METHODS REPORT

Non-Revenue Water: Financial Model for Optimal Management in Developing Countries

Alan S. Wyatt

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About the Author

Alan Wyatt, MS, is a senior water supply and sanitation engineer at RTI International with more than 30 years' experience on both urban and rural water supply in 18 countries, many in Africa. Mr. Wyatt focuses on water service delivery management, especially finance, operations and maintenance, performance measurement, and non-revenue water.

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RTI International
3040 Cornwallis Road
PO Box 12194
Research Triangle Park, NC
27709-2194 USA

Tel: +1.919.541.6000
Fax: +1.919.541.5985
E-mail: rtipress@rti.org
Web site: www.rti.org

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Financial Model for Optimal Management of Non-Revenue Water in Developing Countries

Alan S. Wyatt

Abstract

Non-revenue water (NRW) includes physical losses (pipe leaks) and commercial losses (illegal connections, unmetered public use, meter error, unbilled metered water, and water for which payment is not collected). NRW levels are high in many developing countries, and they can be expensive to reduce. Members of the International Water Association (IWA) Water Loss Task Force developed the Economic Level of Leakage (ELL), which outlines the optimal level of physical losses based on engineering inputs. However, the ELL approach is less useful in developing countries than in developed countries, as it ignores commercial losses, the annualized cost of water supply capacity expansion, and situations in which production capacity does not meet demand.

This report presents a financial model that addresses the limitations noted above and provides acceptably accurate values of optimal, steady-state NRW without the need for large data collection efforts. The model uses an NRW framework adapted from the IWA Water Balance and the Burst and Background Estimates (BABE) and Econoleak methodologies. The report presents specific results for 59 utilities in 27 countries in Asia, Africa, and Eastern Europe; these include optimal NRW, optimal physical losses, optimal commercial losses, optimal meter replacement frequencies, optimal leak detection survey frequencies, actual losses, and impacts on utility revenue and water supply coverage. This model allows utility managers and regulators to establish NRW targets and to optimally allocate resources to NRW management. Ultimately, use of the model will help save water, increase utility revenues, expand coverage, and reduce health and economic impacts.

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Introduction

Urban Water Supply in Developing Countries and Non-Revenue Water

The world faces a huge challenge to provide improved water supply and sanitation, especially in urban areas in the developing world, where population growth rates have been highest. The latest figures from the World Health Organization (WHO)/UNICEF Joint Monitoring Programme (JMP) indicate that in 2008, more than 2.6 billion people were living without access to improved sanitation, and nearly 900 million people lacked improved drinking water supplies (WHO/UNICEF, 2010). The 2010 WHO/UN-Water Global Annual Assessment of Sanitation and Drinking-Water (World Health Organization, 2010) indicates that diarrhea is the second leading contributor to the global burden of disease—more than heart disease and HIV/AIDS. The same report estimates that 1.5 million children die from diarrhea each year. The health care and productivity costs from these diseases place a huge burden on low-income countries.

Despite the impacts of poor sanitation and inadequate drinking water supplies, many countries allocate insufficient resources to address these needs. At the same time, confused sector policies, weak institutions, and lack of incentives create bottlenecks to progress.

Non-revenue water (NRW) is a very large part of the problem. The World Bank estimates that in developing countries, leakage is about 45 million cubic meters per day(m^3/day) (Kingdom, Liemberger, & Marin, 2006). Also, roughly 30 million m^3/day


Photo: Leslie Wyatt

Water transport in peri-urban Kampala, Uganda.

Symbols Used in Equations

α	aggregate leakage flow coefficient for background losses and reported bursts
β	aggregate leakage flow coefficient for unreported leaks
b	economy of scale factor, capital cost function exponent
c	water consumption, in m^3/person/day
C_c	annualized cost of capacity expansion, in $/year
C_{cl}	annual cost of commercial loss control, in $/year
C_m	annual cost of the meter replacement program, $/year
C_{pl}	annual cost of physical loss control, in $/year
CRF	capital recovery factor, dependent on r and z
C_s	survey and repair labor cost, in $/km
C_v	annual variable cost of water production, in $/year
C_w	average unit variable cost of water production, in $/$m^3$ produced
D	length of the distribution network per connection, in km/connection
E	ratio of present capacity to present consumption (i.e., excess capacity)
F	future cost of the capacity expansion, in $
G	assumed population growth rate
k	capital cost function coefficient
km	kilometer
L	liter
L_c	commercial losses, in m^3/day
ℓ_c	commercial loss as a percentage of water consumption
L_m	average loss rate due to meter under-registration, in m^3/day
L_p	physical losses, in m^3/day
ℓ_p	physical loss as a percentage of water production
m	meter
M	average meter replacement cost, including materials, labor, overhead, etc., in $
n	number of new leaks forming, in leaks/km/year
N	total number of connections
NRW	non-revenue water, in m^3/day
p	average number of persons per connection
P_m	meter replacement period, in years
P_s	period of time for a full network survey, in years
PV	present value of a future capital expenditure, $
Q_c	water consumption, in m^3/day
Q_{c0}	base year water consumption, in m^3/day
Q_p	water production, in m^3/day
Q_r	revenue water, in m^3/day
r	interest rate
R	annual revenues, in $/year
s	slope of the meter accuracy line, in %/year
S	annual financial surplus, in $/year
t	time period until water supply capacity expansion, in years
T	unit tariff (or revenue) collected, $/$m^3$
z	design period for capacity expansion, in years

are not paid for. With a basic allocation of 100 liters per person per day (L/person/day), the 45 million m^3/day of leakage could serve roughly half the total population not currently covered. The same report estimates the total financial losses in developing countries to be about $5.8 billion per year.[1]

Reducing leakage and commercial losses costs money, especially if large sections of piping need to be replaced. Nevertheless, studies have shown that efforts toward conservation and NRW reduction can provide water at about one-half to one-third of the cost of water production from new capital plants (World Bank, 1992). In addition, as is very widely recognized, NRW reduction costs rise as losses are reduced. Calculations that properly balance costs and benefits can determine an optimal level of losses, if local costs, benefits, and water system engineering parameters are correctly taken into account.

The issue becomes the following: *What should the loss reduction target be?* In most developing country cases, NRW target setting is simplistic. For example, in Zambia, the water regulator has stipulated a loss target of 25 percent to 35 percent of production for all the regional utilities (National Water Supply and Sanitation Council [NWASCO], 2007). In Tanzania, the regulator has established a target to reduce losses to less than 20 percent, despite the fact that no utility has losses that low (Kingu & Schaefer, 2008). These targets do not use the correct indicator (as explained in the following section), nor are they based on local costs and conditions. Most importantly, the best target for losses depends on the location, taking into account the influence of local costs, benefits, engineering parameters, and other factors.

The financial model described in this report provides a well-reasoned tool to compute the optimal level, without the need for massive data inputs. This model allows donors, policymakers, and managers of municipal, regional, or national utilities to assess their performance in relation to optimal levels for their particular situation and to allocate resources optimally. Ultimately, use of the model will help save water, increase utility revenues, expand coverage, and reduce health and economic impacts.

Non-Revenue Water—Definition, Indicators, and Key Concepts

Definitions and Indicators

Any model depends on a clear set of terms and definitions. The most widely accepted framework for describing NRW is the International Water Association (IWA) Water Balance, which is provided in Figure 1 (Farley & Trow, 2003). The IWA defines NRW as follows:

NRW = System Input Volume –
Billed Authorized Consumption

NRW includes real or physical losses (leakage), apparent or commercial losses (e.g., meter error, unauthorized consumption), and unbilled authorized consumption.

Figure 1. International Water Association Water Balance

System input volume (corrected for known errors)	Authorized consumption	Billed authorized consumption	Billed metered consumption (including water exported)	Revenue water
			Billed unmetered consumption	
		Unbilled authorized consumption	Unbilled metered consumption	Non-revenue water (NRW)
			Unbilled unmetered consumption	
	Water losses	Apparent losses	Unauthorized consumption	
			Customer metering inaccuracies	
			Systematic data handling errors	
		Real losses	Leakage on transmission and/or distribution mains	
			Leakage and overflows at utility's storage tanks	
			Leakage on service connections up to point of customer metering	

Source: Adapted from Farley and Trow (2003).

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[1] All dollar figures in this report represent US dollars.

Many authors use "water production" or "water put into the distribution system" to be synonymous with system input volume. These are acceptable substitutes if water use inside a water treatment plant (e.g., for backwashing filters) is removed from the figures for water production. In addition, these terms are all consistent if losses in major transmission lines are not counted.

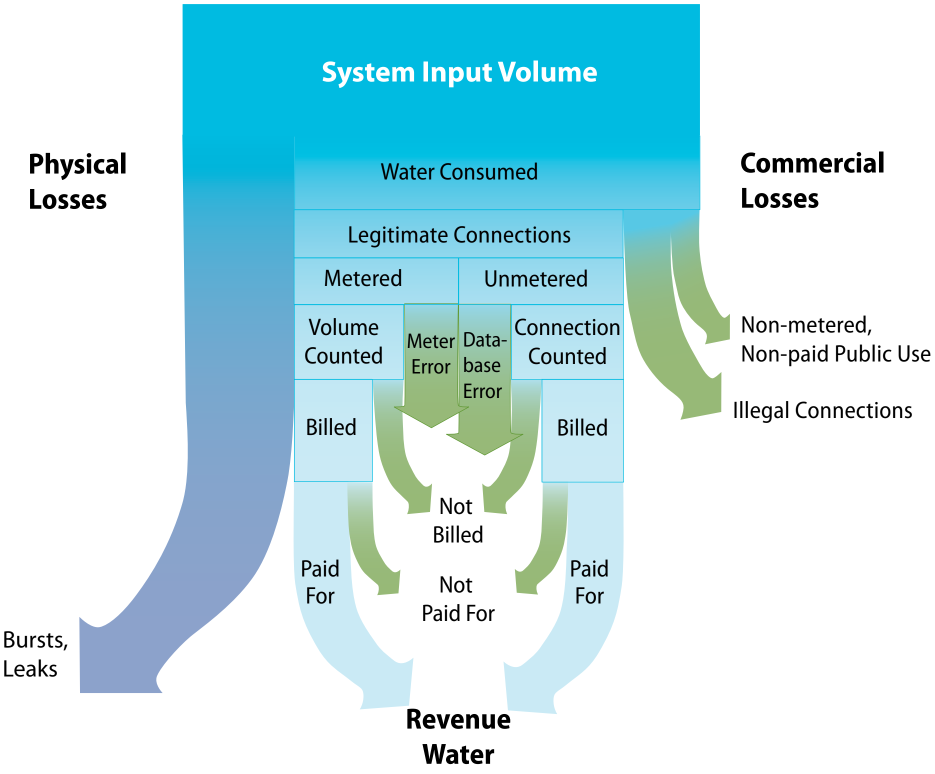
For situations in developing countries, some adjustments to the IWA Water Balance are needed. In developing countries, counting only the water volume that is paid for (actual revenue collected) is important, as opposed to counting the water that is billed (as used in the IWA Water Balance). This distinction is required because nearly all billed water is paid for in developed countries, but this is not true in most developing countries.

Figure 2 shows an adjusted water balance for developing countries. The commercial losses are represented by green shaded arrows and the physical losses in a single dark blue arrow. Although the layout is different, it is consistent with the IWA Water Balance, with the exception outlined above (paid for versus billed).

Another critical point is that representing the losses as a percentage of system input can be misleading. Imagine a simplified, hypothetical situation, depicted in Figure 3, in which losses are constant over time. If consumption were to decrease, owing to a tariff increase or other reasons, the utility would decrease water production proportionately. Therefore, the ratio of losses to production would increase, even though the actual amount of losses had not changed. So, NRW as a percentage depends on consumption and losses.

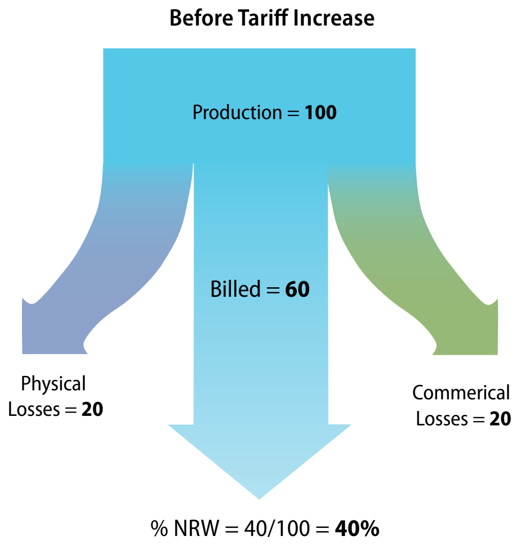
Using the indicator *NRW as a percentage of system input* to compare locations or look at trends over time is accurate only if the consumption is unchanged, which is rarely the case. Therefore, IWA has abandoned the indicator *NRW as a percentage of system input*.

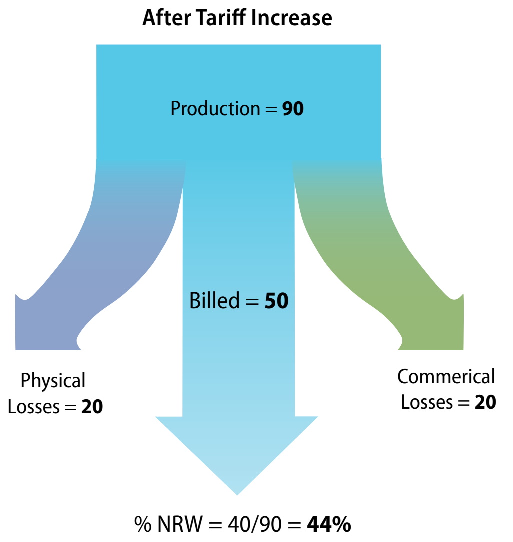
Figure 2. Adjusted water balance for developing countries



Physical Losses and Commercial Losses = Non-Revenue Water

Figure 3. Why percentage non-revenue water is misleading



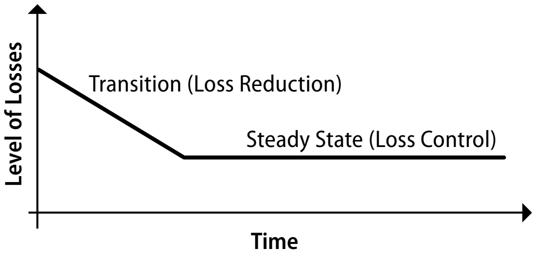


The IWA now recommends several key indicators: *NRW, physical losses*, and *commercial losses*, all measured in L/connection/day; for physical losses alone, IWA recommends the use of m^3/km of pipeline/day. Another salient indicator, which is very important in all discussions of NRW, is the density of connections—connections/km of distribution mains—or its inverse—distribution line length/connection.

Key Concepts

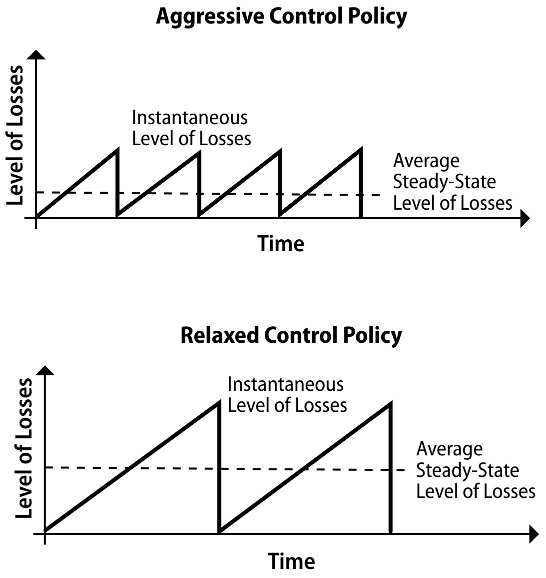
Several key concepts are worth reviewing before proceeding into detailed model development. First, the model distinguishes between *transition* situations and *steady-state* situations, as shown in Figure 4. This model does *not* focus on the transition from a high level of losses to a lower level or on how to achieve such a transition. Instead, it focuses on what the target for steady-state losses should be after transition.

Figure 4. Transition and steady-state losses



As illustrated in Figure 5, an aggressive active leak control program, with frequent surveys and repairs, will yield a low steady-state level of losses. A relaxed approach will yield a higher steady-state level of losses. However, an aggressive program will cost more than a relaxed one. So a trade-off is established between the cost of the losses and the cost of loss control. Again, the key question becomes, "*What should the reduction target be?*" or "*How far down do we take the losses?*"

Figure 5. Impact of alternative programs on steady-state losses



Second, the model has to distinguish between situations in which (1) water production capacity is ample (capacity surplus) or (2) serviceable demand exceeds water supply production capacity (capacity deficit). In the first case, the benefit of reducing leakage will be mainly savings of variable water production costs (electricity and chemicals). In the second case, the benefit will be the revenue that can be collected from the sale of the recovered water. In this second case, if the tariff or collection rate is low, as is common in developing countries, the benefits will be low.

Third, the model must take into account the diminishing return from an increasingly stringent loss-control policy. Economic principles, outlined in the next section of this report, show that the optimal physical loss is reached when the marginal cost of physical loss control has the same magnitude as the sum of the marginal cost of water production and the marginal cost of future capital expansion. The optimal commercial loss is reached when the marginal cost of commercial loss control is the same as the marginal revenue.

Fourth, the model must balance the accuracy of results with the data requirements. In other words, reliable data on some aspects of water system performance are often lacking, but the model still needs to be able to provide an acceptably accurate result. As we discuss later in this report, we derived default values for many parameters. Also, as we show later in the section Generic Model Application, the model presented here is not very sensitive to input parameters, so default parameters can generally be used to get an acceptably accurate result. However, country- or location-specific derivation of parameters will improve accuracy. It remains unclear how much extra effort to add precision on some inputs is needed to have any impact on the results.

Previous Work on Financial or Economic Analysis of Non-Revenue Water Reduction and Control

The literature on the finances of NRW reduction and control programs is abundant. It includes numerous studies on the results, costs, and benefits of leak detection and repair programs; studies on programs to reduce commercial losses; and documents that propose general guidelines or models on the finances of NRW. Within this substantial amount of literature, however, information from developing countries is limited.

These analyses approach the problem in different ways, take different factors into account, and come to different results. Each has its own strengths and weaknesses. All come from developed countries, mostly the United States and the United Kingdom. Although the UK approach has been applied in developing countries, no models exist that are specifically oriented toward the conditions in developing nations. This section provides an overview of this literature, with an emphasis on the financial optimization as applied to developing countries.

Simple Engineering Models

Several sources have provided guidelines on technically unavoidable leakage. Howe (1971) provided an “engineering estimate of the physically irreducible” rate of leakage of 2.3 m^3/day/km. Hudson (1978) computed a level of unavoidable losses of 2.3 to 6.9 m^3/day/km. Wallace (1987) reviewed various flat-rate formulas for unavoidable leakage, with results from 3.4 to 6.0 m^3/day/km. Holtschulte (1989) reviewed specific leakage for different types of pipes in different types of soils; he concluded that a level of 0.1 m^3/hour/km, or 2.4 m^3/day/km, is irreparable. So, during the early 1970s, rough agreement emerged on the level of unavoidable leakage in those years. However, these values are considerably higher than current thinking, which puts unavoidable losses on water distribution mains at about 0.5 m^3/day/km (Lambert, 2009; Lambert, Brown, Takizawa, & Weimer, 1999).

After considering the technical minimum, several authors discuss the economic minimum. Howe presents a parametric model that defines an “economic repair point” for leak detection and repair programs. Following this parametric model, efforts should continue to reduce leakage until this point is reached. According to Howe, this “occurs for a rate where the present value of the water currently being lost, but which might be saved, equals the cost of carrying out the detection-and-repair program” (1971, p. 285). Howe balances the discounted cost of water production and distribution (in excess of the minimum unavoidable leakage) against typical US leak detection and repair costs to arrive at an economic repair point of 6.9 m^3/day/km. Interestingly, Howe's economic level is about three times his own figure for unavoidable leakage.

Detailed Engineering Models from the United States

Walski (1984) explores the issue of benefits of leak detection and repair programs, looking at both short-run and long-run cost savings. For utilities that purchase water, the benefit will be based on the unit purchase price. For those that operate pumping or treatment facilities, Walski argues against using price as an indicator of benefits. Price incorporates a range of fixed costs that are unaffected by leak repair. Utilities can save money only by reducing operational costs. Substantial savings may be realized through leak repair, particularly if a utility is expanding, because the utility can downsize or delay construction of new water production facilities. Walski proposes a formula for benefits that includes (1) long-run savings (a portion of a capital expenditure downsized by leak repair) and (2) short-run savings, based on the unit cost of water pumping and the duration of the savings (described as the difference between the time when a leak is found with a detection program and when it would be found otherwise). Walski estimates duration at 1 to 5 years, but this broad variation and lack of information on the subject make this model difficult to apply.

In an earlier study, Walski (1983) had outlined a more detailed model for estimating long-run cost savings caused by downsizing or deferring capacity expansions because of conservation or leak detection and repair efforts. After proposing detailed parametric models and deriving values of parameters, Walski concluded that "downsizing is only economical for facilities built within a few years of the base year. Otherwise, delaying construction is more economical" (p. 496).

Griffin (1983), of the California Department of Water Resources, presents analyses and models of the benefits and costs of leak detection and repair programs. The analyses examine both short-run transition situations, in which leakage is driven from one level to a lower one, and continuing programs examined from a long-run, steady-state perspective. The models are based on fundamental principles of leak formation; they assume that benefits from the program will decline exponentially after the program begins. Griffin argues that only a portion of the repair costs should be included in the models because the leak detection program causes the repairs to occur sooner than they otherwise would have. His analysis of leak detection and repair efforts shows that benefit/cost ratios range from 0.5 to 10 and are highest when the cost of water and initial leakage are high.

The National Water Commission Manual

The British manual *Leakage Control Policy and Practice* (National Water Commission [NWC], 1980) thoroughly documents the impacts, costs, and benefits of various leakage control strategies. The manual's objective is to assist a water utility manager in selecting the best long-run method of leakage control given local leakage levels and general cost estimates. It explains clearly the strategies water utility managers could adopt and provides concise, experience-based information on the costs and impacts of these alternatives. This manual, and the follow-up work to implement its guidelines in all utilities in the United Kingdom, revolutionized the field, caused immediate shifts in leakage control practice, and led to major reductions in leakage and considerable net savings for the water utilities. The manual does not address commercial losses.

Some of the key elements of the NWC approach include the following:

1. The benefits of leakage control are derived from the "unit cost of leakage," which takes into account variable operating costs and deferred capital costs in a comprehensive calculation procedure. Water-production-related components of future capital costs are discounted to the present and converted to average unit water production costs.
2. The expected levels of leakage, using different control strategies in steady-state situations, are outlined simply, using the indicator L/property/hour.

3. The various unit costs of different leakage control strategies are estimated on a cost-per-property basis, including both setup and ongoing costs. The actual repair costs are not included, as the model is addressing long-run, steady-state conditions, and repair costs will not change, depending on the loss-control strategy used.
4. The results of example calculations indicate that waste (leakage) metering and district metering are generally the most cost-effective methods in the United Kingdom. Taking regular soundings, which is the norm in the United States, is estimated to be considerably less cost-efficient.
5. An analysis of the estimated costs and steady-state leakage levels associated with different control strategies indicates that an optimum level of leakage does exist. In other words, a passive strategy with high leakage is not economical, and a very stringent policy with very low leakage is too costly. A middle ground with intermediate leakage achieves the best economic position.
6. The adoption of a more stringent leakage control policy will result in a temporary backlog of repairs. "However, once the more intensive leakage control method has become established, the long term rate of repair of leaks, which approximates to the rate of occurrence of leaks, will remain substantially unchanged because none of the factors affecting the outbreak of leakage has been changed" (NWC, 1980, p. 31). In other words, the benefits of leak detection are not in reducing repair costs; rather, they lie in finding leaks quickly, soon after they develop, and keeping their leakage rate small, their duration short, and the total system leakage low.
7. The NWC report indicates that areas with low leakage can achieve a leakage rate of between 120 and 190 L/*property*/day, depending on the loss-control method used. In current terminology, we would state that areas with low leakage can achieve a leakage rate of between 120 and 190 L/*connection*/day, depending on the loss-control method used.

DiMichele, Giles, and Ghooprasert (1988) described the application of the NWC approach to the Provincial Waterworks Authority of Thailand. The authors derive new coefficients for predicting leakage levels and costs of implementing the five basic leakage control techniques in small systems in Thailand, based on many local tests and studies. The authors modified the NWC approach to compute the capital cost portion of the unit cost of leakage. In Thailand, demand exceeds supply capacity in the small, growing systems, and capital projects cannot keep up with demand. Instead of including future capital costs in the unit cost of leakage, they used expected increased revenue. The authors derive a nomograph that enables these small systems in Thailand to select the best leakage control strategy for their situation.

Shore (1988) uses a standard optimization approach to derive a simple expression for the optimal level of leakage for a water system in steady state. This optimum occurs when the marginal cost of leakage equals the marginal cost of detection. He proposes a three-part formula for the total cost of leakage: (1) the cost of leakage, directly proportional to the level of leakage, (2) the cost of detection, inversely proportional to the level of leakage, and (3) the repair cost, independent of the level of leakage.

Models on Costs and Benefits of Reducing Commercial Losses

Male, Noss, and Moore (1985) developed a model to predict the optimum meter testing period for 5/8-inch domestic meters. The model minimizes the sum of (1) the cost of the sum of meter repair programs, (2) the cost of water lost through failed meters, and (3) the cost of water lost through inaccurate meters, with period between meter tests as the key dependent variable. They derived an expression for the optimal testing period. For a sample application, based on US utilities, their derived optimal testing period is 9 years. This example indicates that the cost of water loss (the benefits) is about double the cost of the repair/replacement program.

Montenegro and Hwa (1989) presented a benefit/cost analysis for meter maintenance in Brazil. The authors studied the case of Companhia de Saneamento Basico do Estado de Sao Paulo (SABESP), a water and sewerage service provider in Brazil that has about 2 million small meters (3 m^3/hour) and had been removing meters for maintenance every 5 years. Their model considers the cost of meters, meter maintenance costs, and the value of the discounted stream of lost revenue. The results of the model indicate that the optimal meter maintenance period is 9 to 13 years, depending on the flow pattern.

Seago, McKenzie, and Liemberger (2005) conducted a survey of utilities in South Africa to estimate the magnitude of commercial losses. Although it was not a study on the economics of commercial losses per se, they presented estimated commercial losses in South Africa, as shown in Table 1. The table shows the approximate magnitude of commercial losses, as a percentage of water system input, for three types of commercial losses (illegal connections, meter error, and meter reading data transfer quality) under different conditions.

Mutikanga, Sharma, and Vairavamoorthy (2009) used this guidance for similar calculations for Uganda. Data presented later in this report indicate that commercial losses may often be much higher than levels indicated in Table 1. (See Appendix C for a table of commercial and physical losses for 41 utilities in developing countries.)

Further Research in Developed Countries

Some years after the publication of the NWC manual, a team of UK specialists assessed the report and more recent findings and launched a new program of research and publications. May (1994) published a paper on the fixed and variable area discharges (FAVAD) methodology that, based on direct measurements, outlined a power function relationship between flow rate and pressure for different types of pipes and conditions. In 1996, Lambert and Morrison introduced the burst and background estimates (BABE) method, which outlined standard burst frequencies and flow rates for background losses, reported leaks, and unreported leaks for different types of distribution piping. Lambert et al. (1999) combined the BABE and FAVAD methods in an important paper on unavoidable real losses. McKenzie and Lambert (2001), Farley and Trow (2003), Lambert and Lalonde (2005), Pearson and Trow (2005), and Lambert (2009) prepared conference papers that refined all these ideas to produce the short-run economic level of leakage (ELL) method, which outlines the financially optimum level of physical losses. The short-run model was also expanded to derive long-run ELL methods that take into account investments in pressure management and mains rehabilitation (Pearson & Trow, 2005).

Several authors report concerns about the ELL-assumed flow rates, especially in developing countries; these authors include Hamilton (2009; also personal communication with S. Hamilton at Hydro Tec, Northampton, UK, January 30, 2010); Ratnayaka, Brandt, and Johnson (2009); and Lambert (2009). However, their concerns have not led to a change in the ELL model. According to Lambert (2009), definitive data were not available to lead to a change in the approach.

Overall, the ELL approach seems to be the only currently available method for estimating optimal leakage without direct measurements at each site. McKenzie and Lambert (2001) developed a computer program, Econoleak, that allows computation of the ELL algorithms.

