Field Application of a Financial Model for Optimal NRW Management

A. S. Wyatt[1], M. Alshafey[2], L. C. B. Pinto[3]

1. Senior Water and Sanitation Specialist, RTI International, Washington, DC, USA
2. Director, Central Operations/Strategic Planning, Aqaba Water Company, W.L.L., Aqaba, Jordan
3. Director, Water Loss Control and Energy Efficiency, CAGECE, Ceará, Brazil

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Abstract

During 2009-2010, RTI International developed and published a financial model which calculates the financially optimum level of Non-Revenue Water (NRW). The model computes a target (under future steady-state conditions) for NRW reduction and control programs, based on site conditions and local costs. The model was presented at IWA Water Loss Specialist Conferences in Cape Town and Sao Paulo and international meetings in Morocco, Uganda, Jordan and the UK. It has been applied in over 30 countries using secondary data, and applied at a more detailed level in Brazil, Jordan, Uganda, and Zambia.

During 2010-2011, RTI International worked closely with 2 water supply utilities, in Jordan and Brazil on customized in-depth application of the model. The authors of this paper engaged in extensive discussions and data exchange to adapt, apply, and refine the original model to the two utilities in the two countries. The paper first outlines the water resource, water distribution, economic and social conditions in the locations in Brazil and Jordan. Next, the paper reviews historical information on NRW reduction and control programs, including the level of NRW (using several different indicators) as well as the strategies, actions, programs and management approaches included in the NRW efforts implemented by each utility.

The paper then reviews the process of adapting the model to Jordan and Brazil, including a review of terminology – in order to ensure that data and formulae are consistent across the model and the databases in each utility / country. Data availability was not a major constraint – good estimates of model inputs parameters could be easily made. The paper next reviews the model-predicted optimal NRW levels in the two locations. In both cases the utilities have done a good job reducing losses, but each still have room to reduce losses more to reach the optimal level. The target NRW levels in the two locations were actually quite close to each other – despite considerable variation in certain inputs. The model behavior and results were consistent with previous applications. The model sensitivity and confidence levels are also carefully reviewed in the paper, again with similar results in the two locations.

The paper concludes with an assessment of lessons learned from the field applications and a description of future actions by the 2 utilities, and recommended research and development to further refine the model and develop additional, complementary tools.

1. Background

There is considerable published information on target setting and economically optimum management of Non-Revenue Water, physical losses (leakage) and commercial losses, particularly as concerns developed countries. The fundamental principles of setting targets for leakage were developed and refined over the past 20 years by Fanner, Lambert, Liemberger, Pearson, Trow, and others. The application of these principles into operational tools (ELL) has been mainly limited to the use of complex utility-specific models in the UK in the context of a tight regulatory environment. The use of specific economic models has not been extensive in other developed countries. The published literature also includes studies on the optimal management of meter error (Male, Davis, Arregui, et al and others).

The application of the target setting or economic models in the developing world and emerging economies has been limited. The detailed data to formulate ELL cost curves is not readily available. Data on many aspects on commercial losses is also not available. The most commonly used guidance is the IWA International NRW Assessment Matrix, which provides guidelines on the level of physical losses, commercial losses and overall NRW in developing countries. While these are useful, they only provide broad guidance.

During 2009-2010, RTI International developed and published a financial model which calculates the financially optimum level of Non-Revenue Water (NRW). The model computes a target (under future steady-state conditions) for NRW reduction and control programs, based on site conditions and local costs. The tool accounts for the financial costs and benefits of reducing and managing physical losses and commercial losses, as well as the financial aspects of near term water supply capacity expansion needs. The model was presented at IWA Water Loss Conferences in Cape Town and Sao Paulo and international meetings in Morocco, Uganda, Jordan, and the UK. It has been applied in over 30 countries using secondary data, and applied at a more detailed level in Brazil, Jordan, Uganda, and Zambia. The specifics of the model have been extensively reviewed with many members of the IWA Water Loss Specialist Committee, and refinements made.

During 2010-2011, RTI International worked closely with two water supply utilities, in Jordan and Brazil, on in-depth application of the model. The authors of this paper engaged in extensive discussions and data exchange to adapt, apply, and refine the original model to the two utilities. The authors did succeed in applying the model and generating estimates of the optimal levels on NRW, physical Losses, and commercial losses. The paper first outlines the water resource and water distribution utilities in the two locations. Next it explains the process of adapting the model, the results of the applications, lessons learned and perspectives for future work.

The objective of the field tests included to answer the following questions:

1) Were there major adaptations needed to use the model? If so, how could they be resolved ?
2) What were the results from the two locations ? How do the results compare in the two cities? Are they similar to other target setting guidance ?
3) What was the sensitivity of the model in the two locations ? What confidence interval can be placed on the results ?
4) How useful were the results of the model ? How were the results used ? What additional uses if any could there be ?
5) What are the limitations of the model ? What improvements should be made ? Are there other tools needed for NRW reduction planning ?

2. Field Test Sites

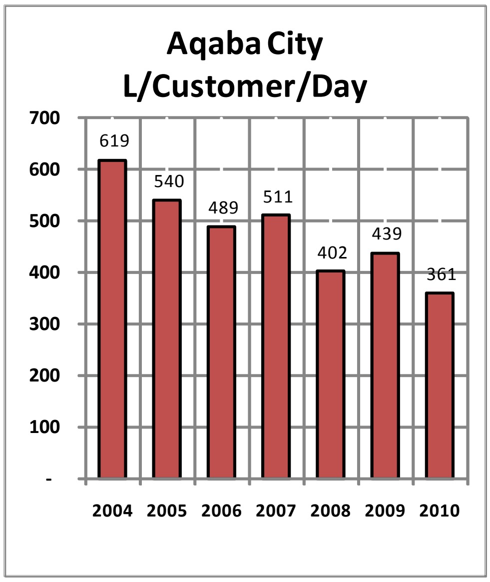
2.1 Aqaba Water Company, Aqaba, Jordan

The Aqaba Water Company (AW) serves approximately 130,000 people in the Governorate of Aqaba in the south of Jordan. The service area is mostly rural, with the exception of the city of Aqaba, Jordan's only port, lying on the Red Sea. The terrain is highly arid, with essentially no surface water resources. The city has witnessed a rapid growth in population, with a major industrial sector, and expanding tourism. AW took on responsibility of owning and operating the water and wastewater services in the Governorate in 2004, after a decision to create the first government-owned, commercial-law water and wastewater company in Jordan.

