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A Cost-Benefit Analysis of Leak Detection and the Potential of Real Water Savings for New Mexico Water Systems

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by

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Committee Approval

The Master of Water Resources Professional Project of Shawn Hardeman is approved by committee:

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I sincerely hope that this project will benefit water systems in their continued pursuit of improving water system efficiency, and delivering highest quality of water and service to their customers. Water is truly the crux of all life and without their dedication to the job our quality of life would be very different.

I dedicate this Professional Project to my son Kalden Cay Hardeman
(born November 1, 2007)

Abstract

Whereas the demand for safe drinking water increases and the availability of fresh drinking water decreases, it becomes evermore important for water systems to make effective use of the drinking water they produce. As populations grow water systems are increasingly in search of new water sources; however, as the competition for new water sources increases, water systems must look at how water is lost in their distribution systems. Water that never makes it to the consumer, or for which no revenue is received is known as "water loss," and is used to represent the water that a water system produces, puts into the distribution system, but then is lost as a result of poor record keeping, illegal connections or leaks in the distribution system. Water loss can be divided into two groups, apparent and real losses. These losses are important to consider because water loss results in a water system having to pump, treat, and deliver additional water to meet customer's demands and reduces revenues, which negatively impact both the water source and the water system. Water systems can better track their real losses by switching from the outdated and ambiguous method of reporting water loss as "Unaccounted-for Water," and adopt the new and tested method of the Infrastructure Leakage Index (ILI). This project will evaluate the ILI for 30 water systems in New Mexico as a means to display its usefulness in assessing water system efficiencies.

Water loss due to leaks from the distribution systems are called real losses; the losses are costly and can affect a water system's ability to provide water to its customers. There are a number of leak detection methods and strategies available to water systems to reduce real losses. However, leak detection is a costly process and only identifies some fraction of the real losses, thus there is a tradeoff between the benefit of reduced real losses and the cost of leak detection. This project developed a process that assist water systems in allocating resources to leak detection activities called the Economic Leakage Level, which is based on the value of the water lost, the faction of real losses recovered using leak detection, and the cost of leak detection method. The process was illustrated by applying it to selected community water systems in New Mexico.

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Introduction

In New Mexico, fresh drinking water is a scarce resource. Add to that the competing interests of water users and the effects of climate change on a finite water resource, and therein lies the justification for water conservation and improved water system efficiencies. For instance, as the demand for safe drinking water increases and the availability of fresh drinking water decreases, it becomes evermore important for water systems to make effective use of the drinking water they produce. However, as the competition for new water sources increases, water systems must take a hard look at how water is used in their distribution systems and identify inefficiencies. Implementing a public outreach program, as part of a water conservation plan, is one method a water system can use to reduce water waste from the customer, but there is an equally important component that addresses the water that never makes it to the consumer, known as "real water loss."

Leak detection is the most effective means to address real losses in a water system. In 2007, Governor Bill Richardson announced Water Innovation Fund to help provide solutions to New Mexico's water crisis by funding projects that could save the state an estimated 32 billion gallons of water per year. The goal of the fund was to fund projects that focused on water recycling, water producing, water conservation and communities in crisis. The projects that qualified for the funding were based on good science and economics, and were ready for testing and deployment. In addition, projects were chosen for their abilities to conserve or deliver useable water through innovation technologies that could be applied statewide. Leak detection was a topic for two of projects that received funding.

Water Loss

Water Loss is a term used in the standardized water balance that was defined by the International Water Association (IWA) Water Loss Task Force in 2000. In the past, the term “Unaccounted-for Water,” (UfW) was inaccurately used to describe the amount of water that was not generating revenue or was lost in the water distribution system. It has been well documented that the definitions and calculations used to describe UfW varied all over the world, and in 2000, the IWA Task Force recommended that water professionals stop using the term UfW because of the misinterpretation and ambiguity associated with the term. A high UfW value did indicate that there were problems in the distribution system, but it could not describe where the problems existed, such as leaks, breaks, or meter errors (Male et al., 1985). There were also issues relating to the size of the water system and quantity of water produced. When losses are given in percent of system input, major input volumes lead to lower percentage of water loss; conversely, lower input volumes lead to high percentage of water loss levels (Weimer, 2001). Because communities differ on extent of metering and usage, it is difficult to make a meaningful judgment about the efficiency of the system based on UfW alone (Male et al., 1985). It would appear that it would be more beneficial to look at the individual components of water loss and the potentially recoverable loss from the water system in making such an assessment.   Currently, the general consensus in the literature and technical papers is to use the term

"Non-Revenue Water," which refers to the water that a water system produces but does not generate revenue because it is either unbilled, unmetered or lost through leakage. Water loss is a subset of non-revenue water, and is used to address both real and apparent losses. Water loss is defined in the water balance as the sum of water equal to the system input volume minus the authorized consumption value (Lambert and McKenzie, 2002), see figure 1.

Figure 1: Water Balance

<table>
<tr><td rowspan="10">Water Input</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed 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 Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="8">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="6">Water Loss</td><td rowspan="3">Apparent Losses</td><td>Customer Metering Inaccuracies</td></tr>
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<tr><td rowspan="3">Real Losses</td><td>Leakage on Transmission and Distribution Mains</td></tr>
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<tr><td>Leakage on Service Connections</td></tr>
</table>

Source: AWWA water audit

Water loss is divided into two groups, apparent and real losses, and includes poor recordkeeping, illegal connections and leakage from the water distribution system. These losses are important to consider because real water losses result in a water system having to pump, treat and deliver additional water to meet customer's demands, and reduced revenues, which negatively impact both the water source and the water system. Reducing water loss can be addressed by focusing in three basic areas; recordkeeping, meter monitoring, and leak detection, which are better defined as Financial, Operational and Water Resources (Male et al., 1986, and Lambert and McKenzie, 2002). These terms are associated with performance indicators and target setting developed by the IWA Task Force to determine best practices for managing water systems.

This paper will address only the real losses associated with leakage in the distribution system, and the potential for recovering that loss through leak detection surveys on the distribution system. Apparent losses, although equally important, are associated more with poor recordkeeping, meter inaccuracies and unauthorized consumption. In 2007, the IWA stated that there was no consensus on the best operational performance indicators for apparent losses, and therefore, no standardized method for analysis and target setting. Apparent losses, also known as “paper” losses, are typically addressed through administrative recordkeeping and general operational maintenance, such as implementing water meter audits and billing programs. It is important to note that water systems should address apparent losses prior to or concurrent with implementation of a program to address real losses. Once the extent of apparent losses is better understood, it may be easier to quantify its real losses. Also, the additional revenue generated from reducing apparent losses can help fund a leak detection program or can help pay for system repairs. The water loss that occurs on the customer’s side of the meter is excluded from this analysis because it is assumed that this water loss is metered and paid for. Losses at the utility’s storage tank, including leaks and overflows, are also excluded from this analysis since the loss can be addressed without the use of leak detection techniques.

Purpose

Since water resources in the southwest are over allocated, and new water sources are scarce, water systems must find ways to improve efficiencies to meet the growing demand for safe drinking water. Water systems, in turn, are quantifying their water use and subsequently water loss in hopes of capturing some or all of the water loss to supply that demand. In addition, water systems must address inefficiencies in the water distribution system that result in lost revenues due to leaks. In order to address real water loss, water systems must ask two questions “what is the water system’s potential to save real water?” and “is it worth it for the water system to invest in leak detection and leak management strategies to reduce real water lost through the water distribution system?” These questions are important because there are limitations regarding the quantity of water that can be economically saved. As Pearson and Trow, 2005, *Every activity aimed at reducing leakage follows a law of diminishing returns; the greater the level of resources employed, the lower the additional marginal benefit which results*.

To investigate these issues, an analysis was conducted on thirty water systems throughout New Mexico. The purpose of the analysis was to (1) estimate Current Annual Real Losses (CARL), and Unavoidable Annual Real Losses (UARL) in order to calculate the Infrastructure Leakage Index (ILI) for 30 water systems; and (2) determine the Economic Leakage Level for four of the thirty water systems, which will estimate how much real water loss can potentially and economically be saved through leak detection. The analysis will show a distribution of ILI values for the thirty water systems throughout New Mexico, and determine the potential for saving real water by evaluating the value of water and the cost of leak detection.

The ILI is a comprehensive assessment of the real losses and water system condition, and can be used to compare water system efficiency. In order to use the ILI appropriately, the thirty water systems selected for this analysis had to meet a minimum criteria. The criteria included a minimum of 3,000 service connections, and a minimum average operating pressure of 35.5 psi.

Leak Detection

Once a water system has made the decision to implement a leak detection program, the next step is to decide on what leak detection technology to use. Leak detection is a process where a water system uses technology to track down suspected leaks in buried water pipes and pinpoint their location. Leak detection entails using technology to listen to valves, hydrants, meters, and other appurtenances for noise, which is generated by vibrations and is transmitted through the pipe. This noise is an indication that water is moving and can mean one of two things. Either water is being used at a point of use such as a house, hydrant, or sprinkler system; or there is a leak in the pipe. The ability for a pipe to transmit vibrations is dependent on its pipe type, pipe size, and the length of pipe between valves. The frequency of the vibration is dependent on the aperture size of the leak in which the water is passing through. It is readily accepted that a smaller aperture generates a greater vibration; however there are limits to this concept. Some leaks are too small and generate very little noise while other leaks may be too big which dampens the vibration at a lower frequency.

The noise that a leak generates in a pipe is dependent on the aperture size of the leak and the pressure of the water in the pipe. This noise is created by the turbulent flow of water passing through the hole in the pipe. Based on the Greeley equation, the flow rate of the leak can be quantified using aperture size, pressure and run time of the leak.

Equation 1: Greeley Equation

$$Q = \left(\frac{43{,}767}{1{,}440} \right) A \sqrt{P}$$

where,

Q = Flow rate, in gallons per minute (gpm)
A = Cross-sectional area of the leak, in square inches (in^2)
P = Pressure, in pounds per square inch (psi)

Typically, leaks in the water distribution systems are only addressed once they have surfaced or when a sinkhole is formed. This technique is known as "managing failures," which is wanting for the asset to fail before the problem is addressed. However, there are two well-known leak detection methods available to water systems known as passive and active leak detection. Passive leak detection is the process where noise data loggers are deployed on valves throughout the system and, during the early morning hours, listen for noise (i.e. vibrations) in the distribution system. Active leak detection is when a crew surveys the entire water system using an acoustic listening device (i.e. microphone) checking hydrants, valves and meters for noise. There is much debate on which method is better at detecting leak. There is no hard data in the literature that suggests which leak detection methods will find more leaks in a distribution system. In general, leak detection technology does not find more leaks; it finds them sooner, before the leak surfaces, creates a sinkhole, or is discovered through a catastrophic failure. Actual water savings through leak detection does not come from the number of leaks found, but rather by fixing the leaks when they are small and have been leaking for a shorter period of time.

As a general rule of thumb, the smallest leak any leak detection method is able to find is between 1 to 5 gpm. It is also well accepted that leaks less than 1 gpm are considered undetectable using conventional leak detection equipment. This undetectable limit contributes to the UARL of a water system, which includes undetectable leaks from joints and fittings as well, and is based on the miles of pipe in a system and the average operating pressure.

Leak detection technologies come in all shapes and sizes. Although the actual technology behind the two leak detection methods has not change substantially over the years, the introduction of computers into the mixed has enabled leak detection technicians to collect and analyze more data from the leak detection devices.

The application of passive leak detection technology in a water system is straightforward. The noise data loggers are deployed in the field either throughout the entire system or in areas where the water utility wants to monitor for a period of time. The loggers themselves are not listening for leaks 24 hours per day; instead, the loggers turn on at 2:00 am for five minutes and listen for noise. The idea behind this early morning read is based on the notion that at 2:00 am typical home water use and interference from daily traffic is negligible. Therefore, if the noise data loggers detect a noise in the early morning hours there is a greater chance that it is due to a leak along the distribution pipe. If the data logger does hear a noise at 2:00 am it will shutoff and turn on again in one hour. This second listening interval helps to eliminate the chance that a sprinkler system or dishwasher is programmed to run during the early morning. To further eliminate the chance of water use being detected, the logger will turn on a third time. If it still hears the noise, the logger will switch to alarm mode indicating that there is a possible leak in the area. The following day, a leak detection technician will patrol the area with a device known as a Patroller that is designed to interrogate the loggers in the field and report whether the individual logger is in alarm mode or not. If the Patroller detects that a logger or loggers are in alarm the technician will turn to a device called a Correlator to pinpoint the leak on the water line. Chances are that if one logger is in alarm mode, at least one adjacent logger will also be in alarm mode. This is an indication that the leak is somewhere between the two loggers. The Correlator is a sophisticated device that has two listening devices that are placed on two points of the system (such as valves, hydrants or meters), that are likely to bracket the location of the leak. The Correlator listens to the noise that the pipe is transmitting. It can determine the location of the leak based in the intensity of the noise received at each of the two points. The Correlator screen shows a peak at the point in between the two listening devices where is leak is located. The technician then marks on the pavement where the suspected leak is located, and repair is dispatched to investigate and repair the leak.