Table 1. Estimated commercial losses in South Africa

Illegal Connections		Meter Error			Meter Reading Data Transfer Quality	
Number	Losses	Meter Condition and Age	Losses of Good Water	Losses of Poor Water	Quality	Losses
Very High	10%	Poor, >10 years	8%	10%	Poor	8%
High	8%					
Average	6%	Average, 5–10 yrs	4%	8%	Average	5%
Low	4%					
Very Low	2%	Good, <5 years	2%	4%	Good	2%

Source: Derived from Seago, McKenzie, and Liemberger, 2005.

However, the ELL model does not address some issues that are important in developing countries. First, ELL ignores the financial optimality of commercial losses, which can be a very large part of NRW in developing countries. Second, it does not account for the annualized cost of future expansions of water production capacity, which is affected by loss reduction policies. Third, the ELL approach does not address situations in which water production capacity does not meet water demand. These considerations are of high importance in developing countries.

Trow and Pearson (2005, 2010) have also reviewed the target-setting process for NRW, which accounts for both physical losses and commercial losses and reviews economic, environmental, political, and technical aspects. Although they present various useful tools, they do not propose any comprehensive decision rules.

As part of a project for the World Bank Institute (WBI), Liemberger and McKenzie (2005) developed targets for both developed and developing countries, for physical losses in L/connection/day for various levels of pressure. A well-performing utility in a developing country should target physical losses to be less than 5 L/connection/day per 1 meter of pressure, or less than 100–200 L/connection/day for 20–40 meters of pressure. These values are about the same as those given for the United Kingdom in the 1980 NWC report. Liemberger and McKenzie presented targets for developed countries at one-half of their targets for developing countries. They did not consider length of line per connection.

Key Concepts from the Literature

This review of the literature has pointed out several fundamental concepts that are useful for a model for developing countries. It also points to some gaps that need to be addressed.

The concept of unavoidable leakage, or background leakage, is well recognized in the literature. The magnitude of leakage that is considered undetectable will depend on the detection technology available, pressure, and other factors. Approaches for developed countries may or may not apply in developing countries, but no basis exists for estimating this leakage other than the IWA methods developed in the United Kingdom.

The net benefits of leak detection and repair depend on the amount of leakage (burst rate, flow rate), the variable cost of water, the avoided capital expense, and the loss-control costs. Critical parameters include *system pressure*, which influences leak flow rate, and *leak duration*, which determines total leak losses. The ELL model, while conceptually sound, is based on burst and flow rates from British research, which may or may not apply well in developing countries. Yet no alternate, well-researched model exists that does not require direct, on-site leak flow measurements.

The literature concerning determination of optimal frequency for leak detection surveys generally does not take into account the actual leakage repair cost, as this cost would occur eventually. However, some authors believe that some repair costs should be included.

The literature provides little detailed information on the magnitude or composition of commercial losses in developing countries or the costs to control them. In this report, we have collected some data from which estimates can be made. Commercial losses in developing countries are clearly an area for considerable research.

Also, the literature does not provide overall targets for total NRW in developing countries, although some targets are available for leakage.

Photo: Myles Elledge

Illegal water connections in Indonesia.

Methods

Model Conceptual Framework

Basic Parameters of Water Flow

The model advanced in this report is based on the water flow shown in Figure 6, which is a simplified version of Figure 2. The water produced in a treatment plant, Q_p, flows into a distribution system. From there, some portion is consumed (Q_c) and goes on to useful purposes, and the balance is assumed to leak from the distribution system with no beneficial result. The total flow that leaks is called a physical loss (L_p). Thus,

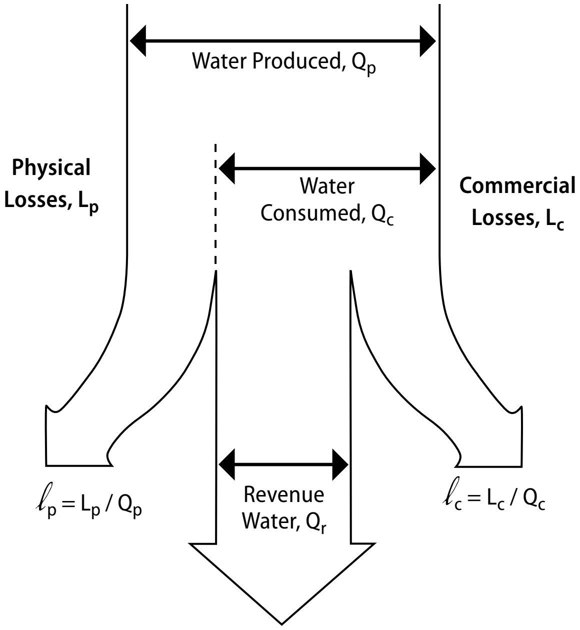
$$L_p = Q_p - Q_c \qquad (1)$$

The portion consumed is the total flow of water actually used by consumers, whether at legitimate or illegal connections, whether the connections are metered or unmetered, and whether the water is billed for and revenue is or is not collected. These water flow parameters are expressed in terms of daily flow, such as m^3/day. The water consumed (Q_c) is divided into revenue water (Q_r) and commercial loss (L_c):

$$L_c = Q_c - Q_r \qquad (2)$$

The commercial loss (L_c) represents water that is actually consumed for beneficial uses but for which no revenue is collected. The revenue water (Q_r) represents water delivered to legitimate users, for which there is a tariff and from which revenue is collected.

Figure 6. Water flow in a water supply system



We can define dimensionless parameters for losses: specific physical losses (ℓ_p) and specific commercial losses (ℓ_c), defined below:

$$\ell_p = L_p / Q_p \qquad (3)$$

$$\ell_c = L_c / Q_c \qquad (4)$$

These dimensionless parameters can be used to show the relationship between water production (Q_p) and water consumption (Q_c). Solving equation 3 for L_p and substituting the result into equation 1, solving for Q_p, yields

$$Q_p = Q_c / (1 - \ell_p) \qquad (5)$$

or

$$Q_c = Q_p\,(1 - \ell_p) \qquad (6)$$

Thus, water production is higher than consumption when ℓ_p is greater than zero and increases as ℓ_p increases.

Similarly, the relationship between water consumption (Q_c) and revenue water (Q_r) is found using equations 2 and 4:

$$Q_c = Q_r / (1 - \ell_c) \qquad (7)$$

or

$$Q_r = Q_c\,(1 - \ell_c) \qquad (8)$$

Thus, revenue water is lower than consumption when ℓ_c is greater than zero and decreases as ℓ_c increases.

The NRW is the sum of the physical loss and the commercial loss:

$$NRW = L_p + L_c \qquad (9)$$

The NRW can be expressed in terms of specific losses, using equations 3, 4, and 6:

$$NRW = Q_p\,(\ell_p + \ell_c - \ell_p\,\ell_c) \qquad (10)$$

The *revenue water* can be found similarly, using equations 5, 8, and 10:

$$Q_r = Q_p\,(1 - (\ell_p + \ell_c - \ell_p\,\ell_c)) \qquad (11)$$

The *water consumption* can also be expressed in terms of the number of connections and the consumption at each one:

$$Q_c = N\,c\,p \tag{12}$$

where

N = total number of connections

c = average water consumption, in m^3/person/day

p = average number of persons per connection.

These formulas outline the definitions and basic relationships used throughout the model presented in this report.

Model Scenarios

We developed this model for two different scenarios pertaining to water production capacity in relation to water demand—capacity surplus and capacity deficit. In both scenarios, the analysis assumes steady-state conditions; the effects of growth in connections or consumption (or both) are ignored. However, we do consider future capacity expansion.

Capacity surplus. This is the typical situation in industrialized countries and in many developing countries: water production exceeds demand and consumption is satisfied. As outlined in the previous section on key concepts (page 5), if the utility adopts more stringent policies on control of physical and/or commercial losses, it will increase its costs for leak detection programs, meter replacement programs, and similar conservation efforts. If leakage is reduced, however, water production will drop, and future capacity expansion will be deferred. The benefit to the utility will be cost savings in both water production and capacity expansion. If commercial losses are reduced, the water that previously fell into that category will become part of revenue water, increasing utility revenue.

In terms of model parameters, water consumption (Q_c) is held constant; therefore, the number of connections (N), people per connection (p), and the average consumption (c) are constant. A reduction in physical loss (L_p) allows water production (Q_p) to be reduced. A reduction in commercial loss (L_c) allows revenue water (Q_r) to be increased.

Capacity deficit. This is the situation in many developing countries where water production is constrained because of a lack of capacity and where demand is not being met, given the current water losses. Again, as outlined above in Key Concepts, if the utility adopts more stringent policies to control physical and/or commercial losses, it will increase its costs for leak detection programs, meter replacement programs, and similar conservation efforts. The result will be that water that would have been lost can be sold to users to meet local demand. This model assumes that all such saved water will be consumed. The benefit to the utility will be an increase in revenue as a function of the tariff (to the extent that such consumption is correctly metered and billed and that fees are collected).

In terms of model parameters, water production (Q_p) is held constant. A reduction in physical losses (L_p) or commercial losses (L_c) allows water consumption (Q_c) and revenue water (Q_r) to be increased.

These two scenarios—capacity surplus and capacity deficit—are summarized in Table 2.

Table 2. Model scenarios

Scenario	Utility Cost	Utility Benefit	Model Assumption
Capacity Surplus	Increased costs to reduce losses	Reduced production costs and capital costs; increased revenue	Q_c held constant
Capacity Deficit	Increased costs to reduce losses	Increased revenue and capital cost savings	Q_p held constant

Mixed case. In a mixed case scenario, production is constrained, but not all the water savings coming from loss-control programs can be consumed by local demand. In this case, reductions in physical losses will yield both revenue increase and production cost savings. This case is not examined in this report.

Objective Function of the Model

To compute optimal conditions, the first step is to define an objective function, in terms of decision variables, and then to determine optimality conditions, in terms of those decision variables. The optimality conditions can then be solved to yield optimal values of the decision variables.

The objective function chosen for this model is the financial surplus of the water utility (total revenues less total costs). However, the model could be framed differently, such as adopting an objective to minimize tariff subject to several criteria on service quality and infrastructure maintenance. Another possible objective would be to maximize coverage, subject to defined constraints on tariff, debt/equity ratio, service quality, and infrastructure maintenance.

The first step is to write an expression for water utility annual financial surplus (or loss) as a function of the level of specific physical and commercial losses (ℓ_p and ℓ_c). The financial surplus consists of the total revenue of the utility less the total of the costs, including water production costs, annualized cost of capacity expansions, physical loss-control costs, and commercial loss-control costs:

$$S = R - (C_v + C_c + C_{pl} + C_{cl}) \qquad (13)$$

where

S = annual financial surplus, in \$/year

R = annual revenues, in \$/year

C_v = annual variable cost of water production, in \$/year

C_c = annualized cost of capacity expansion, in \$/year

C_{pl} = annual cost of physical loss control, in \$/year

C_{cl} = annual cost of commercial loss control, in \$/year.

The following section, Model Development, presents formulas expressing each of the cost components in terms of ℓ_p and ℓ_c.

For purposes of modeling, not all of the costs associated with water utilities are included in the formula for surplus. For example, existing debt service, depreciation, and fixed labor costs are not included, as they are not affected by any change in physical or commercial loss. As far as costs are concerned, only those costs linked to ℓ_p and ℓ_c are put into the equation. However, the full revenue is included to give an accurate estimate of revenue benefits. Therefore, the value of surplus computed by the model will not represent the actual full surplus; rather, it represents a summation of terms linked to the costs or benefits of water loss-control programs. Analysis of this surplus will still allow analysts to find optimal values for ℓ_p and ℓ_c.

Optimal conditions will exist when the surplus is maximized. The expression for surplus is differentiated with respect to ℓ_p and then with respect to ℓ_c, and each is set equal to zero. Solving the resulting formulas yields algebraic expressions for the optimal steady-state values, ℓ_p^* and ℓ_c^*. From these, analysts can compute optimal NRW, revenue, and cost values, and policymakers can formulate program guidelines.

Model Development

This section derives the optimality conditions and related relationships associated with the capacity surplus scenario. The derivation of the capacity deficit scenario appeared in an earlier version of this work (Wyatt, 1994).

This scenario assumes that production capacity exceeds demand and that water consumption is constant. Physical loss reduction leads to reduced water production and production cost savings. Commercial loss reduction leads to revenue increases. The first step in the model is to outline the annual water utility revenue and cost functions in terms of ℓ_p, ℓ_c, consumption, engineering, and loss-control program parameters.

Revenues

The annual utility revenues will depend on the collected tariff and the quantity of revenue water, or

$$R = T\,Q_r\,365 \qquad (14)$$

where

R = annual revenues from water sales, in \$/year

T = unit tariff (or revenue) collected, in \$/m^3

Q_r = revenue water (the water volume for which payment is actually collected), in m^3/day.

Note that the collected tariff or revenue should be used, not the nominal (published) tariff, in keeping with the revised water balance depicted in Figure 2. Annual unit revenue can also be found if utility records show actual total annual revenue collected and the actual volume of water for which consumers made payments. Analysts can find a useful value for unit revenue to replace average tariff.

The annual revenue, in \$/year, can also be expressed in terms of water consumption by using equations 7 and 12:

$$R = T\, N\, c\, p\, 365\, (1 - \ell_c) \tag{15}$$

where

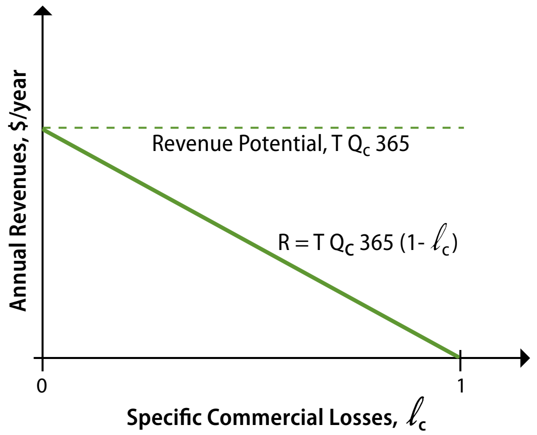
N = total number of connections

c = water consumption, in m^3/person/day

p = average number of persons per connection.

Thus, revenue is a function of local water consumption, the average tariff (or unit revenue collected), and the commercial losses as a percentage of consumption (ℓ_c). As illustrated in Figure 7, if the commercial losses are relatively high, ℓ_c will have a relatively high value and the revenue will be relatively low. As commercial losses are controlled and ℓ_c goes to zero, the revenue reaches it maximum potential value. The revenue does not depend on leakage.

Figure 7. Revenues as a function of specific commercial losses (ℓ_c)



Variable Cost of Water Production

The annual variable costs of water production (C_v), in \$/year, can be written as

$$C_v = C_w\, Q_p\, 365 \tag{16}$$

where

C_w = the average unit variable cost of water production (in \$/m^3), including chemicals and energy costs, water purchase costs, and any other costs dependent on short-run water production

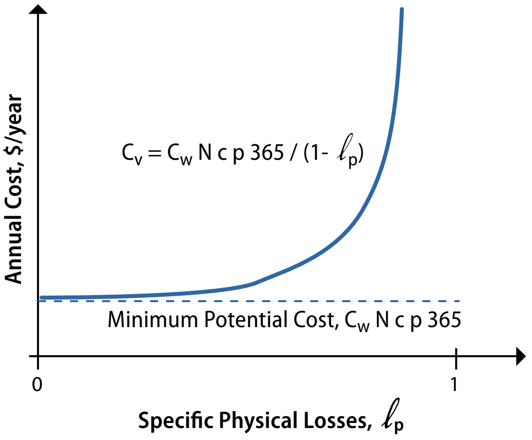
Q_p = water produced, in m^3/day.

Using equations 5 and 12, the annual variable water production cost can be expressed in terms of the physical losses as a percentage of production (ℓ_p), the number of connections (N), the specific water consumption (c), and the average number of persons per connection:

$$C_v = C_w\, N\, c\, p\, 365 \,/\, (1 - \ell_p) \tag{17}$$

This formula indicates that if ℓ_p is equal to zero, production will be at its potential minimum, which is equal to total consumption. As ℓ_p increases, losses will increase, and the variable water production cost will rise. If ℓ_p were to approach a value of one, the production requirement would climb to an infinite value. This is consistent with the presumption that a high leakage rate implies a high water production requirement and high water production costs. This relationship is illustrated in Figure 8.

Figure 8. Variable water production costs as a function of specific physical losses (ℓ_p)



Annualized Cost of Capacity Expansion

As outlined in previous sections, a reduced level of physical losses will mean that future capacity expansion expenditures can be delayed or downsized. This section outlines the key points of a model of capital costs as a function of the physical losses as a percentage of production. The detailed derivation of the capital cost term, summarized below, is presented in Appendix A.

In keeping with the approach of the NWC (1980) and Walski (1983), the model assumes that investments are delayed rather than downsized. Only the next expansion is counted. Later expansions will represent a small additional cost, because of the effect of discounting, and are ignored. The water demand is assumed to grow at a constant linear rate. The growth in demand (in m^3/day/year) is estimated from the product of an assumed population growth rate (in percent per year) and the current consumption (in m^3/day).

The capital cost term combines four elements:

1. An estimate of the future capital cost of the expansion (F). This is derived from a power cost function that relates the cost of the expansion to its capacity, a cost coefficient (k, in \$/m^3/day), and an economy-of-scale factor (b, typically about 0.7–0.8). The capacity is the product of a design period for expansions (z, typically about 10 years), the population growth rate (G), and the base year water consumption (Q_{c0}):

$$F = k\,(z\,G\,Q_{c0})^b \qquad (18)$$

2. The time in years until the expansion is needed (t). This will depend on the ratio of the present water production capacity to the current water consumption (E), the assumed population growth rate (G), and ℓ_p:

$$t = [E - (1/1 - \ell_p)] / G \qquad (19)$$

This expression is derived in Appendix A. Note that if ℓ_p is small, the time will be large, whereas if ℓ_p is large, the time will be small. If ℓ_p is reduced to zero, the time is ([E – 1] / G). As ℓ_p increases, the time will decrease, meaning that the investment will be required sooner.

3. Computation of the present value (PV) of the future capital cost, using standard discounting formulas, which depend on the interest rate (r) and the time until expansion:

$$PV = F\,(1 + r)^{-t} \qquad (20)$$

4. Computation of an annual cost equivalent to the present value of the future capital cost. This conversion is made using the standard capital recovery factor (CRF), which depends on the interest rate and the period over which the cost is annualized. For this model, the period is assumed to be equal to the design period (z).

$$CRF = r\,(1 + r) / [(1+r)^z - 1] \qquad (21)$$

Overall, the formula can be written as

$$C_c = CRF\,F\,(1 + r)^{-[E - (1 / 1 - \ell_p)] / G} \qquad (22)$$

where

C_c = annualized cost of the capacity expansion, in \$/year

CRF = capital recovery factor, dependent on r and z

F = future cost of the capacity expansion, in \$ (from equation 16)

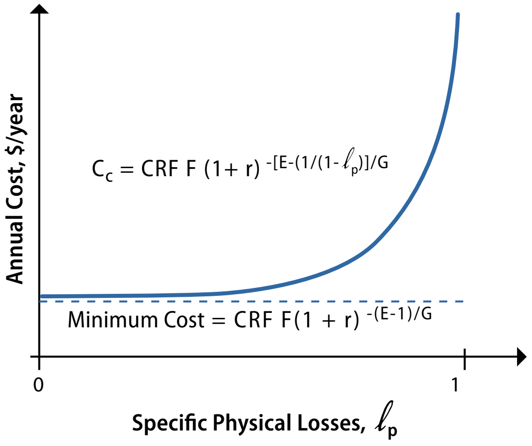
r = interest rate

E = ratio of present capacity to present consumption

G = assumed population growth rate.

The shape of this function is shown in Figure 9. If ℓ_p is zero, then annualized cost of capacity expansion is at a minimum, because the expansion is relatively far away. As ℓ_p increases, the time until the expansion decreases, the expansion must happen sooner, and its equivalent annualized cost increases.

Figure 9. Annualized capital cost as a function of specific physical losses (ℓ_p)



Cost of Physical Loss-Control Programs

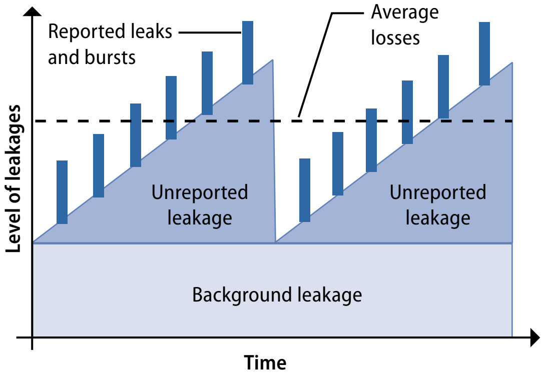
The model determines the steady-state level of losses, based on the loss-control activities conducted, and further, it determines the cost associated with those activities. As outlined previously, if the program is aggressive—involving frequent intervention—the annual cost will be high, and the level of losses will be low. At a different intervention frequency, the costs and losses will be different.

This section presents both the level of steady-state losses and the loss-control program cost as a function of intervention frequency (or period between interventions). These two elements are combined to determine the annual cost of the program as a function of the level of losses.

The approach used here is to assume that a leak detection program (based on sounding) is conducted continuously and that separate repair crews make repairs immediately after each section is surveyed. Leak detection crews move steadily from one section of the distribution network to the next, detecting and alerting the repair teams. After the segment is surveyed and fixed, the leakage in any segment of the distribution network will rise steadily until the next time it is surveyed. When the next survey takes place, new leaks will be detected, they will be fixed, and the segment will be returned to the level of leakage at the end of the previous survey. Thus, as shown in Figure 5 (page 5) and Figure 10, the level of losses in any segment will zigzag up and down over time. If all the segments in the system are added up, this summation will be at a steady state loss value.

Steady-state level of losses. The steady-state level of losses will be a combination of the following elements: background (undetectable) leakage; unreported leaks (usually small), which are discovered by leakage surveys; and reported bursts (usually larger), which occur when an undetected or unreported leak grows, becomes visible, and is reported to the utility. These components are illustrated in Figure 10, based on the work of Fanner and Lambert (2009).

Figure 10. Components of physical losses



Source: Adapted from Fanner and Lambert, 2009.

All these loss components can occur in three locations: (1) distribution mains and joints, (2) service line connections, and (3) service line piping. Thus, we have a matrix of three types of losses in three different locations (Table 3). Key variables are the burst rates,

Table 3. Key variables to determine level of physical losses

System Component	Background (Undetectable) Leakage	Unreported Leaks	Reported Bursts
Distribution mains and joints	Nominal loss rate dependent on length and pressure	• Burst rate • Flow rate • Response time based on survey frequency	• Burst rate • Flow rate • Repair response time
Service line connections	Nominal loss rate dependent on number and pressure	• Burst rate • Flow rate • Response time based on survey frequency	• Burst rate • Flow rate • Repair response time
Service line piping	Nominal loss rate dependent on number and pressure	• Burst rate • Flow rate • Response time based on survey frequency	• Burst rate • Flow rate • Repair response time

flow rates, and leak duration (which depends on the repair response time or survey frequency).

The burst rate and leak flow rate will depend on the type of pipe material, age, system pressure, pressure variation, external loadings, and other variables. Although considerable data have been gathered in developed countries, only sporadic information is available on burst and flow rates, in terms of pressure, from developing countries.

Appendix B has data on burst and flow rates in developing countries, but using such data is problematic. In developed countries, burst and flow rates will rise with pressure. The data in Appendix B show, however, that the opposite takes place in developing countries: Systems with high burst rates have low pressure because of rampant leakage. If leaks are detected and repaired quickly, pressures will rise. This trend gives no indication of how systems will leak after a transition to steady-state. This is clearly an area for more investigation.

Despite some uncertainties in developing countries, we used the Econoleak program developed in South Africa by McKenzie and Lambert (2001). Developed-country values of burst rates and flow rates are scaled by observed pressure. Repair response times for reported bursts are selected constants (3 to 8 days), and response time on unreported leaks depends on survey frequency. Burst and flow rates are scaled up by an infrastructure status factor that depends on the age of the system, real site burst rates, and total current physical losses. Appendix B provides detailed values for all the parameters used.

Appendix B also provides the derivation of the following formula for the physical losses as a function of P_s:

$$L_p = N\ D\ (\alpha + \beta\ P_s) \qquad (23)$$

where

L_p = physical losses, in m^3/day

N = total number of connections

D = length of the distribution network per connection, in km/connection

α = aggregate leakage flow coefficient for background losses and reported bursts

β = aggregate leakage flow coefficient for unreported leaks

P_s = period of time for a full network survey, in years.

This formula is linear. It has an intercept ($N\ D\ \alpha$) reflecting background losses and reported bursts and another term reflecting unreported losses as a function of the leak detection survey frequency.

Annual cost of physical loss control. The annual cost will depend on the number of kilometers surveyed per year and the cost per kilometer for survey work. If utilities conduct surveys on a continuous basis, the average number of kilometers surveyed in a year is the ratio of the total length of the distribution network to the time it takes (in years) to survey the entire network. For example, if a given survey is spread out over 2 years, then one-half of the length of the network will be surveyed in any 1 year.

An additional cost for repair crew labor must be added (but not the material costs of the repairs). This cost is added because if funds are not spent on repair crews to follow the leak detection crews quickly, the leak duration will be long, and the benefits of the survey costs will not be realized. In keeping with literature cited in the section on previous economic analysis, however, hardware costs are not included. Appendix C presents the derivation of a cost or leak survey and repair per kilometer.

The annual cost can be expressed as

$$C_{pl} = C_s\ (D\ N\ /\ P_s) \qquad (24)$$

where

C_{pl} = annual cost of physical loss-control, in \$/year

C_s = survey and repair labor cost, in \$/km

D = length of the distribution network per connection, in km/connection

N = total number of connections

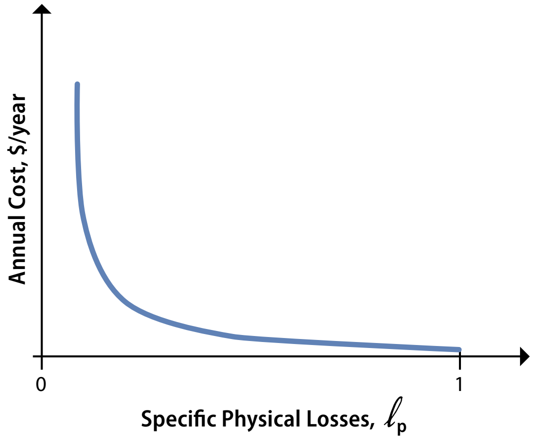
P_s = period of time for a full network survey, in years.

The expression above can be converted to an expression for the cost of physical loss control as a function of specific physical losses (ℓ_p). Equation 23 can be solved for P_s in terms of L_p, and L_p can be expressed in terms of the number of connections (N), the per capita consumption (c), and the number of people per connection (p), using equations 5 and 12, resulting in the following:

$$C_{pl} = [C_s\ D\ N\ 365\ \beta] / (\{ (c\ p / D)\ [\ell_p / (1 - \ell_p)\ ]\ \} - \alpha) \quad (25)$$

This complex expression for the cost of physical loss control is illustrated in Figure 11 below. Note that when ℓ_p is low, the cost curve rises sharply, implying a high cost. The line reaches a very high value at a small value of ℓ_p, which corresponds to the background (undetectable) losses and reported leaks. This formula is not valid for very low values of ℓ_c below the background losses. If ℓ_p is equal to one, implying that all the water is leaking, the cost of the program is minimal.

Figure 11. Cost of physical loss control as a function of ℓ_p



Cost of Commercial Loss-Control Programs

Little is known about the cost of commercial loss-control programs, other than some models and data for metering programs. The model in this report uses the conceptual approach associated with meter replacement programs for efforts to cover all commercial losses. The key decision variable in meter replacement programs is the period of time, in years, between meter installation and replacement.

The average annual cost of the meter replacement program will depend on the average cost of replacing each meter, including materials, labor, and other inputs, and the number of meters replaced in a given year. In a steady-state situation, the meter replacement program would consist of replacing a portion of the total number of meters in the system each year. That is, if the policy is to replace meters every 10 years, then 1/10 of the meters would be replaced in any year. Thus, the average annual cost of the program will be

$$C_m = M\ N / P_m \quad (26)$$

where

C_m = annual cost of the meter replacement program, $/year

M = average meter replacement cost, including materials, labor, overhead, etc., in $

N = total number of connections

P_m = meter replacement period, in years.