The city of Aqaba is the home of the bulk of water customers in the Governorate. The city enjoys continuous water supply due to a direct pipeline to the Disi well field, some 60km to the north. This luxury is in peril partly due to ambitious plans to double the city size within a little more than a decade. Even without the success of the development plans, the natural growth is threatening to test the limit of the available water supply, whether through making extra demands on the well field, or the transmission main connecting the well field to the city. In either case, the capital investment required is substantial, and the future availability of the Disi nonrenewable groundwater is questionable. The alternative, desalination, is also a very expensive proposition. Even in the short run, the cost of water production is high, creating extra incentive for NRW reduction.

The first objective set for the newly established company in 2004 was the reduction of NRW. AW adopted a holistic approach – both commercial and physical losses were significant. From 2004 – 2010, AW conducted a series of integrated actions, which led to a significant decline in NRW in Aqaba City:

Figure 2.1.1 – Non-Revenue Water



- Upgraded network repair teams with new equipment, training and personnel; Reduced burst response time through stricter management.
- Conducted acoustic leak detection surveys 2005- 2006.
- Rehabilitated the old GI network 2006–2007, and 2009-2010 using HDPE pipe.
- Divided the network into pressure controlled distribution zones.
- Installed a SCADA system for the water distribution network in 2007, and expanded to supply wells in 2011.
- Focused on customer meters since 2004, especially large consumer meters.
- Installed continuous monitoring (AMR) meters for large consumers in 2010.
- Installed magnetic flow-meters for zones in 2007, large consumers in 2010, and wells in 2011.
- Created incentives for reporting meter tampering; Increased fines for tampering; Installed robust seals.

The IWA Water Balance for Aqaba City is shown in the Figure 2.1.2 below

Figure 2.1.2 – IWA Water Balance – Aqaba City

<table>
<tr><th colspan="8">Aqaba City: Approximate Water Balance 2010. Volumes shown in m3/day</th></tr>
<tr><td rowspan="4">Water System Input</td><td rowspan="4">42,668</td><td rowspan="2">Authorized Consumption</td><td rowspan="2">33,166</td><td>Billed Authorized Consumption</td><td>32,952</td><td>Revenue Water</td><td>32,952</td></tr>
<tr><td>Unbilled Authorized Consumption</td><td>213</td><td rowspan="3">Non-Revenue Water</td><td rowspan="3">9,716</td></tr>
<tr><td rowspan="2">Water Losses</td><td rowspan="2">9,502</td><td>Apparent Losses</td><td>4,645</td></tr>
<tr><td>Real Losses</td><td>4,858</td></tr>
</table>

The primary motivation for applying the model at AW was to provide insights to help the utility address major challenges. First, while NRW had been reduced significantly, it was not clear whether more expense to further reduce losses more made financial sense. Aqaba had the lowest level of losses in Jordan, but the dire constraints on supply made the issue of physical losses critical to evaluate. The average residential meter age was 9 years – should a replacement program be undertaken ? Also the government regulated tariffs and well extraction surcharges created extra incentives to maximum financial efficiency. The authors elected to apply the model on Aqaba City – where the most of the water use is situated.

2.2 Companhia de Agua e Esgoto do Ceará, Fortaleza, Brazil

CAGECE was created on July 20, 1971, as a quasi-governmental company, operating on commercial principles. It serves the bulk of the residents of the State of Ceará – namely 5.0 million people. It serves 150 cities, but some other cities and towns in the State are served by municipalities and other organizations. The utility operates 228 water systems, which encompass 1,476,658 water connections, 783 water treatment plants, and 10,803km of distribution mains. The largest water system in the State is the one that serves the capital city – Fortaleza. That system, as of 2010, served approximately 3 million people through 760,339 connections, over 5156 km of mains. The network in Fortaleza consists of mostly steel and cast iron mains, with PVC service connections. Less than 5% of the network is composed of asbestos cement pipe.

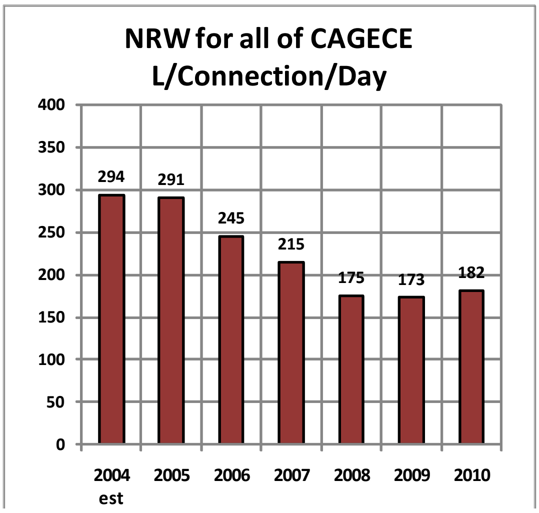
The countryside across the State is generally semi-arid, with an average annual rainfall of 1600mm. The water used in Fortaleza is currently from dams in the hinterlands (around 50km away), which receive water from other reservoirs even more distant 400km from Fortaleza (the Castanhão and Oros dams). The State of Ceará has a separate company (COGERH) which manages water resources including inter-basin transfers. COGERH charges CAGECE for raw water, which it treats and distributes to users.

CAGECE has 12 "business units" which operate the systems in different geographic sectors of the State, conducting water system operations including programs to reduce and control NRW. These teams report into an overall company-wide manager for water loss control.

In 2005, CAGECE launched a new program for NRW reduction, including these actions:

- Preparation of a detailed water balance
- Creation of teams to combat fraud (water theft) and respond to leakage
- Development of SISCOPE - an integrated computerized management tool that facilitates oversight and coordination of planned actions, and helps users assess results. This led to more streamlined and efficient operations
- Calibration and continuous monitoring of 600 macro-meters across the State
- Testing and monitoring of consumer meters; error evaluation with a test bench
- Continuous monitoring of 84 pressure measurements points across the State to facilitate better pressure management
- Preparation of a ten year NRW reduction plan including, installation of DMAs, meter replacement program, expansion of efforts to combat fraud, and rehabilitation of pipes in selected areas

Figure 2.2.1 CAGECE Non-Revenue Water



From 2005 to 2010 NRW was cut by about one third, as shown in Figure 2.2.1

Figure 2.2.2 shows a simplified version of the IWA Water Balance for Fortaleza. Several comments on this diagram are important. First of all, this diagram is a much simplified version of the water balance maintained by CAGECE on an ongoing basis. Each loss component is actually enumerated in much greater detail. For example, physical losses are broken out into 10 components. In addition, an extra component is added to the water balance, to account for the fact that the billed quantity of water is fixed at the minimum charge volume of 10 m3/month, even if actual metered consumption is less.

