5% during conveyance, 7% during treatment, and 7% during distribution.

Applicability to Water-Energy nexus

Presents the energy savings in SCVWD resulting from their water conservation and recycling program.

Provides data on energy savings due to reduced water consumption

Presents energy savings specific to the SCVWD water conservation program.

Provides data or information on link between distribution network efficiency improvements and energy savings

No

Provides data or information on energy use by water systems

Presents the energy factors (ratio of energy consumed to water consumed in kilo Watt hours per acre foot) for source and conveyance, treatment, distribution, and wastewater treatment steps of the water supply chain for each source of water. Where possible, these factors are specific to the SCVWD.

Energy Demands on Water Resources – Report to Congress on the Interdependency of Energy and Water

December 2006

US Department of Energy

Overview

The study discusses the interrelation of water and energy. Large amounts of water are needed to produce energy and energy is needed to produce water. Demand for drinking water supplies has limited the production of energy. The study is "a report on energy and water interdependencies, focusing on threats to national energy production that might result from limited water supplies."

Applicability to Water-Energy nexus

Discusses the connection between water and energy, but concentrates more on the aspect of the water required to produce energy.

Provides data on energy savings due to reduced water consumption

No

Provides data or information on link between distribution network efficiency improvements and energy savings

No

Provides data or information on energy use by water systems

Provides general information on energy use by water systems.

Water and Wastewater industry Energy Efficiency: A Research Roadmap

2004

AwwaRF Project #2923

Overview

This report identifies topics and water and wastewater issues where more research on energy efficiency is needed. Specifically addresses the areas of advanced treatment processes, desalination, energy generation and recovery, societal and institutional issues, energy optimization, sustainability, decentralization, and total energy management.

Applicability to Water-Energy nexus

Identifies areas for additional research in the water and energy field.

Provides data on energy savings due to reduced water consumption

No

Provides data or information on link between distribution network efficiency improvements and energy savings

No

Provides data or information on energy use by water systems

No

California's Water – Energy Relationship

November 2005

California Energy Commission CEC-700-2005-011-SF

Overview

This investigation describes the main sources and uses of water in California and the energy intensities of the sources and uses, including agriculture and urban use. Quantitative data of energy consumption and intensity is given for all the steps of the water supply chain. They present estimates of the energy intensity for the source and conveyance of water for the main sources of water in California: State Water Project, Central Valley Project, Colorado River Aqueduct, desalination, ground water pumping, and Recycled Water.

Chapter 3 describes the basic processes of water supply, including treatment and distribution. It presents estimates and general data of the intensities at various treatment steps. Based on a survey of 30,000 public water supply systems, they conclude that there is little variation in the amount of energy required to treat and distribute a unit of water for systems requiring at least 1

MGD. For public water systems with a capacity of at least 1 MGD, the energy required for the distribution of treated water remained fairly constant at 80 to 85% of the total energy requirements of the treatment and distribution systems combined. Based on the survey data, the report assumes the prototypical water distribution system to have an energy intensity of 1,200 kWh/MG.

An interesting fact on energy consumption is that water utilities often must flush water from the tanks to prevent microbial contamination and then fill them up once again. This flushing accounts for the bulk of electricity used in EBMUD's distribution system.

Water end-use applications in California use more energy than any other part of the state's water use cycle. A differentiation of cold water savings and hot water savings is presented for water supply and end uses.

The study suggests using storage to avoid electric use during peak hours. It estimates that 250 MW of peak demand could be saved if water agencies statewide viewed their storage as an energy asset as well as a water asset; and another 1,000 MW of peak demand could be saved from increased treated water storage in urban areas.

Applicability to Water-Energy nexus

The whole document describes the connection between water and energy in all steps of the water supply process for all users.

Provides data on energy savings due to reduced water consumption

Provides data on water, energy, and cost savings for urban users by some utilities implementing the California Urban Water Conservation BMPs.

Provides data or information on link between distribution network efficiency improvements and energy savings

The report describes qualitatively the energy savings in each water supply step by saving water. Energy intensity data shown throughout the document can be used to calculate energy savings from specific sources and for specific uses.

Provides data or information on energy use by water systems

Provides qualitative data on the energy intensity of all steps of the water supply chain.

Life-Cycle Energy Assessment of Alternative Water Supply Systems in California

July 2005

California Energy Commission CEC-500-2005-101

Overview

The study performs a life-cycle assessment to compare supply alternatives for two water utilities in California. The assessment compares the alternatives of importing, recycling, and desalination. The life-cycle assessment takes into account energy consumption and environmental emissions caused by extraction of raw materials, manufacturing, construction, operation, maintenance, and decommission of the water supply infrastructure.