The level of losses from meter under-registration depends on the total number of meters and the amount of under-registration at each one. Meter studies, such as Male et al. (1985), have adopted the use of meter accuracy (registered volume/actual volume) and developed models for the decline in percentage accuracy per year of age. These models show a linear decline. Male et al. concluded that for small (5/8 inch) meters, the accuracy is initially at 100 percent but declines at rate of 0.5 percent (0.005) per year. After 10 years, the accuracy would be 95 percent. The under-registration is then a function of the actual water flow, the period of time, and the slope of the accuracy line.

These relationships can be combined into an expression for the steady-state level of losses attributable to meter under-registration:

$$L_m = N\ c\ p\ s\ P_m / 2 \quad (27)$$

where

L_m = average loss rate due to meter under-registration, in m^3/day

N = total number of connections

c = average water consumption, in m^3/person/day

p = average number of persons per connection

s = slope of the meter accuracy line, in %/yr

P_m = meter replacement period, in years.

The factor of two appears in the denominator to give the average under-registration over the period of linear decline in accuracy.

The first three terms in this equation represent the total water consumption. Thus, the average rate of losses can be presented as a percentage of consumption (ℓ_c):

$$\ell_c = s\ P_m / 2 \qquad (28)$$

According to equation 28, if the meter replacement period is long, the steady-state losses as a percentage of consumption will be high and, according to equation 26, the average annual costs will be low. Thus, there is a simple tradeoff between program cost and commercial losses. Solving equation 28 for P_m and substituting into equation 26 yields

$$C_m = M\ N\ s / 2\,\ell_c \qquad (29)$$

This is of the form

$$C_m = K / \ell_c$$

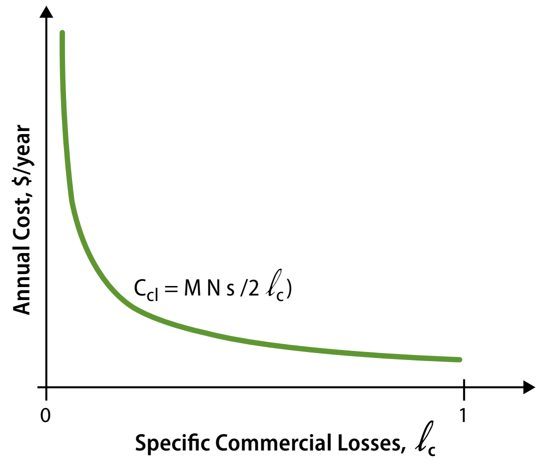
where K is a generic constant.

Thus, the cost of the program increases with the number of meters, the meter replacement cost, and the rate at which error increases over time. If a strict loss-control policy is adopted, the value of ℓ_c will be low and the annual cost will be high. If a relaxed posture is taken, ℓ_c will increase and the cost will be lower. The shape of this cost function is shown in Figure 12.

The cost of other types of commercial loss-control programs, such as finding illegal connections and improving billing and collections, is very difficult to estimate. There are essentially no data from the field on these programs. The various components of programs to address commercial losses are all linked in that they revolve around management of connections and their revenue.

Consequently, for modeling purposes, we adjusted the cost function shown above for meter replacement programs upward and then used it for all commercial losses. Appendix C provides the derivation of estimates of additional costs for reducing other commercial losses along with a meter replacement program. The approach used is to scale up the value of M, the meter replacement cost, for this additional labor.

Figure 12. Cost of commercial loss control as a function of ℓ_c



Development of Optimality Conditions

As noted in the discussion of the model's conceptual framework, optimal conditions will exist when the financial surplus is maximized. To find the optimal levels of steady-state physical and commercial losses, the expression for surplus is differentiated with respect to ℓ_p and ℓ_c and set equal to zero. Solving the resulting formulas yields algebraic expressions for the optimal steady-state values of ℓ_c and ℓ_p. As shown earlier in equation 13, the annual financial surplus can be written as

$$S = R - (C_v + C_c + C_{pl} + C_{cl}) \qquad (13)$$

where

$$R = T\ N\ c\ p\ 365\ (1 - \ell_c)$$

$$C_v = (Cw\ N\ c\ p\ 365) / (1 - \ell_p)$$

$$C_c = CRF\ F\ (1 + r)^{-[E - 1 - (\ell_p / 1 - \ell_p)] / G}$$

$$C_{pl} = (C_s\ D\ N\ 365\ \beta) / (\{ (c\ p / D)\ [\ell_p / (1 - \ell_p)] \} - \alpha)$$

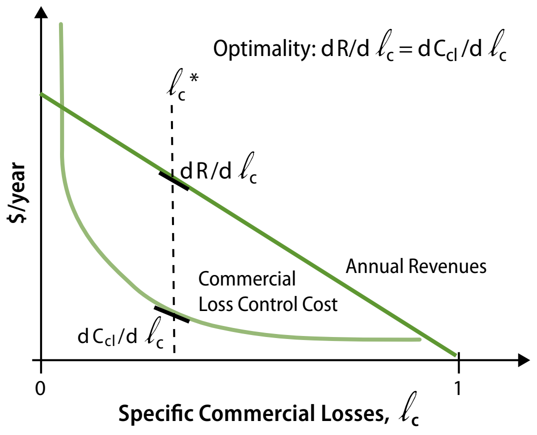
$$C_{cl} = M\ N\ s / 2\,\ell_c.$$

To find the optimal commercial losses as a percentage of consumption, we set the derivative of the surplus with respect to ℓ_c equal to zero. Only the revenue term and the commercial loss term contain ℓ_c, so the results are

$$T\ N\ c\ p\ 365 = M\ N\ s\ /\ 2\ \ell_c^{*2} \qquad (30)$$

This formula and formula 15 are illustrated in Figure 13 below.

Figure 13. Optimality condition for commercial losses



This expression indicates that, at optimal commercial loss, the marginal cost of the meter replacement program should equal the average revenue collected. In other words, meter replacement should be continued until the marginal cost with respect to ℓ_c reaches the average unit revenues.

The optimality condition can be simplified:

$$\ell_c^* = [M\ s\ /\ (2\ T\ c\ p\ 365)]^{1/2} \qquad (31)$$

Thus, the optimum value of ℓ_c can be found directly from the meter replacement cost (M), the rate of meter error growth (s), the collected tariff (T), the specific consumption (c), and the number of people per connection (p). All these factors are in a square root, so the sensitivity of ℓ_c^* to any of the factors will be relatively low. That is, a 10 percent change in any one of these inputs causes only a 3.2 percent change in ℓ_c^*. Under conditions of high tariff or high consumption per connection, the optimal commercial loss as a percentage of production will be low. The tariff is often lower in developing countries, as opposed to developed countries, so, all other factors being equal, l ℓ_c^* will be higher in developing nations.

To find the optimal physical losses as a percentage of production, we set the derivative of the surplus with respect to ℓ_p equal to zero. Only the variable water production cost term, the capital cost term, and the physical loss term contain ℓ_p, so

$$0 = 0 - [(d\ C_v\ /\ d\ \ell_p) + (d\ C_c\ /\ d\ \ell_p) + (d\ C_{pl}\ /\ d\ \ell_p)] \qquad (32)$$

This is a complex formula that requires a numerical solution. The first two terms in the brackets will increase with ℓ_p, while the third will decline with ℓ_p, as shown in Figure 14.

Optimality is achieved when the slope of the physical loss-control program is equal to the sum of the slopes of the capital cost and variable production cost. At this point, the sum of the physical loss-control program cost, the capital cost, and variable production cost is at a minimum, implying that surplus is maximized.

Figure 14. Optimality condition for physical losses

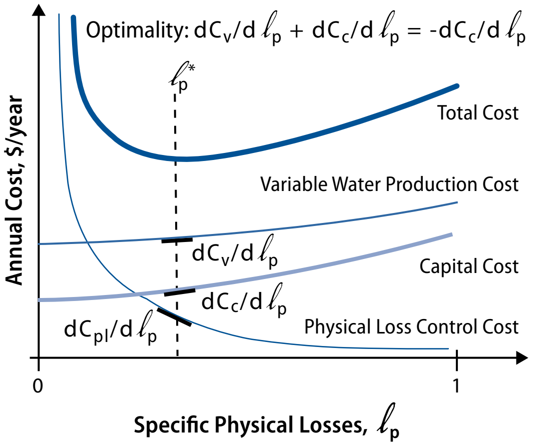



Photo: Leslie Wyatt

Leak-repair crew in Kampala, Uganda.

Results

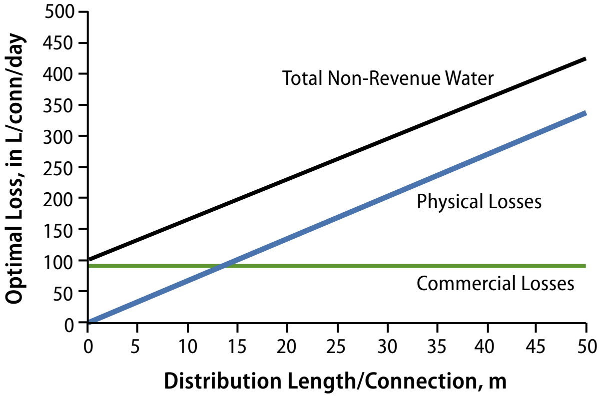
Generic Model Application

To facilitate use of this mathematical framework to analyze NRW status of, and prospects for, real-world water utilities, we developed a spreadsheet version of the model.

We then ran the model for multiple hypothetical locations and parameter values to test that it produced plausible results. In other words, we assessed the impact of changes in input variables, such as average tariff or distribution pipeline length per connection, on the optimal NRW, to verify that the change in results conformed to the theory and expectations. For example, we ran the spreadsheet with a set of 10 increasing unit tariff values to verify that the optimal commercial losses would fall and the optimal physical loss would not change, while holding all other variables constant. We also did 10 runs of the model at 10 increasing values of lengths of line per connection to verify that the physical losses would climb linearly, while optimal commercial losses would hold steady.

Figure 15 depicts a sample of the generic results; it shows results of variation of distribution line length per connection. As expected, as line length increases, optimal physical losses rise linearly while commercial losses hold steady. As a result, the total NRW line is simply shifted vertically up from the line for optimal physical losses. All these trends were as expected.

Figure 15. Generic optimal physical and commercial losses and total non-revenue water



This example also shows that, for the assumed parameter values, the portion of total losses that are commercial or physical depends on the line length. In fact, when line lengths are long (sparsely settled areas), optimal physical losses are much larger than optimal commercial losses, but when pipe lengths per connection are short (densely settled areas), physical and commercial losses are of roughly equal value (in terms of L/connection/day).

Table 4 indicates the influence of key parameters that tend to push optimal losses upward. For example, a low tariff would mean that aggressively controlling commercial losses has a low return, making a low expenditure also optimal but resulting in high commercial losses. If the variable cost of water production is low, such as cases of surface water sources with good raw water quality and low pumping requirements, the return from physical loss control is small, so the optimal physical losses are high. If water is cheap, no financial case can be made for large expenses on physical loss control. Utilities are better off financially to let the system leak (as long as the water cannot be sold to someone else).

Table 4. Influence of key parameters

Optimal losses are high with	
Low values of:	**High values of:**
Water consumption	Cost of loss control
Tariff	Line length
Collection efficiency	Line pressure
Variable water cost	System age and condition
Capacity utilization	
Capacity Cost	

The next step was a large effort to collect data for all the input variables for a wide variety of locations in developing countries. We researched dozens of sources such as the World Bank IBNET (the International Benchmarking Network for Water and Sanitation), national websites, regulator databases, benchmarking studies, project appraisal reports, utility annual reports, and other sources. Some data were easy to find, such as the number of connections or water production; other data, such as system pressure, were very difficult to find.

We then developed a set of default values that could be used to fill a hole in a set of data and allow the model to be used. The default values were derived mostly from the database of sites from which information had been collected. For example, the average of all the sites with data on water production capacity utilization was 67 percent; this value became the default if capacity utilization was missing from a data set. Table 5 lists all the input parameters, their typical sources, and brief summaries of default values that could be used, if necessary. Appendix C provides many tables and analyses to support the default values.

Table 5. Model input parameters

Data Parameter	Sample Value	Units	Comments
Utility Name	Southern—SWSC		
Year	2006.25		Year, taking into account period of the fiscal year
Data Source	NWASCO		Organization or report where data was obtained
Population Served	250,853	people	From utility records—often estimated using an average family size
Population Growth Rate	2.0%		From local or national demographic sources
No. of Connections	24,461	#	From utility records
Existing Production	48,767	m^3/day	From utility records
Existing NRW	43.0%		From utility records
Estimated Commercial Losses/Total	40%		Computed from water balance if such utility information is available. If not, default value of 40% can be used. See Appendix C for data for 41 developing country utilities.
Total Distribution Length	409.4	km	Includes all distribution piping, but not service lines to houses/buildings
Average Service Line Length	10	m	Line length from the main to the meter; estimated from utility records
Infrastructure Status	4.0		Outlined in the Econoleak model guidelines (McKenzie and Lambert, 2001). Estimated from system age, burst rates, physical losses, pressure.
Average Revenue Collected	$0.300	$/$m^3$	Best computed from total revenue collected and volume of water for which revenue is collected.
Variable Cost of Production	$0.044	$/$m^3$	Cost of water production that varies with short-run production variations. Usually consists of energy and chemicals. If no subcomponents of operating costs are available, can be estimated at 25% of total unit operating cost; see information in Appendix C.
Capacity Utilization	67%		Based on utility total water production over water produced if plants were run at practical limits all year long. From utility records. If no data are available, a value of 67% is recommended, which is the average of over 39 developing country utilities with data.
Hours of Service/Day	14	hours	Average value across the water system. From utility records.
Estimated Average Pressure	20.00	m	From utility records, but often hard to obtain
Leak Detection Survey Cost	$87.39	$/km	Derived in Appendix C. Depends on local labor costs.*
Commercial Loss Control Cost	$83.51	$/conn	Derived in Appendix C. Depends on local labor costs.*
Slope of Meter Accuracy Line	0.005	% loss/yr	Derived from Male et al., 1985
Design Period	20	years	Common value, although could be shorter, depending on technology
Capital Cost Curve Coefficient	$2,403	$	Based on data in Appendix C, esp. Schultz & Okun, 1984.*
Capital Cost Curve Exponent	0.75		Based on various literature, esp. Schultz & Okun, 1984
Interest Rate	10%		Common default
Amortization Period	20	years	Common default

* Corrected for inflation based on analysis year.

Our last analysis focused on the sensitivity of the model. Systematic calculations were done on a site from the municipal/regional utility group whose conditions put it roughly in the middle of the range as far as distribution length per connection and proximity to the regression line of optimal conditions. To compute the percentage change in optimal NRW, we first systematically varied each input parameter upwards from 10 percent to 20 percent and so on to 50 percent. The sensitivity analysis was repeated, varying the same input parameter downwards in the same percentage steps from 10 percent down to 50 percent.

The results, shown in Table 6, indicate that the model is generally not very sensitive to any single input parameter; the input parameters are ranked from the most sensitive to the least sensitive. For example, a 20 percent variation, up or down, usually produces only about a 5 percent change in the optimal NRW. A change of 50 percent up or down can produce bigger impacts, but never more than a 50 percent impact. Usually the effects are under 20 percent.

Table 6. Sensitivity analysis

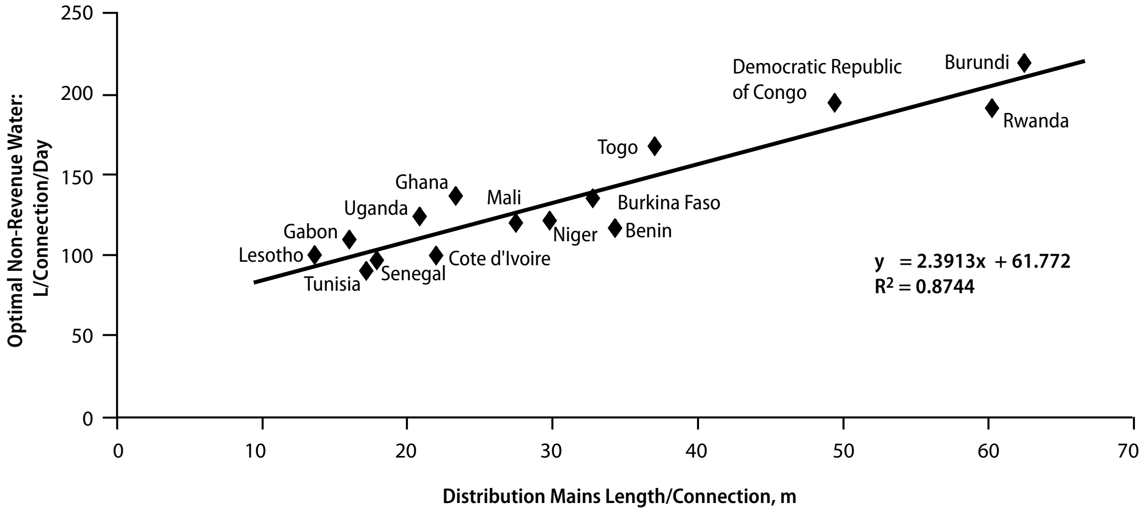
Input	Change in Input	Change in Optimal NRW
1. Connections	+-20% +-50%	-9% to +12% -19% to +46%
2. Pressure	+-20% +-50%	+7% to -7% +16% to -19%
3. Distribution Length/ Connection	+-20% +-50%	+6% to -6% +13% to -15%
4. Unit Collected Tariff or Revenue	+-20% +-50%	-4% to +5% -8% to +19%
5. Capacity Utilization	+-20% +-50%	-8% to +5% -17% to +7%
6. Water Production Volume	+-20% +-50%	+4% to -6% +10% to -16%
7. Commercial Loss Control Cost	+-20% +-50%	+4% to -5% +10% to -13%
8. Infrastructure Status	+-20% +-50%	+5% to -4% +9% to -12%
9. Physical Loss Control Cost	+-20% +-50%	+3% to -4% +8% to -11%
10. Variable Water Production Cost	+-20% +-50%	-2% to +3% -6% to +9%

Specific Model Applications

Model Application in 15 African National Utilities

We then applied the capacity surplus model to 15 national water utilities in Africa, mostly using basic data from secondary sources, including the World Bank Africa Infrastructure Country Diagnostic database (Africa Infrastructure Country Diagnostic, 2009) and the Water Operators Partnership: Africa Utility Performance Assessment (Mugabi & Castro, 2009). In several cases, we either corresponded with local officials to fill gaps or used the default parameters noted above. The full data set is provided in Appendix D. The results, in Figure 16, show the optimal NRW (in L/connection/day) rising linearly, with distribution length/connection, as

Figure 16. Optimal non-revenue water in 15 national utilities—Africa



suggested by the pattern in Figure 15. The data show a close fit to a linear regression.

Also, if a country was noticeably below or above the line, we sought an explanation in the data. For example, Benin has a lower optimal NRW value because of high tariffs, which push optimal commercial losses and then optimal NRW down. Figure 17 shows the physical and commercial losses that make up the total optimal NRW, again demonstrating the pattern in Figure 15.

Figure 18 compares the actual level of losses (red points) with the optimal (black points) for the 15 national utilities. For the most part, these national utilities are considered the most efficient utilities on the African continent, so most should be performing close to optimal. However, Burundi, the Democratic Republic of Congo, and Ghana are far from optimal. Five other developing countries are somewhat above optimal—Lesotho, Gabon, Uganda, Rwanda, and Uganda. The rest are close to the optimal—Benin, Burkina Faso, Côte d'Ivoire, Niger, Senegal, Togo, and Tunisia. The countries close to optimal happen to coincide with general impressions of being high-performing African utilities, so the model results are consistent with expectations.

Figure 17. Optimal physical and commercial losses in 15 national utilities—Africa

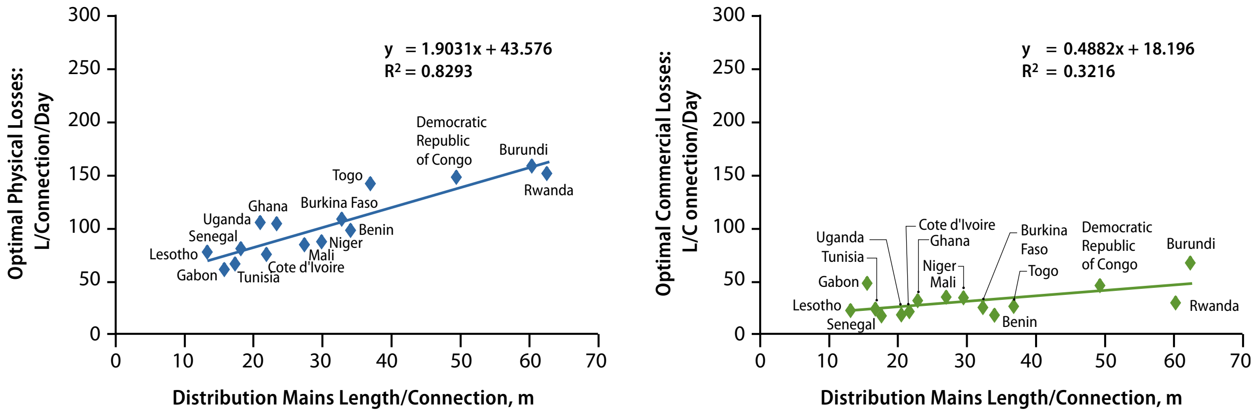
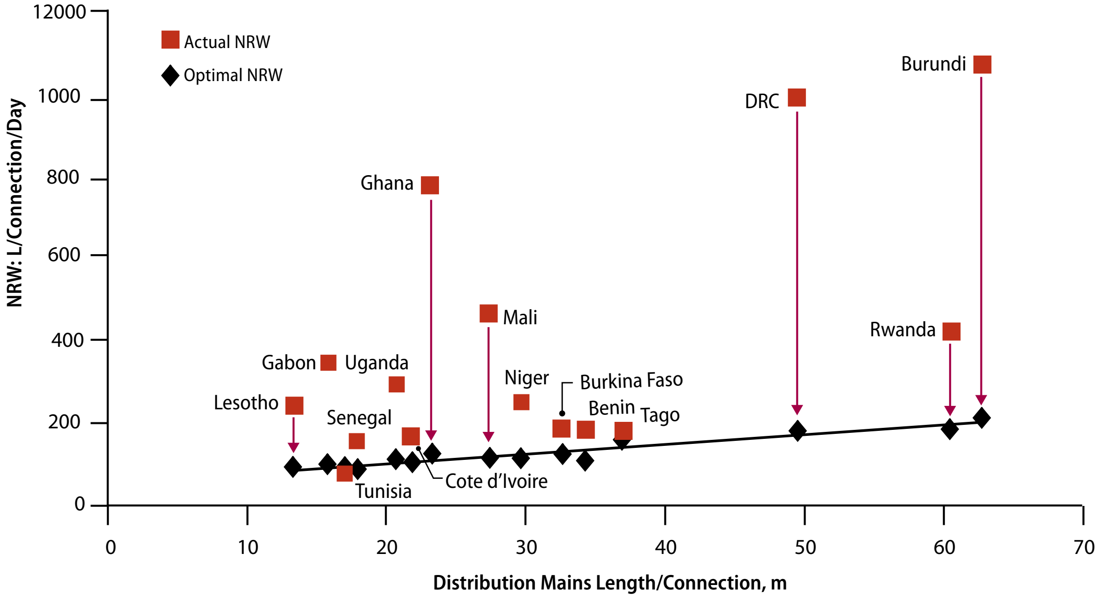


Figure 18. Actual vs. optimal non-revenue water—15 African national utilities



Analysis of Municipal and Regional Utilities

We applied the model to 44 municipal and regional utilities in 12 countries in Africa, Asia, and Eastern Europe, using the sources noted above (Africa Infrastructure Country Diagnostic, 2009; Mugabi & Castro, 2009) as well as reports from national ministries, regulators, or utilities themselves. The full data set is provided in Appendix E. Figure 19 shows the results, with the same linear pattern. More scatter can be seen, probably because of the wide range of sizes and types of utilities and greatly varying tariffs, water production costs, and engineering conditions. The municipal and regional utiltities' optimal NRW levels are higher than those for the national utilities.

Figure 20 shows the resulting meter replacement frequency and leak detection survey frequency, with trends and values about as expected. Optimal meter replacement periods range from 4 to 11

Figure 19. Optimal non-revenue water for municipal and regional developing country utilities

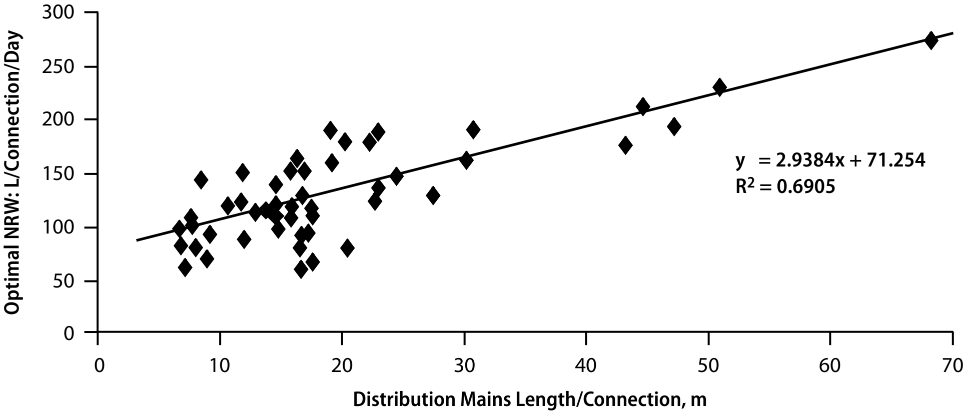
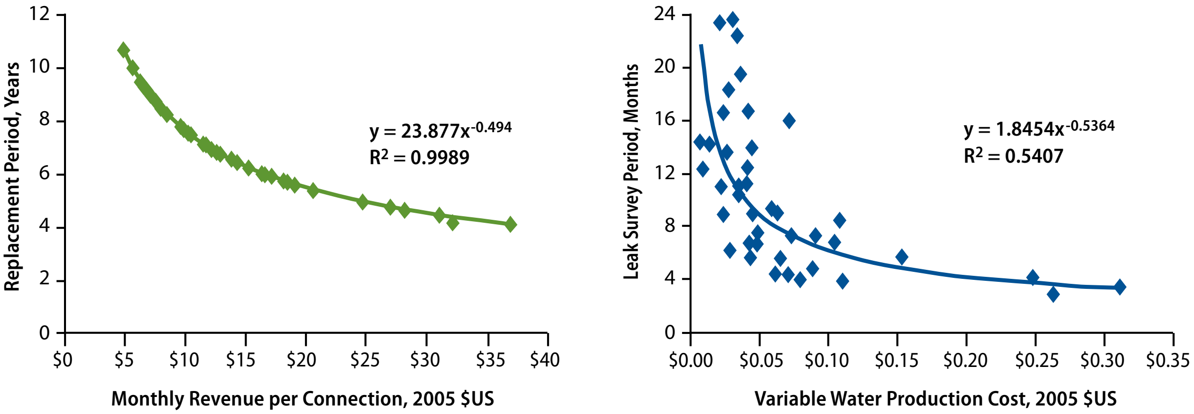


Figure 20. Optimal meter replacement and leak detection survey frequency



years, depending on the revenue derived from the connection. For the bulk of the sites, the frequency is 6 to 8 years. Leak detection survey frequencies range from 4 months to 24 months, with the frequencies for the bulk of the sites ranging from 6 to 18 months. These periods and frequencies are about the same magnitudes as those in many previous studies.

Comparison to Other Analyses

First, we compared the results from national, regional, and municipal utilities with the targets outlined by Liemberger and McKenzie (2005) for the World Bank Institute, referenced in the section on previous analyses of NRW reduction and control (page 6). The results, shown in Table 7, are roughly in line with the World Bank Institute targets. For the African national utilities, the model optimal leakage is between the developing country and developed country targets. For the developing country municipal and regional utilities, the model optimal leakage is close to the developed country target, and for Zambian commercial utilities (discussed in the next section), the model optimal leakage is somewhat above the developing country target.