Figure 2.2.2 – IWA Water Balance for Fortaleza

Fortaleza: Approximate Water Balance 2010. Volumes shown in m3/day

				Billed , Not Consumed	59,893	Revenue Water	425,441
Water System Input	607,005	Authorized Consumption	371,649	Billed Authorized Consumption	365,548		
				Unbilled Authorized Consumption	6,101	Non-Revenue Water	241,458
		Water Losses	235,356	Apparent Losses	153,101		
				Real Losses	82,255		

The primary motivation for applying the model at CAGECE was to provide insights to help the utility set targets and develop reduction plans. While NRW had been reduced significantly, commercial losses were high, mostly due to water theft (fraud). It was not certain what the best target should be. The overarching goal, at the level of the State, was to reach a NRW <20% by 2016, which corresponds to about 140 L/Connection/Day. In addition, CAGECE wants to use new technologies and knowledge to generate the support of the Company Board and the State Government. Ultimately CAGECE wants to become a national and international leader on the control of losses. The authors elected to apply the model on Fortaleza –where the losses are higher than other parts of the State.

2.3 Brief Comparison of the two Locations

The two cities involved in field tests have some similarities. They are both regional capitals on coastlines in arid to semi-arid locations. Both have made significant progress on reducing NRW through a combination of technical, commercial, and management innovations. However they also have striking differences, as outlined in the Table below.

Table 2.3.1 – Comparison of Basic Utility Parameters in the 2 Field Locations - 2010

Utility Parameters	Aqaba	Fortaleza	Comment
Population, thousands	105	2,989	Ratio = 28
Water Supplied, 1000 m^3/day	42.7	607	Ratio = 14
Water Supply Capacity Utilization	95%	70%	
Water Connections	9,247	760,339	Ratio = 82
Distribution length, km	623	5,156	Ratio = 8.3
Distribution Length / Connection, m	**67.4**	**6.8**	**Ratio = 10**
Average System Water Pressure, m	**35**	**15**	
Water Customers	26,944	953,103	Ratio = 35
Customers / Connection	**2.91**	**1.25**	
Revenue Water / Customer / Month, m3	**37.2**	**13.6**	Ratio=2.7
Water Sale Price, $/m3	$1.00	$1.04	
Variable Water Production Cost, $/m3	$0.448	$0.295	
Cost of Skilled Labor, $/day	$42	$76	
Commercial Losses / Physical Losses	50%/50%	66%/34%	Aqaba is estimated
Physical Losses, L/Connection/Day	525	108	More pressure, more line
Physical Losses, m^3/km/day	7.8	16	Not the best indicator
Infrastructure Leakage Index (ILI)	7.4	3.3	
Commercial Losses, L/Connection/Day	525	209	Not the best indicator
Commercial Losses, L/Customer/Day	180	167	Better indicator
Non-Revenue Water, L/Connection/Day	**1051**	**318**	Not the best indicator
Non-Revenue Water, L/Customer/Day	**361**	**253**	Better indicator
Non-Revenue Water / Production	22.8%	36.2%	Not a good indicator due to big consumption difference

In simple terms, Fortaleza is a much larger, more densely populated city. Aqaba, while small, has a relatively large number of industrial and commercial customers – making unit consumption far higher. Aqaba also has about 3 water customers per connection to the network mains, due to the prevalence of individually metered apartments. Therefore the length of distribution line per connection is radically different in the two locations. In rough terms, the level of physical losses seems to be higher in Aqaba, but commercial losses comprise a larger portion of the losses in Fortaleza. Aqaba has much more severe water supply capacity constraints. Water prices are about the same, but variable production costs and labor costs are different.

3. Model Adaptation to Field Conditions

In general, adaptation of the generic RTI model to specific field situations involves:

- A review of the water source, distribution geography and geometry, and collection of data such as number of connections, length of distribution mains, average length of service connection lines, average pressure, etc.;
- Assembly of information to construct an IWA Water Balance, if not already prepared;
- A review of current practice for water loss control including activities undertaken, the cost of labor, materials and such parameters as leak rates, meter error, etc.

Thos steps proceeded well in both locations for the field tests. The paragraphs below outline some special considerations that had to be taken into account and necessitated some model adaptation. These circumstances are important in the interpretation of the results.

3.1 Aqaba Water Company, Aqaba, Jordan

Adaptation of the generic RTI Model to the Aqaba Water circumstances principally involved synchronizing the definition of terms and indicators. In reviewing the AW infrastructure, the authors noted that “customers” (households or businesses that have water service, an account, and a water meter) are not the same as “connections” (actual hookups to the distribution line under the street). In Aqaba City, multiple domestic customers are served from the same connection – such as in the case of small apartment buildings. The ratio of customers to connections was about three to one. This situation required an adaptation in terminology, in model algebra, and in the indicators used. After consulting with IWA specialists, the authors adopted losses per connection as a measure of physical losses, because physical losses are related to the distribution and connection hardware. By similar logic, they adopted losses per customer for commercial losses—because these losses are related to customers. The authors adopted losses per customer for overall NRW.

3.2 Companhia be Agua e Esgoto do Ceara, Fortaleza, Brazil

In Fortaleza, there is also a difference between customers and connections as is the case In most all utilities in Brazil. However the ratio of customers to connections is smaller than Aqaba – about 1.25. The authors agreed to look at commercial losses on a per customer basis, but use a per connection basis for physical losses and NRW.