The results showed that, for both utilities, desalination was the most environmentally detrimental option, because that treatment process is so energy intensive. For all alternatives, energy consumed by system operation dominated the results. The operation component of the analysis took into account the energy for the transport, treatment, and distribution phases; fuel use for transporting and disposing of sludge; fuel use for delivery and operational vehicles; and energy use for producing chemicals and other routinely used materials.

Applicability to Water-Energy nexus

Determines the best alternative for a new water supply taking into consideration the energy use of the complete life cycle of various water supply alternatives.

Provides data on energy savings due to reduced water consumption

No

Provides data or information on link between distribution network efficiency improvements and energy savings

No

Provides data or information on energy use by water systems

Energy use associated with the water systems evaluated was quantified using the Water-Energy Sustainability Tool (WEST). This tool employs user-defined input data to evaluate emissions and energy use throughout the life-cycle of the system, including construction, operation, and maintenance.

Refining Estimates of Water-Related Energy Use in California

December 2006 (CEC-500-2006-118)

California Energy Commission

Overview

This study reviews and updates the estimates of water intensity initially published by the CEC in the 2005 report *California's Water-Energy Relationship* (CEC-700-2005-011-SF). The current study reviewed and updated estimates for the magnitude and intensity of water-related energy consumption by segment of the water-use cycle. The study also describes important data gaps

and includes the collection of primary data from water utilities and the disaggregation of data geographically and within water-use cycle segments.

This study focuses on understanding the key drivers of energy intensity values outside of retail water meters—primarily, the energy consumption and intensities of water and wastewater operations. The estimates of magnitude and intensity of water-related energy consumption by segment of the water-use cycle were used to develop a proxy, or representative, valuation of the amount of energy deemed embedded in a unit of water, by virtue of the amount of energy consumed in collecting, extracting, conveying, treating, and distributing the water to end users (upstream embedded energy) and then by treating and disposing of the wastewater (downstream embedded energy).

The estimates presented in this study were adjusted assuming the following system losses: 5% for conveyance, 5% for water treatment, and 6% for water distribution. Reducing system losses is identified as a strategy to increase energy efficiency. Reducing the amount of water lost in traveling from the source of supply to the retail customer in turn reduces the amount of water that needs to be moved and treated to meet end-use requirements, resulting in energy savings equal to the amount of energy required to move and treat the reduced amount of lost water.

It notes that, outside of the retail water meter, supply and conveyance are the segments of the water-use cycle with the highest energy magnitude

Applicability to Water-Energy nexus

The document updates and refines initial estimates of energy intensity in water supplies.

Provides data on energy savings due to reduced water consumption

The report provides data on the energy intensity (in units of kWh/MG) of water at the different phases of the water supply chain, except for end uses. Energy savings could be determined from this data and the volume of water conserved.

Provides data or information on link between distribution network efficiency improvements and energy savings

Indirectly, it adjusts the energy intensity of water to account for the assumed losses at the different stages of the supply chain.

Provides data or information on energy use by water systems

Yes, provides estimates at a California state level of the energy intensity of water at different stages of the water supply chain (except for end uses). See below Table ES-1 from the report.

Table ES-1. Recommended revised water-energy proxies

	Indoor Uses		Outdoor Uses	
	Northern California (kWh/MG)	**Southern California (kWh/MG)**	**Northern California (kWh/MG)**	**Southern California (kWh/MG)**
Water Supply and Conveyance	2,117	9,727	2,117	9,727
Water Treatment	111	111	111	111
Water Distribution	1,272	1,272	1,272	1,272
Wastewater Treatment	1,911	1,911	0	0
Regional Total	5,411	13,022	3,500	11,111

Water Supply-Related Electricity Demand in California

November 2007 (CEC 500-2007-114)

California Energy Commission

Overview

This study sought to determine the amount of electric demand that is related to the treatment, distribution, and disposal of water within California. Water supply-related electrical demands exceed 2,000 megawatts (MW) on peak days in California. Agricultural groundwater and surface water pumping are almost 60 percent of the total water supply-related peak day electrical demand. Water agency demands compose 40 percent of the water supply-related peak electrical demands in the state, with the majority of this demand being for fresh water supply.

The purpose of this report is to obtain a better understanding of the relationship between existing water agency electrical demands and water agency customer water use, and to understand how this water use relates to the associated electrical energy used by the water agency providing this water. Of specific interest is the ability to estimate the amount of electrical load that water agencies can reduce or shift from on-peak to off-peak as a result of time of use (TOU) changes in the water agency customer water use patterns.