Table 7. Computed optimal levels for non-revenue water and physical losses in comparison to World Bank Institute targets for developing and developed countries

	Losses in L/connection/day		
	Model-Computed Optimal Losses	**WBI Target Physical Losses—Developing Countries**	**WBI Target Physical Losses—Developed Countries**
1. African National Utilities			
• Average Pressure: 26 m			
• Average Line Length: 31 m/connection			
Average Total NRW	140		
Average Physical Losses	100	*<130*	*<65*
2. Developing Country Regional and Municipal Utilities			
• Average Pressure: 20 m			
• Average Line Length: 20 m/connection			
Average Total NRW	130		
Average Physical Losses	90	*<100*	*<50*
3. Zambian Commercial Utilities			
• Average Pressure: 20 m			
• Average Line Length: 31 m/connection			
Average Total NRW	180		
Average Physical Losses	120	*<100*	*<50*

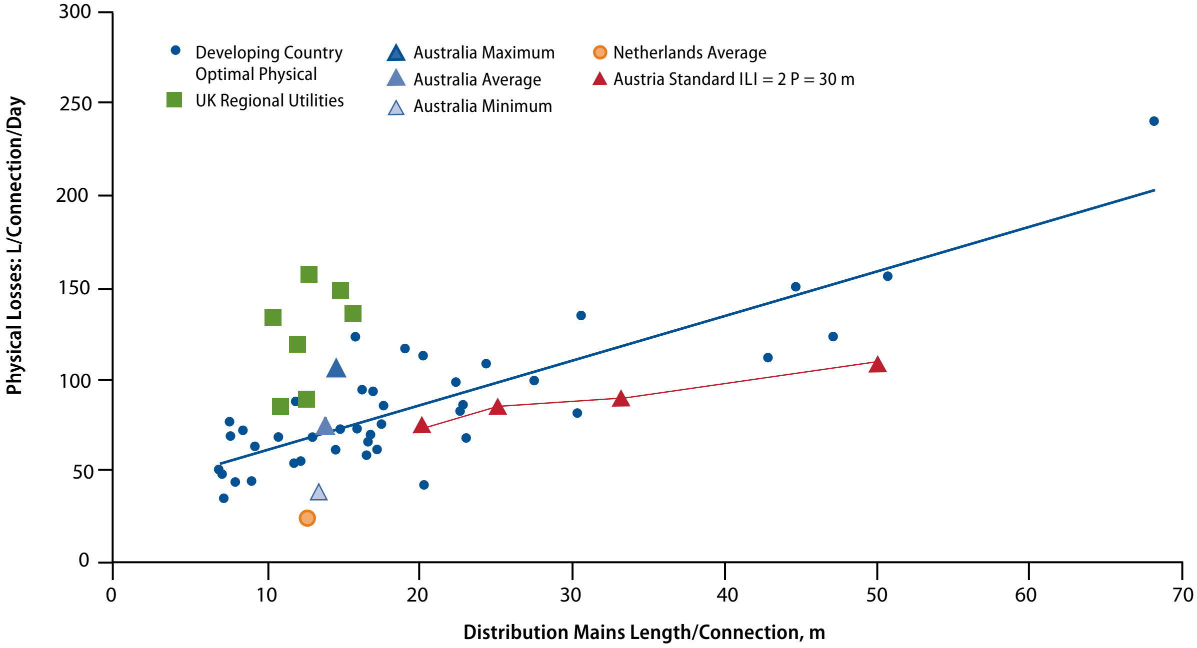
WBI = World Bank Institute
Note: Assumes top technical performance category (A) for WBI targets.
Source: Adapted from Liemberger and McKenzie (2005).

Next, we compared the results of the regional and municipal utility optimal physical loss analysis in developing countries to actual performance of regional and municipal utilities in developed countries. We included data from the UK, Australia, Netherlands, and Austria (Day, 2010; Dellow, 2010; Koelbl and Gschleiner, 2009; and Parker, 2007). These countries all have very advanced loss-control programs and standards. In broad terms, the UK utilities have the reputation for losses a little higher than the others, and the Netherlands has the reputation for such aggressive loss control that losses are very low.

The comparison to developing country utilities, shown in Figure 21, provides interesting results. In terms of *actual physical loss* levels, the developed countries range from above the developing country *optimal* values to the below the developing country *optimal* values. In other words, the developed countries have values close to the developing country optimal levels, although the UK values are on the high side, and the Netherlands, Austria, and Australia have values on the low side.

The fact that the actual developed country NRW and the optimal developing country physical loss levels are not wildly different is interesting. Developed countries certainly have higher tariffs and low commercial losses, which would suggest that developed countries would have a lower optimal value. These effects are presumably counteracted, however, by lower labor costs in developing countries.

Figure 21. Comparison of actual physical losses in developed countries to optimal physical losses in developing countries



Case Study: Zambian Commercial Utilities

We applied the model to 10 commercial utilities, each associated with a province in Zambia. These regional utilities typically serve one or two large towns and a modest number of smaller towns in the same province. Some are highly urbanized, such as Lusaka and utilities in the Copperbelt region, while others serve more dispersed populations. They are regulated by and report performance data to NWASCO (2007). Table 8 provides data on the commercial utilities for 2006–2007, and Figure 22 shows the optimal NRW as a function of the distribution length.

Figure 23 provides the actual NRW compared with the optimal NRW for 2006–2007. The optimal NRW values follow the familiar linear pattern, with a good fit. Two utilities are operating close to the optimal NRW (class A), five are operating not too far from the optimal NRW (class B), and three are operating quite far from the optimal NRW (class C).

Table 8. Inputs and results—non-revenue water in Zambian commercial utilities, 2006–2007

Parameter	Minimum	Average	Maximum
Populations Served	42,000	330,000	1,042,000
Connections	5,500	24,000	75,000
Water Production, m^3/day	7,000	85,000	311,000
Distribution Length/ Connection, m	11.9	31.0	68.0
Unit Revenue Collected, $/$m^3$	$0.164	$0.296	$0.578
Variable Production Cost, $/$m^3$	$0.011	$0.032	$0.049
Actual NRW, L/Connection/Day	380	1,330	2,260
Optimal NRW, L/Connection/Day	120	180	270

Figure 22. Optimal non-revenue water—Zambian commercial utilities

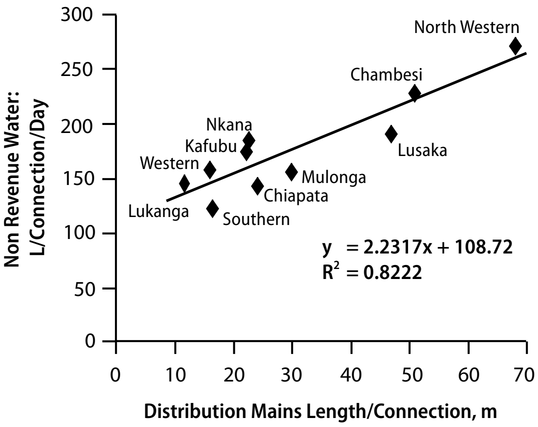
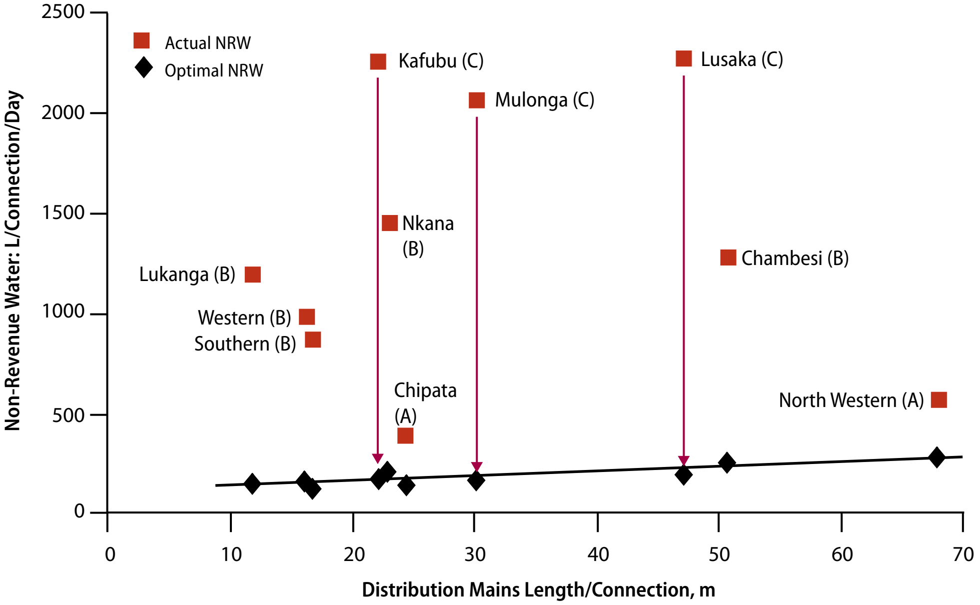


Figure 23. Comparison of actual and optimal non-revenue water—Zambian commercial utilities



We analyzed the benefits of NRW reduction for the different Zambian commercial utilities in terms of increased water supply coverage and increased revenue. The inputs and results are provided in Table 9. The first part of the table shows basic parameters in the current situation, including revenues and coverage, by utility class. The second part shows the financial situation after a major transition investment to reduce losses and bring each utility to its own optimum. A transition investment would include a water audit, leak detection surveys, repair of the backlog of leaks, pressure management, and, in severe cases, line replacement. The cost of such a transition investment is estimated at \$200/m^3 water/day saved (R. Liemberger, personal communication, April 2009). Revenues have risen substantially, which could pay off the transition investment in 3 to 6 years. Class A utilities have the lowest losses, so their revenue gains and transition investments are the lowest. The opposite is true for class C utilities.

The third section of the table models the situation where the physical water savings are sold to unserved people in the utilities' official service territory. The figures show that all three class C utilities could raise water coverage from about 72 percent to 100 percent, and all the commercial utilities together could reach 94 percent coverage. The cost of this effort would be \$66 per capita, which is much less than the per capita cost of a recent World Bank water capital expansion project near Lusaka, at \$160 per capita (World Bank, 2009). In this scenario, the revenue increase would be much higher, because the unit sale price of water is many times more than the unit variable water production costs. The net financial improvement would be \$35 million on a base of \$41 million in original revenues—an increase of 86 percent. A rough estimate of the new transition investment (to account for new water lines to previously unserved populations) reveals that the payback times are even lower! These figures show the great importance of reducing NRW and of having a clear target to strive for.


Photo: Gretchen Mikeska

Check on water flow out of metered zone.

Table 9. Impact of non-revenue water reduction on water supply revenues and coverage

	Class C	Class B	Class A	All
NRW situation	Poor	Moderate	Good	
Total population in service territory	2,322,305	2,034,367	284,473	4,641,145
Population served	1,678,467	1,410,317	201,316	3,290,100
Current coverage	72.3%	69.3%	70.8%	70.9%
Current water production, m^3/day	391,533	439,726	15,616	846,876
Current revenue water, m3/day	180,354	264,970	10,337	455,661
Current revenue, $/yr	$20,349,586	$18,969,383	$2,039,430	$41,358,399
After transition to optimal:				
Water production, m^3/day	275,310	347,293	13,929	636,532
Revenue water, m^3/day	258,109	323,898	11,612	593,618
Revenue, $/yr	$28,907,950	$23,251,863	$2,288,493	$54,448,306
Revenue increase, $/yr	$8,558,365	$4,282,480	$249,062	$13,089,907
Savings less control costs, $/yr	5,736,889	1,263,266	(42,051)	6,958,104
Financial improvement, $/yr	$14,295,254	$5,545,746	$207,012	$20,048,011
Transition investment	$38,795,000	$30,273,000	$592,000	$69,660,000
Payback period, yr	2.7	5.5	2.9	3.5
If saved water is sold to expand coverage:				
Population unserved	643,838	624,050	83,157	1,351,045
Population that could be served	736,624	389,284	28,363	1,131,408
Total new people served	643,838	389,284	28,363	1,061,484
New coverage	100%	88%	81%	94%
Per capita investment cost	$60.26	$77.77	$20.87	$65.63
Revenue, $/yr	$39,996,658	$29,669,978	$2,610,911	$72,014,953
Revenue Increase, $/yr	$19,647,072	$10,700,596	$571,480	$30,656,554
Savings less control costs, $/yr	$3,989,834	$322,505	($66,501)	$4,245,838
Financial improvement, $/yr	$23,636,906	$11,023,100	$504,980	$34,902,393
Adjusted transition investment	$45,233,378	$34,165,839	$875,628	$80,274,845
Payback period, yr	1.9	3.1	1.7	2.3

Discussion

We have presented the model in detail and demonstrated several applications. Here we address how the model can be used in developing countries. The key contribution of the model is that it enables the calculation of water loss reduction targets appropriate to a country's particular situation, using empirical data. Such information can be used, for example, to assist water utility policymakers in devising programs that balance reducing leakage, increasing collections, adjusting tariffs, and investing in new infrastructure.

The model can determine optimal values for physical losses, commercial losses, and total NRW, depending on site conditions and basic engineering parameters. Even when default values have to be used for some parameters (when data are unavailable), the results show clear trends. With the information presented in this report, the model and its results demonstrate basic relationships that will be instructive for many policymakers and practitioners in the developing world.

For example, the fact that low tariffs tend to lead to high optimal commercial losses is likely to surprise many. The fact that water recovered from physical losses (down to financially optimal levels) can provide enough water for full water supply coverage to the main cities in Zambia is a compelling illustration of the model's benefits. The graphs of meter replacement frequency and leak detection survey periods can provide a first estimate for any country (see Figure 20).

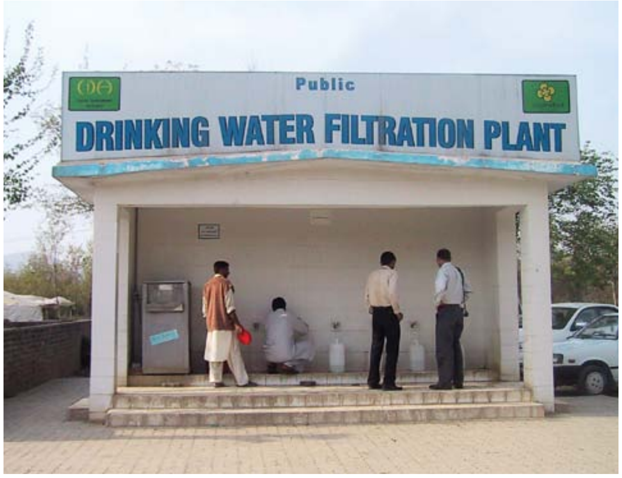


Photo: Myles Elledge

Water kiosk/filtration point in Pakistan.

To bring this report to a close, we should return to the fundamental issue raised in the beginning: *What should the loss reduction target be?* A utility with losses at 20 percent or 30 percent of system input could be close to, or far away from, optimum, depending on many local parameters. No simple rule of thumb is appropriate for target-setting. The model allows decision makers to answer that question by referencing the results for many real-world situations that can be used as approximate guidelines for NRW policy and program designs. Currently, many developing country utilities are performing at NRW levels far from their optimal values, indicating potentially large net financial benefits from NRW reduction and control. Management of NRW, guided by this model, will help countries and their water utilities set sensible targets and reduce losses. Such policy reforms will, in turn, allow countries to increase revenues, hold tariffs down, and expand coverage. Ultimately, these changes are likely to produce health and economic benefits.

Understanding commercial losses is important in designing reforms to reduce NRW in developing countries. Although commercial losses are very low in developed countries, they can be high in developing countries, especially when tariffs or collection rates are low. The average unit tariff or unit revenue collected is usually 5 to 10 times higher than the unit variable cost of water production. The implication is that a utility has more to gain by dealing with commercial losses than from the cost savings from reducing physical losses. Therefore, in most developing countries, the major financial return from NRW reduction and control will be increased annual revenues. Most developed country utilities have already pursued the same strategy and reduced commercial losses to very low levels, although they still may experience challenges in keeping physical losses in check.

Paying greater attention to loss reduction can lead to more rational capital investment. Too often, developing country decision makers have sought to deal with inadequate water supply by investing in new water production plants. Avoiding unnecessary capital costs can be an important factor in the full NRW financial picture in developing countries.

Avoided capital cost has a large influence on the optimal NRW values, when capacity utilization exceeds 75 to 80 percent. Reducing physical losses can lead to capital cost savings by delaying or supplanting new plants.

As for the process of how the model could be used by developing country policymakers and utility managers, we offer the following steps as a template: (1) collect data for country-specific or local parameters, (2) perform utility water audits and apply the model, (3) prioritize utilities to focus programs on, and (4) implement NRW reduction and control programs in those priority locations. NRW management programs may include a combination of activities, such as the following:

- Development of country-specific NRW handbooks and training programs
- Establishment of new incentives and regulatory methods to encourage successful NRW reduction and control programs in individual water utilities
- Improved data collection, quality control, and monitoring
- Performance-based contracts for NRW reduction (between utilities and experienced engineering firms), combined with training and oversight for quality assurance
- New NRW reduction and control financing mechanisms, such as revolving funds or bond banks, to enable utilities to easily access modest amounts of credit with short payback periods
- In-country seminars, twinning programs between utilities within and between developing countries, and regional and international conferences to share experiences, exchange lessons, and offer training in methods and skills.

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Appendixes

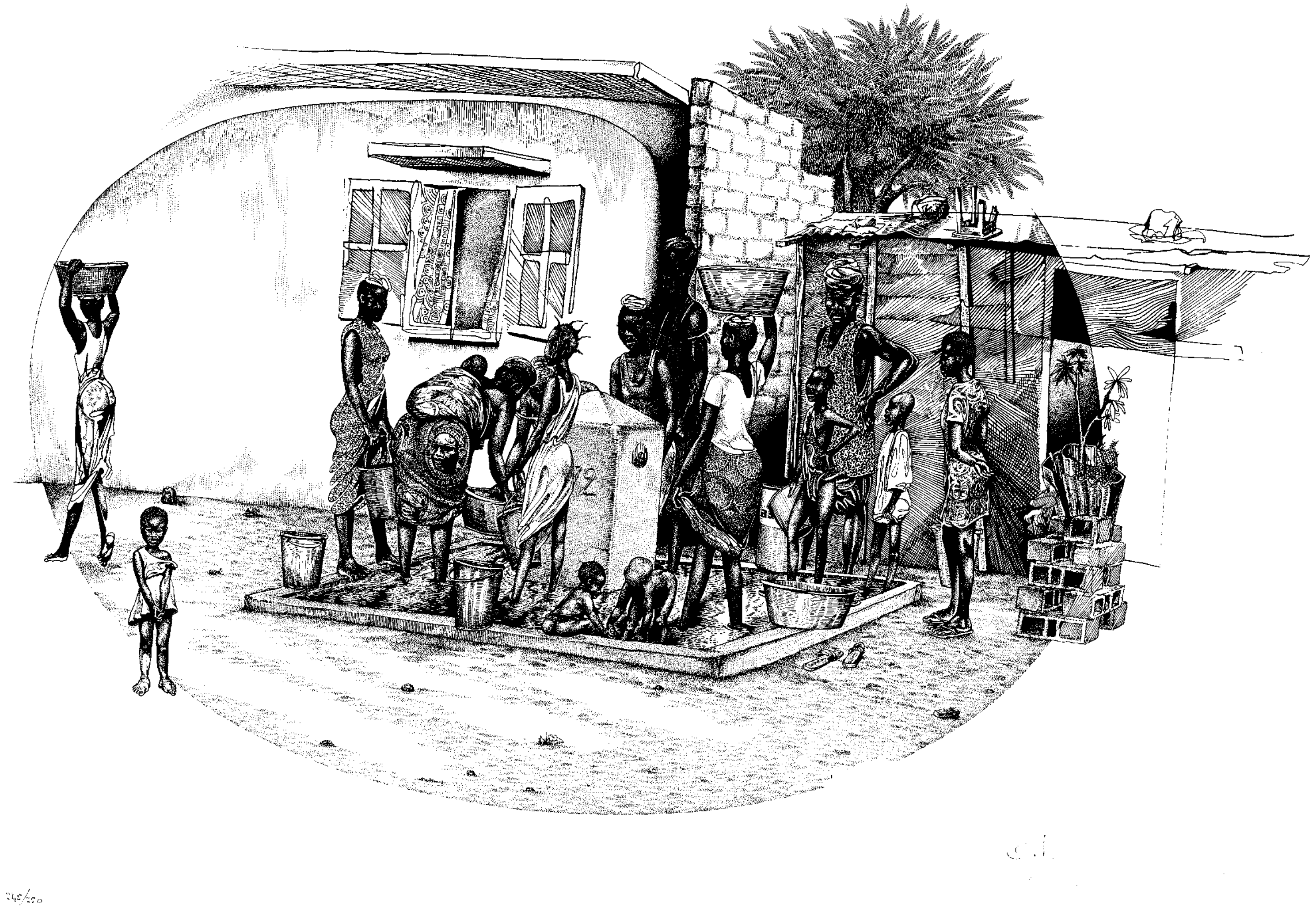
Appendix A: Derivation of Water Production Plant Capital Cost Formulas

Appendix B: Estimation of Physical Water Losses

Appendix C: Estimation of Default Values of Input Parameters

Appendix D: African National Water Utility Data

Appendix E: Developing Country Municipal and Regional Water Utility Data



A typical water kiosk in peri-urban Africa.

Source: Print from Hal Minis collection.

Appendix A

Derivation of Water Production Plant Capital Cost Formulas

Introduction

The Capital Cost term for the financial model was based on several basic assumptions.

1. The literature states that a reduced level of losses will mean that future capacity expansion expenditures can be delayed or "downsized." In keeping with the approach of NWC (1980) and Walski (1983), the model assumes investments are delayed rather than downsized.

2. Only the next expansion is counted. Later expansions will represent a small additional cost, due to the effect of discounting, and are ignored.

3. The water demand is assumed to grow at a constant linear rate. The growth in demand (in m^3/day/year) is estimated from the product of an assumed population growth rate (in % per year), and the current consumption (in m^3/day).

The development of the capital cost term involves four steps:

1. Estimation of the future capital cost of the expansion,

2. Derivation of the time in years until the expansion is needed,

3. Computation of the present value of the future capital cost, and

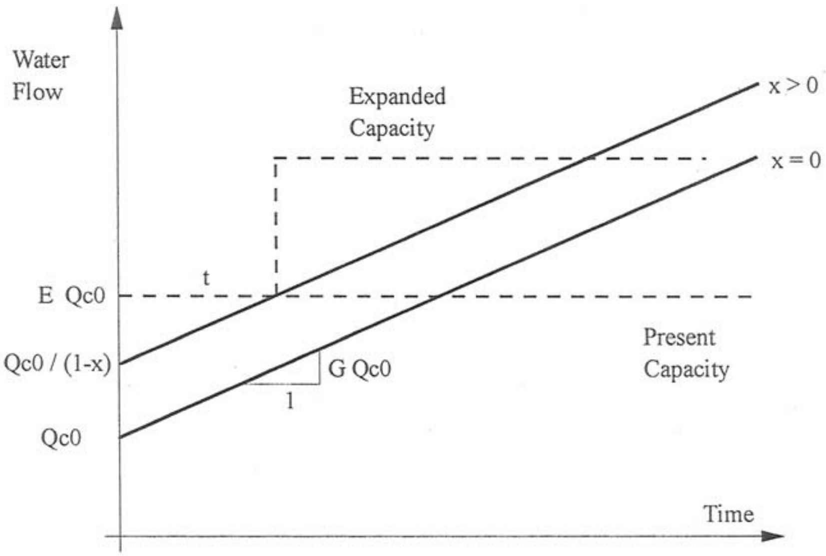
4. Computation of an annual cost equivalent to the present value of the future capital.

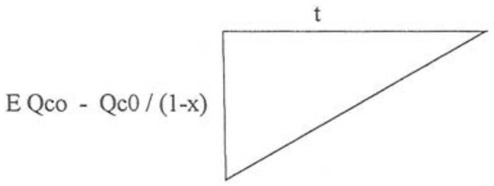
The process is essentially the same for both Capacity Surplus and Capacity Deficit, except as concerns the details of steps 1 and 2. The paragraphs below present these derivations.

In the Capacity Surplus scenario, capacity expansion will be needed at some point in the future, but with a reduction in water loss, this expansion can be delayed. The basic situation is shown in Figure 1. The figure shows water production and consumption increasing over time, at a linear rate. This growth rate is estimated by the simple product of an estimate of the population growth rate (G) and the consumption in the base year (Q_{c0}).

Note: For clarity of presentation, the symbol x is used in place of ℓ_p in this appendix.

FIGURE 1





By the principle of similar triangles:

$$\frac{t}{E\ Qco - Qco\ /\ (1\text{-}x)} = \frac{1}{G\ \ Qco}$$

$$t = \frac{E - (1/(1-x))}{G}$$

1. <u>Estimation of the future capital cost of the expansion.</u>

This is derived from a power cost function which relates the cost of the expansion to its capacity; a cost coefficient, k ($\$/m^3$/day); and an economy of scale factor, b (typically about 0.7). The capacity is the product of a design period for expansions, z (typically about 10 years), the rate of population growth, G; and the base year consumption, Q_{c0}:

$$F = k\ (\ z\ G\ Q_{c0}\ )^{b}$$

Note that size and cost of this expansion do not depend on the physical losses, x.

2. Derivation of the time in years until the expansion is needed.

Figure 1 illustrates the derivation of t, the number of years until the expansion is needed. By using geometry, we can find an estimate for t as a function of the ratio of the present water production capacity to the current water consumption, E; the assumed population growth rate, G; and x:

$$T = [E – (1/1-x)] / G$$

If x is zero, the time until expansion is needed is (E-1)/G. For example, if G is 5 percent population growth rate and E is a ratio of present capacity to consumption of 1.5, and x goes to zero, the value of t goes to 10 years. As x increases, the time is reduced, meaning the investment is required sooner. Note that if x got very large, the t could become negative, indicating the expansion is required "in the past," or there is insufficient capacity to meet actual consumption and those high losses. This simple model is only valid for a values of x up to 0.5, but this range is suitable for modeling purposes.

3. Computation of the present value of the future capital cost.

This is done with standard discounting formulas, which depend on the future cost, the interest rate, and the time until expansion.

$$PV = F (1 + r)^{-t}$$

4. Computation of an annual cost equivalent to the present value of the future capital cost.

Again using the standard capital recovery factor, which depends on the interest rate and the amortization period over which the cost is annualized. For this model the amortization period is assumed to be equal to the design period, z.

$$CRF = r (1+r) / [(1+r)^z -1]$$

The full term is structured as:

$$C_c = CRF\ F\ (1+r)^{-t}$$

where: C_c = Annualized cost of the capacity expansion, in \$/year

CRF = Capital recovery factor, dependent on r and z

F = Future cost of the capacity expansion, in \$

r = Interest rate

t = Time period in years until the expansion is needed.

Assembling all the components from the four steps above, we have:

$$C_c = \{r (1+r)/ [(1+r)^z -1]\} [k (z G Q_{c0})^b] (1+r)^{-[E-(1/1-x)]/G}$$

where: C_c = Annualized cost of the capacity expansion, in \$/year

r = Interest rate

z = Design period in years

k = Capital cost coefficient, in \$/ m^3/day

G = Assumed population growth rate

Q_{c0} = Base year water consumption, in m^3/day

E = Ratio of present capacity to present consumption

x = Physical loss as a percent of water production.

If x is zero, then annualized cost of capacity expansion is at a minimum, because the expansion is relatively far away. As x increases, the time until the expansion decreases, the expansion must happen sooner, and its equivalent annualized cost increases.