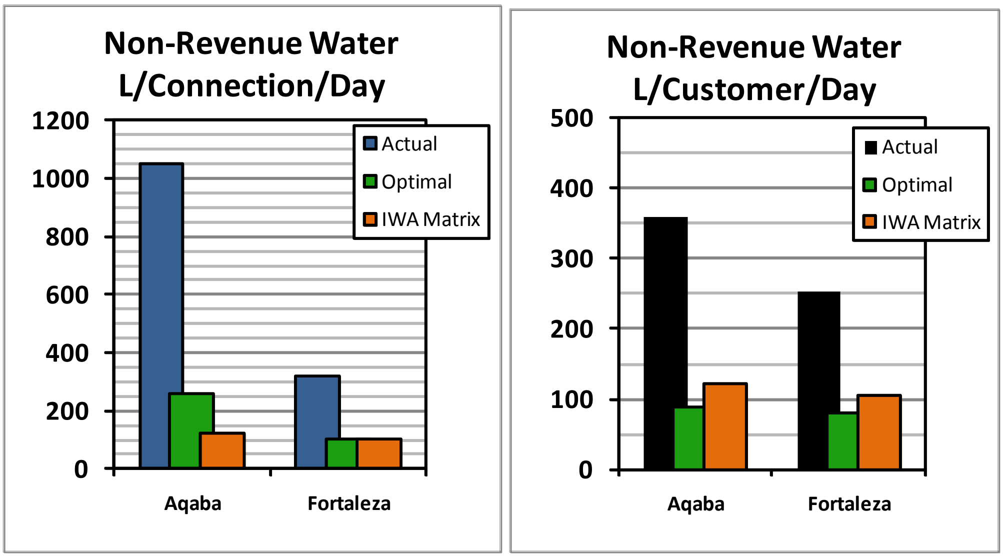
In Fortaleza, there are a significant number of illegal connections, as is the case in most all Brazilian cities. Many are located in clandestine settlements which occur on public lands. In one case in Fortaleza a settlement exists on environmentally sensitive land, and CAGECE is prohibited from extending formal authorized connections, but officials do not intervene in the matter of illegal connections. In some cities in Brazil this consumption is counted as "social consumption" and placed in the part of the IWA water balance known as authorized unbilled consumption. CAGECE does not handle this issue in this manner. Consumption attributed to fraud can be considered high, but it is a real consumption, a part of unauthorized consumption. Thus, compared to some of its peers CAGECE appears to have a very high rate of fraud and commercial losses, but CAGECE believes that this is the correct approach. The model takes this situation into account. However, more work is needed to have full knowledge of these clandestine areas and their actual consumption. The model can be re applied with newer data to fine-tune the understanding.

4. Results of Model Application

4.1 Magnitude of Actual and Optimal NRW and Water Losses

Parameters	Aqaba		Fortaleza	
	Actual	Optimal	Actual	Optimal
Non-Revenue Water, L/Connection/Day	1051	245	**318**	**101**
Non-Revenue Water, L/Customer/Day	**361**	**89**	253	80
Ratio: Actual / Optimal	4.3		3.1	
IWA Matrix (Top of Band A1) (L/Conn/Day)		122		105

Figure 4.1.1 – Actual and Optimal Non-Revenue Water



The graphs and tables above show the principal results from the model – a comparison of the actual to the optimal NRW. Fortaleza, to reach optimal, needs to drop from 318 L/Conn/Day to 101 L/Conn/Day – about a three-fold drop. The implied target of 101 L/Conn/Day for Fortaleza is lower than the provisional target of 140 L/Conn/Day for the State. That target is very close to the value in IWA Guidance Matrix (assuming a pressure of 30 m pressure), of 105 L/Conn/Day. !

In Aqaba, the NRW needs to drop from 361 L/Cust/Day to 89 L/Cust/Day – a ratio of 4.3. It is a bit hard to compare Aqaba to the IWA Matrix because of the NRW units, but the NRW values are in the same "ballpark".

If we compare Aqaba to Fortaleza, we have the same units issue, but the optimum levels of NRW are pretty similar.

Figure 4.1.2 – IWA NRW Matrix

IWA International Non-Revenue Water Assessment Matrix

Liemberger, Water Loss 2010

Technical performance category		NRW in Litres/connection/day when the system is pressurized at an average pressure of:				
		10 m	20 m	30 m	40 m	50 m
Low and Middle Countries	A1	< 55	<80	<105	<130	<155
	A2	55-110	80-160	105-210	130-260	155-310
	B	110-220	160-320	210-420	260-520	310-620
	C	220-400	320-600	420-800	520-	620-1200
	D	>400	>600	>800	>1000	>1200

Parameters	Aqaba		Fortaleza	
	Actual	Optimal	Actual	Optimal
Physical Losses, L/Connection/Day	525	116	108	61
Actual/Optimal = Physical Loss Index=PLI	4.5		1.8	
Infrastructure Leakage Index (ILI)	7.4	1.6	3.3	1.9
Actual ILI / Optimal ILI	4.6		1.7	
IWA Matrix (Top of Band A1) (L/Conn/Day)		87.5		75

If we turn to looking at physical losses, it seems that Aqaba needs to make a more drastic drop in physical losses to reach optimum – a ratio of 4.5, as contrasted with a ratio of 1.8 for Fortaleza. This is mostly due to the higher actual losses in Aqaba, even though the optimal is higher in Aqaba. In fact, Fortaleza's optimal at 61 L/Conn/Day is about one-half of Aqaba's. This higher optimal is most likely explained by the higher pressure and much longer distribution network in Aqaba.

Comparing these optimal physical losses to the IWA guidance we see that Aqaba's optimal is above IWA guidance, while Fortaleza's is below. Again the pressure and distribution length in Aqaba are probably the important factors.