The water agency demand was further divided into the residential and commercial/industrial sectors. Typical residential water use profiles were used to determine residential water customer's contribution to utility peak day electrical demands. Over 500 MW of the 2,000 MW water supply-related electrical demands on peak days in California is used for providing water/sewer services to residential water customers. An average residential embedded peak

electrical demand intensity of 1,445 kilowatts/million gallons (kW/Mgal) and 0.06 kW/residence was determined.

Total water related electrical consumption for the state of California amounts to approximately 52,000 gigawatt.hours (GWh). Electricity to pump water by the water purveyors in the state amounts to 20,278 GWh, which is approximately 8 percent of the statewide total electrical use. The remaining 32,000 GWh represent electricity used on the customer side of the meter, that is, electricity that customers use to move, heat, pressurize, filter, and cool water.

This report examines the water supply.related peak day demands of the California investor owned utilities (IOUs): PG&E, Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E). The water supply.related demands of the public electric utilities (e.g., Sacramento Municipal Utility District (SMUD), Los Angeles Water and Power (LADWP), Imperial Irrigation District (IID) etc.) are not included in this analysis. This report also excludes the electrical demand of the State Water Project used to convey water from Northern California to Southern California. The State Water Project was not included in this analysis, primarily because it does not draw off the electric utilities during on.peak hours, and also because it does its own electrical generation. Finally, this report excludes electrical demand associated with customer use of the water, that is, uses on the customer side of the water meter.

Applicability to Water-Energy nexus

This study sought to determine the amount of electric demand that is related to the treatment, distribution, and disposal of water within California.

Provides data on energy savings due to reduced water consumption

No

Provides data or information on link between distribution network efficiency improvements and energy savings

No

Provides data or information on energy use by water systems

Yes, the main purpose of the report is to determine the use of energy by water systems. However, it does not include demands of the public utility districts or of the State Water Project.

Energy Index Development for Benchmarking Water and Wastewater Utilities

2007

AwwaRF

Overview

The project presented in this report set out to develop metrics that allow comparison of energy use among wastewater treatment plants and among water utilities. The comparisons normalize for factors such as specific plant configurations or loadings.

Benchmarking is used to compare similar organizations that operate well or exhibit best practices for the purpose of improvement. The metrics developed follow the template created by the EPA in benchmarking buildings. The approach is to correlate utility characteristics to energy use in a statistically representative sample of the industry. This correlation provided a means to normalize or remove the influence of multiple factors impacting energy use that are outside the control of the utility, (e.g. water source, distribution topography, effluent quality, etc) so that a meaningful comparison could be made among utilities.

To collect data of energy use and characteristics, surveys were sent to wastewater treatment plants and water utilities. The final analysis data set consists of 266 wastewater treatment plants and 125 water utilities. This effort created a representative data set of energy use and utility characteristics for wastewater utilities exceeding 1.5 MGD and water utilities serving populations of 10,000 or more.

The wastewater treatment plant model relates energy consumption to: average influent flow, influent BOD, effluent BOD, the ratio of average influent flow to design influent flow, the use of trickle filtration, and nutrient removal. The water utility energy use model relates energy consumption to: total flow, total pumping horsepower, distribution main length, distribution elevation change, raw pumping horsepower, and the amount of purchased flow.

Applicability to Water-Energy nexus

This is a tool to compare the energy consumption of a specific facility with a representative sample group of facilities in the country.

Provides data on energy savings due to reduced water consumption

No

Provides data or information on link between distribution network efficiency improvements and energy savings

Finds that unaccounted for flow was to be a significant parameter in the water utility model, but was not included in the metric, so that its effect would still be reflected in the metric.

Provides data or information on energy use by water systems

Provides a range in distribution of energy use for utilities by certain parameters, such as average influent flow, influent BOD, effluent BOD, the ratio of average influent flow to design influent flow, the use of trickle filtration, and nutrient removal for wastewater facilities, and total flow, total pumping horsepower, distribution main length, distribution elevation change, raw pumping horsepower, and the amount of purchased flow for water facilities.

California Water 2030: An Efficient Future

September 2005

The Pacific Institute

Overview

The State of California has routinely prepared water scenarios and water demand projections as part of long-term water planning. These official projections routinely project substantial increases in water use over time, often far in excess of the use that actually materializes.

The 2005 Draft California Water Plan introduced a long-term effort to develop multiple scenarios of water supply and demand. The three scenarios developed for the 2005 version provide estimates of the quantity of water that would be used in 2030 under specified demographic, economic, agricultural, and water management conditions. These scenarios are: Current Trends, Less Resource Intensive, More Resource Intensive. A close analysis reveals that these scenarios are not radical, or even dramatic, departures from past analyses. All three DWR scenarios include only modest efficiency improvements achievable with current policies and programs.