There are other passive leak detection technologies that can do more extensive services than the basic loggers described here. There are several passive leak detection companies in the United States and United Kingdom that sell different products and offer different features. There are leak detection loggers that are designed to operate during the day at set intervals and are capable of correlating a leak using a wireless connection to a laptop computer without the need for a Correlator. There are also noise data loggers that are capable of not only indicating if there is a leak but can also estimate the amount of water being lost in gallons per minute.

Active leak detection, as the name suggests, takes an active approach to detecting and pinpointing leaks. Typically, an active leak detection survey includes a one or two person crew that will survey the entire water system listening to hydrants, valves and appurtenances to identify leaks using a listening device or microphone. If a suspected leak is detected, the crew will either use a Correlator, similar to the passive method, or what is called a geophone, (which is similar to a doctor's stethoscope) to pinpoint the location of the leak. It takes an active leak detection crew longer to cover an equivalent area of the water system compared to passive leak detection methods, sometimes up to three times as long. However, some will argue that active leak detection is more accurate than passive.

In a head to head analysis of passive versus active leak detection methods, it took active leak detection crews on average ten times as long to cover one square mile of pipe when compared to the passive leak detection crew covering the same area (NMEFC 2007). However, this analysis also revealed that both leak detection methods yielded significantly different results.

Even with the various different types of passive and active leak detection equipment there is really only one thing that matters: being able to find leaks when they are small and before they become major breaks. Other concerns include the robustness of the technology and its ease of use. It makes very little sense to invest in a technology that is susceptible to the elements and is troublesome to use.

Since no two water systems are the same, there is no set standard on how to deploy and use leak detection technology. In choosing a particular type of leak detection technology a water system should first outline goals for a real loss reduction strategy, identify problem areas in the distribution system that need monitoring, and scale a leak detection program based on the size of the system and affordability. Water systems can use water audits and Economical Leakage Level estimation to help determine how to scale a leak detection project appropriately.

Literature Review

In 2000, the IWA developed standardized performance indicators to help water systems throughout the world better assess, analyze and compare water loss and water distribution efficiencies. These performance indicators replace the previous methods used for understanding water loss in the water balance. For example, the term “Unaccounted for Water” (UfW) was commonly used to express water loss as a percent of water system input. This percentage was derived by taking the difference of water produced minus water sold divided by the water produced, which resulted in a percent of water loss based on the system inputs, typically reported as “% by input volume.” Whereas this percentage appeared to rationally explain the water that was not making it to the customer, it did little to explain where in the water balance that water was being lost, or whether the loss was real or apparent. In addition, there was no standardized method or calculation for determining UfW. Therefore, it was impossible to adequately compare water loss between water systems and set appropriate performance targets for reducing water loss. In addition, the UfW did nothing to address the potential for real water savings associated with real losses.

Based on IWA Task Force, McKenzie and Lambert, 2004, stated that “% by input volume” is unsuitable for assessing the efficiency of operational management of real losses. The “% by input volume” does not allow for density of connections (per mile of main line), the length of service pipe between the main line and the customer meter, and the average operating pressure of the system

There was also an issue with how data is collected for determining UfW. Most water system use a three-month average to compare water produced and water sold data. The water-produced data is reported once a month either at the beginning or the end of the month, but water sold data may be collected at intervals over the course of the entire month. No one really knows what affect this has on reporting water loss as a "percent by input volume," but it does raise concerns as to its accuracy. However, the performance indicators developed for real losses by the IWA have been statistically proven worldwide as a means of comparing water loss and water distribution system efficiencies throughout the world.

Adopted in 1999, the ILI became the preferred performance indicator for real losses throughout the world. In the beginning, ILI was not regularly used due to lack of awareness, or limited understanding and acceptance of the ILI. However, since 1999, significant promotional efforts have been made to promote its use in making it an industry standard (Liemberger and McKenzie, 2005). Organizations and countries responsible for supporting and promoting this method include; United Kingdom, Germany, South African Bureau of Standards, American Water Works Association (AWWA), Malta Water Service Corporation, Water Services Association of Australia, and World Bank Institute.

The ILI is a dimensionless ratio of CARL divided by UARL and is an indication of how well a distribution system is being managed and maintained at its current operating pressure.

Equation 2: ILI Equation

$$ILI = \frac{CARL}{UARL}$$

Being unitless helps to compare ILI values between water systems nationwide and in different countries that use different units of measure

(Liemberger and McKenzie, 2005). The ILI measures how effectively a utility is managing real losses under the current operating pressure; however, it does not imply that pressure management is optimal (McKenzie and Lambert, 2004). Pressure affects the rate at which losses flow from the system and also has a major effect on the frequency with which new leaks and breaks occur (Lambert 2000). The accuracy of the ILI is dependent more on annual real losses, average pressure, and distribution system data, than the accuracy of UARL. Liemberger and McKenzie (2005) stated that implementing ILI as a performance indicator will encourage water systems to introduce active leak control, carry out flow and pressure measurements, and improve the quality of data collected for analysis. This in turn will help water systems in refining, managing, and reducing their real water losses on an annual basis. In addition, in theory it will decrease operating expenses by reducing the additional water required to compensate for losses in the system. This is extremely beneficial since the cost to pump, treat, and deliver water will increase as energy costs continue to increase. This method has gained the confidence of the World Bank Institute who uses the ILI to determine funding for water projects in developed and developing countries, and in 2007, the Texas Water Development Board completed an ILI analysis based on water loss data reported by public water suppliers in Texas (Mathis and McDonald, 2007).

In calculating the ILI, a good place to start is by determining the UARL of the water system. The greatest portion of UARL is from the background (undetectable) leakage, rather than detectable leaks (Lambert and McKenzie, 2004). The definition of UARL is the lowest technically achievable volume of annual real loss for well-maintained and managed systems. The UARL also takes into account all of the leaks that occur at joints and fittings throughout the system. The limitations placed on calculating the UARL are such that water systems utilizing ILI must have at least 3,000 service connections and a minimal operating pressure of 35.5 psi. The UARL is calculated using an empirical equation that was developed based on four system-specific factors (Lambert and McKenzie, 2004) that include:

- Total length of main lines
- Number of service connections
- Location of customer meters on service connection
- Average operating pressure

Reporting UARL values can be in units of either “gallons/service connections/day” or “gallons/length of mains/day;” however, it is recommended to use units of “gallons/service connection/day” when reporting UARL. Distribution losses in “gallons/service connections/day” are influenced less by the density of service connections than distribution losses expressed in “gallons/length of mains/day.” However, “gallons/length of mains/day” is preferred for systems with connection density less than 32 connections per mile of main water lines (Liemberger et al., 2007, and Op24.) The AWWA Water Loss Control Committee water audit spreadsheet reports UARL in “gallons/day.” The standard equation used for calculating UARL in “gallons/day” is as follows:

Equation 3: Calculating the UARL

$$UARL = (A * Lm) + (B * Nc) + (C * Lp) * P$$

(gallons/day)

Lm = Length of main lines
Lp = Length of the service line connection
Nc = Number of service connections
P = Average operating pressure
A=5.41, B=0.15, and C=7.5

This equation can be modified to report in units of "gallons/service connections/day" or "gallons/length of mains/day." The constants A, B, and C are used specifically for working in English units and only change if metric units are desired. Water systems with less that 3,000 service connections should employ a nighttime-metered flow program to assess unavoidable losses.

The ILI is a purely technical performance indicator and does not take economics into consideration (Liemberger, 2002). The determination of how low to reduce real losses is ultimately an economic decision. The point of the ELL is to assist water system in determining how much money to invest in a leak detection or real loss reduction strategy based on the current value of water and the cost of particular leak detection method being used. The ELL is strongly dependent on the value of water. As the value of water increases so does the number of options available to the water system to reduce real losses. The cost of leak detection is dependent on the size and miles of pipe in the water system. The ELL can also be used as a tool to show stakeholders that the water system is managing real losses effectively (AwwaRF 2007). The methods on how to calculate the ELL are discussed later in this paper.

Data Collecting

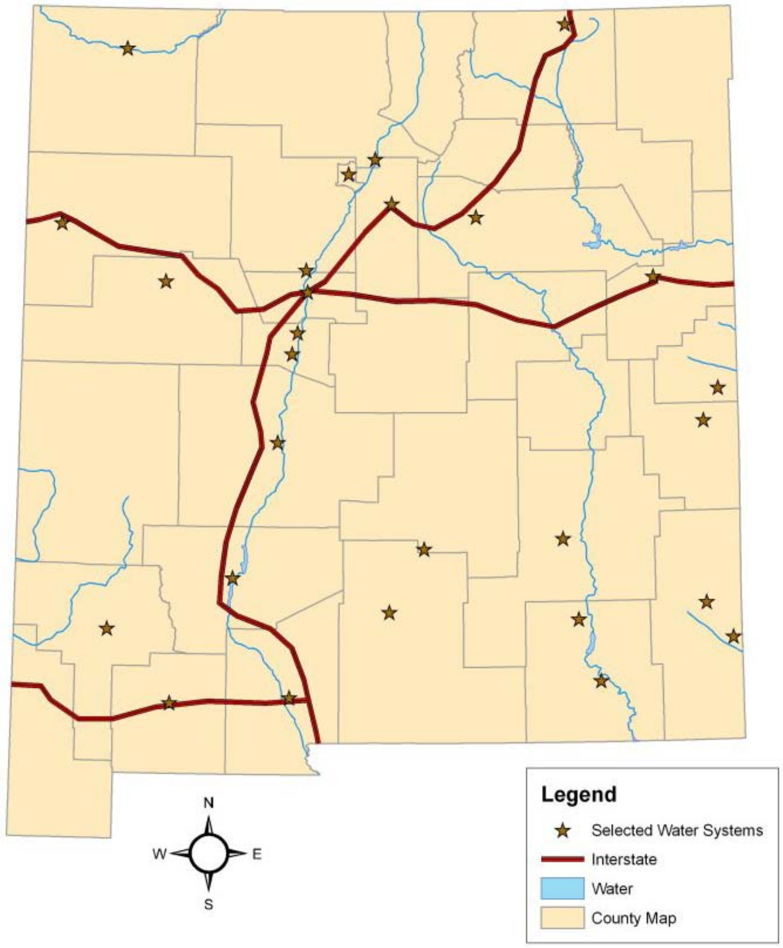
Most water systems in New Mexico do at least a basic estimation of water loss on a monthly or annual basis. The procedures used in collecting this data are often very basic, such as subtracting water sold from water pumped. The New Mexico Drinking Water Bureau (DWB) has been collecting this and similar data by conducting capacity assessments and sanitary surveys on water systems throughout the state. The surveys and assessments contain information such as water use, percent water loss, water rates, miles of pipe, and number of service connections, as well as additional technical information about the systems. In addition, the New Mexico Office of the State Engineer (OSE) recommends that water systems conduct water audits based on the AWWA Water Loss Control Committee water audit spreadsheet, and has four completed water audits posted on its website as examples. It is understood that most of the data collected are approximations because of the difficulty of assessing all the components within a water system with complete accuracy (Lambert and Hirner, 2000). Quality control was addressed by contacting the water system directly if there appeared to be any discrepancy or missing data. Data that was collected was compared against the data complied from the other water systems for a reality check and to ensure that the data was acceptable and valid. Following-up with the individual water systems to solicit additional information was beneficial because it helped to determine how well water systems monitored real losses and the quality of the data reported. Information that was not readily available was either estimated or calculated accordingly. A spreadsheet was created to compile the information collected from each water system, of which contained of the following information in Table 1.