Figure 4.1.3 Actual & Optimal Losses

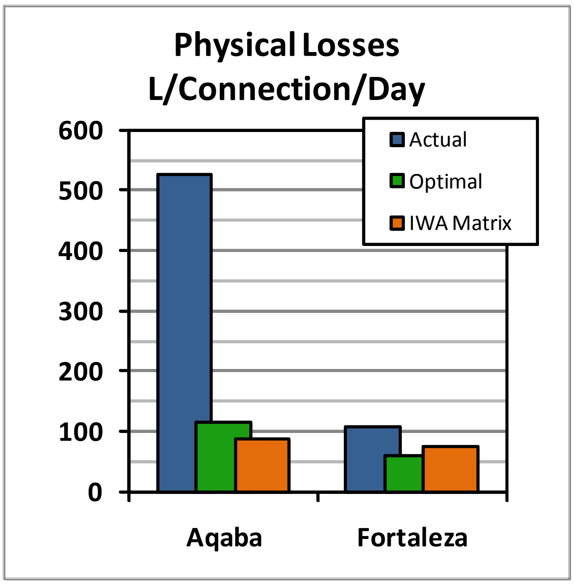


Figure 4.1.4 – IWA Physical Loss Matrix

IWA International Physical Loss Assessment Matrix

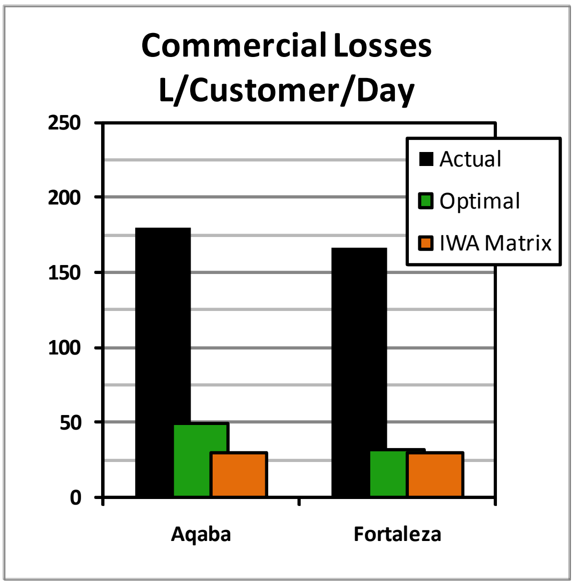
Liemberger, Water Loss 2010

Technical performance		ILI	Real Losses in Litres/connection/day				
			10 m	20 m	30 m	40 m	50 m
Low and Middle Countries	A1	< 2	< 25	< 50	< 75	< 100	< 125
	A2	2 - 4	25-50	50-100	75-150	100-200	125-250
	B	4 - 8	50–100	100–200	150–300	200–400	250–500
	C	8 -16	100–200	200–400	300–600	400–800	500–1,0
	D	> 16	> 200	> 400	> 600	> 800	> 1,000

Parameters	Aqaba		Fortaleza	
	Actual	Optimal	Actual	Optimal
Commercial Losses, L/Customer/Day	180	49	167	32
Actual / Optimal = Commercial Loss Index (CLI)	3.7		5.2	
Commercial Loss / Revenue Water, %	14.7%	3.6%	37%	5.5%
IWA Matrix (Top of Band A1) (L/Conn/Day)		30		30

An examination of the results for commercial losses, shows that Fortaleza needs to make a bigger drop - a ratio of over 5. But the large drop is only partly because of the actual values, which are quite close. The optimal loss for Aqaba is quite a bit higher than Fortaleza. This difference seems a bit puzzling at first, as the price of water is the same and other factors like the steady state meter error should also be close in the two locations. The main difference between the two sites is the water consumption per connection. Aqaba connections, on average, consume 2.7 times as much water as Fortaleza. A higher consumption leads to a higher level of optimal commercial losses, just as a higher pressure leads to a higher level of optimal physical losses.

Figure 4.1.3 Actual & Optimal Losses



Overall, these results show that the two sites have roughly similar optimums, with differences due to input parameters. Also, the IWA Guidance and the model results are in the same "ballpark", but there are some interesting differences, which can only be explained by inputs to the model, which are not accounted for in the IWA Matrices.

Figure 4.1.4 – IWA Commercial Loss Matrix

Commercial Loss Allowances for Water Utilities

Liemberger, Water Loss 2010

		Percent of billed consumption			
		Meter under registration and data handling error	Additional provision for water theft	Total	Liters per connection per day
Low and Middle Countries	A1	<2.5%	<0.5%		<30
	A2	2.5% - 5%	0.5% - 1%	3% - 6%	30-60
	B	5% - 10%	1% - 2%	6%-12%	60-120
	C	10% - 15%	2% - 5%	12%-20%	120-200
	D	>15%	>5%	>20%	>200

4.2 Analysis of Model Confidence

In previous writings, the authors have addressed the topic of "reliability" of the model, or in other words, the "certainty" of, or the "confidence" in the model results. The basic framework for this analysis has been to look at

1. the ***accuracy*** of the estimated values of the input parameters,
2. the mathematical ***sensitivity*** of the target water losses derived by the model to the assumed value of input parameters, and,
3. the combination of these two element above, which forms an estimate of the ***confidence*** in the model results.

The topic is important because a low accuracy of an input parameter, or a high model sensitivity of the model to such a parameter, could yield a low confidence in the model results. A confidence interval should be found in order to interpret the "reliability" or "certainty" of a target. In addition, an understanding of which parameters have significant influence on the confidence in the target allows the user to focus on the correct parameters, when trying to improve the accuracy of the model and conducting planning of NRW reduction and control work.

Table 4.2.1 – Qualitative Confidence Analysis

Input Parameter	Accuracy	Sensitivity		Confidence
		Avg Var	Rating	
Parameters which Impact Commercial Losses				
# of Customers	Very High	36.6%	High	Medium
Water Sales Revenue	High	11.2%	Medium	Medium
Water Consumption	High	10.3%	Medium Low	Medium-High
Meter Accuracy Degradation	Low	10.0%	Medium Low	Medium-Low
Commercial Loss Control Cost	Medium	10.0%	Medium Low	Medium
Parameters which Impact Physical Losses				
Pressure	High	11.9%	Medium Low	Medium-High
Distribution Length	Very High	10.5%	Medium Low	High
# of Connections	Very High	8.7%	Low	Very High
Physical Loss Control Cost	Medium	3.9%	Very Low	Medium-High
Water Production Cost	High	3.6%	Very Low	Very High
Leak Rate	High	2.3%	Very Low	Very High

The confidence in model results for Aqaba were examined, in a semi-qualitative manner in Wyatt and Alshafey (2010), and Alshafey (2011). ***Parameter accuracy*** was estimated on a qualitative basis (High, Medium, Low, etc) and ***model sensitivity*** was evaluated mathematically, yielding a qualitative assessment of the ***confidence*** in the results. See Table 4.2.1 This analysis concluded that the model- derived optimal NRW should have a confidence interval of ***approximately*** plus or minus 10%, and 2) that the ***confidence*** in the optimal NRW was lower, when looking at inputs which influence commercial losses, than the confidence in the Optimal NRW, when looking at inputs which influence physical.