In an attempt to describe a more efficient scenario, this study (California Water 2030: An Efficient Future) presents the projected estimate for an alternative, High Efficiency scenario. The scenario was produced with the same model used by DWR to generate their three future demand scenarios for the 2005 California Water Plan. This studies scenario adopted the same projections of population, housing distribution, agricultural land area, crop type and distribution, and income projections used by DWR. For the Pacific Institute High Efficiency scenario, the assumptions about the potential for improving efficiency of water use were modified based on more comprehensive implementation of existing technology and application of historical trends for water prices.

The Pacific Institute High Efficiency scenario is based on widespread adoption of existing water-efficiency technologies, not on the invention of new efficiency options, and on different estimates of water prices and trends. Overall statewide agricultural and urban water demand is projected to decline in both scenarios (DWR scenario and Pacific Institute scenario), but in the Pacific Institute High Efficiency scenario total human use of water declines by 8.5 MAF—a reduction of around 20 percent from 2000.

Applicability to Water-Energy nexus

None

Provides data on energy savings due to reduced water consumption

No

Provides data or information on link between distribution network efficiency improvements and energy savings

No

Provides data or information on energy use by water systems

No

Waste Not Want Not: The Potential for Urban Water Conservation in California

November 2003

The Pacific Institute

Overview

This study attempts to quantify the true potential for water conservation and efficiency improvements in California's urban sector.

Overall, California's urban water use in 2000 is estimated to be approximately 7 million acre-feet (MAF), with an uncertainty of at least 10 percent. This is equivalent to around 185 gallons per capita per day (gpcd) for the nearly 34 million people living in California in 2000. Total indoor and outdoor residential use was roughly 3.75 MAF, with the greatest uncertainty around outdoor landscape use. Commercial and industrial uses in 2000 are estimated to have been 1.9 million AF and approximately 700,000 AF respectively, with governmental and institutional uses included in the commercial estimate. No independent estimate of unaccounted-for water (UfW) was done here; the California Department of Water Resources estimate for UfW of around 10 percent of all urban use was adopted.

The report notes that the vast majority of water used in California goes to the agricultural sector, which is not discussed in this report. Current estimates are that more than three-quarters of California's applied water, and an even higher percentage of consumed water, is used for irrigation of food, fodder, and fiber crops.

The report's best estimate is that existing technologies and policies can reduce current urban water use by 2.3 MAF, where at least 2 MAF of these savings are cost-effective. If current water use in California becomes as efficient as readily available technology permits, total urban use

will drop from 7 MAF to around 4.7 MAF – a savings of 33 percent. This will reduce California's urban water use from around 185 gallons per capita per day to around 123 gpcd.

The conservation potential of urban water uses is estimated for four categories: indoor residential use, outdoor residential use, and commercial, industrial, and institutional (CII) uses.

The residential sector (indoor and outdoor combined) is the largest urban water use sector, and it offers the largest volume of potential savings compared with other urban sectors. Indoor residential use could be reduced by approximately 890,000 AF/yr – almost 40 percent – by replacing remaining inefficient toilets, washing machines, showerheads, and dishwashers, and by reducing the level of leaks. For outdoor residential uses, cost-effective reductions of at least 32.5% (a savings of 470,000 AF/yr) could be made relatively quickly with improved management practices and available irrigation technology. Specific examples of these outdoor conservation practices are presented in the report.

For the CII sector, water conservation potential varies greatly among technologies, industries, and regions. Overall, the range of potential savings is estimated to be between 710,000 AF/yr and 1.3 MAF/yr over current use. The best estimate of practical savings in the CII sector is about 975,000 AF, or 39 percent of total current annual water use.

The report also presents an assessment of the cost-effectiveness of the conservation technologies and options in each of the urban sectors. Conservation measures are considered cost-effective when their unit cost – called "the cost of conserved water" – is less than the unit cost of the lowest-cost option for new or expanded water supply. Furthermore, the analysis includes reasonably quantifiable and financially tangible "co-benefits" of water conservation as "negative costs" (i.e., as economic benefits). Co-benefits are benefits that automatically come along with the intended objective. For example, low-flow showerheads reduce water heating bills and improved irrigation scheduling reduces fertilizer use. Not all co-benefits were evaluated, only those that could be quantified in a reasonably objective fashion. Other benefits not quantified include ecosystem benefits of taking less water from rivers and lakes, lower wastewater treatment costs that result from using and polluting less water, and reductions in greenhouse gas emissions that result from using less energy, among others.

All five indoor residential conservation measures evaluated – toilets, washing machines, showerheads, leak detection and reduction, and dishwashers – are cost-effective under natural replacement. The outdoor measures that were evaluated – improved irrigation scheduling, operation, and maintenance, including some replacement of irrigation technology – are also cost-effective.