Table 1: Data Collected

Fields	Units
Name of water system	Name
Total volume of water produced	Million gallons/year
Customer retail unit cost	$/gallons
Estimated Water Loss	% of system input
Total length of water mains	Miles
Number of service connections	Total # of service connections
Average length of service lines per connection	Feet
Average operating pressure	PSI
Current Annual Real Losses (CARL)	Million gallons/day
Unavoidable Annual Real Losses (UARL)	Million gallons/day

The water systems selected for this analysis were distributed throughout the state. In New Mexico, there are approximately 1,190 registered water systems, with only 634 listed as active community water systems (53 percent). Thirty of the 634 water systems have greater than 3,000 service connections and met the criteria for calculating UARL and ILI based on the IWA and AWWA methods and were used in the analysis. The map below shows the distribution of water systems selected for this project.

Map 1: Water System Distribution



Calculating Unavoidable Annual Real Loss (UARL) and Infrastructure Leakage Index (ILI):

Calculating the UARL and ILI were based on four system-specific factors and the CARL. The CARL is defined as the volume of water lost from reported leaks, unreported leaks, and background losses. Based on the AWWA Water Audit Manual M36, ideally, one would use the top-down water audit approach in estimating CARL, in which the real losses are estimated by subtracting apparent losses from the total water loss, CARL = WL - AL. In this analysis, the CARL was not readily available from most of the water systems participating. It was apparent after contacting the water systems directly, that keeping track of the CARL was not a priority. Therefore, a majority of the CARL values were estimated based on additional information gathered; such as, number of leaks reported in a year, estimated apparent losses, or the water operator's best guess at percent water loss due to leaks. Accordingly, most of the CARL values were calculated by assuming that a water system's percent water loss is based on the sum of apparent and real losses. Therefore, the total percent water loss was divided by half and multiplied by the annual volume of water produced for that water system in order to estimate CARL. In cases where the percent water loss was extremely low and the water system verified that they addressed apparent losses regularly, the CARL was calculated based on the total percent water loss. A table of estimated CARL, UARL and ILI values are included in the results section, Table 6.

The UARL is defined as the lowest technically achievable volume of annual real losses for a well-maintained and well-managed system (Lambert and McKenzie, 2002). It is well understood that real losses in the distribution system cannot be completely eliminated. The calculation for the UARL allows for background leakage, and takes into account the unavoidable leaks associated with all the joints and fittings in a distribution system at the average operating pressure of the system. For this analysis, the equation from the AWWA Water Audit Worksheet was used to calculate UARL. The equation used was quite extensive, which was a slightly modified version of the equation method earlier.

Equation 4: Calculating the UARL Using AWWA Method

$$UARL = \frac{(A * Lm) + (B * Nc) + (C * ((Nc * Lp) / 5280) * P}{1,000,000}$$

This equation accounts for the total length of main and service lines, number of service connections, and average operating pressure. It also uses the same values for A, B, and C as shown in Equation 3. The UARL is reported in "million gallons per day" (MGD). The ILI is then calculated using Equation 2, dividing the CARL by the UARL.

Deriving the Economic Leakage Level (ELL)

Deriving the ELL entails estimating how much water a water system can save economically through leak detection. In order to derive the ELL, it was necessary to work through a series of simple equations and tables developed for this analysis, which is explained in the following sections. The ELL is the economical balance point at which the sum of the cost of leak detection and the value of water lost through real losses is at a minimum. In addition, this analysis will determine how much of a role leak detection will play in the reducing real losses in the overall water budget for a water system. The purpose of this method is to determine the economic balance between the cost of leak management and the benefits, or water saved.

This analysis helps water systems understand the potential for real water loss reduction and the cost of leak detection. The ELL is specific to each individual water system and leak detection strategy. It incorporates labor cost, equipment cost, value of water, and miles of pipe in the system. Since it is specific to an individual water system, it is possible for two nearby water systems to have very unique ELL values. The ELL also shows that to reclaim 100 percent of a water system's real losses is unrealistic and cost prohibitive. The current thinking on ELL is based on the knowledge that each activity aimed at reducing leakage follows a law of diminishing returns (Pearson and Trow, 2005).

Deriving the ELL in this paper was segmented into a five-step process. The five steps includes; setting physical boundaries and estimating the value of water; estimating real water loss reduction based on the potential to recover real water; estimating the cost of a leak detection survey; correlating the cost of leak control to the potential of recovering real water loss; and creating and evaluating the ELL curve.

This five-step process was not covered in the water loss literature, and much of the data and methods used in this paper were derived empirically for a particular water system and leak detection strategy. The following is a description of how to work through the five steps in order to derive an ELL graphically for a particular water system and leak detection strategy. This process is outline conceptually in the AwwaRF Report # 91163, titled "Evaluating Water Loss and Planning Loss Reduction Strategies" chapter 4, but it provided little guidance on how to derive the ELL.

Step 1: Setting Boundaries and Estimating the Value of Water

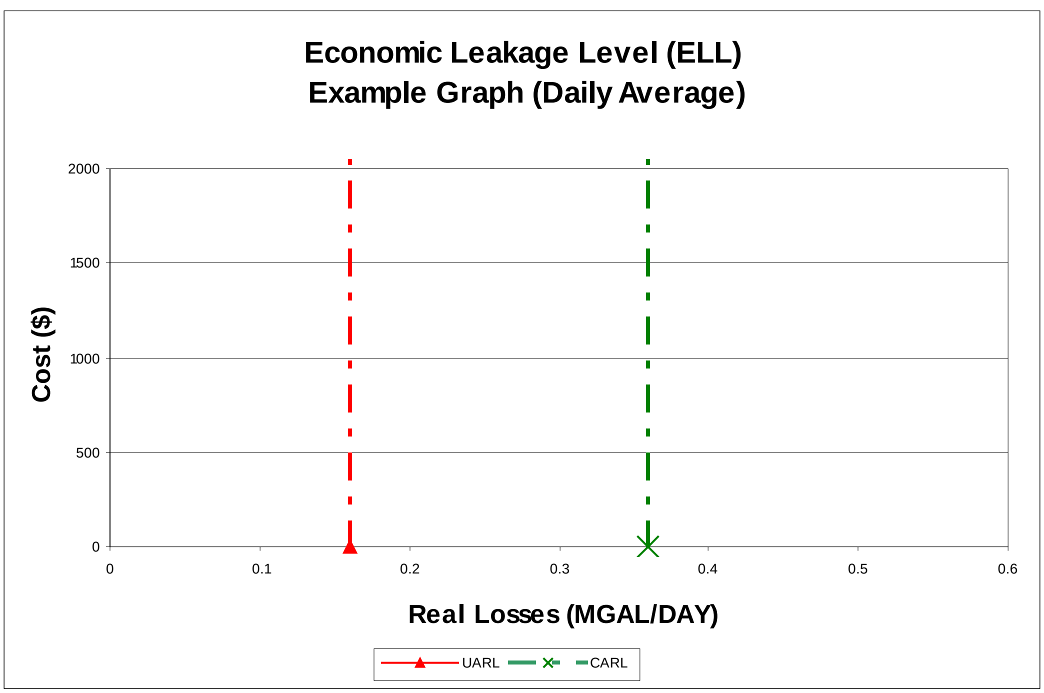
The following table lists the variables necessary to set boundaries on a graph and determine the value of water. The graph will have an x-axis of Real Losses (MGAL/DAY) and Cost (DOLLARS/DAY) on the y-axis.

Table 2: Setting Boundaries

Fields	**Units**
CARL	MGAL/DAY
UARL	MGAL/DAY
Miles of Pipe	MILES
Annual Leak Repair Budget	DOLLARS/DAY (annual cost divided by 365 days)
Recoverable Current Annual Real Loss (RCARL)	MGAL/DAY (RCARL = CARL – UARL)
Value of Water	DOLLARS/MGAL

From the table above, the difference between the CARL and UARL is equal to the Recoverable Current Annual Real Losses (RCARL). This RCARL is the total volume of water that is potentially recoverable through leak detection. It is the UARL that sets the low boundary at the lowest level of real losses that can be achieved through leak detection, and the CARL sets the upper boundary see Graph 1.

Graph 1: Setting Boundaries



The next step is to determine in the Value of Water (DOLLARS/MGAL), this is the actual retail value of the water produced by the water system. Most water systems in New Mexico are non-profit system and therefore it is recommended to use the retail value of the water. The retail value of water is based on the marginal costs of water associated with producing and distributing the water to its customers. The appropriate value of water can vary depending on the water system and rate structure. When water is scarce or in high demand it can have enormous value; however, most utilities do not include the capital, environmental, and social costs associated with producing water. For the purpose of this analysis, we will exclusively focus on the retail value of water at today's cost. However, future analysis should include the cost of purchasing new water in estimating the value of water.

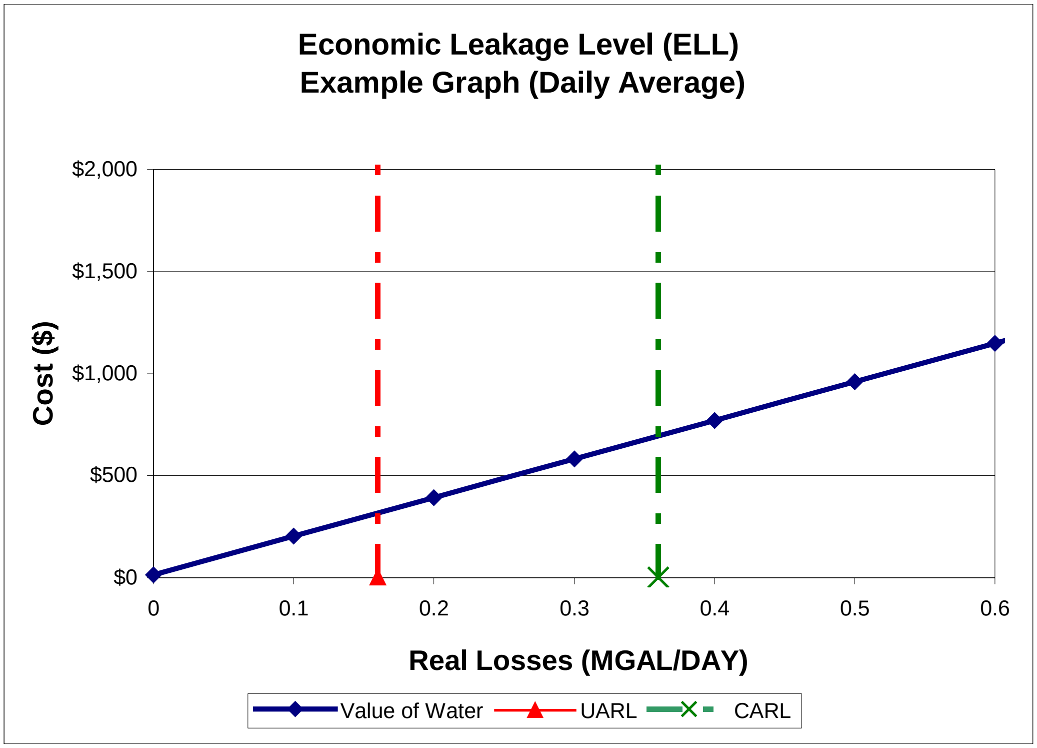
On Graph 2, the value of water is represented as a straight line with the monthly base fee as the y-intercept and dollars/million gallons as the slope as in Equation 5. This equation puts a value to the water that is lost due to leaks and is supposed to be representative of the entire customer base; however, for this analysis the value of water was representative of residential customers only.

Equation 5: Value of Water Equation

$$C(x) = Vx + B$$

C(x) = Unit cost of water per million gallon
V = slope, Value of water in dollars/million gallons
B = Monthly base rate, dollars
x = Volume of water in million gallons

Graph 2: Value of Water Graph



Step 2: Estimate Real Water Loss Reduction based on the Recoverable Real Water Loss

In estimating the real water loss reduction based on the recoverable real water loss, the AwwaRF Report 91163 recommends using a 50 percent reduction in the recoverable real water loss per survey conducted. This means that for every leak detection survey conducted over the entire system, the recoverable real water loss will be reduced by half. Subsequently, for each additional leak detection survey conducted, the remaining recoverable real water loss will be reduced by half and so on. Therefore, in determining real water loss reduction it is recommended to use an equation that will reduce the recoverable real water loss in half for each survey conducted. The following equation is the one used for this analysis.