Table 4.2.2 – Model Sensitivity in 2 Locations

	Variation in Optimal NRW, based on Input Changes					
	Aqaba			Fortaleza		
	-+20%	-+50%	Average	-+20%	-+50%	Average
Water Sales Revenue	5.7%	16.6%	11.1%	4.0%	20.0%	12.0%
Meter Accuracy Degradation	5.6%	14.3%	10.0%	4.0%	16.0%	10.0%
Commercial Loss Control Cost	5.6%	14.3%	10.0%	4.0%	16.0%	10.0%
Water Consumption	5.5%	14.3%	9.9%	4.7%	12.3%	8.5%
# of Customers **	17.2%	56.9%	37.1%	1.1%	10.9%	6.0%
Pressure	6.0%	15.2%	10.6%	8.6%	21.9%	15.2%
Distribution Length	6.0%	15.2%	10.6%	4.3%	11.1%	7.7%
# of Connections ***	5.0%	12.9%	9.0%	7.8%	46.3%	27.1%
Water Production Cost	2.1%	6.1%	4.1%	3.3%	9.4%	6.4%
Physical Loss Control Cost	2.3%	5.6%	3.9%	3.4%	8.9%	6.2%
Leak Rate	1.4%	3.1%	2.2%	3.8%	7.2%	5.5%

** For Aqaba, the No, of Customers is the divisor of the NRW, so it has a higher sensitivity

*** For Fortaleza, the No, of Connections is the divisor of the NRW, so it has a higher sensitivity

Next, the ***sensitivity*** of the Optimal NRW output of the model in Aqaba was compared to that in Fortaleza. Table 4.2.2 shows a ranking of important parameters in the two locations in descending order. Interestingly, the magnitudes of the sensitivity and rank order are very similar. While it is hard to say if other sites will have such consistent sensitivity, but wide variations in sensitivity are unlikely, because sensitivity comes from the theoretical and formulaic structure of the model, which not vary from site to site.

Most recently, an improved, statistically-based method was developed to assess ***confidence***. Instead of qualitative estimates of parameter accuracy, an estimated confidence interval was derived for each input parameter. For example we estimated that the 95% confidence interval of the Aqaba distribution network length is plus or minus 2.5%, yielding a possible low value of 607km, an expected value of 623km and a possible high value of 639km. These three values were introduced into the model with all other input parameters set at their expected values, and the three model output values tabulated. This same process was conducted for all relevant inputs and a "batch" of model output values assembled. See Table 4.2.3.

In essence, we were running a simulation of the model running with each low value, each high value and each expected value. (The result from the model run using the expected value was weighted double because of its expected nature).

Table 4.2.3 – Simulation Results

Input Parameter	Possible Error	Model Output, Optimal NRW, L/Cust/D			Variance	
		Low Input	Expected	High Input	Low Input	High Input
Parameters which Impact Commercial Losses						
# of Customers	2.5%	91.0	89.0	87.4	2.3%	-1.8%
Water Sales Revenue	5.0%	90.3	89.0	87.8	1.5%	-1.3%
Water Consumption	5.0%	87.9	89.0	90.2	-1.3%	1.4%
Meter Accuracy Degradation	50%	74.5	89.0	100.1	**-16.2%**	**12.5%**
Commercial Loss Control Cost	25%	82.4	89.0	94.8	**-7.4%**	**6.5%**
Parameters which Impact Physical Losses						
Pressure	14.3%	84.5	89.0	93.4	**-5.0%**	**5.0%**
Distribution Length	2.5%	88.2	89.0	89.7	-0.8%	0.8%
# of Connections	2.2%	88.6	89.0	89.7	-0.4%	0.8%
Physical Loss Control Cost	50%	83.4	89.0	93.4	**-6.2%**	**5.0%**
Water Production Cost	5.0%	89.3	89.0	88.6	0.4%	-0.4%
Leak Rate	50%	86.0	89.0	91.2	-3.3%	2.5%

Next the "batch" of model outputs was analyzed using the statistical mathematics of the Normal Distribution, to determine the 95% Confidence Interval for the model results. The findings, for both Aqaba and Fortaleza, for Non-Revenue Water, are shown in the Table 4.2.4. The confidence intervals are of a similar magnitude. Also, in the case of Aqaba, we can compare the previous qualitative finding of plus or minus 10% to the new Confidence interval derived with a more robust analysis of parameter accuracy, and the use of statistical analysis. The new 95% Confidence Interval of plus or minus 7.7% is probably more reliable than the previous estimate of plus or minus 10%.

Table 4.2.4 - Confidence Bands for Non-Revenue Water (95% Confidence)

Aqaba			**Fortaleza**		
Non-Revenue Water L/Customer/Day			**Non-Revenue Water** L/Connection/Day		
Low	Mean	High	Low	Mean	High
82 *-7.7%*	**89**	**96** *+7.7%*	**93** *-8.2%*	**101**	**109** *+8.2%*

These same type of Confidence intervals can be found for physical losses and commercial losses. The results, shown in Table 4.2.5 below, demonstrate clearly that the Confidence interval for commercial losses is quite a bit wider than for NRW or for Physical Losses. This occurs because there are fewer parameters which govern Commercial losses, increasing model sensitivity to these input parameters. This suggests that in developing countries and emerging economies, where commercial losses tend to be high, more effort is not only needed to reduce these losses, but more assessment is needed to set appropriate targets.

Table 4.2.5 - Confidence Bands for Water Losses (95% Confidence)

	Aqaba			**Fortaleza**		
	Low	**Mean**	**High**	**Low**	**Mean**	**High**
Physical Loss L/Connection/Day	**103** *-11%*	**116**	**128** *+11%*	**55** *-10%*	**61**	**67** *+10%*
Commercial Loss L/Customer/Day	**42** *-19%*	**49**	**56** *+19%*	**24** *-24%*	**32**	**39** *+24%*

4.3 Provisional Target Setting Guidance

With improved understanding of the 1) size of the confidence intervals, and of the 2) key parameters influencing the confidence of the model output, it is possible to develop tables for targets for physical losses and commercial losses, in tabular format. Whether in the form of a computer spreadsheet or a series of printed tables, these “nomographs” could, once fully developed and verified, be very useful to get a quick, approximate target. The authors suspects that these model-derived tables would be more accurate than the current IWA matrices.

A sample for Commercial Losses is shown below. The confidence intervals for these tables assume a similar level of accuracy in the input parameters, and a similar model sensitivity as in the two city cases analyzed here.