For the CIII sector it was found that at least 657,000 AF of water used in California at present could be conserved cost-effectively. Examples of cost-effective options are replacement of all commercial toilets with low-flow models as the new fixtures are needed, accelerated replacement with ultra-low-flow toilets in establishments where toilets are flushed more than 15 times per day, and using low-flow showerheads in all urban sectors. Other examples include recirculating water used by x-ray machines and sterilizing equipment in hospitals, a wide variety

of “good housekeeping” and leak-detection options in all establishments, water-efficient dishwashers and pre-rinse nozzles in restaurants, efficient washing machines and recycling systems in laundromats, acid recovery and textile dye-water recycling in the textile industry, a wide variety of microfiltration systems in the food industry, and use of recycled/reclaimed water in refineries, among others.

Applicability to Water-Energy nexus

The report recognizes that there is energy savings related to water conservation at the end user. However, it does not discuss the potential for saving energy in other steps of the water supply chain by the improved efficiency and conservation.

Provides data on energy savings due to reduced water consumption

Provides data on energy savings at the end use of water due to more efficient appliances (less water heated). It does not provide data on the energy savings at the other steps of the water supply chain by reduced water consumption.

Provides data or information on link between distribution network efficiency improvements and energy savings

No

Provides data or information on energy use by water systems

No

California Water Plan Update 2009(Public Review Draft)

Volume 2 Resource Management Strategies – Chapter 3 Urban Water Use Efficiency

January 2009

Department of Water Resources Bulletin 160-09

Overview

This chapter of the California Water Plan Update provides background information supporting the need for urban water use efficiency. It also describes past and current efforts to increase urban water use efficiency and presents proposed measures and recommendations to further increase efficiency. Estimated costs of the urban water use efficiency are also discussed.

The benefits of water use efficiency extend far beyond the basic improvement of the water supply reliability and include increased energy conservation, deferred new generation, or reduction in peak demand; reduced greenhouse gas (GHG) emissions; reduced flows to wastewater treatment plants; reduced urban runoff; and, economic savings, among others.

An urban water use efficiency cost and savings estimate prepared for the Department of Water Resources (DWR) Climate Action Team found that an investment of $3.6 billion in water use efficiency measures would produce savings of $10.2 billion from 2008 through 2030. However savings may be greater since the estimate does not include savings to water suppliers and wastewater treatment operators from reduced capital and operating costs and to consumers from reduced energy costs for hot water and disposal of green waste.

Current challenges to California's water supply security include:

- Environmental degradation: There has been a dramatic decline in organisms living in the Delta.
- Legal and regulatory actions: Various legal decisions have required the reduction of water withdrawals from the Colorado River and the Sacramento Delta.
- Climate change: Climate change is having an impact on water resources as evidenced by changes in snowpack, river flows, and sea levels.
- Drought: October 1, 2006 thru September 30, 2008 left a deficit of nearly 28" precipitation in the northern and central Sierra, source of much of California's water supply.

California's plan for water supply security encompasses:

- Governor's 20 percent reduction target by 2020: A plan to achieve a 20 percent reduction in per capita water use statewide by 2020.
- Delta Vision: Establishes an independent Blue Ribbon Task Force to develop a durable vision for sustainable management of the Delta. The task force recommended two foundational and co-equal goals: restore the Delta ecosystem and create a reliable water supply for California.
- AB 1420: A project that requires urban water suppliers to implement water demand management measures for eligibility to any water management grant or loan. It also directs DWR to convene an Independent Technical Panel to help it develop new demand management measures, technologies, and approaches.
- Climate Change Strategy: To achieve greenhouse gas emissions reductions, DWR has identified an initial target of 1.11 maf of annual urban water savings (California Water Plan Update 2005) by 2030. This level of water conservation will be achieved in by the implementation of locally cost-effective conservation measures and through the accelerated investment of State grant funding.
- Landscape Model Ordinance: DWR is directed to update the Model Water Efficient Landscape Ordinance to specify requirements for the efficient use of water for landscape use.

The CALFED Record of Decision (ROD) estimated that applied water savings of existing urban water use efficiency efforts would range between 0.8 million and 1 million acre-feet per year by 2030 (CALFED Record of Decision, 2000). A state-sponsored study (Pacific Institute's "Waste Not,

Want Not") indicated potential savings of 2 million to 2.3 million acre-feet per year from existing urban conservation technologies and practices.

The major issues facing urban water use efficiency are funding, environmental justice, program implementation, data collection, education and motivation, and innovation.

Some recommendations to achieve additional urban water use efficiency presented in this document are adopting 20X2020 recommendations, legislation, secure funding to support incentive programs, Provide opportunities for small districts and economically disadvantaged communities, technical assistance, gray water and rain water capture, community involvement, and metering among many others.