Equation 6: Calculating Real Water Loss Reduction

$$R(t) = R_0(1-k)^t + UARL$$

R(t) = the remaining recoverable real water loss based on the number of surveys
R0 = the initial recoverable current annual real loss (RCARL)
k = 0.5, to represent 50% reduction per survey, or efficiency rating
t = the number of surveys conducted in a year
UARL = Unavoidable Annual Real Loss

This equation calculates the remaining RCARL reduction per survey, per year, based on the initial RCARL value. This equation is based on the volume of real water loss and not number of leaks, because conducting a leak detection survey does not change the number of leaks in the system, only the runtime of leaks are affected (AwwaRF, 2007). It is assumed that a water system will experience a certain number of leaks per year because of the age of pipe, operating pressure, and seasonal variation. It is also assumed that each leak in the system will have a runtime of one year before it surfaces or is repaired (AwwaRF 2007, Chung et al. 2005, Moyer et al. 1983). These leaks are assumed to be small and are losing water at a low gallon per minute rate. The benefit of leak detection is to help find these while they are small leaks and before they turn into major breaks. Therefore, the k value assumes that best-case scenario; one leak detection survey will reduce the RCARL in half, and is set at 0.5. Although not proven, this k value takes into consideration leak detection efficiencies, volume of RCARL, and the reduction in leak runtime. There is more work needed in this area to better define the variables involved in reducing real losses.

The RCARL is then added to the UARL in order to graph it appropriately. The level of real loss reduction that can be achieved through leak detection is strongly influenced by the average operating pressure for the water system, and is the reason for calculating the UARL.

The cost of leak detection and number of surveys that can be completed is influenced by the miles of pipe in the system, the number of work hours in a year, the rate at which a work crew can survey the entire system, and the total amount of labor dedicated to leak detection surveys. Correlating the cost of leak detection to the number of surveys that can be completed is covered in step 3.

Step 3: Estimating the Cost per Leak Detection Survey

Estimating the cost of a leak detection survey is a straightforward process that includes labor cost, equipment cost, miles of pipe, and a rate at which survey crews can move through the system surveying and pinpointing leaks. The survey rate is dependent on which leak detection method is used, either passive or active. This report does not address which method is preferred, since each method has its own benefits and limitations. However, this report will use the example of a water system using an active leak detection method. Also, this example assumes that the survey crew is traveling at a rate of 1 mile of pipe/hour, which includes surveying and pinpointing suspected leaks. It is important to note that the cost per leak detection survey is primarily comprised of labor cost for an entire year. Larger water systems are limited to fewer surveys per year when compared to smaller systems. The ability to survey an entire system is dependent on the size of the water system, and the amount of labor dedicated to leak detection. There is a limit to the number of miles one survey crew can cover in a year. In addition, there are approximately 1880 work hours per year, which accounts for time off during holidays and vacation. If warranted, larger systems may want to add additional survey crews to cover the system multiple times per year; however, this would then double the labor cost per survey. Based on the example used in this paper, the cost per survey is a linear relationship.

The following table is used to estimate a cost per survey if a water system decides to buy the equipment and conduct the surveys itself. Otherwise, if a water system decides to hire a subcontractor then the water system would just use the quoted price for a single survey divided by 365 days per year to obtain a cost per day value. In simulating a multiple survey events within a year, just multiply the quoted price accordingly or ask the subcontractor for a multiple survey quote.

Table 3: Estimating Labor Cost per Survey

Field	Units	Comment
Miles of Pipe	Miles	Miles of pipe is the controlling factor in determining how many surveys are conducted in one year.
Survey rate	Hours/Mile	Survey rate is estimated based on how many hours it takes a survey to cover one mile of pipe.
Labor Cost	Dollars/Hour	Labor cost includes salary, overhead and benefits for one employee.
Vehicle Cost	Dollars/Hour	Vehicle cost includes maintenance, fuel and insurance for one vehicle.
Equipment Cost	Dollars/Day	Equipment cost includes the upfront cost for leak detection equipment plus training. Assuming the equipment last for five years; take the cost of the equipment and divide by five and add it to the total cost.
Leak Repair Cost	Dollars/Day	Repair cost includes the average annual budget for repairing main line leaks. This is calculated by dividing the annual leak repair budget by 365 days.

The goal is to sum up the labor, vehicle and equipment cost to a total dollar amount per survey, and then divide by 365 days for a cost per day. As mentioned before, this cost per day has linear relationship to the number of surveys conducted. Therefore, the cost per survey per day represents the slope of the line with the annual leak repair cost (cost per day) at the y-intercept.

Equation 7: Cost Per Survey

$$C(t) = At + L$$

C(t) = Cost per survey (dollars/day)
A = Cost per survey per day (dollars/day)
t = Number of surveys
L = Cost of Leak repairs per day (dollars/day)

The cost of leak repairs per day becomes the y-intercept based on the assumption that before leak detection the water system was already spending a certain amount of money per year repairing main line leaks. It is important to point out that leak detection does not actually find more leaks in a water system; it finds leaks when they are small (approximately 5 gpm), before they surface, and before they become major breaks disrupting water service. In addition, finding leaks when they are small reduces the amount of water lost from leaks annually. Increasing the awareness time from reported leak to repairing the leak is what accounts for the real loss water reduction. The actual number of leaks that go unreported in a water system is relatively small, estimated at less than 5 percent in most cases, and does not have a major affect on this type of analysis. This analysis is based on total volume of recoverable real water loss and not the individual number of leaks. In the end, the cost of leak detection should be proportional to the real loss water reduction based on the number of surveys conducted throughout the system annually. The next step in this analysis is to correlate the recoverable real water loss and the cost per survey.

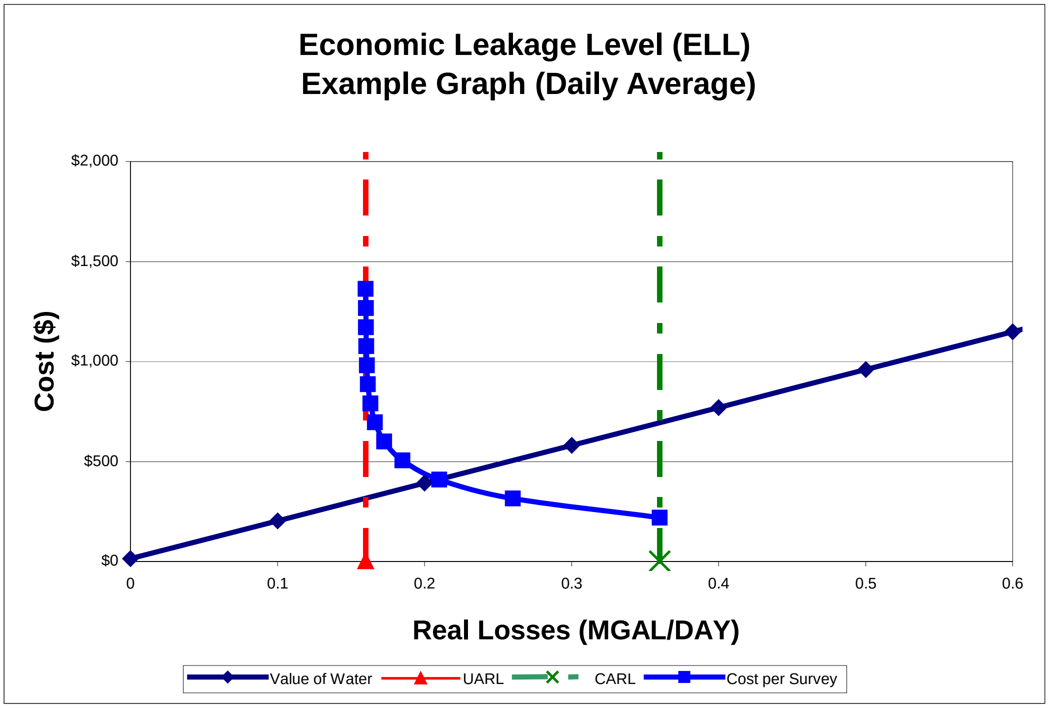
Step 4: Correlate Real Water Loss Reduction and Cost per Survey

Correlating the recoverable real loss water and the cost per survey is necessary in order to determine recoverable real loss water in terms of cost per survey. Equations 6 and 7 are used to relate recoverable real loss water to cost per survey since both equations share the t, number of surveys, term. The purpose of relating the two is to generate a graph that will show water loss reduction on the x-axis and cost on the y-axis. This graph should be an asymptotic curve to show that real loss reduction and cost per survey follows the law of diminishing returns, as the cost per survey increases the total amount of recoverable real loss water decreases. The simplest way to correlate equation 6 and 7 is to create a table of calculated values. Then, by graphing the real loss water reduction on the x-axis and cost per survey on the y-axis will produce an asymptotic curve like in Graph 3.

Table 4: Correlating Real Water Loss and Cost per Survey

Number of Surveys	Real Water Loss Reduction	Cost per Survey
t	$R(t) = R_0(1-k)^t + UARL$	$C(t) = At + L$
1	0.26	\$314
2	0.21	\$409
3	0.19	\$504
4	0.17	\$599
5	0.17	\$694
6	0.16	\$789
Example data: R_0 = 0.2 MGAL/D, UARL = 0.16 MGAL/D, k = 0.5, A = \$95.00/D, and L = \$219/D		

Graph 3: Correlate Real Water Losses and Cost



Step 5: Calculating and Evaluating the Economic Leakage Level

The ELL curve is calculated by adding the cost per survey line to the value of water line. To complete this task add two more columns to Table 4, one for the value of water and the second for the ELL value. Then, add the value of water for the remaining real loss water to the cost per survey, and the end result will be a value for the ELL line, as shown in Table 5.

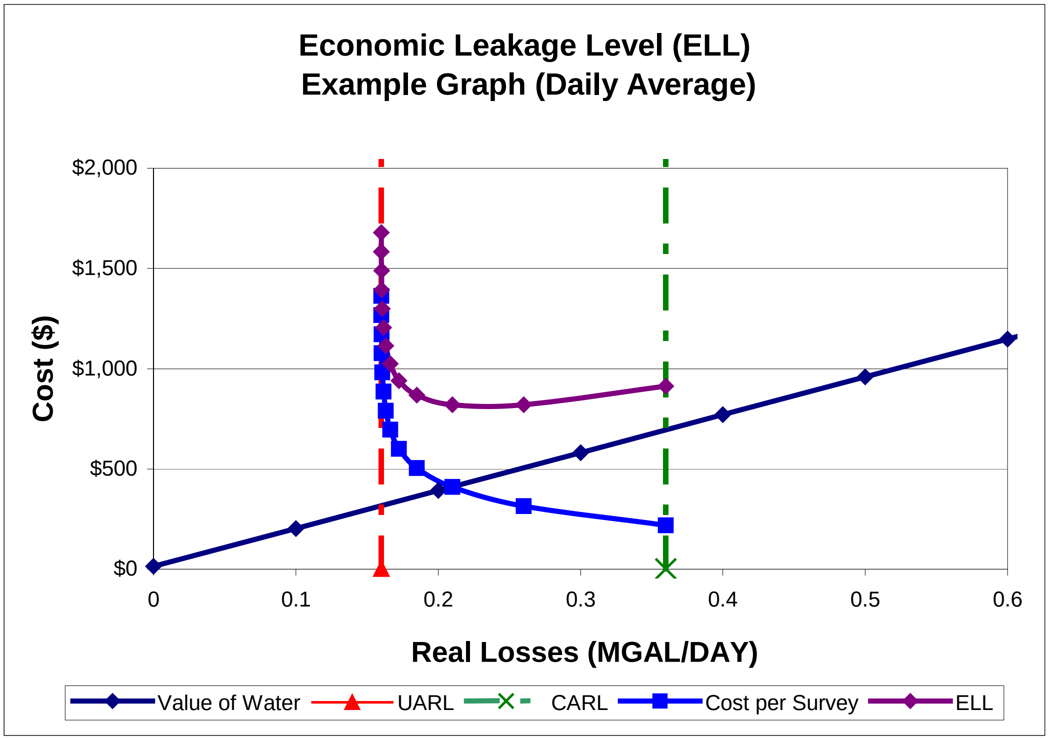
Table 5: Calculating the Economic Leakage Level