Table 4.3.1 - Optimal Commercial Losses – L/Customer/Day

Confidence = approx + or - 20%

Slope of Meter Accuracy Line 1.0% | Commercial Loss Control Cost $120

	L/ Customer / Day						
Water Sales Revenue Collected	**Measured Water Consumption, m3 / consumer / day**						
57.3	**0.25**	**0.50**	**0.75**	**1.00**	**1.25**	**1.50**	**2.00**
$0.10	70	100	120	140	160	180	200
$0.20	50	70	90	100	113	120	140
$0.30	40	60	70	80	93	100	120
$0.40		50	60	70	80	90	100
$0.50	30			60	70	80	90
$0.60		40	50			70	80
$0.70				50	60		
$0.80	25	35	40			60	70
$0.90					50		
$1.00		30					60
$1.10	20		35	40		50	
$1.20							

This table would allow an estimate of the optimal commercial losses in an industrial section of a city where consumption is high and tariff charges are high, as contrasted with a residential area where consumption is lower and tariffs are also lower.

Next, nomograph style tables were constructed for physical losses.

With a spreadsheet version of the tool, the tables could be customized to the most appropriate ranges for a given country, for any of the key parameters. Similar tables of nomographs could be created to cover the range of expected values for different water systems in a regional utility, or for different zones or DMAs in a city. For example a table like one of the three tables in Table 4.3.2 could indicate the optimal physical losses in all the DMAs in a city. If actual losses were compared to optimal, the DMAs with the widest gap between actual and optimal could be pinpointed for special attention.

Table 4.3.2 – Optimal Physical Losses

Confidence = approx + or - 8%

Variable Water Cost = $0.10 | Loss Control: $/km = 400

Liters / Connection / Day

Connections per km	Distribution per Connection, m	Average Water Pressure, m				
		10	**20**	**30**	**40**	**50**
100	**10**	40	61	80	97	112
67	**15**	49	74	96	116	133
50	**20**	57	86	110	132	153
40	**25**	64	97	123	148	171
33	**30**	71	107	137	163	188
25	**40**	78	117	149	178	205

Variable Water Cost = $0.25 | Loss Control: $/km = 400

Liters / Connection / Day

Connections per km	Distribution per Connection, m	Average Water Pressure, m				
		10	**20**	**30**	**40**	**50**
100	**10**	30	48	64	78	92
67	**15**	37	57	75	92	108
50	**20**	42	66	86	105	122
40	**25**	48	74	96	117	136
33	**30**	53	81	106	129	150
25	**40**	58	89	116	140	163

Variable Water Cost = $0.50 | Loss Control: $/km = 400

Liters / Connection / Day

Connections per km	Distribution per Connection, m	Average Water Pressure, m				
		10	**20**	**30**	**40**	**50**
100	**10**	24	40	53	66	79
67	**15**	29	47	63	78	92
50	**20**	33	54	71	88	103
40	**25**	38	60	79	98	115
33	**30**	42	66	87	107	126
25	**40**	46	72	95	116	137

4.4 Other results from Model application

Beyond the derivation of actual and optimal NRW and water losses, the model produced outputs that helped address specific issues of interest to the two field test utilities. Aqaba Water faces major water scarcity / supply constraints, so the optimal level of NRW was useful to assess NRW as a potential "source" of future water supply. As outlined in more detail in AlShafey (2011) and Wyatt and Alshafey (2011), AW could reach optimal NRW by 2014 to 2017, depending on the effort expended and investment made. Approximate projections show that NRW reduction can be a "source" of water supply for the near future by delaying the date when Aqaba reaches full capacity of its current source of supply. In fact well field expansion could be delayed by three years with physical loss reduction. However, a major new source of water will be needed for the long term.

In both cases, rough estimates were made of the investment cost to transition from the current moderate level of losses to the optimal level. The capital cost was derived from Kingdom, et al (2006). The calculations showed substantial revenue increases from the reduction of commercial losses. Overall operating costs generally did decline with variable production cost savings partially offset by loss control cost increases. The payback periods were on the order of 1.5 to 3.5 years, which is very financially attractive. These financial results were helpful for the loss control managers in the two utilities to obtain approval and actual funding for specific NRW reduction investments.

5 Lessons Learned

5.1 Process Lessons

It is clear that some model adaptation is needed, but the necessary changes were not dramatic. It is important the terminology and indicators are consistent with the practice in the country. Also a careful study of the water balance is important to be sure that situational nuances are not ignored. There was no major problem obtaining the required data, but it should be pointed out that Aqaba Water and CAGECE are two well organized utilities, with very competent staff. That will not always be the case.

The experiences applying the model show that the model is helpful in that it:

- creates incentives to gather and organize diverse data
- derives a customized – site specific - target, which holds a bit more credibility than other broad estimates.
- dispels myths or hunches held by utility management about NRW targets
- can specify the confidence interval associated with the target
- shows the overall financial return in investing in NRW reduction, which bolsters the case for budget allocations or financing.
- can help address utility objectives, such as water supply facility planning
- if applied in different locations or zones, can show where the biggest problems are and where financial return is highest
- sets the stage for a rational NRW reduction program
- is easy to re-run as time progresses or circumstances changes

5.2 Substantive Lessons

Several important substantive observations are worth highlighting briefly:

1. The NRW model and the water balance are good companions. An accurate water balance is needed to achieve a useful result. It will make the model results more useful by focusing attention on the important losses – the right “places” in colloquial terms. As the water balance is improved the model can be fine-tuned with it. The model can also indicate where more precision in the water balance would be useful.

2. Large data collection efforts are not needed to get a reasonably accurate target. The generally low model sensitivity means that some parameters need only be roughly specified. This fact means that more effort can be expended on improving the accuracy of several key inputs, to narrow the confidence interval of the result. In other words the generally low sensitivity is our friend.

3. The IWA NRW and Water Loss Matrices are adequate for a “one-shot” at a glance indication of targets. But the model can generate a modest series of tables, covering the expected range of several key variables, which can give a more precise result, without impractical complexity.

4. The model despite doing pretty well, could use some enhancements, to be able to, for example, model cost control for different sub-types of losses, pin down the finances of commercial loss reduction versus physical loss reduction, and having a bit more precision in modeling overall financial impact and attractiveness.