Appendix B

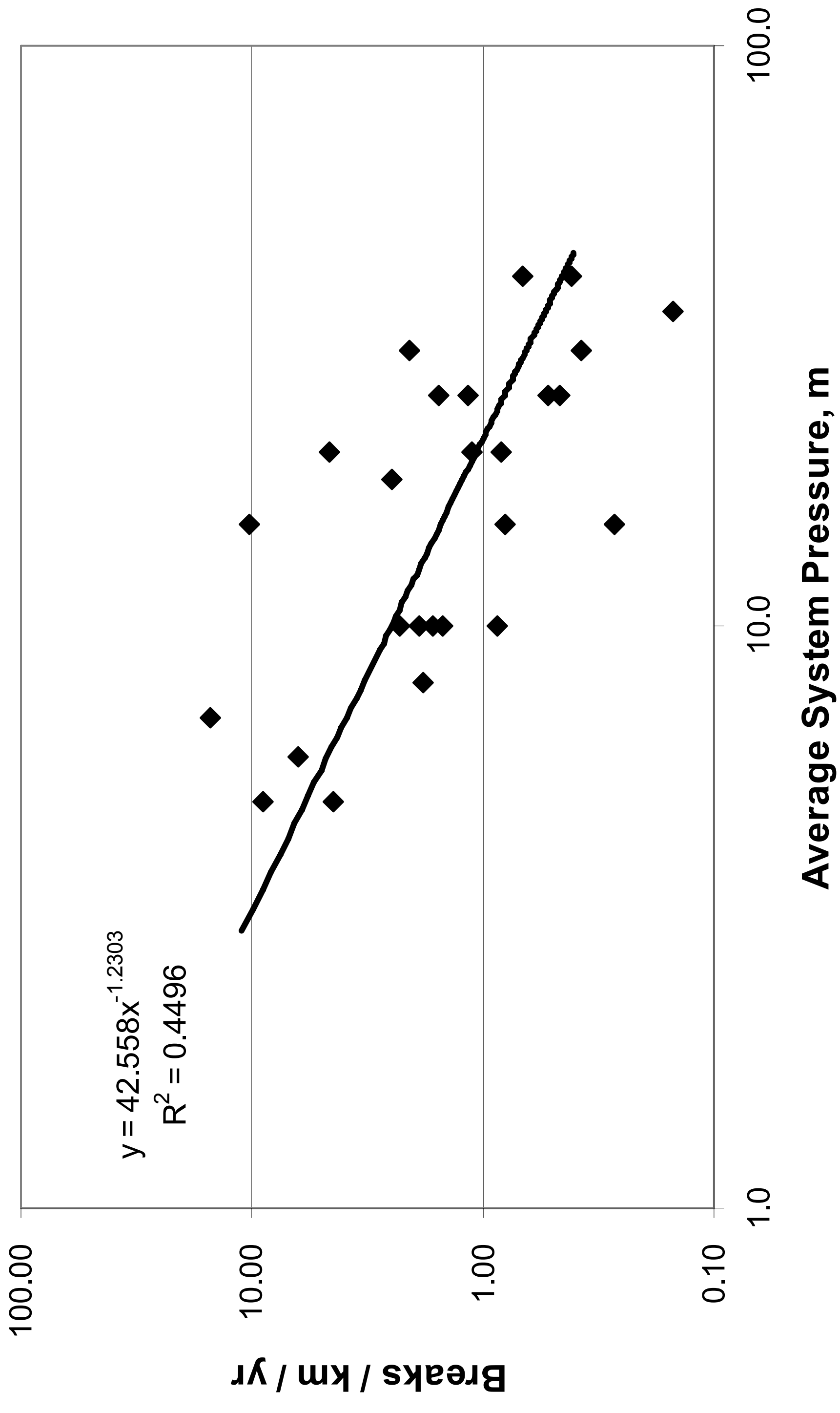
Estimation of Physical Water Losses

- Burst, Flow, and Pressure Data for Developing Country Utilities
- Econoleak Model Application Data—Sample for SWSC Zambia

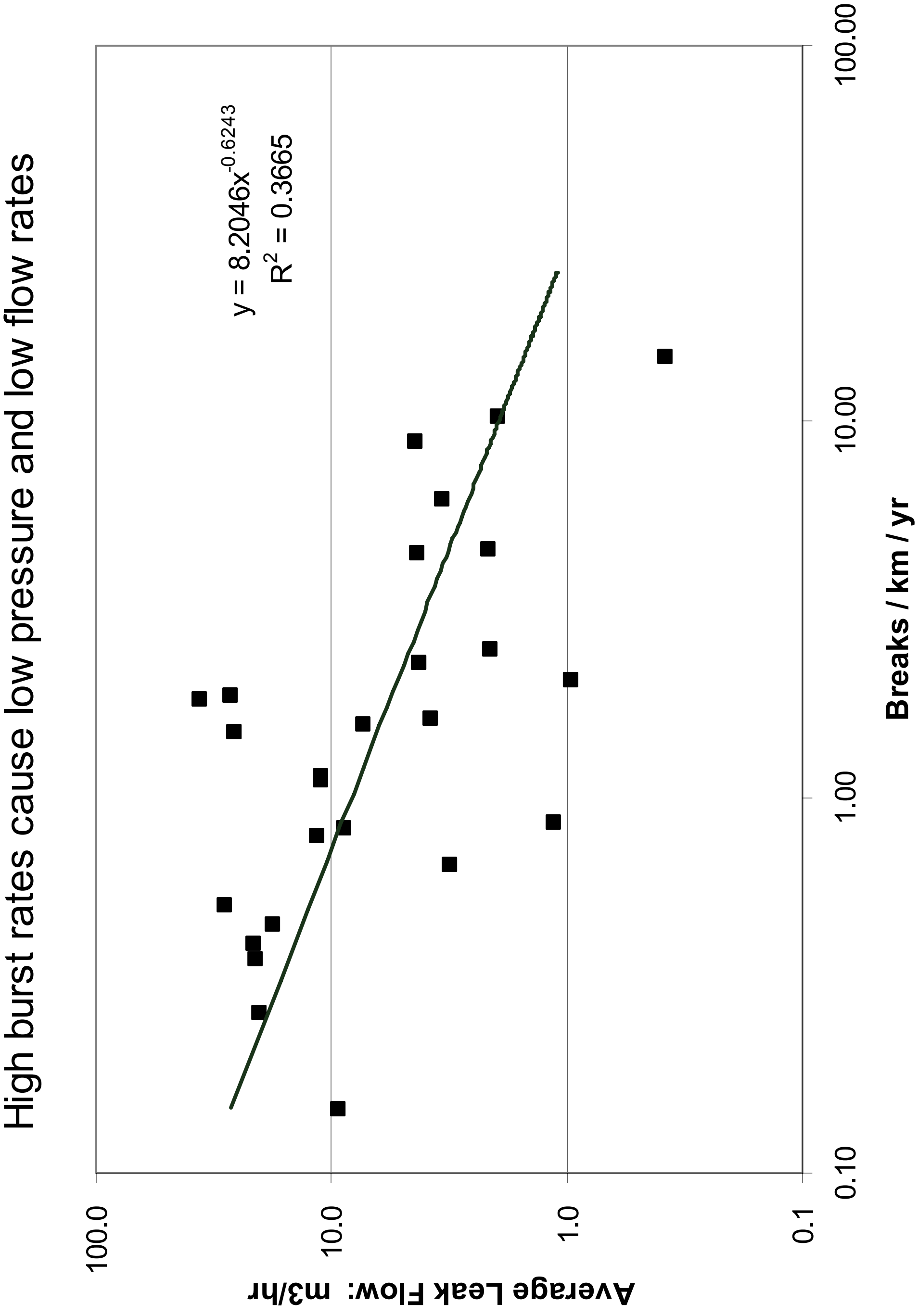
BURST RATE AND LEAK FLOW RATE DATA FOR SELECTED LDC UTILITIES

Data Source	Utility	City	Country	Year	Total Water Produced, m3/yr	Total Metered Water Consumption, m3/yr	Total Water Sales, m3/yr	Total Connections	Distribution Network , km	Typical duration of supply, hrs	Typical Pressure in Mains, m	No of total pipe breaks/year
SEAWUN BENCHMARKING STUDY, 2003	CTCTN Hue	Thua Thien Hue	Vietnam	2003	20,200,000	17,300,000	16,000,000	45,467	680	24.0	18	1,697
	HCMWSA	Ho Chi Minh	Vietnam	2003	286,700,000	209,400,000	209,400,000	393,269	3,422	23.6	5	15,335
	HPWSC	Hai Phong	Vietnam	2003	42,500,000	30,000,000	30,000,000	139,000	1,300	21.5	25	600
	CTWSC	Can Tho	Vietnam	2003	28,500,000	18,600,000	18,500,000	55,507	220	24.0	10	332
	DTWSEC	Dong Thap	Vietnam	2003	9,700,000	6,700,000	6,800,000	27,545	123	20.0	15	1,273
	DNWSC	Da Nang	Vietnam	2003	34,500,000	17,200,000	17,200,000	54,400	382	24.0	5	3,400
	HWBC	Hanoi	Vietnam	2003	135,500,000	78,100,000	78,100,000	257,915	742	24.0	8	1,360
	LDWSC	Lam Dong	Vietnam	2003	12,500,000	10,200,000	10,200,000	36,382	990	24.0	30	2,054
	Vinh Long WSC	Vinh Long	Vietnam	2003	8,200,000	5,800,000	5,800,000	18,895	224	24.0	15	178
	PPWSA	Phnom Penh	Cambodia	2003	48,000,000	40,100,000	40,100,000	106,000	921	24.0	20	772
	SAJH	Johor	Malaysia	2003	471,000,000	291,800,000	291,800,000	764,384	12,071	24.0	25	13,921
	SWB	Sibu	Malaysia	2003	29,300,000	21,200,000	21,200,000	43,370	874	24.0	30	329
	PBAPP	Penang	Malaysia	2003	277,000,000	223,400,000	218,800,000	402,777	3,407	23.9	25	1,775
	MWA	Bangkok	Thailand	2003	1,516,000,000	1,006,000,000	962,300,000	1,540,203	22,176	24.0	6	139,068
	PDAM Kota Padang Panjang	Kota Padang Panjang	Indonesia	2003	1,800,000	1,700,000	1,700,000	4,865	87	18.0	10	75
	PDAM Pandeglang	Kab. Pandeglang	Indonesia	2003	2,800,000	2,600,000	1,800,000	7,882	17	24.0	10	32
	PDAM Kab Banyumas	Kab. Banyumas	Indonesia	2003	13,900,000	13,800,000	9,800,000	33,559	570	24.0	10	937
	PDAM Tirta Sakti	Kab. Kerinci	Indonesia	2003	6,400,000	4,300,000	4,400,000	28,666	300	20.0	7	4,500
	PDAM Kota Surakarta	Kota Surakarta	Indonesia	2003	23,400,000	15,900,000	19,200,000	51,164	658	24.0	15	178
	PDAM Banjarmasin	Banjarmasin	Indonesia	2003	28,900,000	19,400,000	19,300,000	66,425	836	23.5	20	3,844
	PDAM Tirta Pakuan	Kota Bogor	Indonesia	2003	33,300,000	22,600,000	22,600,000	66,095	741	24.0	20	830
	PDAM Kota Makassar	Kota Makassar	Indonesia	2003	71,000,000	32,600,000	32,600,000	115,624	2,842	24.0	25	4,459
NWSC Annual Report	Kampala	Kampala	Uganda	2008/09	50,444,460	28,803,610	28,803,610	133,198	2,107	24.0	40	864
	Entebbe	Entebbe	Uganda	2008/09	2,507,550	2,111,525	2,111,525	14,574	240	24.0	35	36
	Jinja	Jinja	Uganda	2008/09	4,458,475	3,393,040	3,393,040	15,727	431	24.0	40	289
	MINIMUM				1,800,000	1,700,000	1,700,000	4,865	17	18.0	5.0	32
	AVERAGE				121,619,634	81,765,699	79,761,853	170,391	2,173	23.3	18.4	7,634
	MEDIAN				28,700,000	17,950,000	18,850,000	52,782	711	24.0	16.5	900
	MAXIMUM				1,516,000,000	1,006,000,000	962,300,000	1,540,203	22,176	24.0	40.0	139,068
	STD DEV				305,343,542	203,033,870	195,028,206	326,992	4,726	1.6	10.6	27,083
	Std dev / median				2.511	2.483	2.445	1.919	2.174	0.068	0.574	3.548

Data Source	Utility	Total Pipe Breaks / km / yr	Total Pipe Breaks / km/ yr / m of pressure	NRW, m3/yr	NRW, L/Conn/day	Mains Length / Connection	Estimated Physical loss m3 / km / day	Estimated Physical loss L / conn / day	Estimated Physical loss m3 / km / day / m of pressure	Average Leak Flow Rate, m3/hr	Flow Rate m3/hr per m of pressure
SEAWUN BENCHMARKING STUDY, 2003	CTCTN Hue	2.50	0.139	4,200,000	253	15.0	12.7	189.8	0.705	2.12	0.118
	HCMWSA	4.48	0.896	77,300,000	539	8.7	46.4	403.9	9.283	4.32	0.863
	HPWSC	0.46	0.018	12,500,000	246	9.4	19.8	184.8	0.790	17.84	0.713
	CTWSC	1.51	0.151	10,000,000	494	4.0	93.4	370.2	9.340	25.79	2.579
	DTWSEC	10.35	0.690	2,900,000	288	4.5	48.4	216.3	3.230	1.95	0.130
	DNWSC	8.90	1.780	17,300,000	871	7.0	93.1	653.5	18.611	4.36	0.871
	HWBC	1.83	0.229	57,400,000	610	2.9	159.0	457.3	19.869	36.14	4.517
	LDWSC	2.07	0.069	2,300,000	173	27.2	4.8	129.9	0.159	0.96	0.032
	Vinh Long WSC	0.79	0.053	2,400,000	348	11.9	22.0	261.0	1.468	11.54	0.770
	PPWSA	0.84	0.042	7,900,000	204	8.7	17.6	153.1	0.881	8.76	0.438
	SAJH	1.15	0.046	179,200,000	642	15.8	30.5	481.7	1.220	11.02	0.441
	SWB	0.38	0.013	8,100,000	512	20.2	19.0	383.8	0.635	21.08	0.703
	PBAPP	0.52	0.021	58,200,000	396	8.5	35.1	296.9	1.404	28.07	1.123
	MWA	6.27	1.045	553,700,000	985	14.4	51.3	738.7	8.551	3.41	0.568
	PDAM Kota Padang Panjang	0.86	0.086	100,000	56	17.9	2.4	42.2	0.236	1.14	0.114
	PDAM Pandeglang	1.88	0.188	1,000,000	348	2.2	120.9	260.7	12.087	26.76	2.676
	PDAM Kab Banyumas	1.64	0.164	4,100,000	335	17.0	14.8	251.0	1.478	3.75	0.375
	PDAM Tirta Sakti	15.00	2.143	2,000,000	191	10.5	13.7	143.4	1.957	0.38	0.054
	PDAM Kota Surakarta	0.27	0.018	4,200,000	225	12.9	13.1	168.7	0.874	20.20	1.347
	PDAM Banjarmasin	4.60	0.230	9,600,000	396	12.6	23.6	297.0	1.180	2.14	0.107
	PDAM Tirta Pakuan	1.12	0.056	10,700,000	444	11.2	29.7	332.6	1.484	11.04	0.552
	PDAM Kota Makassar	1.57	0.063	38,400,000	910	24.6	27.8	682.4	1.111	7.37	0.295
NWSC Annual Report	Kampala	0.41	0.010	21,640,850	445	15.8	21.1	333.8	0.528	21.45	0.536
	Entebbe	0.15	0.004	396,025	74	16.5	3.4	55.8	0.097	9.42	0.269
	Jinja	0.67	0.017	1,065,435	186	27.4	5.1	139.2	0.127	3.16	0.079
	MINIMUM	0.15	0.004	100,000.00	56.32	2.16	2.36	42.24	0.10	0.38	0.03
	AVERAGE	2.79	0.32	41,857,781.15	415.78	13.34	36.61	311.83	3.83	11.09	0.80
	MEDIAN	1.54	0.08	8,000,000.00	371.94	12.72	22.73	278.95	1.31	8.07	0.49
	MAXIMUM	15.00	2.14	553,700,000.00	984.93	27.41	158.96	738.69	19.87	36.14	4.52
	STD DEV	3.61	0.56	111,123,991.73	246.88	6.97	38.60	185.16	5.61	10.22	1.02
	Std dev / median	1.294	1.718	2.655	0.594	0.522	1.054	0.594	1.465	0.921	1.275



High Burst Rates lead to Low Network Pressure


High burst rates cause low pressure and low flow rates
y = 8.2046x^-0.6243
R^2 = 0.3665
Average Leak Flow: m3/hr
100.0
10.0
1.0
0.1
Breaks / km / yr
0.10
1.00
10.00
100.00

ESTIMATION OF PHYSICAL LOSSES IN TERMS OF LEAK DETECTION SURVEY PERIOD

SITE INPUTS

Time of Service	58%	
Pressure	20	m
Condition Factor	4	
Length Mains	409.4	km
Service Lines	10	m
Connections	24,461	

Note: Color Shading is used for ease in understanding mathematical processes.

ECONOLEAK	Background		Reported		Unreported		Total	
Mains	20	l/km/hr	0.124	bursts/km/yr	0.006	leaks/km/yr		
		at 50 m head	12	m3/hr @ 50m	6	m3/hr @ 50m		
	9.6	l/km/day/m	3	days	50	days		
			5.8705	l/km/day/m	2.3671	l/km/day/m	17.84	l/km/day/m
Service Conns	1.25	l/conn/hr	0.00225	burst/conn/yr	0.00075	burst/conn/yr		
		at 50 m head	1.6	m3/hr @ 50m	1.6	m3/hr @ 50m		
	0.600	l/conn/day/m	8	days	100	days		
			0.038	l/conn/day/m	0.158	l/conn/day/m	0.796	l/conn/day/m
Service Line	0.5	l/conn/h	0.0015	burst/conn/yr	0.0005	burst/conn/yr		
		at 15 m pipe	1.6	m3/hr @ 50m	1.6	m3/hr @ 50m	assumes 15 m line	
		at 50 m head	9	days	101	days		
	16	l/km/day/m	1.89	l/km/day/m	7.08	l/km/day/m	24.98	l/km/day/m

ADJUSTED	Background		Reported		Unreported		Total	
Mains	20	l/km/hr	0.124	bursts/km/yr	0.006	leaks/km/yr		
		at 50 m head	6	m3/hr @ 50m	3	m3/hr @ 50m		
	9.6	l/km/day/m	2	days	50	days		
			1.96	l/km/day/m	1.18	l/km/day/m	12.7	l/km/day/m
Service Conns	1.25	l/conn/hr	0.00225	burst/conn/yr	0.00075	burst/conn/yr		
		at 50 m head	0.6	m3/hr @ 50m	0.6	m3/hr @ 50m		
	0.600	l/conn/day/m	6	days	100	days		
			0.0107	l/conn/day/m	0.0592	l/conn/day/m	0.670	l/conn/day/m
Service Line	0.5	l/conn/h	0.0015	burst/conn/yr	0.0005	burst/conn/yr		
		at 15 m pipe	0.6	m3/hr @ 50m	0.6	m3/hr @ 50m	assumes 15 m line	
		at 50 m head	6	days	100	days		
	16	l/km/day/m	0.47	l/km/day/m	2.63	l/km/day/m	19.1	l/km/day/m

In Context	Background		Reported		Unreported				
Mains									
	0.1920	m3/km/day	0.1565	m3/km/day	0.0947	m3/km/day	0.4432	m3/km/day	
	79	m3/day	64	m3/day	39	m3/day	181	m3/day	L/Conn/day
	16,736	m3/yr	13,646	m3/yr	8,254	m3/yr	38,636	m3/yr	4.33
Service Conns									
	0.7170	m3/km/day	0.02970	m3/km/day	0.1650	m3/km/day	0.9117	m3/km/day	
	294	m3/day	12	m3/day	68	m3/day	373	m3/day	L/Conn/day
	62,498	m3/yr	2,589	m3/yr	14,383	m3/yr	79,470	m3/yr	8.90
Service Line									
	0.1912	m3/km/day	0.0226	m3/km/day	0.1257	m3/km/day	0.3395	m3/km/day	
	78	m3/day	9	m3/day	51	m3/day	139	m3/day	L/Conn/day
	16,666	m3/yr	1,973	m3/yr	10,959	m3/yr	29,597	m3/yr	3.31
Total									
	1.100	m3/km/day	0.209	m3/km/day	0.385	m3/km/day	1.694	m3/km/day	
	450	m3/day	86	m3/day	158	m3/day	694	m3/day	L/Conn/day
	95,900	m3/yr	18,207	m3/yr	33,595	m3/yr	147,703	m3/yr	16.54
	10.74	L/Conn/day	2.04	L/Conn/day	3.76	L/Conn/day	16.54	L/Conn/day	
							0.99	m3/km/day	

Leakage =	1.3091	+	2.8135	* Ps	in m3/km/day
	alpha		beta		

Appendix C

Estimation of Default Values of Input Parameters

1. Estimated Commercial Losses/Total
2. Variable Cost of Water Production
3. Leak Detection Survey Cost
4. Commercial Loss Control Cost
5. Water Production Plant Capital Cost Coefficient
6. Population Growth Rate

1. Estimated Commercial Losses/Total

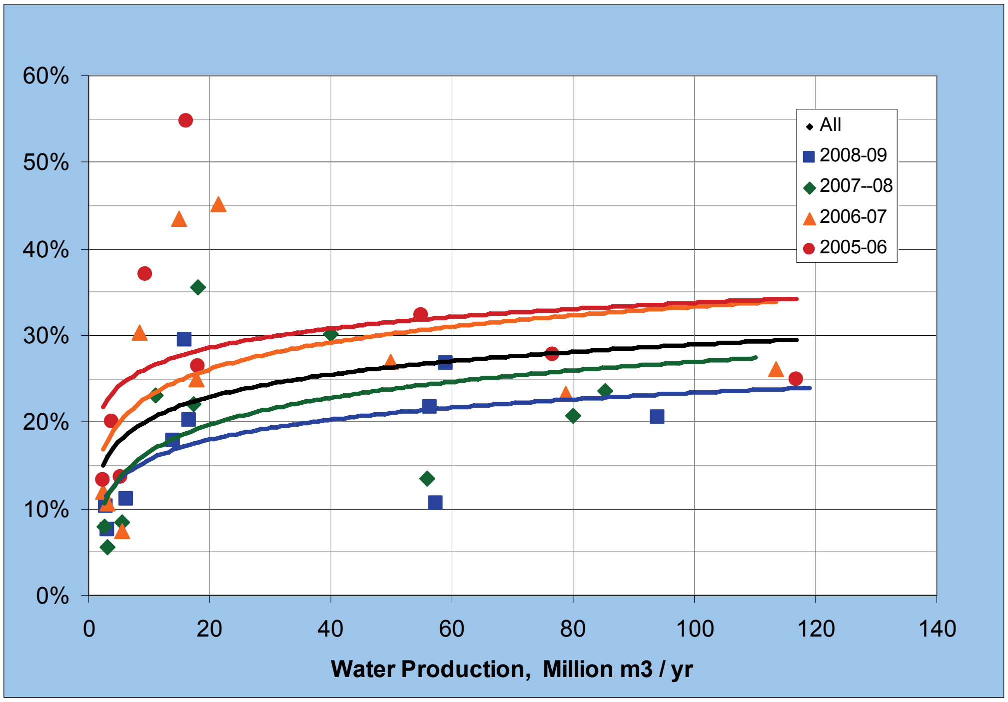
There is huge variation in this parameter, but 40% would seem a reasonable estimate if not other data is available. Fortunately the model is not very sensitive to this parameter.

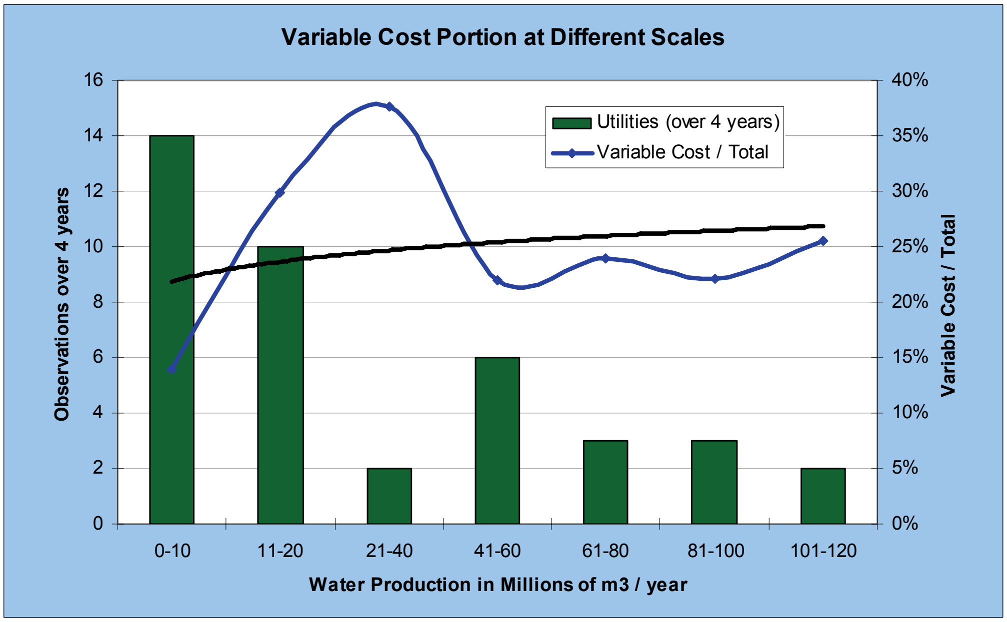
		Standard IWA Water Balance				
Location	Year	% Authorized Consumption	% Physical Losses	% Commercial Losses	Total %	Commercial Losses / Total
Utility #35, Colombia	2000	57.1%	30.9%	12.0%	100.0%	28.0%
Utility #18, Colombia	2000	79.8%	3.5%	16.8%	100.0%	82.8%
Utility #38, Colombia	2000	60.9%	26.3%	12.8%	100.0%	32.7%
Utility #12, Colombia	2000	89.2%	6.4%	4.5%	100.0%	41.2%
Utility #1, Colombia	2000	75.5%	8.7%	15.9%	100.0%	64.7%
Utility #39, Colombia	2000	54.3%	34.4%	11.4%	100.0%	24.9%
Utility #36, Colombia	2000	61.5%	25.6%	12.9%	100.0%	33.5%
Utility #5, Colombia	2000	70.3%	14.9%	14.8%	100.0%	49.8%
Utility #2, Colombia	2000	76.9%	7.0%	16.1%	100.0%	69.8%
Utility #14, Colombia	2000	65.2%	21.0%	13.7%	100.0%	39.4%
Utility #20, Colombia	2000	74.2%	10.2%	15.6%	100.0%	60.4%
Utility #33, Colombia	2000	73.6%	11.0%	15.5%	100.0%	58.5%
Utility #4, Colombia	2000	49.2%	40.5%	10.3%	100.0%	20.3%
Utility #19, Colombia	2000	76.5%	7.4%	16.1%	100.0%	68.4%
Utility #10, Colombia	2000	66.5%	19.5%	14.0%	100.0%	41.8%
Utility #23, Colombia	2000	64.6%	21.8%	13.6%	100.0%	38.3%
Utility #15, Colombia	2000	66.1%	20.0%	13.9%	100.0%	41.0%
Utility #32, Colombia	2000	75.3%	8.8%	15.8%	100.0%	64.2%
Utility #8, Colombia	2000	46.1%	44.2%	9.7%	100.0%	18.0%
Utility #37, Colombia	2000	71.0%	14.1%	14.9%	100.0%	51.4%
Utility #21, Colombia	2000	53.8%	34.9%	11.3%	100.0%	24.4%
Utility #24, Colombia	2000	69.8%	16.3%	14.0%	100.0%	46.1%
Utility #9, Colombia	2000	71.3%	14.5%	14.3%	100.0%	49.6%
Utility #40, Colombia	2000	67.9%	18.5%	13.6%	100.0%	42.4%
Utility #17, Colombia	2000	61.1%	26.1%	12.8%	100.0%	32.9%
Utility #25, Colombia	2000	63.7%	23.6%	12.7%	100.0%	35.0%
Utility #13, Colombia	2000	58.5%	29.2%	12.3%	100.0%	29.6%
Utility #28, Colombia	2000	74.2%	10.2%	15.6%	100.0%	60.4%
Utility #22, Colombia	2000	67.6%	18.9%	13.5%	100.0%	41.7%
Utility #16, Colombia	2000	60.9%	23.9%	15.2%	100.0%	38.9%
Utility #26, Colombia	2000	57.7%	34.2%	8.1%	100.0%	19.1%
Utility #3, Colombia	2000	59.9%	26.9%	13.2%	100.0%	32.9%
Papua, New Guinea	2002	55.0%	34.7%	10.3%	100.0%	22.9%
Larisa, Greece	2006	70.1%	23.9%	6.0%	100.0%	20.1%
Kampala, Uganda	2007	60.9%	18.1%	21.0%	100.0%	53.7%
Managua, Nicaragua	2007	44.0%	35.1%	20.9%	100.0%	37.3%
Tehran, Iran	2007	78.6%	9.9%	11.5%	100.0%	53.8%
Busan, Korea	2004	86.9%	9.5%	3.6%	100.0%	27.4%
Bhaktapur, Nepal	2004	39.0%	24.4%	36.6%	100.0%	60.0%
Dhulikhel, Nepal	2004	83.6%	12.3%	4.1%	100.0%	25.0%
Alexandria Egypt	2008	64.0%	15.0%	21.0%	100.0%	58.3%

Minimum	39.0%	3.5%	3.6%	100.0%	18.0%
Average	65.9%	20.4%	13.7%	100.0%	42.5%
Median	66.1%	19.5%	13.6%	100.0%	41.0%
Maximum	89.2%	44.2%	36.6%	100.0%	82.8%

2. Analysis of Variable Cost portion of O&M Costs of Zambian Commercial Utilities

The portion of total O&M costs that constitute variable cost is estimated below, for 4 different years. This portion varies somewhat with scale, but overall an average portion of 25% seems like a good estimate, if precise data are not available.