Applicability to Water-Energy nexus

Recognizes the connection between water and energy, and presents benefits of energy reductions by water conservation.

Provides data on energy savings due to reduced water consumption

No

Provides data or information on link between distribution network efficiency improvements and energy savings

No

Provides data or information on energy use by water systems

Provides general statewide information on energy use by water systems.

Proposed WETCAT Strategies and Measures

March 24, 2008

Overview

The Water-Energy (WET-CAT) Subgroup of the Climate Action Team is tasked with coordinating the study of greenhouse gas effects on California's water supply system. Below are strategies proposed by WETCAT.

Strategy 1: Water Recycling. This measure proposes the preparation and implementation of water recycling plans at wastewater treatment plants (WWTP) in communities that rely on imported water supplies. It is estimated that approximately 10% of California's wastewater is recycled, but as much as 23% could be recycled. Water recycling provides a less energy intensive source of local water. An estimated potential energy savings of 2.5 MWh/AF could be achieved by water recycling in Southern California.

Strategy 2: Urban Water Reuse. This measure proposed to evaluate the potential benefits of an urban water reuse strategy. Currently, there is not sufficient information on volume of water that could be captured or energy savings that could be realized. This measure would capture runoff, discharged water from urban stormwater systems, and leaking water from urban sources and would reuse the water for local applications such as irrigation.

Strategy 3: End Use Water Conservation and Efficiency. The Governor has directed state agencies to develop and implement plans to achieve a 20% reduction in water use by 2020 as a key conservation strategy to provide water for Californians and protect and improve the Delta ecosystem. This measure builds on that directive to increase water use efficiency and thereby reduce greenhouse gas emissions related to water use. It is estimated that California will achieve 1.76 MAF of urban water savings by 2020 to meet the 20% reduction target.

Strategy 4: Energy Intensity of Water Systems. Draft Measure 1 seeks to reduce the magnitude and intensity of the California's water system through the further implementation of energy efficiency measures in infrastructure projects. Draft Measure 2 proposes the development of tools and protocols to evaluate, measure, and verify the energy impacts of water systems and end use conservation activities to assist water agencies to determine the most effective measures to implement. Draft Measure 3 proposes research and demonstration projects to identify new and innovative technologies and measures for mutually achieving energy and water savings.

Strategy 5: Increase Renewable Energy Production. The purpose of this measure is to identify and implement specific projects that take advantage of the state's water system-related opportunities to generate renewable electricity.

Applicability to Water-Energy nexus

Proposes measures to reduce greenhouse gas emissions by the reduction of water-related energy consumption.

Provides data on energy savings due to reduced water consumption

Presents data of energy savings from reduced water consumption estimated in other studies.

Provides data or information on link between distribution network efficiency improvements and energy savings

No

Provides data or information on energy use by water systems

Provides general information on energy use by water systems.

Joint Water and Energy Efficiency to Meet Conservation Challenges in California

Melissa Harris, Patrick Roehrdanz, Sara Hughes, Samuel Bennett, Robert Wilkinson, Arturo Keller

Bren School of Environmental Science and Management, University of California, Santa Barbara

Overview

This report evaluates seven residential end uses at three study areas to determine whether a 20% per capita decrease in water consumption is possible with available technologies. The end use technologies assessed are toilets, faucet aerators, showers, dishwashers, single family (SF) clothes washers, outdoor pools, and irrigation technologies including drip irrigation, irrigation controllers, soil moisture probes and sensors, and shutoff devices activated by rainfall.

The model created for this analysis varies the market saturation rates of efficient measures from the current levels identified in the three study areas to calculate the total potential water savings and total costs incurred as a result of this new distribution at the end of a defined planning horizon. The ratio of total costs to total water savings for each distribution is reported as Simple Cost in dollars per acre-foot.

The energy and emissions co-benefits of the water savings were determined by applying dollar values for embedded energy (conveyance, wastewater treatment, and water treatment), end use energy (heating, mechanical agitation), and the CO2 emissions of both embedded an end use energy. The ratio of total cost less the monetized co-benefits to the total water savings is reported as Total Resource Cost (TRC).

According to the model, residential water demand can be reduced by up to 45% in all three study areas with full market saturation of the most water efficient measures considered in this study: 1.5 gpm showerheads and faucet aerators, pool covers, SF clothes washers, irrigation technologies, efficient dishwashers, and composting toilets. However, to be cost-effective, the reduction in demand would be less than 45%. Each of the study areas has a different value for maximum residential water demand reduction or level of cost-effectiveness. Break even points for each district, the maximum potential water savings where the TRC equals zero are: EBMUD 40.2%, LAMET 41.3%, and SCVWD 36.8%.