Number of Surveys	Real Water Loss (x)	Cost per Survey	Value of Water Lost	ELL Cost per Survey + Cost of Water
1	0.26	$314	$505	$819
2	0.21	$409	$411	$820
3	0.19	$504	$373	$877
4	0.17	$599	$335	$934
5	0.17	$694	$335	$1029
6	0.16	$789	$316	$1105

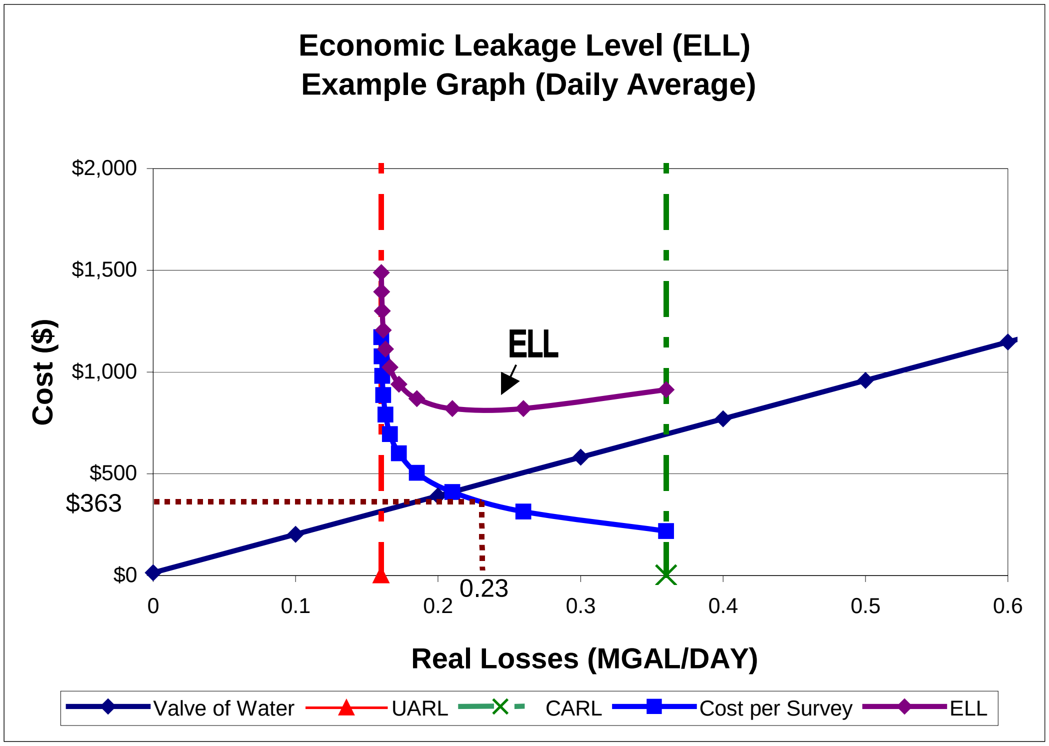
Graph the ELL values on the y-axis and the real loss water on the x-axis will result in a curved line similar to the one in Graph 4. This is known as the ELL curve and is specific to a particular water system and leak detection method/strategy. The ELL curve supports the theory that it is never economical for a water system to completely remove all of the real losses from the system, and the cost of reducing real losses increases for each additional gallon of water recovered. The point on the graph where total cost is at a minimum is the ELL. This is typically the flattest part of the ELL curve. Once the flattest part of the ELL curve is identified, trace a line down towards the x-axis until it intercepts with the Cost of Leak Detection and Real Losses curve. At that point, read the Real Loss value on the x-axis and trace another line to the y-axis to find the cost associated with reducing real losses, or the ELL, see Graph 5.

This method allows water systems to evaluate the cost of leak detection, valve of water, and the potential for real loss reductions in order to make an informed and economic decision about reducing real losses. The ELL is the economic balance point at which the sum of the cost of leak detection and the value of water lost through real losses is at a minimum (AwwaRF, 2007).

Graph 4: Calculating the ELL



Graph 5: Evaluating ELL



Results

Evaluating Unavoidable Annual Real Loss (UARL) and Infrastructure Leakage Index (ILI):

The interpretation of ILI values is straightforward. The ILI is a unitless number that is the ratio of the CARL divided by the UARL. Hence, an ILI value of 3.0 means that the CARL is three times as large as the UARL. In addition, ILI values that are close to 1.0 mean that the CARL is almost equal to the UARL based on the current operating pressure, and have reached the "technical minimum" leakage level (Lambert and McKenzie, 2002). The range of ILI values, as described by the AWWA Water Loss Control Committee water audit, are grouped into target ranges to assist water systems in gauging an approximate ILI for their system and local condition.

Table 6: Target ILI Ranges

Optimum	Good	Fair	Poor	Bad
< 1.0	**1.0 – 3.0**	**>3.0 – 5.0**	**>5.0 – 8.0**	**>8.0**

A large ILI value translates into a decrease in water system efficiency, and is an indication that the water system is in disrepair, whereas a lower ILI valve is an indication of improved water system efficiencies. Given the current situation in New Mexico, water resources are costly to develop or purchase, and the availability of water resources are in limited supply; the recommended ILI target range for New Mexico would be 1.0 to 3.0, based on AWWA Water Loss Control Committee recommendations. It is possible for a water system to calculate an ILI value of less than 1.0, however, it is based on one of two possibilities. It either means that the water system is maintaining it's leakage levels effectively and at such low levels that real losses are actually below the calculated UARL, or it could mean that the data used to calculate the CARL and UARL may be flawed. Such flaws can be attributed to over- or underestimating an average pressure for the system, especially when it is known that the operating pressure varies widely.

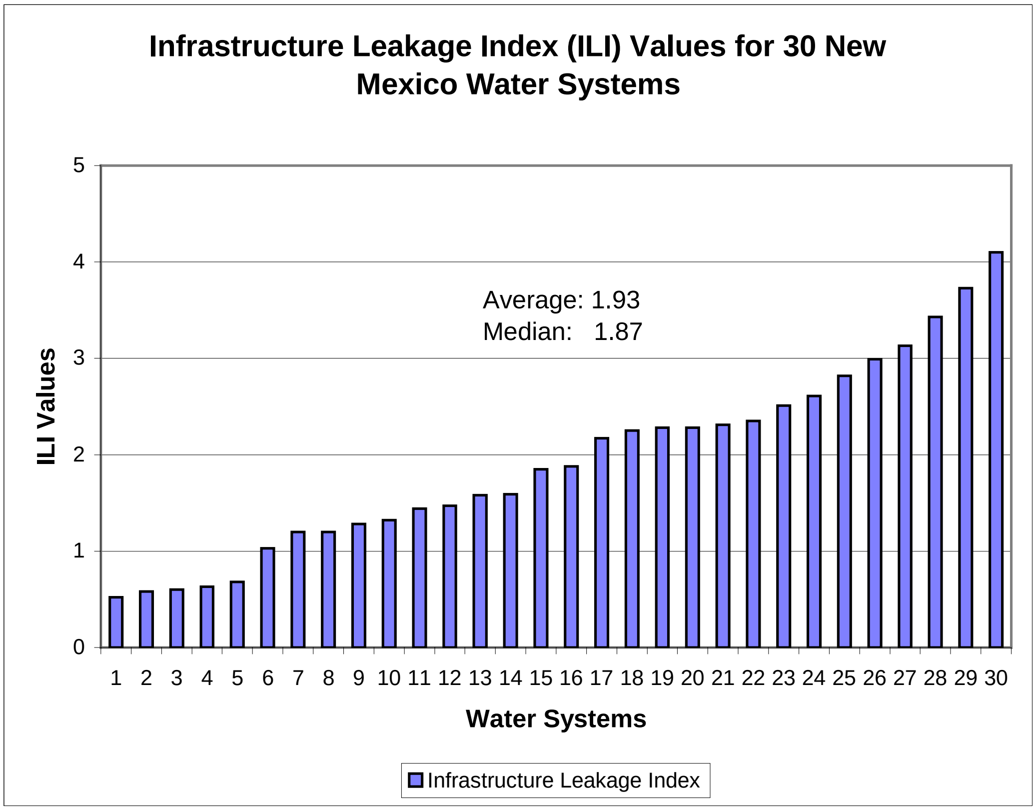
The following table outlines the CARL, UARL and ILI values for the 30 water systems that participated in this analysis. Although the ILI is reported to the third significant digit, this is not an indication of accuracy. The literature reports the ILI to the hundredth decimal place, and therefore it is used here. The following water systems in Table 7 are sorted by number of service connections from low to high.

Table 7: CARL, UARL and ILI

WATER SYSTEM NAME	CARL (MGAL/DAY)	UARL (MGAL/DAY)	ILI
BELEN WATER SYSTEM	0.12	0.03	3.73
LAKE SECTION WATER COMPANY	0.04	0.05	0.68
DONA ANA MDWCA	0.11	0.08	1.44
GRANTS DOMESTIC WATER SYSTEM	0.31	0.08	4.10
TRUTH OR CONSEQUENCES	0.12	0.06	1.85
ESPANOLA WATER SYSTEM	0.06	0.10	0.60
TUCUMCARI WATER SYSTEM	0.08	0.05	1.58
CITY OF RATON/RATON WATER WORKS	0.12	0.09	1.32
SOCORRO WATER SYSTEM	0.09	0.06	1.47
LOVINGTON MUNICIPAL WATER SUPPLY	0.33	0.11	2.99
LOS LUNAS WATER SYSTEM	0.06	0.10	0.58
NEW MEXICO UTILITIES INC	0.19	0.16	1.20
PORTALES WATER SYSTEM (CITY OF)	0.15	0.07	2.28
ARTESIA MUNICIPAL WATER SYSTEM	0.15	0.09	1.59
DEMING MUNICIPAL WATER SYSTEM	0.04	0.08	0.52
SILVER CITY WATER SYSTEM	0.32	0.17	1.88
LAS VEGAS (CITY OF)	0.36	0.16	2.28
GALLUP WATER SYSTEM	0.27	0.11	2.35
RUIDOSO WATER SYSTEM	0.48	0.38	1.28
ALAMOGORDO DOMESTIC WATER SYSTEM	0.23	0.19	1.20
CARLSBAD MUNICIPAL WATER SYSTEM	0.46	0.45	1.03
HOBBS MUNICIPAL WATER SUPPLY	0.56	0.16	3.43
FARMINGTON WATER SYSTEM	0.79	0.31	2.51
NEW MEXICO AMERICAN WATER CO (CLOVIS)	0.54	0.23	2.31
LOS ALAMOS MUNICIPAL WATER SYSTEM	0.40	0.18	2.25
ROSWELL MUNICIPAL WATER SYSTEM	0.71	0.33	2.17
RIO RANCHO SEWER AND WASTEWATER SERVICES	1.14	0.44	2.61
SANTA FE WATER SYSTEM (CITY OF)	0.43	0.68	0.63
LAS CRUCES MUNICIPAL WATER SYSTEM	1.45	0.46	3.13
ALBUQUERQUE WATER SYSTEM	8.74	3.10	2.82

The following is a graphical display showing the distribution of ILI values for the 30 water systems. A basic statistical analysis shows that the 30 water systems have an average ILI of 1.93, which means that at least half of the water systems are very efficient at managing leaks and real losses. In addition, further analysis shows that 87 percent of the water systems are below 3.0, 17 percent are below 1.0, and 70 percent are within the target range of 1.0 - 3.0. As mentioned before, the target range for ILI for most water systems is between 1.0 – 3.0, and is a sign of efficiency.

Graph 6: Infrastructure Leakage Index Values



It is important to point out that a majority of the water systems in this analysis were not proactively detecting leaks, or keeping detailed accounts of their real losses. Also, some of the data used in the calculation were based on estimations and assumption. There could be a number of reasons why the average ILI valve for the state is so low. There are, of course, other factors such as pressure management, age of pipe and pipe type that play an important role in assessing real losses. However, unlike other parts of country, particularly the in the east, most pipes in New Mexico were installed within the past 30 years as a result of recent population growth, are relatively young, and in pretty decent condition. This could very well account for low reported water loss percentages in the state. However, the age and pipe type were not addressed or included in this analysis.