3. Active Leakage Control Costs

Based on Farley & Trow - Losses in Water Distribution Networks, IWA Publishing, 2003

A two person crew can "sound" 2000 connections in 5-10 working days
with connections spaced 15 - 20 m apart
this is equivalent to 200-400 connections per day

Therefore the crew, with van and sounding gear cover 30 to 40 km over the 5 to ten working days

Note that the NWC Guide - Leakge Control Policy and Practice from 1979 estimates
that one person can sound 20 properties an hour or 160 per day, which is ;lower than the estimate above
The current higher productivity is likely due to more dense settlements and better equiopment

1.1 Costs over an average 8 day working days include

	Unit	Qty	Unit Cost	Total	Notes
Leak detection crew labor	Labor hours	128.0	$13.00	$1,664.00	
Crew downtime, equipment maintenance	Labor hours	25.6	$13.00	$332.80	
Recordkeeping/technician	Labor hours	2000	$12.00	$800.00	30 surveys/yr
Social Insurance	% of labor cost	30%		$839.04	
Supervision at 20% of direct labor hours	% of labor cost	20%		$559.36	
Computer/supplies for recordkeeping	Annual. Depr	10% /yr	$ 2,500	$250.00	
Vehicle fuel and maintenance	km	338	$1.00	$337.50	includes travel to site
Vehicle straight line depreciation	Annual. Depr	10% /yr	$ 20,000	$66.67	30 surveys/yr
Leak detection equipment depreciation	Annual. Depr	10% /yr	$ 3,000	$10.00	30 surveys/yr
Subtotal				$4,859	

With an average of 35 km in mains covered, the estimated cost per km is $138.84
This result is very close to results of a surevy of costs on ALC crews in Noth America,
by Brothers (2010) which gave results of an average of $138 and a median of $153.

1.2 Additional Cost of Repair crew labor. Note that actual materials are not counted,
but the labor cost of the must be counted as this expenditure reduces leak duration

	Unit	Qty	Unit Cost	Total	Notes
Leak repair crew labor	Labor hours	192.0	$10.00	$1,920.00	
Crew downtime, equipment maintenance	Labor hours	38.4	$10.00	$384.00	
Social Insurance	% of labor cost	30%		$691.20	
Supervision at 20% of labor hours above	% of labor cost	20%		$460.80	
Vehicle fuel and maintenance	km	338	$1.00	$337.50	includes travel to site
Vehicle straight line depreciation	Annual. Depr	10% /yr	$20,000	$66.67	30 surveys/yr
Leak repair equipment depreciation	Annual. Depr	10% /yr	$ 3,000	$10.00	30 surveys/yr
Subtotal				$3,870	

With an average of 35 km in mains covered, the cost per km is $110.58

Total Cost per km of line covered is **$249.42**

1.3 In Developing Countries assume labor cost is 15% of developed countries, and
equipment related costs are 25% higher LDC labor cost scaling is based ILO data-
for a variety of countries for a variety of skilled trade jobs

1.4 Costs over an average 8 day working days include

15%
25%

	Unit	Qty	Unit Cost	Total	Notes
Leak detection crew labor	Labor hours	128.0	$1.95	$249.60	
Crew downtime, equipment maintenance	Labor hours	25.6	$1.95	$49.92	
Recordkeeping/technician	Labor hours	2000	$1.80	$120.00	30 surveys/yr
Social Insurance	% of labor cost	30%		$125.86	
Supervision at 20% of direct labor hours	% of labor cost	20%		$83.90	
Computer/supplies for recordkeeping	Annual. Depr	10% /yr	$ 3,125	$312.50	
Vehicle fuel and maintenance	km	338	$ 1.25	$421.88	includes travel to site
Vehicle straight line depreciation	Annual. Depr	10% /yr	$ 25,000	$66.67	30 surveys/yr
Leak detection equipment depreciation	Annual. Depr	10% /yr	$ 3,750	$12.50	30 surveys/yr
Subtotal				$1,443	

With an average of 35 km in mains covered, the estimated cost per km is $41.22

1.2 Additional Cost of Repair crew labor. Note that actual materials are not counted,
but the labor cost of the must be counted as this expenditure reduces leak duration

	Unit	Qty	Unit Cost	Total	
Leak repair crew labor	Labor hours	192.0	$1.50	$288.00	
Crew downtime, equipment maintenance	Labor hours	38.4	$1.50	$57.60	
Social Insurance	% of labor cost	30%		$103.68	
Supervision at 20% of labor hours above	% of labor cost	20%		$69.12	
Vehicle fuel and maintenance	km	338	$ 1.25	$421.88	includes travel to site
Vehicle straight line depreciation	Annual. Depr	10% /yr	$ 25,000	$66.67	30 surveys/yr
Leak repair equipment depreciation	Annual. Depr	10% /yr	$ 3,750	$12.50	30 surveys/yr
Subtotal				$1,019	

With an average of 35 km in mains covered, the cost per km is $29.13

Total Cost per km of line covered is **$70.35**

Assume $ 70.00 in $2007

4. Commercial Loss Control Costs

Planned Meter Replacement Program

7

Rule of thumb is to replace every 7 years, so an average of 14286 per year or using 250 days 57 per day

This will require 2 technician / recordkeepers for every 100 meters/day, requiring at total of 2 technicians

a plumber can replace 15 meters in one day requiring 4 plumbers, assume 5 plumbers

	Unit	Qty	Unit Cost	Total	Notes
Meter test / repair technician	Labor hours	2000	$1.95	$3,900	
Meter replacement personnel	Labor hours	10000	$1.50	$15,000	
Recordkeeping/technician (2)	Labor hours	2000	$1.50	$3,000	
Social Insurance	% of labor cost	30%		$6,570	
Supervision at 20% of direct labor hours	% of labor cost	20%		$4,380	
Computer/supplies for recordkeeping	Annual. Depr	10% /yr	$ 8,400	$840	
Meters - domestic		12,857	$ 35	$450,000	
Meters - Commercial Industrial		1,429	$ 250	$357,143	
Meter Test bench - depreciation	Initial Cost	10% /yr	10000	$1,000	
Vehicle fuel and maintenance	km	214,286	$1.40	$300,000	includes travel to sites
Vehicle straight line depreciation	Annual. Depr	10% /yr	$ 28,000	$2,800	
Meter installatiion repair tools	Annual. Depr	10% /yr	$ 1,500	$150	
Subtotal				$1,144,783	

Illegal Connections

	Unit	Qty	Unit Cost	Total	Notes
Field Investigator	Labor hours	2000	$1.95	$3,900	
Crew members	Labor hours	6000	$1.50	$9,000	
Social Insurance	% of labor cost	30%		$3,870	
Supervision at 20% of direct labor hours	% of labor cost	20%		$2,580	
Vehicle fuel and maintenance	km	72,000	$1.40	$100,800	
Vehicle straight line depreciation	Annual. Depr	10% /yr	$ 28,000	$2,800	
Misc Supplies and tools	Annual. Depr	10% /yr	$ 1,000	$100	
Subtotal				$123,050	

Total Cost	$1,267,833
Annual Cost / per connection	$80.13
Assume **$ 80.00**	in $2007

5. **Water Production Plant Capital Cost Coefficient**

This table derives a coefficient for a cost model where Cost = 2288 Q ^0.75

Country		Capacity	Observed Cost $2005	Cost / m3/day	Capacity^0.75	Coefficient	Cost
Uganda		1,460	$1,087,933	745	236.2	4606	$561,365
Tanzania	Arusha	3,850	$1,957,000	508	488.8	4004	$1,161,653
Burkina Faso	Bobo-Dioulasso	10,000	$1,619,804	162	1000.0	1620	$2,376,736
Burkina Faso	Bobo-Dioulasso	10,000	$1,451,923	145	1000.0	1452	$2,376,736
Burkina Faso	Dedougou	14,000	$1,400,000	100	1287.1	1088	$3,058,983
Senegal	DIOULOULOU	25,000	$3,266,432	131	1988.2	1643	$4,725,372
Senegal	TENGHORY	30,000	$4,326,400	144	2279.5	1898	$5,417,787
Senegal	EBINAKO	30,000	$3,019,231	101	2279.5	1325	$5,417,787
Senegal	BESSIRE	30,000	$6,083,580	203	2279.5	2669	$5,417,787
Zimbabwe		35,616	$7,401,221	208	2592.6	2855	$6,161,960
Lesotho	Check date	93,800	$16,001,934	171	5359.8	2986	$12,738,936
India	CHANDORI	3,500	$295,766	85	455.0	650	$1,081,514
China		7,440	$1,709,608	230	801.1	2134	$1,903,973
China		15,960	$854,804	54	1420.0	602	$3,374,859
China		50,000	$11,970,000	239	3343.7	3580	$7,947,097
China		60,000	$8,598,720	143	3833.7	2243	$9,111,596
China		77,760	$5,200,562	67	4656.6	1117	$11,067,466
China		78,000	$23,199,000	297	4667.4	4970	$11,093,076
India	RAMTEK	86,000	$7,357,176	86	5022.0	1465	$11,935,891
China		99,965	$24,333,058	243	5621.9	4328	$13,361,842
India	VARANGAON	260,000	$9,365,919	36	11514.1	813	$27,365,982
Average						2288	

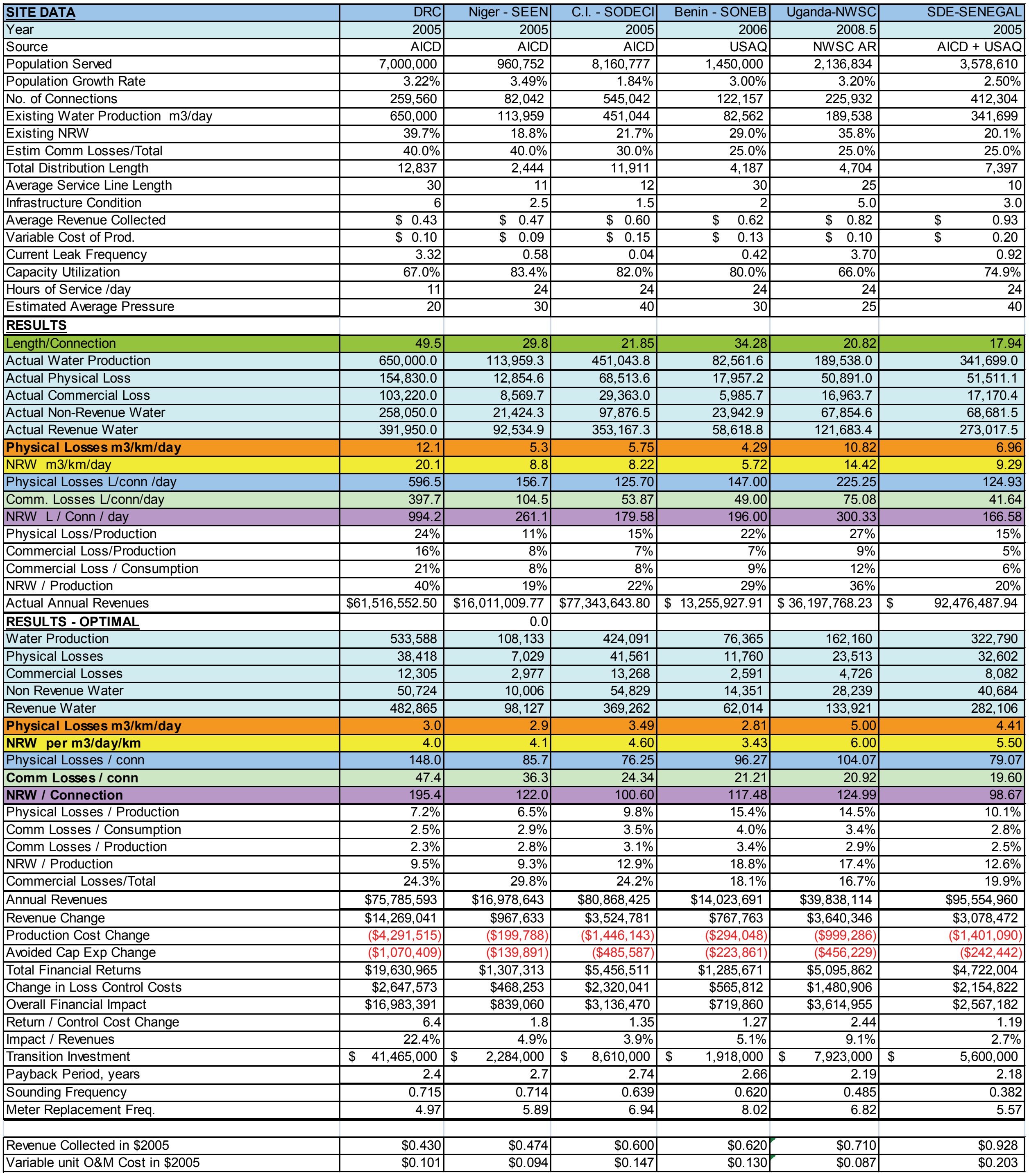
6. Population Growth Rates

Country	UN Population Growth Rate (%)
Benin	3.02
Burkina Faso	2.89
Côte d'Ivoire	1.84
DRC	3.22
Ghana	1.99
Kenya	2.65
Kosovo	1.00
Lesotho	0.63
Malaysia	1.69
Malawi	2.57
Mali	3.02
Niger	3.49
Philippines	1.72
Rwanda	2.76
Senegal	2.46
South Africa	0.55
Thailand	0.66
Tunisia	1.08
Uganda	3.24
Ukraine	0.00
Zambia	1.91

*Kosovo figure (2008) was from the World Bank's World Development Indicators & Global Development Finance database

Appendix D

African National Water Utility Data



SITE DATA	DRC	Niger - SEEN	C.I. - SODECI	Benin - SONEB	Uganda-NWSC	SDE-SENEGAL
Year	2005	2005	2005	2006	2008.5	2005
Source	AICD	AICD	AICD	USAQ	NWSC AR	AICD + USAQ
Population Served	7,000,000	960,752	8,160,777	1,450,000	2,136,834	3,578,610
Population Growth Rate	3.22%	3.49%	1.84%	3.00%	3.20%	2.50%
No. of Connections	259,560	82,042	545,042	122,157	225,932	412,304
Existing Water Production m3/day	650,000	113,959	451,044	82,562	189,538	341,699
Existing NRW	39.7%	18.8%	21.7%	29.0%	35.8%	20.1%
Estim Comm Losses/Total	40.0%	40.0%	30.0%	25.0%	25.0%	25.0%
Total Distribution Length	12,837	2,444	11,911	4,187	4,704	7,397
Average Service Line Length	30	11	12	30	25	10
Infrastructure Condition	6	2.5	1.5	2	5.0	3.0
Average Revenue Collected	$ 0.43	$ 0.47	$ 0.60	$ 0.62	$ 0.82	$ 0.93
Variable Cost of Prod.	$ 0.10	$ 0.09	$ 0.15	$ 0.13	$ 0.10	$ 0.20
Current Leak Frequency	3.32	0.58	0.04	0.42	3.70	0.92
Capacity Utilization	67.0%	83.4%	82.0%	80.0%	66.0%	74.9%
Hours of Service /day	11	24	24	24	24	24
Estimated Average Pressure	20	30	40	30	25	40
RESULTS						
Length/Connection	49.5	29.8	21.85	34.28	20.82	17.94
Actual Water Production	650,000.0	113,959.3	451,043.8	82,561.6	189,538.0	341,699.0
Actual Physical Loss	154,830.0	12,854.6	68,513.6	17,957.2	50,891.0	51,511.1
Actual Commercial Loss	103,220.0	8,569.7	29,363.0	5,985.7	16,963.7	17,170.4
Actual Non-Revenue Water	258,050.0	21,424.3	97,876.5	23,942.9	67,854.6	68,681.5
Actual Revenue Water	391,950.0	92,534.9	353,167.3	58,618.8	121,683.4	273,017.5
Physical Losses m3/km/day	12.1	5.3	5.75	4.29	10.82	6.96
NRW m3/km/day	20.1	8.8	8.22	5.72	14.42	9.29
Physical Losses L/conn /day	596.5	156.7	125.70	147.00	225.25	124.93
Comm. Losses L/conn/day	397.7	104.5	53.87	49.00	75.08	41.64
NRW L / Conn / day	994.2	261.1	179.58	196.00	300.33	166.58
Physical Loss/Production	24%	11%	15%	22%	27%	15%
Commercial Loss/Production	16%	8%	7%	7%	9%	5%
Commercial Loss / Consumption	21%	8%	8%	9%	12%	6%
NRW / Production	40%	19%	22%	29%	36%	20%
Actual Annual Revenues	$61,516,552.50	$16,011,009.77	$77,343,643.80	$ 13,255,927.91	$ 36,197,768.23	$ 92,476,487.94
RESULTS - OPTIMAL		0.0				
Water Production	533,588	108,133	424,091	76,365	162,160	322,790
Physical Losses	38,418	7,029	41,561	11,760	23,513	32,602
Commercial Losses	12,305	2,977	13,268	2,591	4,726	8,082
Non Revenue Water	50,724	10,006	54,829	14,351	28,239	40,684
Revenue Water	482,865	98,127	369,262	62,014	133,921	282,106
Physical Losses m3/km/day	3.0	2.9	3.49	2.81	5.00	4.41
NRW per m3/day/km	4.0	4.1	4.60	3.43	6.00	5.50
Physical Losses / conn	148.0	85.7	76.25	96.27	104.07	79.07
Comm Losses / conn	47.4	36.3	24.34	21.21	20.92	19.60
NRW / Connection	195.4	122.0	100.60	117.48	124.99	98.67
Physical Losses / Production	7.2%	6.5%	9.8%	15.4%	14.5%	10.1%
Comm Losses / Consumption	2.5%	2.9%	3.5%	4.0%	3.4%	2.8%
Comm Losses / Production	2.3%	2.8%	3.1%	3.4%	2.9%	2.5%
NRW / Production	9.5%	9.3%	12.9%	18.8%	17.4%	12.6%
Commercial Losses/Total	24.3%	29.8%	24.2%	18.1%	16.7%	19.9%
Annual Revenues	$75,785,593	$16,978,643	$80,868,425	$14,023,691	$39,838,114	$95,554,960
Revenue Change	$14,269,041	$967,633	$3,524,781	$767,763	$3,640,346	$3,078,472
Production Cost Change	($4,291,515)	($199,788)	($1,446,143)	($294,048)	($999,286)	($1,401,090)
Avoided Cap Exp Change	($1,070,409)	($139,891)	($485,587)	($223,861)	($456,229)	($242,442)
Total Financial Returns	$19,630,965	$1,307,313	$5,456,511	$1,285,671	$5,095,862	$4,722,004
Change in Loss Control Costs	$2,647,573	$468,253	$2,320,041	$565,812	$1,480,906	$2,154,822
Overall Financial Impact	$16,983,391	$839,060	$3,136,470	$719,860	$3,614,955	$2,567,182
Return / Control Cost Change	6.4	1.8	1.35	1.27	2.44	1.19
Impact / Revenues	22.4%	4.9%	3.9%	5.1%	9.1%	2.7%
Transition Investment	$ 41,465,000	$ 2,284,000	$ 8,610,000	$ 1,918,000	$ 7,923,000	$ 5,600,000
Payback Period, years	2.4	2.7	2.74	2.66	2.19	2.18
Sounding Frequency	0.715	0.714	0.639	0.620	0.485	0.382
Meter Replacement Freq.	4.97	5.89	6.94	8.02	6.82	5.57
Revenue Collected in $2005	$0.430	$0.474	$0.600	$0.620	$0.710	$0.928
Variable unit O&M Cost in $2005	$0.101	$0.094	$0.147	$0.130	$0.087	$0.203

SITE DATA	BURKINA	GHANA-GWCL	TUNISIA	LESOTHO	MALI	TOGO
Year	2005	2006	2007	2007	2007	2006
Source	AICD +USAQ	USAQ	y, USAQ, Website	AICD	AICD	USAQ
Population Served	998,770	9,361,760	8,515,365	274,002	1,500,000	1,201,696
Population Growth Rate	2.89%	2.00%	1.08%	0.63%	3.02%	2.65%
No. of Connections	104,400	363,900	2,067,000	43,548	103,286	56,842
Existing Water Production m3/day	113,382	580,000	1,143,014	42,584	193,344	54,795
Existing NRW	18.3%	49.0%	16.6%	26.0%	25.5%	20.0%
Estim Comm Losses/Total	25.0%	50.0%	25.0%	40.0%	40.0%	25.0%
Total Distribution Length	3,413	8,470	35,403	590	2,831	2,103
Average Service Line Length	15	25	10	50	12	30
Infrastructure Condition	4	8	2.5	6	5	2.5
Average Revenue Collected	$ 0.62	$ 0.54	$ 0.40	$ 0.73	$ 0.64	$ 0.54
Variable Cost of Prod.	$ 0.15	$ 0.11	$ 0.08	$ 0.16	$ 0.05	$ 0.08
Current Leak Frequency	2.94	5.37	1.06	4.07	4.95	0.97
Capacity Utilization	58.4%	73.9%	90.0%	67.6%	80.0%	19.1%
Hours of Service /day	23	12	24	24	24	24
Estimated Average Pressure	30	20	30	15	15	30
RESULTS						
Length/Connection	32.7	23.28	17.13	13.55	27.41	37.00
Actual Water Production	113,382.2	580,000.0	1,143,014.0	42,583.8	193,343.7	54,794.5
Actual Physical Loss	15,549.1	142,100.0	142,305.2	6,643.1	29,585.9	8,219.2
Actual Commercial Loss	5,183.0	142,100.0	47,435.1	4,428.7	19,723.9	2,739.7
Actual Non-Revenue Water	20,732.2	284,200.0	189,740.3	11,071.8	49,309.8	10,958.9
Actual Revenue Water	92,650.0	295,800.0	953,273.7	31,512.0	144,033.9	43,835.6
Physical Losses m3/km/day	4.6	16.78	4.02	11.26	10.45	3.91
NRW m3/km/day	6.1	33.55	5.36	18.77	17.42	5.21
Physical Losses L/conn /day	148.9	390.49	68.85	152.55	286.45	144.60
Comm. Losses L/conn/day	49.6	390.49	22.95	101.70	190.96	48.20
NRW L / Conn / day	198.6	780.98	91.80	254.24	477.41	192.80
Physical Loss/Production	14%	25%	12%	16%	15%	15%
Commercial Loss/Production	5%	25%	4%	10%	10%	5%
Commercial Loss / Consumption	5%	32%	5%	12%	12%	6%
NRW / Production	18%	49%	17%	26%	26%	20%
Actual Annual Revenues	$ 20,968,090.96	$ 58,734,048.00	$ 140,569,736.26	$ 8,361,874.62	$33,398,935.00	$8,563,063.72
RESULTS - OPTIMAL						
Water Production	109,189	475,461	1,135,878	39,237	172,377	54,538
Physical Losses	11,356	37,561	135,170	3,296	8,619	7,963
Commercial Losses	2,889	12,423	52,967	1,086	3,819	1,614
Non Revenue Water	14,244	49,985	188,136	4,382	12,438	9,577
Revenue Water	94,944	425,477	947,742	34,855	159,938	44,961
Physical Losses m3/km/day	3.3	4.43	3.82	5.59	3.04	3.79
NRW per m3/day/km	4.2	5.90	5.31	7.43	4.39	4.55
Physical Losses / conn	108.8	103.22	65.39	75.68	83.45	140.08
Comm Losses / conn	27.7	34.14	25.62	24.94	36.98	28.40
NRW / Connection	136.4	137.36	91.02	100.62	120.43	168.48
Physical Losses / Production	10.4%	7.9%	11.9%	8.4%	5.0%	14.6%
Comm Losses / Consumption	3.0%	2.8%	5.3%	3.0%	2.3%	3.5%
Comm Losses / Production	2.6%	2.6%	4.7%	2.8%	2.2%	3.0%
NRW / Production	13.0%	10.5%	16.6%	11.2%	7.2%	17.6%
Commercial Losses/Total	20.3%	24.9%	28.2%	24.8%	30.7%	16.9%
Annual Revenues	$21,487,313	$84,482,688	$139,754,061	$9,248,849	$37,086,900	$8,782,891
Revenue Change	$519,222	$25,748,640	($815,676)	$886,974	$3,687,965	$219,828
Production Cost Change	($234,637)	($4,273,536)	($208,363)	($193,033)	($362,204)	($7,908)
Avoided Cap Exp Change	($21,634)	($1,435,785)	($255,980)	($1,409)	($441,653)	($0)
Total Financial Returns	$775,493	$31,457,960	($351,332)	$1,081,417	$4,491,823	$227,736
Change in Loss Control Costs	$447,594	$3,213,392	($489,590)	$291,028	$884,686	$138,839
Overall Financial Impact	$327,899	$28,244,568	$138,258	$790,388	$3,607,136	$88,896
Return / Control Cost Change	0.7	8.79	-0.28	2.72	4.08	0.64
Impact / Revenues	1.5%	33.4%	0.1%	8.5%	9.7%	1.0%
Transition Investment	$ 1,298,000	$ 46,843,000	$ 321,000	$ 1,338,000	$ 7,374,000	$ 276,000
Payback Period, years	4.0	1.66	2.32	1.69	2.04	3.11
Sounding Frequency	0.545	0.479	0.587	0.348	0.899	0.901
Meter Replacement Freq.	5.91	5.67	10.59	6.04	4.66	6.93
Revenue Collected in $2005	$0.620	$0.523	$0.374	$0.672	$0.587	$0.515
Variable unit O&M Cost in $2005	$0.153	$0.108	$0.074	$0.146	$0.044	$0.081

SITE DATA	RWANDA	BURUNDI	GABON
Year	2006	2006	2006
Source	AICD	AICD	USAQ
Population Served	380,865	400,000	728,400
Population Growth Rate	2.76%	3.90%	1.93%
No. of Connections	38,519	33,902	100,600
Existing Water Production m3/day	43,397	91,014	200,000
Existing NRW	38.3%	40.1%	17.8%
Estim Comm Losses/Total	40.0%	40.0%	40.0%
Total Distribution Length	2,325	2,122	1,603
Average Service Line Length	60	15	10
Infrastructure Condition	3	3	4
Average Revenue Collected	$ 0.42	$ 0.23	$ 0.37
Variable Cost of Prod.	$ 0.08	$ 0.06	$ 0.08
Current Leak Frequency	1.35	0.71	0.94
Capacity Utilization	84.0%	19.1%	86.4%
Hours of Service /day	24	18	24
Estimated Average Pressure	25	20	20
RESULTS			
Length/Connection	60.4	62.6	15.9
Actual Water Production	43,397.0	91,014.0	200,000.0
Actual Physical Loss	9,972.6	21,898.0	21,369.9
Actual Commercial Loss	6,648.4	14,598.6	14,246.6
Actual Non-Revenue Water	16,621.1	36,496.6	35,616.4
Actual Revenue Water	26,775.9	54,517.4	164,383.6
Physical Losses m3/km/day	4.3	10.3	13.3
NRW m3/km/day	7.1	17.2	22.2
Physical Losses L/conn /day	258.9	645.9	212.4
Comm. Losses L/conn/day	172.6	430.6	141.6
NRW L / Conn / day	431.5	1076.5	354.0
Physical Loss/Production	23%	24%	11%
Commercial Loss/Production	15%	16%	7%
Commercial Loss / Consumption	20%	21%	8%
NRW / Production	38%	40%	18%
Actual Annual Revenues	$ 4,104,752.98	$ 4,497,139.17	$ 22,430,734.85
RESULTS - OPTIMAL			
Water Production	39,555	74,238	184,726
Physical Losses	6,131	5,122	6,096
Commercial Losses	1,271	2,337	5,032
Non Revenue Water	7,402	7,460	11,128
Revenue Water	32,154	66,779	173,598
Physical Losses m3/km/day	2.6	2.4	3.8
NRW per m3/day/km	3.2	3.5	6.9
Physical Losses / conn	159.2	151.1	60.6
Comm Losses / conn	33.0	68.9	50.0
NRW / Connection	192.2	220.0	110.6
Physical Losses / Production	15.5%	6.9%	3.3%
Comm Losses / Consumption	3.8%	3.4%	2.8%
Comm Losses / Production	3.2%	3.1%	2.7%
NRW / Production	18.7%	10.0%	6.0%
Commercial Losses/Total	17.2%	31.3%	45.2%
Annual Revenues	$4,929,134	$5,508,584	$23,688,032
Revenue Change	$824,381	$1,011,445	$1,257,297
Production Cost Change	($110,771)	($373,507)	($423,135)
Avoided Cap Exp Change	($211,135)	($31)	($340,768)
Total Financial Returns	$1,146,286	$1,384,983	$2,021,199
Change in Loss Control Costs	$293,330	$232,383	$579,939
Overall Financial Impact	$852,955	$1,152,600	$1,441,260
Return / Control Cost Change	2.9	5.0	2.5
Impact / Revenues	17.3%	20.9%	6.1%
Transition Investment	$ 1,844,000	$ 5,807,000	$ 4,898,000
Payback Period, years	2.2	5.0	3.4
Sounding Frequency	0.595	1.649	0.634
Meter Replacement Freq.	7.60	6.76	5.63
Revenue Collected in $2005	$0.420	$0.217	$0.359
Variable unit O&M Cost in $2005	$0.079	$0.059	$0.073