Applicability to Water-Energy nexus

Determines the cost effectiveness of water conservation measures taking into account energy savings from each step of the water supply chain, in addition to the water savings.

Provides data on energy savings due to reduced water consumption

This study does not provide direct data on energy savings.

Provides data or information on link between distribution network efficiency improvements and energy savings

No

Provides data or information on energy use by water systems

No

Energy Audit of Water Networks

Enrique Cabrera, Miguel A. Pardo, Ricardo Cobacho, Enrique Cabrera Jr.

ITA – Polytechnic University of Valencia, Spain

Currently under review for publishing in the Journal of Water Resources Planning and Management

Overview

This paper presents the energy audit of the distribution phase of a water network obtained from the energy equation in integral form and its time integration extended over a given period (day, month or year). The analysis allows accounting for all the energy in the system, showing that the energy balance is fulfilled. Energy sources and energy supplies accounted include reservoirs, pumps, water demand, leakage, friction losses, and compensation energy associated with internal tanks.

Previous works that have looked at the energy efficiency of a water network have consisted in dividing the energy paid (kWh) by the volume of water delivered to users (m^3). This ratio provides for this phase a global estimation of the energy costs per volume. However, it is a global indicator which does not provide information about how that energy is used along the distribution process, which is the final objective of the energy audit presented in this paper.

From this balance, it is possible to obtain performance indicators to assess the system from the energetic point of view. To measure how well the system is managed, four performance indicators are proposed:

- I_1- *Global efficiency of the network* is the ratio of the energy supplied to users over the energy input into the system. This is the main indicator for the suggested analysis, as it provides a measure of efficiency in the use of the energy injected to the system (how much of it is useful).
- I_2- *Dissipated energy* is the ratio of energy dissipated in the system due to friction over the energy input into the system. This represents the hydraulic capacity of the network. The higher the value, the worse the efficiency. Although it can be brought to values very close to zero, eliminating friction losses implies a very costly design. Target values depend on a balance between investment and running costs.

- I_3- *Leaked energy* is the ratio of the energy output through leaks over the energy input into the system. This represents energy lost as water leaves through leaks, however it does not cover all energy lost due to leakage. The existence of leaks, generates a higher flow rate in pipes (after all, demand needs to be met anyway) and therefore, overall friction losses are also increased.
- I_4- *Adequacy of the service* is the ratio of energy supplied to users over the strictly necessary amount. Values greater than 1 are the most common case. The pressure is kept above the service standards. The closer to 1, the greater the efficiency in meeting them. Values less than 1 show that average pressure levels are insufficient and below the standards.

From these indicators, it is possible to identify the improvement actions that will make the system more efficient. This energy audit requires a previous water balance and the mathematical model of the network, both necessary to know the energy flows through the system boundaries.

Applicability to Water-Energy nexus

Provides a method to evaluate the energy efficiency of a distribution system or a section of it from the energy equations.

Provides data on energy savings due to reduced water consumption

No. Provides a method to determine energy savings due to reduced water consumption in a system with a water balance and calibrated hydraulic model.

Provides data or information on link between distribution network efficiency improvements and energy savings

No

Provides data or information on energy use by water systems

Presents data on the energy use of one system used as an example of the method.

PI for assessing effectiveness of energy management processes in water supply systems

P. Duarte, D. I. C. Covas and H. Alegre

National Laboratory of Civil Engineering, Lisbon, Portugal

Water Loss 2009 IWA Conference, Cape Town, South Africa

Overview

The aim of this work is to assist in the implementation of sustainable energy practices, by providing a procedure for identifying the systems with a higher potential of energy savings, quantifying this potential, and monitoring the results of the interventions adopted. The recommended approach is based on the definition of objectives, assessment criteria and performance measures, as stated in the ISO 24500 standards. Advantages and shortcomings of the current performance measures commonly used are identified and three new ones are proposed and defined in order to fulfill the gaps.

The energy performance measures are based on the concepts of minimum energy and of energy in excess proposed by Alegre (1992), which allow identifying the systems with higher potential of energy efficiency improvement.

The three different measures to assess the energy efficiency are defined as follows:

- E1 - Energy in excess per unit of input volume (kWh/m^3): This performance index represents the theoretical potential of energy reduction per m^3 of the input volume. It should be as low as technically possible, though it is always a positive non-zero value. It is an adequate index to assess the impact of different energy management measures; however it does not allow for the assessment of the impact of leakage control measures in energy efficiency.
- E2 - Energy in excess per unit of the revenue water (kWh/m^3): This index represents the theoretical potential of energy reduction per m^3 of revenue water. Similarly to the previous index, E2 is always a positive non-zero value, ideally as low as possible. The aim of using the revenue water in denominator (instead of the input flow) is to allow the index to reflect the impact of leakage control measures in terms of energy.
- E3 - Ratio of the energy in excess (dimensionless): This index quantifies, in a straightforward way, the theoretic energy in excess that is provided to the system.