In comparing the average ILI for New Mexico with other analyses conducted, New Mexico appears to be above average. A similar ILI analysis conducted for water systems in Texas reported an average statewide ILI value of 2.04 (Mathis and McDonald, 2007). In addition, Lambert et al., 2000, calculated an average ILI of 7.40 for seven North American water systems in the eastern part of the United States. The following table compares this ILI analysis with others conducted throughout the world over the past ten years.

Table 8: Comparing ILI Analyses

Analysis	Anonymous Data Set for 27 Systems in 20 Countries (1999)	Seven North American Water Systems (2000)	Ten Australian Urban Water Systems (2002)	Twenty Six South African Water Systems (2002)	Statewide Analysis of Water Systems in Texas (2007)	Thirty Water Systems in New Mexico (2008)
Avg. ILI	4.38	7.40	2.10	6.00	2.04	1.93

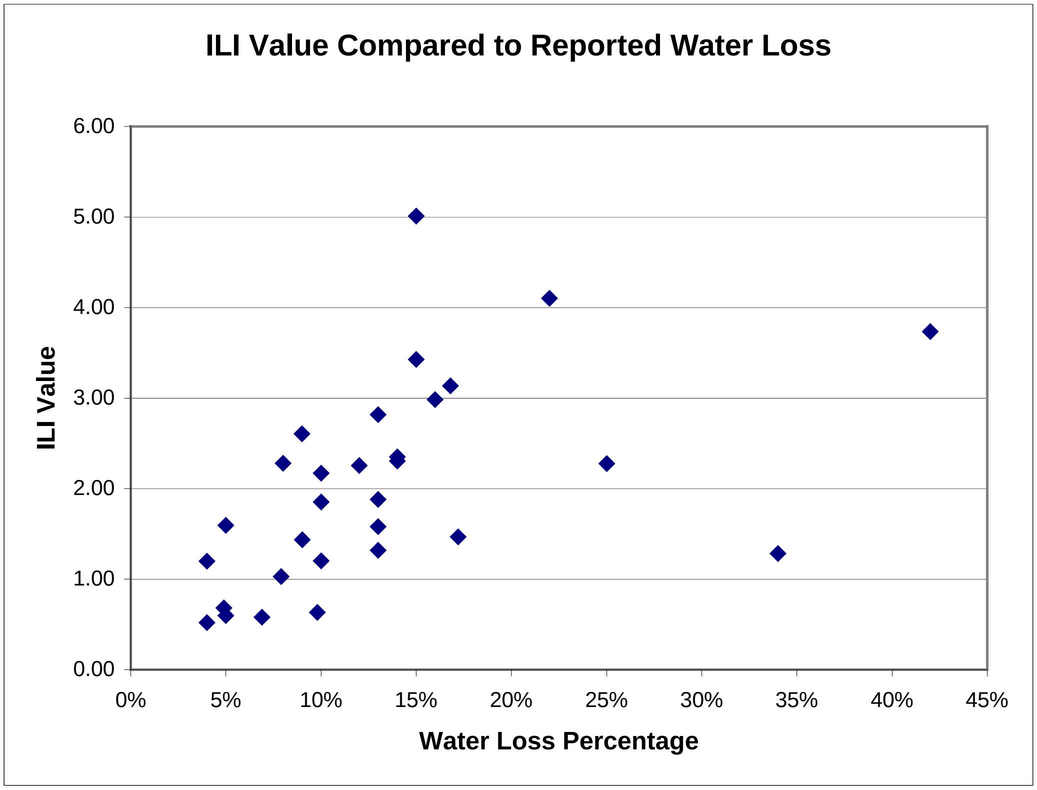
Source: Mathis and McDonald, 2007, and Lambert and McKenzie, 2002.

It is apparent that ILI values are not the industry's norm, and that many water systems still prefer to report water loss as a percent of system input. For whatever reason, water loss report at less than 10 percent is widely accepted as an acceptable level of water loss for any system regardless of size or operating pressure. However, the issue still remains that the percent of system input provides no indication of water system efficiency nor where water losses are occurring in the system. Percent of system input also fails to differentiate apparent versus real losses. As mentioned before, a few of the water systems that participated in this analysis expressed concerns over the accuracy of the percent water loss being reported.

For example, if a water system reports its real losses at 3 percent, what would be an appropriate goal for reducing real losses? The decision is almost completely arbitrary based on the percentage alone. However, if a water system reports its real losses using the ILI method, that value is immediately translated into a measure of efficiency, and how much water is potentially available for recovery. If the water system reports that its ILI is 3.0 then it is known that real losses are three times that of the unavoidable real losses and can set its target performance level at 2.0 for the following year. The following graph compares ILI values to the reported percent water loss for 28 of the 30 water systems. It is apparent from the graph that ILI values and reported percent water loss do not correlate very well, and is an indication that additional information is needed when water loss percentage in addressing real water loss reduction.

Of course, the ILI has its own limitations based on size of the system, accuracy of variables in the UARL equation, and collecting the data required. However, the importance of the ILI coincides with the next part of the analysis, which is calculating and evaluating the Economic Leakage Level (ELL).

Graph 7: ILI Values Compared to Reported Water Loss



The following table is a summary of the data collected on the 30 water systems for this analysis. The purpose of the summary table is to show the status of real losses for 30 of the relatively larger water systems in New Mexico. The data is reported in totals or averages in an attempt to show how much water the 30 water systems are losing as a whole, how much can potentially be recovered, and what is the total value of the water that is potentially recoverable through leak detection or real loss reduction strategies.

Table 8: Summary Table for the Data Collected

Total Population	1,155,370
Total Number of Service Connections	428,030
Total Miles of Pipe	12,077
Total Annual Water Use (MGAL)	81,078
Total Annual Water Lost (MGAL)	7,167
Total CARL (MGAL/DAY)	19.64
Total UARL (MGAL/DAY)	8.58
Total RCARL (MGAL/DAY)	11.06
Average ILI	2.01
Average Operating Pressure (PSI)	70.4
Average Length of Service Connection (FT)	19
Average Value per Gallon	$0.002
Total Value of Water Used	$162,156,000
Total Value of Water Loss	$14,334,302
Total Value of Potentially Recoverable Water	$8,073,800
Average Gallons Per Capita Per Day (GPCD)	192
Average Water Loss/GPCD	17

The 30 water systems evaluated in this analysis supplies water to approximately 59 percent of New Mexico's population. The total annual water use is approximately 81 billion gallons, and 9 percent of that total is lost through real losses. As for the real losses, approximately 56 percent of the total CARL is potentially recoverable and has an estimated retail value of $8.1 million dollars. The remaining 44 percent classified as unavoidable real losses or UARL. Of course, only a portion of that recoverable CARL is truly recoverable using leak detection; one third according to AwwaRF Report 91163.

The following section is an evaluation of the cost of leak detection and amount of water that can economically be recovered through leak detection methods for four New Mexico water systems.

Evaluating the Economic Leakage Level for Four Water Systems in New Mexico

In order to provide a better understanding of the ILI approach to optimizing leak detection efforts, four water systems were subjected to further analysis to determine their Economic Leakage Level (ELL). The four water systems were picked for the ELL evaluation because each water system recently had an AWWA Water Audit conducted and the information was readily available on the New Mexico Office of the State Engineer's web site. This was important because each water audit required a private consultant to work directly with the water system to collect the data required for the audit, and it was assumed that the information provided in the audit water accurate. The four water systems that were evaluated in this section were the City of Las Vegas, City of Gallup, City of Rio Rancho and the Village of Ruidoso.

The five-step process described in the previous section, and the results from the water audit were used to derive and evaluate the ELL. In the evaluations, the cost per survey value was based on the water system hiring a private leak detection firm to conduct an active leak detection survey over the entire system. This value was then used to determine the cost of multiple surveys conducted within the year. Of course, there are other leak detection methods and options available to water systems when planning a real loss reduction strategy; however, this analysis will only focus on the active leak detection method.

It is important to understand that the ELL is specific to the leak detection method being evaluated. The ELL value is derived from the ELL curve, which is the sum of the value of water and the cost per survey based on a particular leak detection method and current rate structure. It is recommended that a new ELL value be calculated for each leak detection method under consideration, or if the rate structure has changed.

City of Las Vegas, New Mexico

The City of Las Vegas (Las Vegas) is located in the central to northeastern part of the state along Interstate 25 on the east side of the Sangre de Cristo Mountains. In 2007, a private consulting firm completed a water audit for the city's water system. Table 9 included summary of the results from the audit.

Table 9: Las Vegas AWWA Water Audit Summary

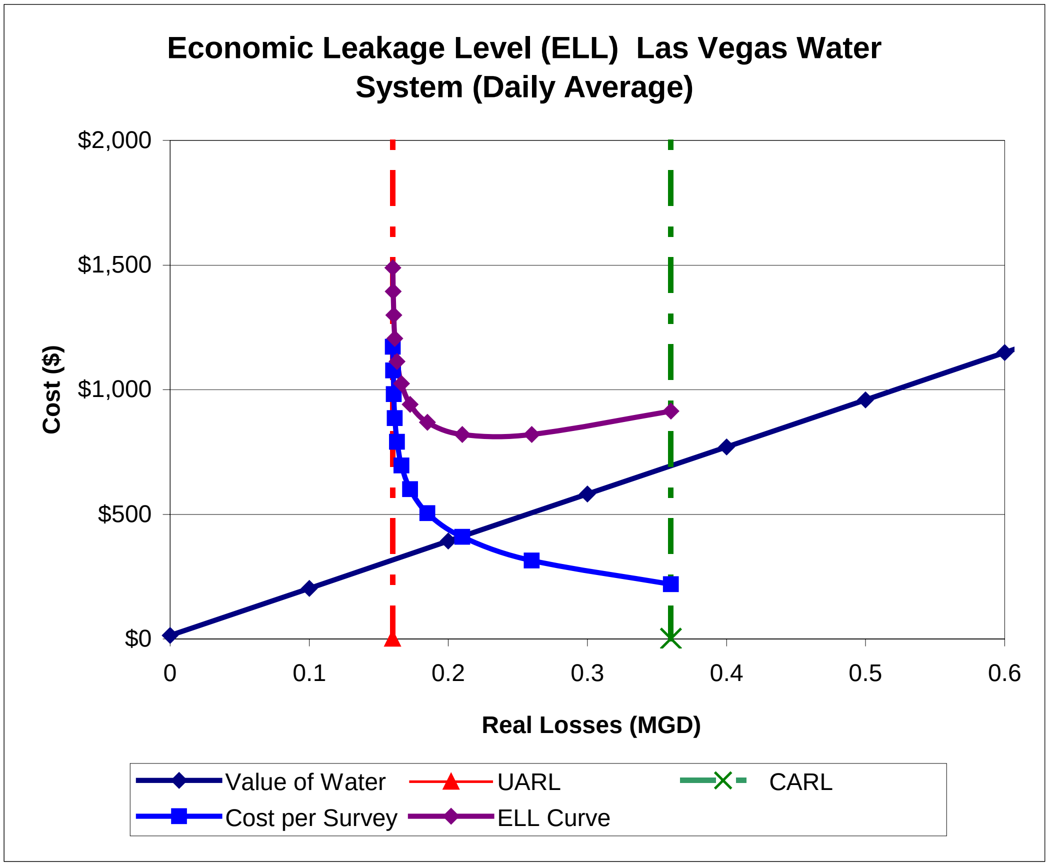
Miles of Pipe	124.2
Number of Service Connection	6,445
Average Operating Pressure PSI	75
CARL* (MGD)	0.36
UARL (MGD)	0.16
RCARL**(MGD)	0.20
ILI	2.25

Source: Hydroshpere Resource Consultants, 2007; * adjusted from gallons/connection/day; ** CARL-UARL

The data from the audit revealed that Las Vegas is a relatively small water system with less than 10,000 service connections. The system has an average operating pressure of 75 psi, and the reported ILI was within the acceptable target range of ILI values. In addition, based on the real loss, approximately 56 percent of the CARL is potentially recoverable through implementing a real loss reduction strategy. Considering all the data above, the water system may believe that having real loss approximately twice the unavoidable real losses is acceptable and would rather not spend money on a leak detection program. This is an important concept to understand when addressing real losses, because reducing real losses must be based on actual data and not a preconceived notion of water loss.