SITE DATA	Average	Median	Min	Max	Std Dev	Total
Year	2,006.0	2,006.0	2,005.0	2,008.5	1.0	
Source						
Population Served	3,109,855	1,450,000	274,002	9,361,760	3,345,409	46,647,831
Population Growth Rate	2.54%	2.76%	0.63%	3.90%	0.89%	
No. of Connections	303,936	104,400	33,902	2,067,000	511,709	4,559,034
Existing Water Production m3/day	286,022	189,538	42,584	1,143,014	306,990	4,290,331
Existing NRW	27.8%	25.5%	16.6%	49.0%	10.3%	
Estim Comm Losses/Total	34.0%	40.0%	25.0%	50.0%	8.5%	
Total Distribution Length	6,823	3,413	590	35,403	8,746	102,340
Average Service Line Length	23	15	10	60	15	
Infrastructure Condition	3.9	3.0	1.5	8.0	1.8	
Average Revenue Collected	$0.557	$0.544	$0.226	$0.928	$0.181	
Variable Cost of Prod.	$0.108	$0.100	$0.047	$0.203	$0.042	
Current Leak Frequency						
Capacity Utilization	68.8%	74.9%	19.1%	90.0%	22.0%	
Hours of Service /day	22	24	11	24	4	
Estimated Average Pressure	26	25	15	40	8	
RESULTS						
Length/Connection	30.9	27.4	13.5	62.6	15.6	
Actual Water Production	286,022	189,538	42,584	1,143,014	306,990	4,290,331
Actual Physical Loss	50,280	21,898	6,643	154,830	52,904	754,200
Actual Commercial Loss	29,225	14,599	2,740	142,100	40,305	438,377
Actual Non-Revenue Water	79,505	36,497	10,959	284,200	90,419	1,192,577
Actual Revenue Water	206,517	121,683	26,776	953,274	238,917	3,097,754
Physical Losses m3/km/day	8.3	7.0	3.9	16.8	4.1	
NRW m3/km/day	13.3	9.3	5.2	33.6	8.2	
Physical Losses L/conn /day	246	157	69	646	172	
Comm. Losses L/conn/day	151	102	23	431	141	
NRW L / Conn / day	397	261	92	1,077	309	
Physical Loss/Production	17.9%	15.3%	10.7%	26.9%	5.5%	
Commercial Loss/Production	9.9%	7.5%	4.2%	24.5%	5.7%	
Commercial Loss / Consumption	12.4%	9.3%	4.7%	32.5%	7.9%	
NRW / Production	27.8%	25.5%	16.6%	49.0%	10.3%	
Actual Annual Revenues	$39,895,318	$22,430,735	$4,104,753	$140,569,736	$39,310,284	$598,429,766
RESULTS - OPTIMAL						
Water Production	260,822	162,160	39,237	1,135,878	292,257	3,912,327
Physical Losses	25,080	11,356	3,296	135,170	33,415	376,196
Commercial Losses	8,493	3,819	1,086	52,967	13,005	127,389
Non Revenue Water	33,572	14,244	4,382	188,136	46,312	503,585
Revenue Water	227,249	133,921	32,154	947,742	247,643	3,408,742
Physical Losses m3/km/day	3.63	3.49	2.41	5.59	0.91	
NRW per m3/day/km	4.87	4.55	3.18	7.43	1.28	
Physical Losses / conn	102	96	61	159	33	
Comm Losses / conn	33	28	20	69	13	
NRW / Connection	136	122	91	220	40	
Physical Losses / Production	9.8%	9.8%	3.3%	15.5%	3.9%	
Comm Losses / Consumption	3.3%	3.0%	2.3%	5.3%	0.7%	
Comm Losses / Production	2.9%	2.8%	2.2%	4.7%	0.6%	
NRW / Production	12.8%	12.6%	6.0%	18.8%	4.2%	
Commercial Losses/Total	24.8%	24.3%	16.7%	45.2%	7.6%	
Annual Revenues	$43,867,858	$23,688,032	$4,929,134	$139,754,061	$41,321,212	$658,017,877
Revenue Change	$3,972,541	$1,011,445	($815,676)	$25,748,640	$6,995,995	$59,588,112
Production Cost Change	($987,931)	($362,204)	($4,291,515)	($7,908)	$1,409,591	($14,818,964)
Avoided Cap Exp Change	($355,121)	($242,442)	($1,435,785)	($0)	$406,179	($5,326,814)
Total Financial Returns	$5,315,593	$1,384,983	($351,332)	$31,457,960	$8,709,542	$79,733,889
Change in Loss Control Costs	$1,015,267	$565,812	($489,590)	$3,213,392	$1,083,493	$15,229,010
Overall Financial Impact	$4,300,325	$1,152,600	$88,896	$28,244,568	$7,825,878	$64,504,880
Return / Control Cost Change	2.77	2.44	(0.28)	8.79	2.42	
Impact / Revenues	9.8%	6.1%	0.1%	33.4%	9.6%	
Transition Investment	$9,186,600	$4,898,000	$276,000	$46,843,000	$14,501,261	$137,799,000
Payback Period, years	2.69	2.44	1.66	5.04	0.90	
Sounding Frequency	0.68	0.62	0.35	1.65	0.31	
Meter Replacement Freq.	6.53	6.04	4.66	10.59	1.46	
Revenue Collected in $2005	$0.537	$0.523	$0.217	$0.928	$0.171	
Variable unit O&M Cost in $2005	$0.105	$0.094	$0.044	$0.203	$0.043	

Appendix E

Developing Country Municipal and Regional Utility Data

Full Name	Bansalan Water District	Tandag Water Dsitrict	Metro Carigara Water District	San Francisco Water District	Silay City Water District	Victorias Water District
Country	Philippines	Philippines	Philippines	Philippines	Philippines	Philippines
Year	2003	2003	2003	2003	2003	2003
Source	SEAWUN	SEAWUN	SEAWUN	SEAWUN	SEAWUN	SEAWUN
Population Served	20,230	24,872	19,769	16,212	21,899	21,210
Population Growth Rate	1.72%	2%	2%	2%	1.72%	1.72%
Connections	3551	4120	3500	2878	3872	3695
Existing Production, m3 / day	2354	2708	3070	2517	3859	3981
Existing NRW, % of Production	20.8%	31.8%	38.0%	14.7%	38.2%	23.8%
Estim Comm Losses/Total	25.0%	25.0%	25.0%	25.0%	25.0%	25.0%
Distribution length, km	60.7	28.8	28.0	50.0	50.0	25.0
Average Service Line Length, m	10	5	5	10	10	5
Infrastructure Condition	4	10	10	3	8	10
Avg Tariff Collected $ / m3	$0.404	$0.377	$0.332	$0.291	$0.231	$0.255
Variable Oper Cost $US / m3	$0.058	$0.058	$0.042	$0.015	$0.045	$0.041
Reported pipe breaks / km /yr	27.2	37.50	29.46	1.00	3.62	6.16
Capacity Utilization	67%	67%	67%	67%	67%	67%
Hours of Service /day	18	24	24	24	24	20
Estimated Average Pressure	20	15	10	20	15	15
Length/Connection	17.1	7.0	8.0	17.4	12.9	6.8
Actual Water Production	2,354	2,708	3,070	2,517	3,859	3,981
Actual Physical Loss m3/day	367	646	875	277	1,106	711
Actual Commercial Loss	122	215	292	92	369	237
Actual Non-Revenue Water	490	861	1,167	370	1,474	947
Actual Revenue Water	1,864	1,847	1,903	2,147	2,385	3,034
Physical Loss m3/km/day	6.05	22.43	31.25	5.55	22.11	28.42
NRW m3/km/day	8.07	29.90	41.66	7.40	29.48	37.90
Physical Losses L/conn /day	103.4	156.8	250.0	96.4	285.5	192.3
Comm. Losses L/conn/day	34.5	52.3	83.3	32.1	95.2	64.1
NRW L / Conn / day	137.9	209.0	333.3	128.6	380.7	256.4
Physical Loss/Production	15.6%	23.9%	28.5%	11.0%	28.7%	17.9%
Commercial Loss/Production	5.2%	8.0%	9.5%	3.7%	9.6%	6.0%
Commercial Loss / Consumption	6.2%	10.4%	13.3%	4.1%	13.4%	7.2%
NRW / Production	20.8%	31.8%	38.0%	14.7%	38.2%	23.8%
Actual Annual Revenues	$274,920	$254,094	$230,598	$228,012	$201,237	$282,120
RESULTS - OPTIMAL						
Water Production	2,210	2,266	2,353	2,461	3,022	3,464
Physical Losses	223	204	158	221	269	194
Commercial Losses	90	103	104	102	147	149
Non Revenue Water	314	307	262	323	416	343
Revenue Water	1,896	1,959	2,091	2,138	2,606	3,121
Physical Losses: m3 / km / day	3.68	7.08	5.63	4.43	5.38	7.76
NRW per m3/day/km	5.17	10.65	9.35	6.47	8.32	13.72
Physical Losses / conn	62.9	49.5	45.0	77.0	69.5	52.5
Comm Losses / conn	25.5	24.9	29.7	35.4	38.0	40.3
NRW / Connection	88.3	74.4	74.8	112.4	107.4	92.8
Physical Losses / Production	10.1%	9.0%	6.7%	9.0%	8.9%	5.6%
Comm Losses / Consumption	4.6%	5.0%	4.7%	4.5%	5.3%	4.6%
Comm Losses / Production	4.1%	4.5%	4.4%	4.1%	4.9%	4.3%
NRW / Production	14.2%	13.5%	11.1%	13.1%	13.8%	9.9%
Commercial Losses/Total	28.8%	33.5%	39.8%	31.5%	35.3%	43.4%
Annual Revenues	$279,634	$269,577	$253,317	$227,018	$219,933	$290,288
Revenue Change	$4,714	$15,483	$22,719	($994)	$18,696	$8,168
Production Cost Change	($3,049)	($9,355)	($10,997)	($307)	($13,741)	($7,697)
Avoided Cap Exp Change	($2,044)	($8,848)	($17,790)	($635)	($21,004)	($6,168)
Total Financial Returns	$9,807	$33,686	$51,506	($53)	$53,441	$22,033
Change in Loss Control Costs	$5,872	$10,754	$10,585	($426)	$11,615	$7,557
Overall Financial Impact	$3,935	$22,932	$40,921	$373	$41,826	$14,477
Return / Control Cost Change	0.67	2.13	3.87	-0.88	3.60	1.92
Impact / Revenues	1.41%	8.51%	16.15%	0.16%	19.02%	4.99%
Transition Investment	$35,000	$111,000	$181,000	$9,000	$212,000	$121,000
Payback Period, years	8.94	4.84	4.42	25.02	5.06	8.35
Sounding Frequency, years	0.766	0.389	0.579	1.194	0.582	0.488
Meter Replacement Freq.	9.10	9.97	9.49	9.10	10.68	9.11
Unt Revenue or Unit Tariff in $2005	$0.44	$0.41	$0.36	$0.32	$0.25	$0.28
Revenue /connection/month	$7.01	$5.81	$6.44	$7.02	$5.04	$6.99
Variable Unit Water Prod Cost, $US 2005	$0.06	$0.06	$0.05	$0.02	$0.05	$0.04

Full Name	SAJ Holdings Sdn Bhd	Sibu Water Board	Perbadanan Bekalan Air Pulau Pinang Sdn. Bhd	Syarikat Air Terengganu SDN. Bhd	Thai PWA	Thai MWA
Country	Malaysia	Malaysia	Malaysia	Malaysia	Thailand	Thailand
Year	2003	2003	2003	2003	2003	2003
Source	SEAWUN	SEAWUN	SEAWUN	SEAWUN	SEAWUN	SEAWUN
Population Served	2,922,855	229,471	1,416,064	880,000	11,000,000	6,931,000
Population Growth Rate	1.69%	1.69%	1.69%	1.69%	0.66%	1.50%
Connections	764,384	43,370	402,777	187,056	1,967,292	1,540,203
Existing Production, m3 / day	1,290,411	80,301	775,342	369,041	2,054,795	4,153,425
Existing NRW, % of Production	38.0%	27.6%	21.1%	32.7%	26.7%	33.7%
Estim Comm Losses/Total	10.00%	47.1%	19.5%	67%	25%	25%
Distribution length, km	12,071	874	3,407	4,283	40,000	22,176
Average Service Line Length, m	6	9	20	50	15	20
Infrastructure Condition	6.0	3.0	4.0	2.0	6	10
Avg Tariff Collected $ / m3	$0.370	$0.210	$0.1600	$0.210	$0.381	$0.322
Variable Oper Cost $US / m3	$0.068	$0.026	$0.062	$0.035	$0.067	$0.0225
Reported pipe breaks / km /yr	1.15	0.38	0.52	0.04	3.75	6.27
Capacity Utilization	73%	67%	65%	71%	69%	89%
Hours of Service /day	24	24	24	24	24	24
Estimated Average Pressure	20	30	25	10	5	6
Length/Connection	15.8	20.2	8.5	22.9	20.3	14.4
Actual Water Production	1,290,411	80,301	775,342	369,041	2,054,795	4,153,425
Actual Physical Loss m3/day	441,321	11,720	131,712	39,243	410,959	1,048,562
Actual Commercial Loss	49,036	10,443	31,885	81,434	136,986	349,521
Actual Non-Revenue Water	490,356	22,163	163,597	120,676	547,945	1,398,082
Actual Revenue Water	800,055	58,138	611,745	248,365	1,506,849	2,755,343
Physical Loss m3/km/day	36.56	13.41	38.66	9.16	10.27	47.28
NRW m3/km/day	40.62	25.36	48.02	28.18	13.70	63.04
Physical Losses L/conn /day	577.4	270.2	327.0	209.8	209	681
Comm. Losses L/conn/day	64.2	240.8	79.2	435.3	70	227
NRW L / Conn / day	641.5	511.0	406.2	645.1	279	908
Physical Loss/Production	34.2%	14.6%	17.0%	10.6%	20.0%	25.2%
Commercial Loss/Production	3.8%	13.0%	4.1%	22.1%	6.7%	8.4%
Commercial Loss / Consumption	5.8%	15.2%	5.0%	24.7%	8.3%	11.3%
NRW / Production	38.0%	27.6%	21.1%	32.7%	26.7%	33.7%
Actual Annual Revenues	$108,047,403	$4,456,272	$35,725,899	$19,037,146	$209,442,578	$324,101,007
RESULTS - OPTIMAL						
Water Production	906,180	73,506	672,550	342,826	1,728,534	3,200,890
Physical Losses	57,089	4,925	28,920	13,027	84,698	96,027
Commercial Losses	28,664	2,576	27,548	11,730	63,069	83,369
Non Revenue Water	85,753	7,501	56,468	24,757	147,767	179,396
Revenue Water	820,427	66,006	616,082	318,068	1,580,767	3,021,494
Physical Losses: m3 / km / day	4.73	5.63	8.49	3.04	2.12	4.33
NRW per m3/day/km	7.10	8.58	16.57	5.78	3.69	8.09
Physical Losses / conn	74.7	113.6	71.8	69.6	43.1	62.3
Comm Losses / conn	37.5	59.4	68.4	62.7	32.1	54.1
NRW / Connection	112.2	172.9	140.2	132.4	75.1	116.5
Physical Losses / Production	6.3%	6.7%	4.3%	3.8%	4.9%	3.0%
Comm Losses / Consumption	3.4%	3.8%	4.3%	3.6%	3.8%	2.7%
Comm Losses / Production	3.2%	3.5%	4.1%	3.4%	3.6%	2.6%
NRW / Production	9.5%	10.2%	8.4%	7.2%	8.5%	5.6%
Commercial Losses/Total	33.4%	34.3%	48.8%	47.4%	42.7%	46.5%
Annual Revenues	$110,798,617	$5,059,322	$35,979,176	$24,379,922	$219,716,650	$355,407,420
Revenue Change	$2,751,214	$603,050	$253,277	$5,342,776	$10,274,072	$31,306,413
Production Cost Change	($9,536,619)	($64,484)	($2,326,193)	($334,902)	($7,970,094)	($7,820,857)
Avoided Cap Exp Change	($6,615,761)	($32,603)	($226,537)	($108,427)	($131,038)	($25,347,972)
Total Financial Returns	$18,903,594	$700,136	$2,806,008	$5,786,105	$18,375,204	$64,475,242
Change in Loss Control Costs	$2,632,116	$178,804	$578,631	$884,602	$6,192,859	$8,766,188
Overall Financial Impact	$16,271,478	$521,332	$2,227,377	$4,901,502	$12,182,345	$55,709,053
Return / Control Cost Change	6.18	2.92	3.85	5.54	1.97	6.35
Impact / Revenues	14.69%	10.30%	6.19%	20.10%	5.54%	15.67%
Transition Investment	$80,921,000	$2,933,000	$21,426,000	$19,184,000	$80,036,000	$243,737,000
Payback Period, years	4.97	5.63	9.62	3.91	6.57	4.38
Sounding Frequency, years	0.639	1.149	0.485	1.631	1.345	0.941
Meter Replacement Freq.	6.75	7.51	8.56	7.11	7.67	5.37
Unt Revenue or Unit Tariff in $2005	$0.40	$0.23	$0.17	$0.23	$0.41	$0.35
Revenue /connection/month	$12.94	$10.40	$7.95	$11.63	$9.96	$20.64
Variable Unit Water Prod Cost, $US 2005	$0.07	$0.03	$0.07	$0.04	$0.07	$0.02

Full Name	Nkana Water and Sewerage Company	Lusaka Water & Sewerage Company Limited	Kafubu Water and Sewerage Company Limited	Southern Water and Sewerage Company Limited	Lukanga Water and Sewerage Company Limited	Mulonga Water and Sewerage Company Limited
Country	Zambia	Zambia	Zambia	Zambia	Zambia	Zambia
Year	2006.25	2006.25	2006.25	2006.25	2006.25	2006.25
Source	NWASCO	NWASCO	NWASCO	NWASCO	NWASCO	NWASCO
Population Served	875,872	1,041,654	424,819	250,853	120,494	211,994
Population Growth Rate	2.0%	2.5%	2.5%	2.0%	2.0%	2.5%
Connections	75,364	48,767	35,130	24,461	21,083	10,610
Existing Production, m3 / day	311,233	216,164	136,438	48,767	41,096	38,930
Existing NRW, % of Production	35.0%	51.0%	58.0%	43.0%	61.0%	56.0%
Estim Comm Losses/Total	40%	40%	40%	40%	40%	40%
Distribution length, km	1,715	2,300	784	409	250	320
Average Service Line Length, m	10	10	10	10	5	10
Infrastructure Condition	4	5.5	6	4	7	6
Avg Tariff Collected $ / m3	$0.183	$0.359	$0.237	$0.300	$0.200	$0.243
Variable Oper Cost $US / m3	$0.030	$0.039	$0.045	$0.044	$0.011	$0.038
Reported pipe breaks / km /yr	0.47	1.03	0.61	0.85	1.00	0.94
Capacity Utilization	67%	88%	66%	67%	67%	81%
Hours of Service /day	20	15	15	14	15	17
Estimated Average Pressure	15	20	20	20	20	15
Length/Connection	22.8	47.2	22.3	16.7	11.9	30.2
Actual Water Production	311,233	216,164	136,438	48,767	41,096	38,930
Actual Physical Loss m3/day	65,359	66,146	47,481	12,582	15,041	13,081
Actual Commercial Loss	43,573	44,098	31,654	8,388	10,027	8,720
Actual Non-Revenue Water	108,932	110,244	79,134	20,970	25,068	21,801
Actual Revenue Water	202,301	105,921	57,304	27,797	16,027	17,129
Physical Loss m3/km/day	38.11	28.76	60.56	30.73	60.16	40.88
NRW m3/km/day	63.52	47.93	100.94	51.22	100.27	68.13
Physical Losses L/conn /day	867.2	1356.4	1352	514.4	713.4	1232.9
Comm. Losses L/conn/day	578.2	904.2	901	342.9	475.6	821.9
NRW L / Conn / day	1445.4	2260.6	2253	857.3	1189.0	2054.8
Physical Loss/Production	21.0%	30.6%	34.8%	25.8%	36.6%	33.6%
Commercial Loss/Production	14.0%	20.4%	23.2%	17.2%	24.4%	22.4%
Commercial Loss / Consumption	17.7%	29.4%	35.6%	23.2%	38.5%	33.7%
NRW / Production	35.0%	51.0%	58.0%	43.0%	61.0%	56.0%
Actual Annual Revenues	$13,516,060	$13,872,679	$4,959,863	$3,048,717	$1,170,000	$1,517,045
RESULTS - OPTIMAL						
Water Production	252,437	156,106	92,472	37,930	27,926	26,732
Physical Losses	6,563	6,088	3,514	1,745	1,871	882
Commercial Losses	7,339	3,294	2,648	1,252	1,209	776
Non Revenue Water	13,902	9,382	6,162	2,997	3,080	1,658
Revenue Water	238,535	146,724	86,310	34,933	24,846	25,074
Physical Losses: m3 / km / day	3.83	2.65	4.48	4.26	7.48	2.76
NRW per m3/day/km	8.11	4.08	7.86	7.32	12.32	5.18
Physical Losses / conn	87.1	124.8	100.0	71.3	88.7	83.1
Comm Losses / conn	97.4	67.5	75.4	51.2	57.3	73.1
NRW / Connection	184.5	192.4	175.4	122.5	146.1	156.2
Physical Losses / Production	2.6%	3.9%	3.8%	4.6%	6.7%	3.3%
Comm Losses / Consumption	3.0%	2.2%	3.0%	3.5%	4.6%	3.0%
Comm Losses / Production	2.9%	2.1%	2.9%	3.3%	4.3%	2.9%
NRW / Production	5.5%	6.0%	6.7%	7.9%	11.0%	6.2%
Commercial Losses/Total	52.8%	35.1%	43.0%	41.8%	39.3%	46.8%
Annual Revenues	$15,936,878	$19,216,870	$7,470,404	$3,831,376	$1,813,753	$2,220,676
Revenue Change	$2,420,818	$5,344,192	$2,510,541	$782,658	$643,753	$703,632
Production Cost Change	($649,391)	($860,316)	($715,491)	($173,335)	($51,588)	($171,247)
Avoided Cap Exp Change	($365,940)	($3,266,679)	($795,342)	($143,586)	($396,806)	($832,576)
Total Financial Returns	$3,436,149	$9,471,187	$4,021,374	$1,099,580	$1,092,147	$1,707,455
Change in Loss Control Costs	$477,584	$555,549	$263,511	$140,681	$92,303	$85,703
Overall Financial Impact	$2,958,565	$8,915,639	$3,757,863	$958,899	$999,843	$1,621,752
Return / Control Cost Change	6.19	16.05	14.26	6.82	10.83	18.92
Impact / Revenues	18.56%	46.39%	50.30%	25.03%	55.13%	73.03%
Transition Investment	$19,006,000	$20,172,000	$14,594,000	$3,595,000	$4,398,000	$4,029,000
Payback Period, years	6.42	2.26	3.88	3.75	4.40	2.48
Sounding Frequency, years	1.534	0.932	0.941	1.050	1.042	0.893
Meter Replacement Freq.	5.97	4.39	5.95	6.92	9.28	6.00
Unt Revenue or Unit Tariff in $2005	$0.17	$0.34	$0.23	$0.29	$0.19	$0.23
Revenue /connection/month	$16.64	$31.08	$16.73	$12.31	$6.74	$16.47
Variable Unit Water Prod Cost, $US 2005	$0.03	$0.04	$0.04	$0.04	$0.01	$0.04

Full Name	Chambesi Water & Sewerage Company Limited	Chipata Water & Sewerage Company	North Western Water Supply and Sewerage Company Limited	Western Water and Sewerage Company	Blantyre	Lilongwe
Country	Zambia	Zambia	Zambia	Zambia	Malawi	Malawi
Year	2006.25	2006.25	2006.25	2006.25	2005	2005
Source	NWASCO	NWASCO	NWASCO	NWASCO	AICD	AICD
Population Served	120,798	84,633	116,684	42,300	389,000	369,000
Population Growth Rate	1.5%	2.0%	1.5%	2.0%	3.0%	3.0%
Connections	9,840	5,522	5,587	7,409	45,921	23,820
Existing Production, m3 / day	23,288	6,849	8,767	15,342	79,411	83,000
Existing NRW, % of Production	54.0%	31.0%	36.0%	47.0%	49.7%	22.1%
Estim Comm Losses/Total	40%	40%	25%	40%	40%	40%
Distribution length, km	500	134	380	120	1,037	1,023
Average Service Line Length, m	25	13	30	15	6.00	10.00
Infrastructure Condition	4	3.0	2.5	5	12	3
Avg Tariff Collected $ / m3	$0.164	$0.496	$0.578	$0.200	$0.485	$0.412
Variable Oper Cost $US / m3	$0.024	$0.049	$0.034	$0.011	$0.112	$0.044
Reported pipe breaks / km /yr	0.70	0.96	0.35	0.70	8.004	1.466
Capacity Utilization	67%	26%	32%	67%	95%	67%
Hours of Service /day	9	24	20	8	17	24
Estimated Average Pressure	15	25	25	20	20	20
Length/Connection	50.8	24.3	68.0	16.2	22.6	42.9
Actual Water Production	23,288	6,849	8,767	15,342	79,411	83,000
Actual Physical Loss m3/day	7,545	1,274	2,367	4,327	23,680	11,006
Actual Commercial Loss	5,030	849	789	2,884	15,787	7,337
Actual Non-Revenue Water	12,575	2,123	3,156	7,211	39,467	18,343
Actual Revenue Water	10,712	4,726	5,611	8,132	39,944	64,657
Physical Loss m3/km/day	15.09	9.51	6.23	36.05	22.84	10.76
NRW m3/km/day	25.15	15.85	8.31	60.09	38.06	17.93
Physical Losses L/conn /day	766.8	230.7	423.7	584.0	515.7	462.0
Comm. Losses L/conn/day	511.2	153.8	141.2	389.3	343.8	308.0
NRW L / Conn / day	1278.0	384.5	564.9	973.3	859.5	770.1
Physical Loss/Production	32.4%	18.6%	27.0%	28.2%	29.8%	13.3%
Commercial Loss/Production	21.6%	12.4%	9.0%	18.8%	19.9%	8.8%
Commercial Loss / Consumption	32.0%	15.2%	12.3%	26.2%	28.3%	10.2%
NRW / Production	54.0%	31.0%	36.0%	47.0%	49.7%	22.1%
Actual Annual Revenues	$642,276	$855,686	$1,183,744	$592,329	$7,071,039	$9,723,120
RESULTS - OPTIMAL						
Water Production	17,280	6,181	7,748	11,719	59,541	74,683
Physical Losses	1,538	606	1,348	703	3,811	2,689
Commercial Losses	708	182	181	466	1,635	1,452
Non Revenue Water	2,246	787	1,530	1,170	5,446	4,141
Revenue Water	15,034	5,394	6,219	10,549	54,096	70,542
Physical Losses: m3 / km / day	3.08	4.52	3.55	5.86	3.67	2.63
NRW per m3/day/km	4.49	5.88	4.03	9.75	5.25	4.05
Physical Losses / conn	156.3	109.7	241.3	94.9	83.0	112.9
Comm Losses / conn	72.0	32.9	32.5	63.0	35.6	61.0
NRW / Connection	228.3	142.6	273.8	157.9	118.6	173.8
Physical Losses / Production	8.9%	9.8%	17.4%	6.0%	6.4%	3.6%
Comm Losses / Consumption	4.5%	3.3%	2.8%	4.2%	2.9%	2.0%
Comm Losses / Production	4.1%	2.9%	2.3%	4.0%	2.7%	1.9%
NRW / Production	13.0%	12.7%	19.7%	10.0%	9.1%	5.5%
Commercial Losses/Total	31.5%	23.1%	11.9%	39.9%	30.0%	35.1%
Annual Revenues	$901,397	$976,560	$1,311,933	$768,459	$9,576,281	$10,608,116
Revenue Change	$259,121	$120,874	$128,189	$176,130	$2,505,242	$884,996
Production Cost Change	($52,256)	($11,848)	($12,601)	($14,191)	($812,274)	($133,575)
Avoided Cap Exp Change	($136,807)	($0)	($1)	($75,200)	($1,481,189)	($84,546)
Total Financial Returns	$448,184	$132,722	$140,791	$265,521	$4,798,705	$1,103,117
Change in Loss Control Costs	$50,863	$30,558	$35,944	$34,404	$431,324	$213,412
Overall Financial Impact	$397,321	$102,164	$104,848	$231,117	$4,367,381	$889,705
Return / Control Cost Change	7.81	3.34	2.92	6.72	10.13	4.17
Impact / Revenues	44.08%	10.46%	7.99%	30.08%	45.61%	8.39%
Transition Investment	$2,066,000	$267,000	$325,000	$1,208,000	$6,804,000	$2,840,000
Payback Period, years	5.20	2.62	3.10	5.23	1.56	3.19
Sounding Frequency, years	1.959	1.180	1.977	1.208	0.349	1.398
Meter Replacement Freq.	9.00	6.52	5.67	8.47	5.87	4.03
Unt Revenue or Unit Tariff in $2005	$0.16	$0.47	$0.55	$0.19	$0.49	$0.41
Revenue /connection/month	$7.18	$13.90	$18.49	$8.13	$17.24	$36.91
Variable Unit Water Prod Cost, $US 2005	$0.02	$0.05	$0.03	$0.01	$0.11	$0.04