The paper also further demonstrates the use of the proposed indices in energy management programs in three fictitious systems.

Applicability to Water-Energy nexus

Presents performance indicators for managing the efficiency of energy in water distribution systems.

Provides data on energy savings due to reduced water consumption

Provides fictitious case studies of the use of performance indicators to maximize energy efficiency. One case study examines the reduction of losses.

Provides data or information on link between distribution network efficiency improvements and energy savings

Provides a mechanism to determine energy savings with distribution system improvements.

Provides data or information on energy use by water systems

No

Reducing Greenhouse Gas Impacts in California's Urban Water Cycle

John Rosenblum, Ph.D.

March 24, 2009

Overview

This paper reviews energy use and Greenhouse gas (GHG) emissions in the urban water cycle, specifically for the City of Santa Rosa and presents a strategy for meeting California's mandated GHG emissions target of returning to 1990 emissions by 2020.

Although the energy efficiency projects at water/wastewater facilities can be very cost-effective, they do not reduce GHG emissions nearly enough to meet GHG reduction targets – neither for the facilities themselves nor for the urban water cycle as a whole.

Detailed data analysis reveals that water-related GHG emissions from end-users are approximately 10 times larger than the combined GHG inventory for water and wastewater systems. This implies that end use efficiency improvements could have a much larger impact on GHG emissions from the urban water cycle than improvements in water/wastewater operations. Since the water-related end-use GHG emissions are large, they also represent the largest opportunity for feasibly meeting reduction targets.

Combining widely available outdoor efficiency measures to an indoor high-performance program, and assuming high participation rates, indoor water use (and wastewater) could be reduced by 26% and outdoor use by 19% - for an overall reduction of 24%. This would reduce daily water use per person (gpd/person) from 133 gpd/person to 102 gpd/person.

The analysis in this report reveals that high-performance water/energy efficiency programs, mostly for the residential sector, could reduce 22% of the GHG emissions in the urban water cycle. GHG reductions could reach 47% by combining efficiency improvements with a modest solar program. Capturing large site-specific opportunities for efficiency improvements and solar installations across all end-use sectors should be adequate for meeting California's mandated GHG emissions target of returning to 1990 emissions by 2020.

Applicability to Water-Energy nexus

This investigation estimates the reduction in greenhouse gas emissions related to energy use by the City of Santa Rosa's water/wastewater utility with the implementation of a high-performance end-use water efficiency program.

Provides data on energy savings due to reduced water consumption

Provides the energy savings for the City of Santa Rosa due to efficiency projects in the wastewater system. Also provides estimates of greenhouse gas reductions with end-use water efficiency program.

Provides data or information on link between distribution network efficiency improvements and energy savings

Provides the energy savings for efficiency improvements in wastewater system.

Provides data or information on energy use by water systems

Provides the energy use by the City of Santa Rosa water/wastewater utilities.

Section 10.3 CASE STUDY ONE – Conservation Project Saves $24M for Utilities

By Tim Brown, Heath Consultants, Inc.

From *Water Loss Control Manual*

Julian Thornton

2002

Overview

In January 1988, Heath Consultants, Inc., contracted with the Energy Division of Tennessee's Department of Economic and Community Development to conduct a two-phase program to identify energy and water loss and to make recommendations for corrective action. The project was divided into two phases: (I) to identify energy and water loss and to make recommendations for corrective action; (II) to conduct a leakage detection/pinpointing survey of the distribution system. Phase II was scheduled to be initiated if the benefit-to-cost ratio was favorable.

It was estimated that the project saved $24.4 million per year at a cost of $2.7 million for 278 water utility companies in the state of Tennessee as of January 1991. This is a benefit-cost ratio of 9.5:1 and represents a payback period of just 38 days. The average system savings was $91,398 per year.

Applicability to Water-Energy nexus

Briefly describes the results of a program by the Energy Division of Tennessee's Department of Economic and Community Development to identify energy and water loss and to make recommendations for corrective action.

Provides data on energy savings due to reduced water consumption

Estimates energy savings of 72,698,052,000 avoidable Btu's, representing an avoided cost of $1,496,860.

Provides data or information on link between distribution network efficiency improvements and energy savings

No, it briefly states the avoided cost savings and energy savings from the program.

Provides data or information on energy use by water systems

No

Appendix A: Sources for Literature Review

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