As mentioned before, reducing real losses to zero is cost prohibitive and nearly impossible. In calculating the ELL water systems are able to make an economic decision based on the value of water and the potential for recovering real losses through leak detection. A water system can use the ELL to set practical limits to how much money to spend, or evaluate each project on the amount of water that can potentially be recovered. Based on the data collected and using the five steps described in the previous section, the following graphs were created to help determine the ELL for the Las Vegas water system using an active leak detection survey.

Graph 8: The ELL Graph for the City of Las Vegas, NM



This graph highlights the UARL, CARL, value of water, cost per survey and the ELL Curve. The red UARL line sets the lower boundary and the green CARL line sets the upper boundary. The area in between represents the RCARL, and is the amount of real losses that is potentially recoverable through leak detection. In this scenario, the recoverable portion of the CARL is approximately 0.2 million gallons per day (MGD). The dark blue line represents the value of water, which is in dollars. The light blue curved line represents the daily average cost per survey for the chosen leak detection method. Each node on the survey curve represents one survey of the entire water system and correlates to the amount of remaining real losses in the system. Based on Graph 8, after the first leak detection survey the real losses are reduced in half and the remaining real losses are further reduced in half for each consecutive survey there after. The purple line on the graph represents the ELL curve, and is creating by adding the cost per survey curve and the value of water line together. It is where the ELL curve is at its minimum we find the optimum daily cost of a leak detection program, and by tracing a line down to the cost per survey curve and reading the cost on the y-axis we obtain actual values for the ELL. The results are summarized in the Table 10 below.

Table 10: Las Vegas ELL Results Summary

Real Losses at ELL	0.23
Cost at ELL	$363
Number of Surveys	1.5
Total Annual Costs of Leak Detection	$132,495
Total Water Saved Annually	47.5 MG ($89,789)
New ILI Value	1.44

Based on the results in Table 10, the ELL for the Las Vegas water system is $363 per day, which translates into an annual cost of $132,495 per year for leak detection. This is the maximum amount that the water system should spend on leak detection. Based on this analysis, at best the water system can hope to reduce its real water loss by 36 percent from 0.36 MGD to 0.23 MGD. Spending more than the estimated annual ELL amount for leak detection would not be economical for most water systems. Basically, by spending more than the estimated ELL you are spending more on the reducing real losses than the water that is lost is actually worth. In practical terms, the ELL is based on surveying the system 1.5 times; however, the water system would not go through the effort of paying for a half of a survey. Instead, the water system would treat the ELL as an approximation and survey the system only once. In this case, making an economical decision about leak detection it is appropriate to move to the next closest survey point on the curve below the value of water line. The point on the cost per survey curve where it intercepts the value of water line indicates the point of maximum benefit, in which case the systems would be spending an amount on leak detection that is equal to the remaining real loss.

It is important to point out that in making an economic decision on leak detection it is more appropriate to look at the value of water that is being lost instead of the value of water that is being saved. Real loss reduction should not be considered as a money making proposition, and the focus should be on reducing real losses than saving water. There are some cases, if the value of water is priced appropriately; the value of water saved is worth more than the money spent on leak detection. In the case for the City of Las Vegas, the value of water saved is 32 percent less than the ELL for leak detection.

City of Rio Rancho, New Mexico

The City of Rio Rancho is located in the central part of the state, west of the Rio Grande and in southern Sandoval County. The city has been ranked one of the fastest growing communities in the state. Its water system is the second largest in the state after the Albuquerque Bernalillo Water Utility Authority with approximately 28,000 service connections. The following is a summary table of data compiled from its 2007 water audit survey.

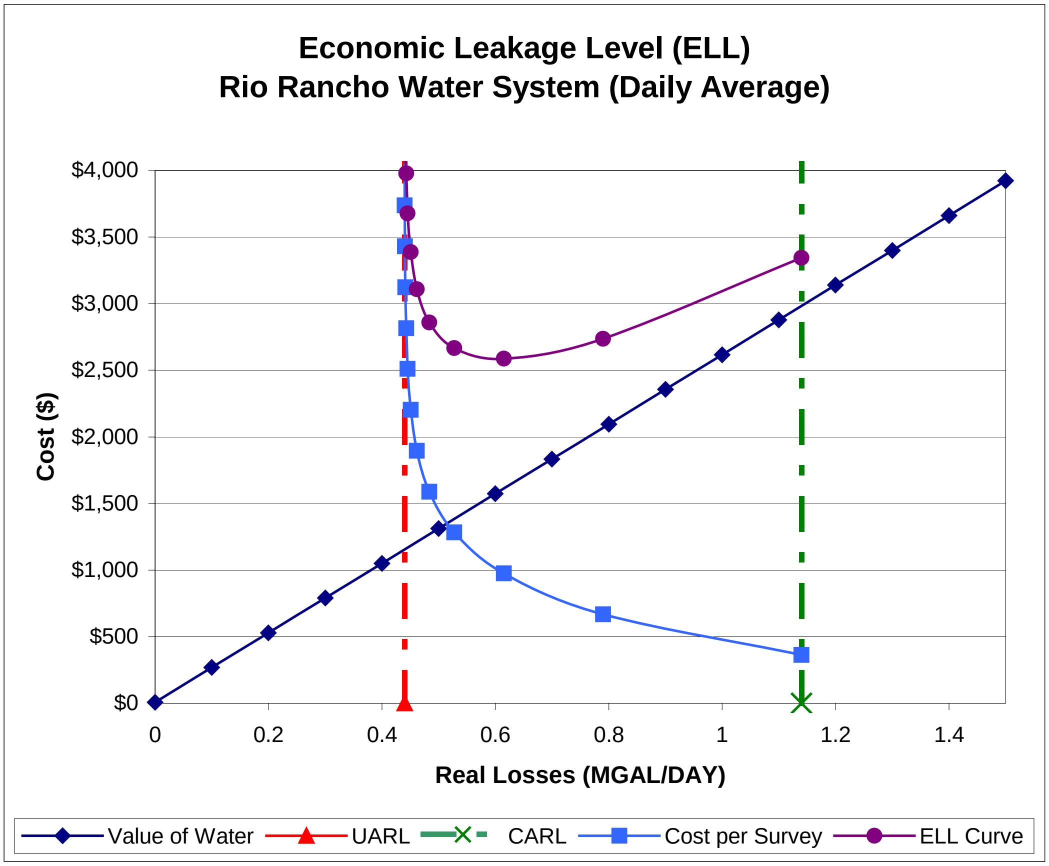
Table 11: Rio Ranch AWWA Water Audit Summary

Miles of Pipe	400
Number of Service Connection	27,937
Average Operating Pressure PSI	65
CARL* (MGD)	1.14
UARL (MGD)	0.44
RCARL**(MGD)	0.70
ILI	2.61

Source: Water Prospecting and Resource Consulting, 2007; * adjusted from gallons/connection/day; ** CARL-UARL

Based on the summary table above Rio Rancho has an average operating pressure of 65 psi and an ILI value of 2.61. Rio Rancho is considered a large water system, approximately 4 times as large when compared to the other three water systems in this analysis. In addition, in addressing the economics of real loss reduction and leak detection strategies, larger water systems deal with a larger volume of real losses when compared to smaller systems. This is important to consider because a large volume of water has a greater monetary value associated with it and therefore more money can be dedicated to leak detection. However, when comparing water system efficiencies, the ILI enables the comparison of water system efficiencies across the board regardless of size or volume of water loss.

Graph 9: The ELL Graph for the City of Rio Ranch, NM



Based on the graph above, the Rio Rancho water system has approximately 0.70 MGD of potential recoverable real losses. Since Rio Rancho is much larger system than Las Vegas, it is apparent that its real losses have greater monetary value, which will allow for a greater investment in leak detection strategies. However, spending is still constrained, because since Rio Rancho is a larger system it will also cost more in labor to survey the entire system. Based on Graph 9 and Table 12 below, the ELL for Rio Rancho falls at about two surveys per year with a daily estimated cost of $975, or $355,875 annually. Based on this ELL estimation, Rio Rancho could expect its real losses reduced by approximately 46 percent. In this case the value of water saved is worth more than the money spent on leak detection. This can be attributed to the City of Rio Rancho's rate structure to promote water conservation.

Table 12: Rio Rancho ELL Results Summary

Real Losses at ELL	0.62
Cost at ELL	$975
Number of Surveys	2
Total Annual Costs of Leak Detection	$355,875
Total Water Saved Annually	189.8 MG ($495,385)
New ILI Value	1.41

City of Gallup, New Mexico

The City of Gallup is located on the western edge of the state along Interstate 40, and is the third largest water system of the four. The following is a summary table of data compiled from its 2007 water audit survey.

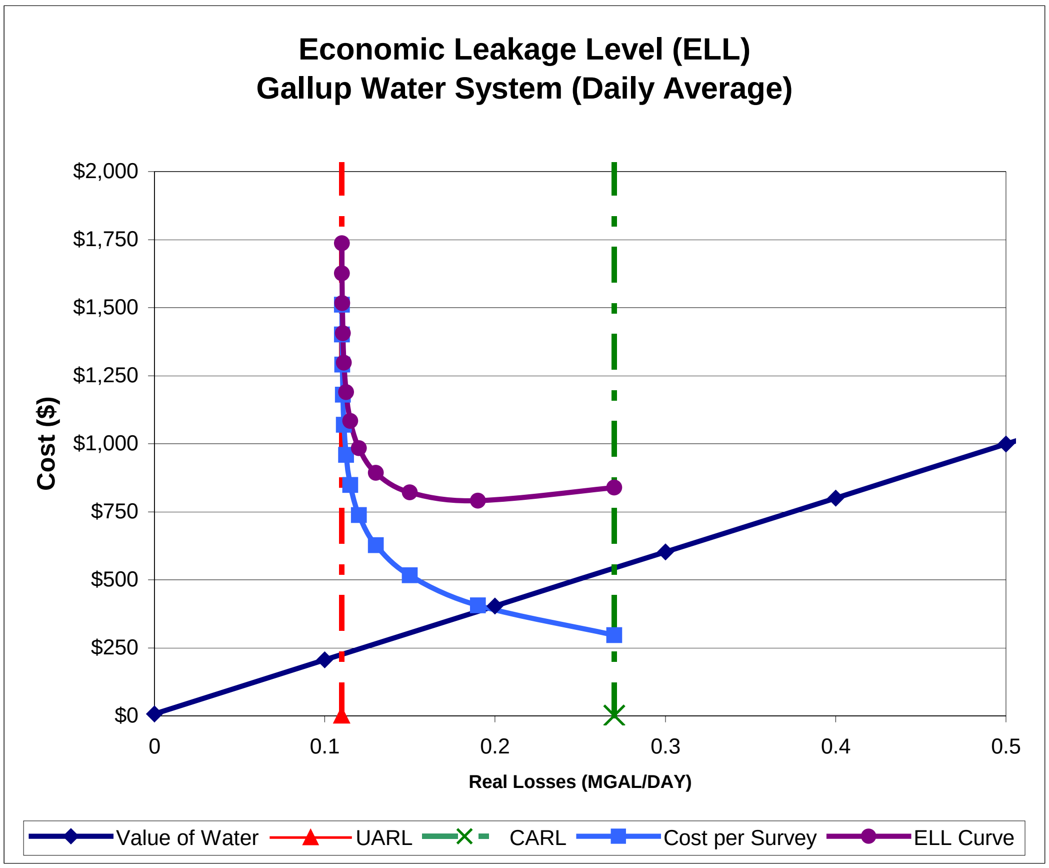
Table 13: Gallup AWWA Water Audit Summary

Miles of Pipe	144
Number of Service Connection	5,916
Average Operating Pressure PSI	65
CARL* (MGD)	0.27
UARL (MGD)	0.11
RCARL**(MGD)	0.16
ILI	2.35

Source: Daniel B. Stephens and Associates, 2007; * adjusted from gallons/connection/day; ** CARL-UARL

Based on the table above, Gallup has an average operating pressure of 65 psi and an ILI value of 2.35, which is very comparable to Las Vegas and Rio Rancho's ILI values. Essentially, all three of the four water systems have an ILI value that is a little more than twice its UARL, which indicates that all three systems are considered fairly efficient according to the AWWA water loss standards for target ILI values. However, in the case for Gallup, the question remains whether or not it is economical to pursue leak detection and real loss reduction strategies.