Full Name	Cape Town Metro	Drakenstein Municipality	Johannesburg	eThekwini	NWASCO	MWSC
Country	South Africa	South Africa	South Africa	South Africa	Kenya	Kenya
Year	2005	2005	2005	2005	2005	2005
Source	AICD	AICD	AICD	AICD	AICD+USAQ	AICD+USAQ
Population Served	2,993,455	193,137	3,316,591	4,000,000	2,396,160	371,700
Population Growth Rate	1.0%	1.0%	1.0%	1.0%	3.0%	3.0%
Connections	889,314	49,727	1,206,207	716,855	235,465	62,756
Existing Production, m3 / day	720,548	41,741	1,300,701	806,575	431,081	55,553
Existing NRW, % of Production	18.0%	11.6%	30.9%	32.1%	37.8%	38.3%
Estim Comm Losses/Total	25.0%	40.0%	25.00%	25%	25.0%	25.0%
Distribution length, km	8,000	597	20,000	12,575	2,500	452
Average Service Line Length, m	10.00	10.00	15.00	10.00	20.00	20.00
Infrastructure Condition	2.0	3	4	8.0	8.00	9.0
Avg Tariff Collected $ / m3	$0.927	$0.571	$1.103	$1.113	$0.334	$0.668
Variable Oper Cost $US / m3	$0.249	$0.154	$0.311	$0.264	$0.030	$0.090
Reported pipe breaks / km /yr	0.200	0.559	1.022	4.317	1.520	2.655
Capacity Utilization	67.0%	67%	67.00%	67%	82.1%	74.4%
Hours of Service /day	24	24	24	24	16	8
Estimated Average Pressure	30	30	30	30	15	10
Length/Connection	9.0	12.0	16.6	17.5	10.6	7.2
Actual Water Production	720,548	41,741	1,300,701	806,575	431,081	55,553
Actual Physical Loss m3/day	97,274	2,912	301,047	193,973	122,212	15,946
Actual Commercial Loss	32,425	1,941	100,349	64,658	40,737	5,315
Actual Non-Revenue Water	129,699	4,853	401,396	258,630	162,949	21,262
Actual Revenue Water	590,849	36,888	899,305	547,945	268,133	34,291
Physical Loss m3/km/day	12.16	4.88	15.05	15.43	48.88	35.28
NRW m3/km/day	16.21	8.13	20.07	20.57	65.18	47.04
Physical Losses L/conn /day	109	58.6	250	270.6	519	254
Comm. Losses L/conn/day	36	39.0	83	90.2	173	85
NRW L / Conn / day	146	97.6	333	360.8	692	339
Physical Loss/Production	13.5%	7.0%	23.1%	24.0%	28.4%	28.7%
Commercial Loss/Production	4.5%	4.7%	7.7%	8.0%	9.5%	9.6%
Commercial Loss / Consumption	5.2%	5.0%	10.0%	10.6%	13.2%	13.4%
NRW / Production	18.0%	11.6%	30.9%	32.1%	37.8%	38.3%
Actual Annual Revenues	$200,000,000	$7,692,794	$362,164,285	$222,636,090	$32,660,647	$8,354,619
RESULTS - OPTIMAL						
Water Production	662,353	41,617	1,080,707	674,673	325,126	41,779
Physical Losses	39,079	2,788	81,053	62,070	16,256	2,172
Commercial Losses	17,401	1,308	23,530	14,137	10,507	1,373
Non Revenue Water	56,480	4,097	104,583	76,207	26,764	3,546
Revenue Water	605,873	37,521	976,124	598,466	298,362	38,233
Physical Losses: m3 / km / day	4.88	4.67	4.05	4.94	6.50	4.81
NRW per m3/day/km	7.06	6.86	5.23	6.06	10.71	7.85
Physical Losses / conn	43.9	56.1	67.2	86.6	69.0	34.6
Comm Losses / conn	19.6	26.3	19.5	19.7	44.6	21.9
NRW / Connection	63.5	82.4	86.7	106.3	113.7	56.5
Physical Losses / Production	5.9%	6.7%	7.5%	9.2%	5.0%	5.2%
Comm Losses / Consumption	2.8%	3.4%	2.4%	2.3%	3.4%	3.5%
Comm Losses / Production	2.6%	3.1%	2.2%	2.1%	3.2%	3.3%
NRW / Production	8.5%	9.8%	9.7%	11.3%	8.2%	8.5%
Commercial Losses/Total	30.8%	31.9%	22.5%	18.6%	39.3%	38.7%
Annual Revenues	$205,085,473	$7,824,779	$393,100,617	$243,163,128	$36,342,872	$9,315,040
Revenue Change	$5,085,473	$131,985	$30,936,332	$20,527,038	$3,682,225	$960,421
Production Cost Change	($5,281,100)	($6,941)	($24,974,589)	($12,722,325)	($1,173,968)	($451,786)
Avoided Cap Exp Change	($43,778)	($135)	($363,344)	($289,666)	($2,816,018)	($417,211)
Total Financial Returns	$10,410,351	$139,061	$56,274,266	$33,539,029	$7,672,211	$1,829,418
Change in Loss Control Costs	$3,847,624	$96,108	$10,926,386	$7,070,554	$1,221,347	$311,493
Overall Financial Impact	$6,562,726	$42,954	$45,347,880	$26,468,474	$6,450,863	$1,517,925
Return / Control Cost Change	1.71	0.45	4.15	3.74	5.28	4.87
Impact / Revenues	3.20%	0.55%	11.54%	10.89%	17.75%	16.30%
Transition Investment	$14,644,000	$151,000	$59,363,000	$36,485,000	$27,237,000	$3,543,000
Payback Period, years	2.23	3.52	1.31	1.38	4.22	2.33
Sounding Frequency, years	0.375	0.493	0.301	0.251	0.537	0.420
Meter Replacement Freq.	5.58	6.74	4.71	4.62	6.80	6.94
Unt Revenue or Unit Tariff in $2005	$0.93	$0.57	$1.10	$1.11	$0.33	$0.67
Revenue /connection/month	$19.07	$12.74	$26.98	$28.09	$12.74	$12.25
Variable Unit Water Prod Cost, $US 2005	$0.25	$0.15	$0.31	$0.26	$0.03	$0.09

Full Name	KIWASCO	Prizren	Peje	Prishtine	Mitrovice	Gjakove
Country	Kenya	Kosovo	Kosovo	Kosovo	Kosovo	Kosovo
Year	2005	2007	2007	2007	2007	2007
Source	AICD+USAQ	Regulator	Regulator	Regulator	Regulator	Regulator
Population Served	140,000	259,471	171,330	500,000	400,000	192,267
Population Growth Rate	3.0%	0.5%	0.5%	0.5%	0.5%	0.5%
Connections	7,619	29,493	27,779	77,406	19,557	25,866
Existing Production, m3 / day	17,271	33,035	99,309	120,558	45,462	50,237
Existing NRW, % of Production	71.5%	39.0%	77.0%	51.0%	48.0%	62.0%
Estim Comm Losses/Total	40.0%	40%	40%	40%	40%	40%
Distribution length, km	112	221	466	1,073	872	491
Average Service Line Length, m	15.00	25.00	15.00	25.00	25.00	20.00
Infrastructure Condition	9.0	5.5	10.0	5.5	4.0	6.0
Avg Tariff Collected $ / m3	$0.647	$0.378	$0.349	$0.494	$0.262	$0.465
Variable Oper Cost $US / m3	$0.081	$0.070	$0.013	$0.065	$0.038	$0.027
Reported pipe breaks / km /yr	2.5	1.0	1.0	1.0	1.0	1.0
Capacity Utilization	79%	67%	67%	67%	67%	67%
Hours of Service /day	18	18	12	12	12	12
Estimated Average Pressure	20	20	5	15	15	15
Length/Connection	14.7	7.5	16.8	13.9	44.6	19.0
Actual Water Production	17,271	33,035	99,309	120,558	45,462	50,237
Actual Physical Loss m3/day	7,404	7,730	45,881	36,891	13,093	18,688
Actual Commercial Loss	4,936	5,153	30,587	24,594	8,729	12,459
Actual Non-Revenue Water	12,340	12,884	76,468	61,485	21,822	31,147
Actual Revenue Water	4,931	20,151	22,841	59,073	23,640	19,090
Physical Loss m3/km/day	66.11	34.98	98.46	34.38	15.01	38.06
NRW m3/km/day	110.18	58.30	164.09	57.30	25.02	63.44
Physical Losses L/conn /day	972	262.1	1651.6	476.6	669.5	722.5
Comm. Losses L/conn/day	648	174.7	1101.1	317.7	446.3	481.7
NRW L / Conn / day	1620	436.8	2752.7	794.3	1115.8	1204.2
Physical Loss/Production	42.9%	23.4%	46.2%	30.6%	28.8%	37.2%
Commercial Loss/Production	28.6%	15.6%	30.8%	20.4%	19.2%	24.8%
Commercial Loss / Consumption	50.0%	20.4%	57.2%	29.4%	27.0%	39.5%
NRW / Production	71.5%	39.0%	77.0%	51.0%	48.0%	62.0%
Actual Annual Revenues	$1,163,841	$2,780,282	$2,909,610	$10,651,528	$2,260,716	$3,240,060
RESULTS - OPTIMAL						
Water Production	10,430	27,357	56,063	89,388	35,299	34,593
Physical Losses	563	2,052	2,635	5,721	2,930	3,044
Commercial Losses	243	1,040	1,527	2,680	1,151	981
Non Revenue Water	806	3,092	4,161	8,401	4,080	4,025
Revenue Water	9,624	24,265	51,902	80,987	31,218	30,568
Physical Losses: m3 / km / day	5.03	9.28	5.65	5.33	3.36	6.20
NRW per m3/day/km	7.20	13.99	8.93	7.83	4.68	8.20
Physical Losses / conn	73.9	69.6	94.9	73.9	149.8	117.7
Comm Losses / conn	31.9	35.3	55.0	34.6	58.8	37.9
NRW / Connection	105.8	104.8	149.8	108.5	208.6	155.6
Physical Losses / Production	5.4%	7.5%	4.7%	6.4%	8.3%	8.8%
Comm Losses / Consumption	2.5%	4.1%	2.9%	3.2%	3.6%	3.1%
Comm Losses / Production	2.3%	3.8%	2.7%	3.0%	3.3%	2.8%
NRW / Production	7.7%	11.3%	7.4%	9.4%	11.6%	11.6%
Commercial Losses/Total	30.1%	33.6%	36.7%	31.9%	28.2%	24.4%
Annual Revenues	$2,271,625	$3,347,799	$6,611,502	$14,602,772	$2,985,408	$5,188,191
Revenue Change	$1,107,784	$567,517	$3,701,892	$3,951,244	$724,692	$1,948,131
Production Cost Change	($201,093)	($144,852)	($212,147)	($733,954)	($139,599)	($153,486)
Avoided Cap Exp Change	($540,798)	($2,989)	($5,020,794)	($98,832)	($24,124)	($820,301)
Total Financial Returns	$1,849,675	$715,359	$8,934,833	$4,784,030	$888,415	$2,921,918
Change in Loss Control Costs	$74,087	$141,684	$196,004	$514,487	$121,816	$174,460
Overall Financial Impact	$1,775,587	$573,675	$8,738,829	$4,269,543	$766,598	$2,747,458
Return / Control Cost Change	23.97	4.05	44.58	8.30	6.29	15.75
Impact / Revenues	78.16%	17.14%	132.18%	29.24%	25.68%	52.96%
Transition Investment	$2,307,000	$1,958,000	$14,461,000	$10,617,000	$3,548,000	$5,424,000
Payback Period, years	1.30	3.41	1.65	2.49	4.63	1.97
Sounding Frequency, years	0.349	0.464	2.699	0.791	1.882	1.403
Meter Replacement Freq.	4.92	8.22	5.71	6.41	7.11	6.22
Unt Revenue or Unit Tariff in $2005	$0.65	$0.35	$0.32	$0.46	$0.24	$0.43
Revenue /connection/month	$24.68	$8.64	$18.19	$14.41	$11.64	$15.32
Variable Unit Water Prod Cost, $US 2005	$0.08	$0.07	$0.01	$0.06	$0.04	$0.03

Full Name	Ferizaj	Gjilan	Zagreb	Ukraine Luhansk
Country	Kosovo	Kosovo	Croatia	Ukraine
Year	2007	2007	2007	2009
Source	Regulator	Regulator	Con Papers	Utility Reports
Population Served	81,000	94,500	616,000	985,511
Population Growth Rate	0.5%	0.5%	0.5%	0%
Connections	13,796	14,592	88,000	560,991
Existing Production, m3 / day	10,516	14,008	333,551	786,930
Existing NRW, % of Production	54.0%	46.0%	41.1%	66.0%
Estim Comm Losses/Total	40%	40%	25%	26%
Distribution length, km	104	133	2,700	8,159
Average Service Line Length, m	25.00	25.00	10.00	20.00
Infrastructure Condition	5.5	5.0	5.5	9.0
Avg Tariff Collected $ / m3	$0.581	$0.523	$0.500	$0.443
Variable Oper Cost $US / m3	$0.026	$0.051	$0.100	$0.059
Reported pipe breaks / km /yr	1.0	1.0	1.00	2.13
Capacity Utilization	67%	67%	77%	63%
Hours of Service /day	12	12	24	24
Estimated Average Pressure	15	15	30	15
Length/Connection	7.5	9.1	30.7	14.5
Actual Water Production	10,516	14,008	333,551	786,930
Actual Physical Loss m3/day	3,407	3,866	102,817	384,389
Actual Commercial Loss	2,271	2,577	34,272	134,985
Actual Non-Revenue Water	5,679	6,444	137,089	519,374
Actual Revenue Water	4,837	7,564	196,462	267,556
Physical Loss m3/km/day	32.76	29.07	38.08	47.11
NRW m3/km/day	54.60	48.45	50.77	63.66
Physical Losses L/conn /day	247.0	265.0	1168	685
Comm. Losses L/conn/day	164.6	176.6	389	241
NRW L / Conn / day	411.6	441.6	1558	926
Physical Loss/Production	32.4%	27.6%	30.8%	48.8%
Commercial Loss/Production	21.6%	18.4%	10.3%	17.2%
Commercial Loss / Consumption	32.0%	25.4%	14.9%	33.5%
NRW / Production	54.0%	46.0%	41.1%	66.0%
Actual Annual Revenues	$1,025,835	$1,443,991	$35,854,231	$43,262,500
RESULTS - OPTIMAL				
Water Production	8,171	11,072	242,622	460,574
Physical Losses	1,062	930	11,888	58,032
Commercial Losses	304	394	4,717	17,381
Non Revenue Water	1,366	1,324	16,606	75,414
Revenue Water	6,805	9,748	226,017	385,160
Physical Losses: m3 / km / day	10.21	6.99	4.40	7.11
NRW per m3/day/km	13.14	9.95	6.15	9.24
Physical Losses / conn	77.0	63.7	135.1	103.4
Comm Losses / conn	22.0	27.0	53.6	31.0
NRW / Connection	99.0	90.7	188.7	134.4
Physical Losses / Production	13.0%	8.4%	4.9%	12.6%
Comm Losses / Consumption	4.3%	3.9%	2.0%	4.3%
Comm Losses / Production	3.7%	3.6%	1.9%	3.8%
NRW / Production	16.7%	12.0%	6.8%	16.4%
Commercial Losses/Total	22.3%	29.7%	28.4%	23.0%
Annual Revenues	$1,443,036	$1,860,850	$41,248,056	$62,278,464
Revenue Change	$417,202	$416,860	$5,393,825	$19,015,964
Production Cost Change	($22,432)	($54,734)	($3,318,894)	($7,028,082)
Avoided Cap Exp Change	($32,356)	($6,465)	($9,219,012)	($515,219,369)
Total Financial Returns	$471,989	$478,058	$17,931,731	$541,263,415
Change in Loss Control Costs	$61,711	$73,572	$1,022,455	$3,245,913
Overall Financial Impact	$410,279	$404,486	$16,909,275	$538,017,502
Return / Control Cost Change	6.65	5.50	16.54	165.75
Impact / Revenues	28.43%	21.74%	40.99%	863.89%
Transition Investment	$862,000	$1,024,000	$24,097,000	$88,792,000
Payback Period, years	2.10	2.53	1.43	0.17
Sounding Frequency, years	0.928	0.771	0.620	0.637
Meter Replacement Freq.	8.56	7.77	4.09	8.64
Unt Revenue or Unit Tariff in $2005	$0.54	$0.48	$0.46	$0.38
Revenue /connection/month	$7.96	$9.72	$32.17	$7.81
Variable Unit Water Prod Cost, $US 2005	$0.02	$0.05	$0.09	$0.05

Full Name	Kampala	Entebbe	Jinja	Surabaya
Country	Uganda	Uganda	Uganda	Indonesia
Year	2008.5	2008.5	2008.5	2009
Source	NWSC ARs	NWSC ARs	NWSC ARs	MOF, MOHA, Web
Population Served	1,215,273	49,651	199,883	2,500,000
Population Growth Rate	3.8%	3.5%	3.5%	3.0%
Connections	133,198	14,574	15,727	403,263
Existing Production, m3 / day	138,204	6,870	12,215	715,651
Existing NRW, % of Production	42.9%	15.8%	23.9%	34.4%
Estim Comm Losses/Total	54%	25%	25%	40.0%
Distribution length, km	2,107	240	431	4,741
Average Service Line Length, m	40	25	40	12
Infrastructure Condition	3	1.50	3	3
Avg Tariff Collected $ / m3	$0.803	$0.995	$0.724	$0.220
Variable Oper Cost $US / m3	$0.083	$0.126	$0.122	$0.030
Reported pipe breaks / km /yr	0.41	0.15	0.67	1.00
Capacity Utilization	75%	57%	61%	94%
Hours of Service /day	24	24	24	22
Estimated Average Pressure	40	25	40	21
Length/Connection	15.8	16.5	27.4	11.8
Actual Water Production	138,204	6,870	12,215	715,651
Actual Physical Loss m3/day	27,273	814	2,190	147,710
Actual Commercial Loss	32,016	271	730	98,474
Actual Non-Revenue Water	59,290	1,085	2,919	246,184
Actual Revenue Water	78,914	5,785	9,296	469,467
Physical Loss m3/km/day	12.94	3.39	5.08	51.93
NRW m3/km/day	28.14	4.52	6.77	31.2
Physical Losses L/conn /day	204.8	55.9	139.2	366.29
Comm. Losses L/conn/day	240.4	18.6	46.4	244.19
NRW L / Conn / day	445.1	74.5	185.6	610.48
Physical Loss/Production	19.7%	11.9%	17.9%	20.6%
Commercial Loss/Production	23.2%	4.0%	6.0%	13.8%
Commercial Loss / Consumption	28.9%	4.5%	7.3%	17.3%
NRW / Production	42.9%	15.8%	23.9%	34.4%
Actual Annual Revenues	$23,129,441	$2,100,800	$2,456,459	$37,698,215
RESULTS - OPTIMAL				
Water Production	127,360	6,921	11,617	590,375
Physical Losses	16,429	865	1,592	22,434
Commercial Losses	3,270	227	356	24,839
Non Revenue Water	19,700	1,092	1,947	47,273
Revenue Water	107,661	5,829	9,670	543,102
Physical Losses: m3 / km / day	7.80	3.60	3.69	4.73
NRW per m3/day/km	9.35	4.55	4.52	9.97
Physical Losses / conn	123.3	59.4	101.2	55.6
Comm Losses / conn	24.6	15.6	22.6	61.6
NRW / Connection	147.9	74.9	123.8	117.2
Physical Losses / Production	12.9%	12.5%	13.7%	3.8%
Comm Losses / Consumption	2.9%	3.7%	3.5%	4.4%
Comm Losses / Production	2.6%	3.3%	3.1%	4.2%
NRW / Production	15.5%	15.8%	16.8%	8.0%
Commercial Losses/Total	16.6%	20.8%	18.3%	52.5%
Annual Revenues	$31,554,820	$2,116,896	$2,555,317	$43,611,064
Revenue Change	$8,425,379	$16,096	$98,858	$5,912,849
Production Cost Change	($326,927)	$2,347	($26,629)	($1,371,774)
Avoided Cap Exp Change	($269,474)	$642	($11,492)	($4,192,424)
Total Financial Returns	$9,021,780	$13,107	$136,979	$11,477,047
Change in Loss Control Costs	$1,100,056	$10,269	$70,620	$1,929,616
Overall Financial Impact	$7,921,723	$2,837	$66,359	$9,547,431
Return / Control Cost Change	7.20	0.28	0.94	4.95
Impact / Revenues	25.10%	0.13%	2.60%	21.89%
Transition Investment	$7,918,000	-$1,000	$194,000	$39,782,000
Payback Period, years	1.00	-0.47	2.93	4.17
Sounding Frequency, years	0.377	0.717	0.589	0.738
Meter Replacement Freq.	5.90	7.50	7.10	8.75
Unt Revenue or Unit Tariff in $2005	$0.700	$0.867	$0.631	$0.188
Revenue /connection/month	$17.21	$10.55	$11.80	$7.70
Variable Unit Water Prod Cost, $US 2005	$0.072	$0.110	$0.106	$0.026

Full Name	Average	Median	Minimum	Maximum	Std Dev	Total
Country						
Year	2005.5	2006	2003	2009	1.9	
Source						
Population Served	1,096,082	255,162	16,212	11,000,000	2,055,120	48,227,611
Population Growth Rate	1.7%	1.7%	0.1%	3.8%	1.0%	
Connections	223,464	28,636	2,878	1,967,292	436,051	9,832,396
Existing Production, m3 / day	352,071	52,895	2,354	4,153,425	730,641	15,491,107
Existing NRW, % of Production	39.4%	38.0%	11.6%	77.0%	15.5%	
Estim Comm Losses/Total	33.8%	40.0%	10.0%	67.5%	10.4%	
Distribution length, km	3590.9	548.5	25.0	40000.0	7540.6	158,000
Average Service Line Length, m	16.5	14.0	5.0	50.0	10.1	
Infrastructure Condition	5.6	5.5	1.5	12.0	2.7	
Avg Tariff Collected $ / m3	$0.443	$0.377	$0.160	$1.113	$0.246	
Variable Oper Cost $US / m3	$0.068	$0.045	$0.011	$0.311	$0.065	
Reported pipe breaks / km /yr	3.62	1.00	0.04	37.50	7.87	
Capacity Utilization	68.8%	67.0%	25.9%	95.0%	12.0%	
Hours of Service /day	19.2	21.2	8.0	24.0	5.4	
Estimated Average Pressure	19.6	20.0	5.0	40.0	8.0	
Length/Connection	19.8	16.5	6.8	68.0	13.1	
Actual Water Production	352,071	52,895	2,354	4,153,425	730,641	15,491,107
Actual Physical Loss m3/day	88,475	14,067	277	1,048,562	186,017	3,892,903
Actual Commercial Loss	33,574	9,378	92	349,521	60,207	1,477,249
Actual Non-Revenue Water	122,049	21,992	370	1,398,082	243,601	5,370,152
Actual Revenue Water	230,022	31,044	1,847	2,755,343	495,363	10,120,955
Physical Loss m3/km/day	28.9	28.9	3.4	98.5	19.9	
NRW m3/km/day	43.5	39.3	4.5	164.1	31.7	
Physical Losses L/conn /day	494	347	56	1652	389	
Comm. Losses L/conn/day	285	202	19	1101	266	
NRW L / Conn / day	779	588	74	2753	642	
Physical Loss/Production	25.5%	26.4%	7.0%	48.8%	9.5%	
Commercial Loss/Production	13.9%	12.7%	3.7%	30.8%	7.6%	
Commercial Loss / Consumption	19.8%	15.2%	4.1%	57.2%	12.9%	
NRW / Production	39.4%	38.0%	11.6%	77.0%	15.5%	
Actual Annual Revenues	$40,089,086	$3,848,166	$201,237	$362,164,285	$86,169,933	$1,763,919,787
RESULTS - OPTIMAL						
Water Production	278,389	41,698	2,210	3,200,890	573,662	12,249,114
Physical Losses	14,793	2,738	158	96,027	25,407	650,910
Commercial Losses	8,322	1,341	90	83,369	16,581	366,159
Non Revenue Water	23,115	4,089	262	179,396	40,784	1,017,069
Revenue Water	255,274	37,877	1,896	3,021,494	534,918	11,232,045
Physical Losses: m3 / km / day	5.1	4.7	2.1	10.2	1.8	
NRW per m3/day/km	7.8	7.6	4	17	3.0	
Physical Losses / conn	86.4	75.8	34.6	241.3	37.2	
Comm Losses / conn	43.0	36.6	16	97	19.3	
NRW / Connection	129.3	117.9	56.5	273.8	46.3	
Physical Losses / Production	7.2%	6.6%	2.6%	17.4%	3.3%	
Comm Losses / Consumption	3.5%	3.5%	2.0%	5.3%	0.8%	
Comm Losses / Production	3.3%	3.2%	1.9%	4.9%	0.8%	
NRW / Production	10.5%	9.9%	5.5%	19.7%	3.5%	
Commercial Losses/Total	33.5%	33.5%	11.9%	52.8%	9.8%	
Annual Revenues	$44,182,302	$5,899,847	$219,933	$393,100,617	$92,734,757	$1,944,021,288
Revenue Change	$4,093,216	$833,827	($994)	$31,306,413	$7,448,117	$180,101,501
Production Cost Change	($2,047,713)	($172,291)	($24,974,589)	$2,347	$4,618,548	($90,099,373)
Avoided Cap Exp Change	($13,170,124)	($133,922)	($515,219,369)	$642	$77,558,253	($579,485,437)
Total Financial Returns	$19,311,053	$1,768,437	($53)	$541,263,415	$81,656,196	$849,686,311
Change in Loss Control Costs	$1,225,029	$176,632	($426)	$10,926,386	$2,462,784	$53,901,257
Overall Financial Impact	$18,086,024	$1,569,839	$373	$538,017,502	$81,001,517	$795,785,054
Return / Control Cost Change	10.85	5.39	-0.88	165.75	25.14	
Impact / Revenues	44.0%	18.2%	0.1%	863.9%	128.9%	
Transition Investment	$19,786,727	$3,812,000	($1,000)	$243,737,000	$41,307,009	$870,616,000
Payback Period, years	4.09	3.47	-0.47	25.02	3.89	
Sounding Frequency, years	0.91	0.77	0.25	2.70	0.54	
Meter Replacement Freq.	7.06	6.93	4.03	10.68	1.68	
Unt Revenue or Unit Tariff in $2005	$0.431	$0.390	$0.156	$1.113	$0.234	
Revenue /connection/month	$14.17	$12.28	$5.04	$36.91	$7.67	
Variable Unit Water Prod Cost, $US 2005	$0.067	$0.046	$0.010	$0.311	$0.065	

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