5. While the model has considerable usefulness, it also has limitations. The model can help a utility set more precise targets for NRW and for physical and commercial losses, as compared to existing IWA guidance. But, it does not indicate exactly how to go about reducing those losses. The use of the model in different locations can tell you where the “problem” is biggest, but more detailed assessments will be needed to know the exact course of corrective action. It can give an estimate of the financial attractiveness of investments in NRW, but does not spell out the details of that investment plan. It can tell you whether physical or commercial are a bigger problem, to the extent that the water balances is accurate, but does not assess the relative merits of pressure management, versus mains replacement, for example. Thus this tool needs to be paired with other tools and knowledge.

6 Future Directions

6.1 Ongoing work in FieldTest Utilities

Aqaba Water will be conducting a number of activities to improve the accuracy of its water balance, reduce losses and continue to use the model. These actions include programs to:

- Monitor the master meter at the entry to the city, on a daily basis, and verified against other measurement to improve accuracy;
- Installation of additional bulk meters to improve accuracy
- Installation of additional valves to facilitate step testing to assess physical losses
- Refine DMA boundaries and read DMA meters daily. When sufficient data is available, model will be applied at the DMA level.
- Formation of a specialized unit for leak and illegal connection detection in 2012. Besides performing surveys, the unit will perform bottom-up assessment of NRW to determine physical and commercial losses, and apply the model on a periodic basis in the future
- Soon after first model application, AW has purchased 10,000 class C domestic meters towards decreasing commercial losses(2011)
- Use of a test bench to assess accuracy of class C and class B multi-jet meters in comparison to class C volumetric meters
- Gradually apply the model to rural areas outside of Aqaba City, but within the AW service area.

CAGECE will be conducting a number of activities to reduce losses and continue to use the model. These actions include programs to:

- Begin the development of DMAs in Fortaleza. Due to the high cost of developing DMAs, the DMAs will have around 15,000 connections per DMA in this first phase. Future plans call for each DMA to have around 5000 connections. CAGECE just received funding for this project through a loan from a commercial bank in Brazil.
- Pursuit of funding for other NRW reduction activities including construction of DMAs in other cities, mains rehabilitation in selected areas a meter replacement program, additional network monitoring equipment, reinforcement of teams to reduce leakage and water theft.
- Combating fraud through provisional connections. CAGECE cannot legally provide “official” water connections to squatters sitting on public, environmentally-sensitive lands. Yet these people consume considerable water at no charge. CAGECE will investigate the possibility of providing provisional connections, billed at special, subsidized rates.
- Conduct a special analysis to develop a model of costs and benefits of reduction and control of water theft to determine an optimal level of theft. Collect data from other utilities and assess the costs of options for CAGECE. Develop a program cost curve which would allow determination of the optimal program, optimal expenditure and optimal level of theft.
- Application of the NRW model at the level of the “business unit” (geographic sector of the State) to identify those areas which are furthest from the optimal, in order to prioritize actions.
- Application of the NRW model at the level of the DMAs in Fortaleza to identify those areas which are furthest from the optimal, in order to prioritize actions.

6.2 <u>Research and Development</u>

6.2.1 We need a major Research Program to compile and synthesize better data on cost of, and the specific results from NRW reduction and control programs, in order to:

- **Refine Target setting**. While the model sensitivity is low to moderate, some variables are worth investigating more. Things like repair costs, burst frequencies, meter accuracy decline, commercial loss control costs can have a impact on the optimal water losses and on the confidence interval of this target. We need real data, real cases and careful analysis of the results - just in the case of transition from high losses to low, but also in steady state conditions. Ultimately, the water loss scientific community needs a comprehensive research program to build a worldwide database for program costs and impacts. Those data can lead to cost curves for each type of water loss which, when integrated into the model, will give better targets. The data and analysis results will allow utilities to set benchmarks for NRW program planning and NRW program evaluation**. It is very important that a standard data collection and assessment process be developed to make the results meaningful.**

- **Refine Financial Assessment** To fully assess financial attractiveness, we must better understand the costs and time frame for taking a utility and a water distribution network from a high state of losses to a lower state-state level. While many papers report activities undertaken and the resulting drop in NRW, few provide accurate tabulations of the costs incurred. Some may report aggregate investment, but those are hard to utilize in other contexts unless the specific actions, associated costs and associated results are quantified. **It is very important that a standard data collection and assessment process be developed to make the results meaningful.**

6.2.2 Develop Model Enhancements / Applications

- **Water Theft Management.** It would be very worthwhile to develop a model of costs and benefits of reduction and control of water theft to determine an optimal level of theft. In many locations, in many countries, water theft is a large problem. There is very little good empirical data on the costs and benefits of a theft reduction program. Collection and synthesis of such data could lead to a program cost curve which would allow determination of the optimal program, optimal expenditure and optimal level of theft.

- **Meter Management by Meter Sizes**. The current model treats all meters as if they were the same size and cost. This is obviously a sonsiderable simplification. It may be acceptable as a means of determining the optimal commercial loss, but it is not sufficiently precise to determine the replacement period for different size meters. The model could and should be revised to perform meter replacement analyses for three or four categories – large industrial, commercial, residential, or similar categories

- **DMA or Zone Analysis.** The current model could be applied at the DMA or zone level. Its simply a matter of plugging DMA characteristics into the model and reading the optimal physical loss and commercial loss. Or a nomograph, like those in Section 4.3 could be developed for DMAs in a given city. Then a comparison of the actual losses to the optimal losses, by DMA would immediately point out the areas or zones where the biggest gap exists. Such as exercise would be helpful in priority-setting.

6.2.3 Develop associated tools:

- **Tariff minimization model.** Current model has an objective function of maximizing utility surplus with a given tariff. It would be interesting to reorient the model to minimize tariff, with a fixed operating margin.

- **Model to determine optimal DMA size.** Network sectorization and metering is a very common component of NRW reduction and control programs**.** There is some basic guidance on the size of DMAs which are in general use in the UK and many other countries. Yet the costs of technology and labor are different in other parts of the world. At the same time, "smart networks", SCADA systems and improved meter accuracy could suggest larger DMAs may be more attractive (Brothers 2011). A model which looked at the costs and benefits of different DMA measurement schemes at different scales could be very useful.

- **Develop "Program Optimizer"** – As noted above, one of the main limitations of the model is that it determines a target, but does not provide specific guidance on the best set of actions to achieve the transition from a high level of losses to the optimal one. The lead author has begun the process of developing a new model (or expert system?) to select the types of interventions and investments to be expended on each intervention / program to reach optimal. At the current time considerable program cost data is not available. But with the results of the R&D Program outlined above in Section 6.2.1, such a tool could be constructed.

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