Graph 10: The ELL Graph for the City of Gallup, NM



According to the Graph 10, pursuing an active leak detection survey at the current value of water may not be in the best interest of the water system. According to the ELL analysis, it is not economical for the water system to survey the entire system once a year. This can be for two reasons. One, the Gallup Joint Utility charges such a low rate for its water that it is not enough to justify paying for an active leak detection survey, and two, active leak detection may be too costly for the water system to pursue. It would most likely be in the best interest of the water system to pursue a less expensive leak detection method or strategy.

Graph 10 is an excellent example of how using the ELL method can benefit water systems in making economical decision towards leak detection strategies. Based on the graph, it is not economical for the water system to pursue leak detection but the system could reduce its CARL to 0.19 MGD, which is a 30 percent reduction of CARL. In addition, based on Graph 10 and Table 14, the Gallup Joint Utility would want to look for alternatives leak detection strategies that are less than $148,190 annually. Another option for the utility would be to raise water rates, which would increase the value of the water and make additional leak detection methods more affordable.

Table 14: Gallup ELL Results Summary

Real Losses at ELL	0.19
Cost at ELL	$790
Number of Surveys	1
Total Annual Costs of Leak Detection	$148,190
Total Water Saved Annually	29.2 MG ($57,910)
New ILI Value	1.72

Village of Ruidoso, New Mexico

The Village of Ruidoso is a mountain town in the Sacramento Mountains located in central eastern New Mexico. The Village of Ruidoso is the second largest of the four systems analyzed in this paper. The following is a summary table of data compiled from its 2007 water audit survey.

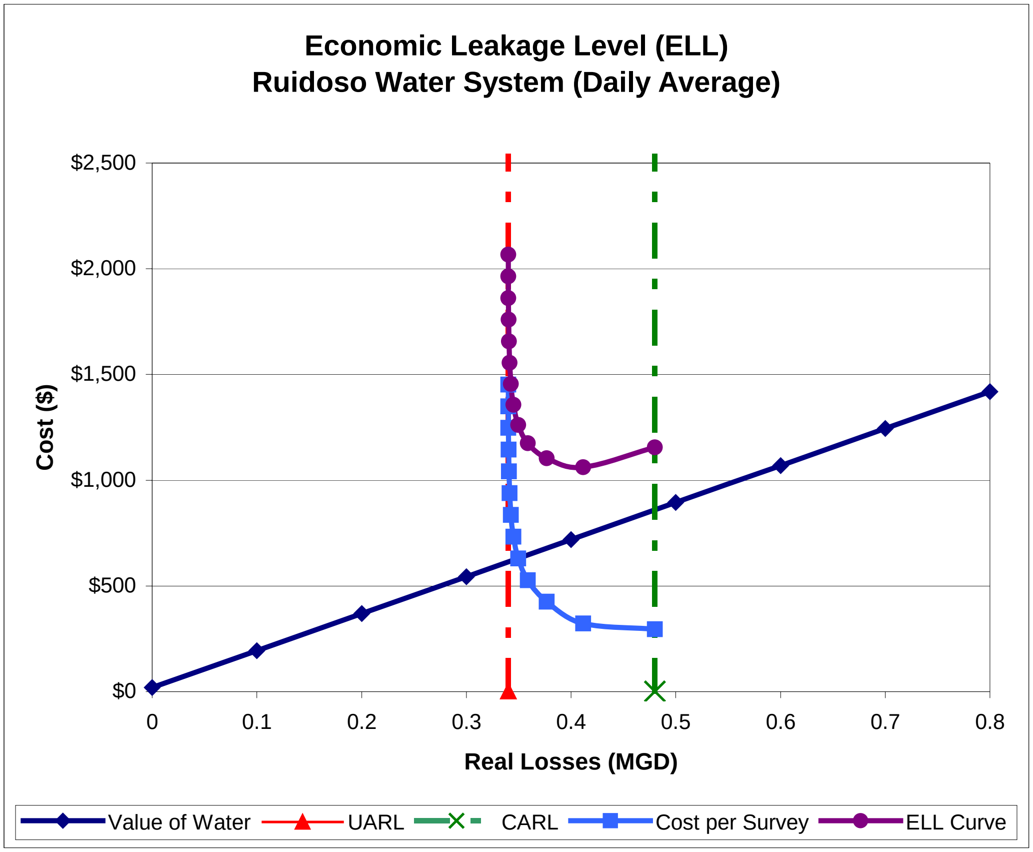
Table 15: Ruidoso AWWA Water Audit Summary

Miles of Pipe	134
Number of Service Connection	8,500
Average Operating Pressure PSI	145
CARL* (MGD)	0.48
UARL (MGD)	0.38
RCARL**(MGD)	0.10
ILI	1.28

Source: Daniel B. Stephens and Associates, 2007; * adjusted from gallons/connection/day; ** CARL-UARL

The Village of Ruidoso is unique in this analysis because of the four the water systems it is the only one that has an ILI closest to 1 at 1.28. This is interesting because 1.0 or close to one is considered the “golden number” and means that its CARL is almost equal to its UARL. In addition, this translates into a smaller portion of the CARL being potentially recoverable through leak detection. The low ILI is possibly due to the extremely high average operating pressure of the system, which is estimated at 145 psi for the entire system. This results in almost 80 percent of Ruidoso's real losses being classified as unavoidable real losses (UARL). In this case, leak detection may not be the best choice for the water system if its goal is to reduce real losses, and may want to pursue pressure management instead. The Graph 11 illustrates this by showing the relatively small portion of recoverable real water loss compared to larger portion of UARL.

Graph 11: The ELL Graph for the Village of Ruidoso, NM



According to the Graph 11, the recoverable real water loss is a relatively small portion of the CARL. In addition, based on the ELL analysis, it does not appear to be economical for the water system to pursue one full survey using an active leak detection method. Unlike the reasons mentioned for the Gallup Joint Utility, Ruidoso issues are not associated with the value of water. Instead, the ELL is limited due the small amount of potentially recoverable CARL. In this example, as with the other examples, as the cost required to conduct the next survey doubles, the benefit of reducing real losses decreases by half. Since the amount of recoverable CARL is so low for Ruidoso, it is not economical for the system to pursue real water loss reduction through leak detection beyond recommend three quarters of a survey. Beyond that point the cost exceed the benefits. Of course, increasing the value of water would change the results; however, it would be in the water systems best interest to pursue other methods to reduce real losses, such as pressure management to reduce the UARL.

Based on Graph 11 and Table 16 below, Ruidoso has very little to gain by pursuing the leak detection method used in this example. Not to say that leak detection has no place in managing real losses for this water system. Ruidoso should pursue a less expensive leak detection method and focus on trouble areas instead of the surveying entire system. However, as mentioned before, the ILI estimated for Ruidoso is close to 1.0 making the water system exceptionally efficient according to AWWA.

Table 16: Ruidoso ELL Results Summary

Real Losses at ELL	0.42
Cost at ELL	$296
Number of Surveys	0.75
Total Annual Costs of Leak Detection	$108,040
Total Water Saved Annually	21.9 MG ($38,344)
New ILI Value	1.11

Table 17 summarizes the potential benefits of using the ELL method for evaluating cost versus real loss reduction, which could help the water systems justify if the real water loss reduction is worth the expense. However, based on this method, it is apparent that the end result is strongly dependent on the price of water. If the price of water increases so does the value of the water being lost, and could justify an increase in spending on leak detection aside from the percent of real loss reduction.

Table 17: Summary of the Four Water Systems

Water System	Las Vegas	Rio Rancho	Gallup	Ruidoso
Current ILI	2.25	2.61	2.35	1.28
Potential ILI	1.44	1.41	1.72	1.11
% RL Reduction	36%	46%	30%	13%

Conclusions

By evaluating ILI and employing the ELL method water systems are able to make basic economical decisions regarding leak detection or other real water loss reduction strategies. Also, based on the ILI alone, water systems are able to evaluate efficiency and make management decisions based on the AWWA ILI target ranges. Since the ILI is a ratio, it is easier for water systems to compare real losses to unavoidable real losses in assessing water use efficiency, as opposed to addressing real loss as a percentage of system input. Therefore, the ILI is a beneficial tool for water systems to effectively manage real losses through leak detection by identifying upfront the portion of real losses that are potentially recoverable. It also enables water systems to rely less on the often-misleading percent water loss based on system input.

There are skeptics of the ILI method. Critics have cited that the ILI term is just an indicator that contains a judgment in itself and is based on an empirical expression (Liemberger et al., 2008). In addition, other shortcomings related to ILI pertain to the meaning or confidence level when the variability of the operating pressure and service connections length is high; especially, in hilly or mountainous regions like Ruidoso, New Mexico. Liemberger, et al., 2008, stated that the parameters that were used in the UARL formula were researched over a four year period, and the equation was subject to sensitivity testing before being first published in 1999. He goes on to say that it has proved to be robust in application with many hundreds of ILIs having been calculated in numerous countries. Also, in practice, the largest error impacting water balances have been the reliability of the system input volume measurement and estimates of apparent losses (Liemberger et al., 2008). Liemberger and McKenzie, 2005, stated that as soon as water systems start active leak control, carry out flow and pressure measurements, and improve overall data quality their confidence in ILI will greatly improve.

Using the ILI and ELL in the decision making process, whether or not to pursue real loss reduction using a leak detection method, enables the water system to select what technology to use and how to scale the size of the leak detection program appropriately with a certain level of confidence, or decide if a leak detection program is warranted at all. However, there may be political pressure to pursue a real loss reduction program to achieve the lowest level of real loss possible, in which case the ILI would also prove useful. Considering the alternative, or lack of alternatives available to water systems to assess efficiency, the methods outlined in this paper can provide water systems with valuable information that is often overlooked when considering leak detection strategy or a real loss reduction plan.

The AWWA water audit method is a relatively new concept in New Mexico; however, it is the next logical step in managing water systems efficiently and reducing real losses. It is in the best interest of water systems throughout the state to start taking note of real losses versus apparent losses, understand how much is recoverable, and what that water is worth. It is evident from Table 7 that New Mexico water systems are in relatively good shape when comparing ILI values and real losses. Even though some of the data used in this paper was estimated based on assumptions, the purpose of the AWWA water audit approach is to continue improving on the quality of data year after year. Water systems would benefit greatly from using this water audit as a planning and target-setting document, and water managers would begin to better understand how the water is managed. In addition, it would enable water systems to continue improving efficiencies and reduce water loss by setting tangible target performance goals based on the results. As for leak detection, aside from the two predominate methods, active versus passive; there are a wide range of methods and alternatives to utilize this technology to best serve the interest and goals of the water system. This is also why it is important for a water system to know its ILI and ELL based on a particular leak detection strategy. By setting appropriate real loss reduction goals and limiting expenses based on the value of water; water systems can effectively save water while preserving and improving its revenues, and as a result, better prioritize water loss projects. Presented below are a list of take-home points based on the evaluation of ILI and ELL in this paper.

Bullet Points

- Before addressing Real Losses, it is more economical and effective to address Apparent Losses first. By addressing Apparent Losses a water system can recover lost revenue quickly, and once Apparent Losses are known, a water system can better estimate Real Losses by subtracting Apparent Losses from its total Water Loss.

- The term "Unaccounted for Water" is no longer acceptable as an industry standard, and does not accurately describe how well a water system is being managed. Water systems should consider conducting an AWWA water audit on a regular basis to get a handle on water loss.

- The ILI value is a far more meaningful term than reported percent water loss based on system input at describing water system efficiency, and allows water systems to compare performance between systems and set tangible goals regarding water system performance.

- The reduction of real losses is based on the law of diminishing returns; the more resources dedicated to real loss reduction, the return benefit is significantly diminished.

- The ELL is strongly dependent on the Value of Water. Based on the ELL of the four water systems evaluated it was apparent that two of the water systems could hardly justify conducting one full survey of their system. This was primarily due to how the water system valued its water. As a result, the two water systems had to either find a less expensive leak detection method or increase its water rate in order justify one complete survey of their system.

- Since the ELL is dependent on the Value of Water, it is safe to assume that as the value of water increases, i.e. increase water rates, so does the number of options available to a water system in managing real losses.

- The Cost per Survey is dependent on the miles of pipe, labor costs, and the rate at which survey crews can move through the system utilizing the leak detection technology.

- There is a wide variety of leak detection technology available for water systems to use, whereas price and application may vary, leak detection technology does not find more leaks in a system. The benefit of leak detection comes from finding leaks sooner, before they become major breaks, and reduce the runtime of the leaks.

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