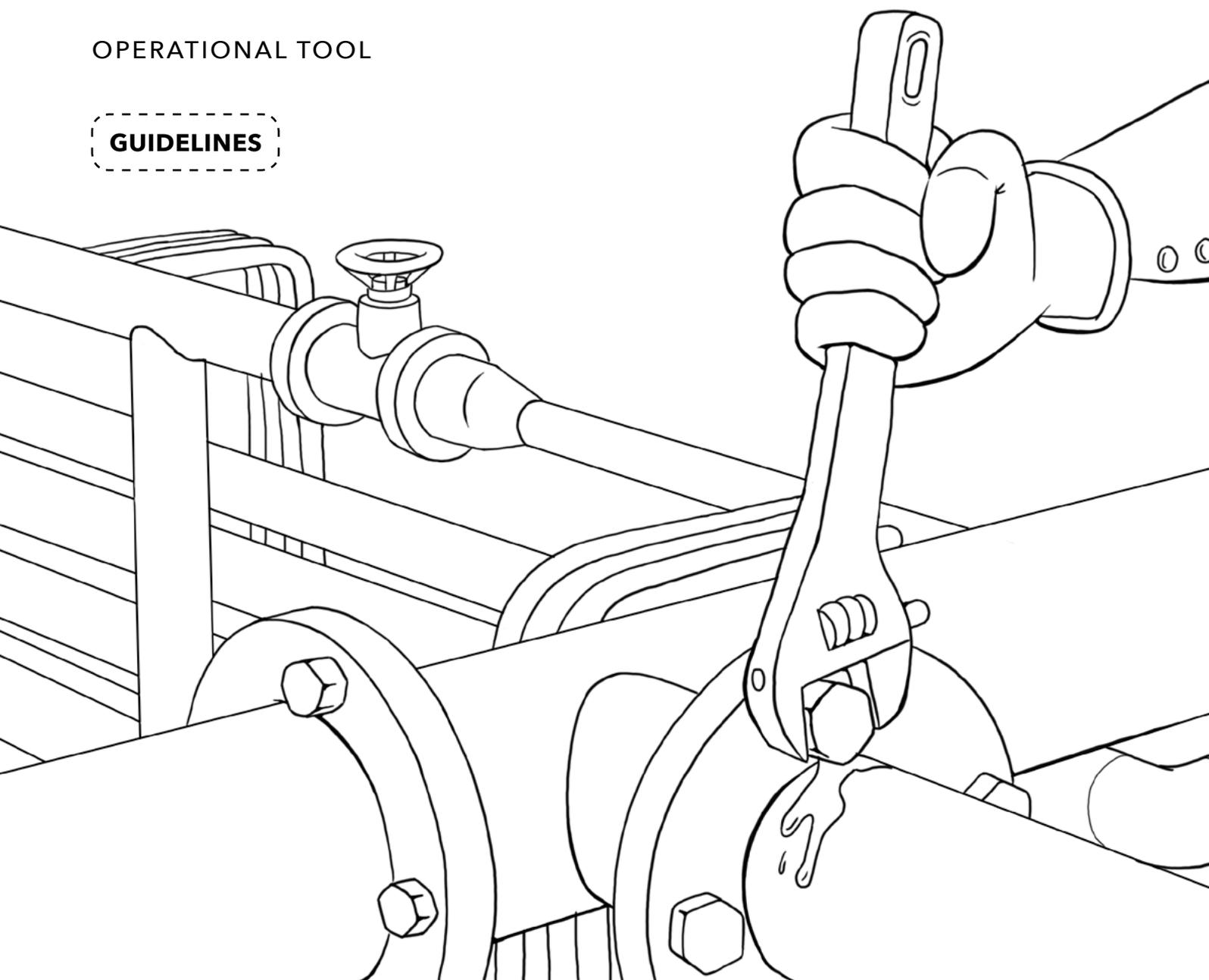


Roadmap to non-revenue water reduction and management

OPERATIONAL TOOL

GUIDELINES



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BEWOP

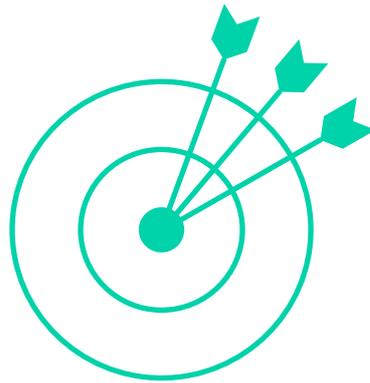
Water Operators' Partnerships are peer support arrangements between two or more water and sanitation operators, carried out on a not-for-profit basis with the objective of strengthening operator capacity.

The Boosting Effectiveness of Water Operators' Partnerships (BEWOP) initiative is producing a series of guidance materials, tools and games to help WOP partners expertly plan and implement WOP partnerships and effectively learn and share knowledge with one another.

Two types of products feature in the second phase of this BEWOP initiative. Process Tools support WOP participants prepare for, design, implement and follow through with their WOPs. Operational Tools support in the transfer of knowledge on specific operational topics relevant for water utilities.

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Objectives

This tool gives a guiding framework for not only the long-term NRW management process, but also hands-on support to everyone who works on the activities, whether they be trainers, managers, team leaders, commercial officers or plumbers. The primary goals of the approach presented are the reduction of NRW, improved customers satisfaction, improved collection, effective debt management and the affordability of water for the poorest part of the population.



How this tool works

This tool offers a comprehensive NRW approach through:

- **A strategic manual to give managers the complete oversight of a NRW management strategy and how to run NRW reduction pilots.**
- **A practical guide that offers tools for different NRW activities that need to be run by either management, technical or commercial teams. These tools might include:**
 - Customer survey questionnaire
 - NRW task team member responsibility descriptions
 - DMA checklist
 - International performance assessment
 - Template for business case writing, etc.
- **Introductory NRW lectures (presentations) aimed at different staff members that need to be involved in the respective NRW activities.**

Access the full Non-Revenue Water Reduction Training Tool [here](#).

Contents

1. Introduction	1		
I. Non-Revenue Water	1		
II. Roadmap to NRW Reduction and Management	4		
2. NRW Reduction and Management Plan	4		
I. Get buy-in from the management team	5		
1. Obtain an initial picture of the NRW problem	5		
2. International NRW Assessment	7		
3. NRW target level	9		
4. Develop a business case	10		
II. Organizational measures	11		
1. Steering committee	11		
2. NRW task team	11		
3. KPIs	12		
4. Performance management of non-managerial staff	13		
5. Planning, reviewing, documentation and reporting	13		
III. Framework for a multi-year NRW strategy	13		
3. District Metered Areas	15		
I. Creating a DMA	15		
1. Criteria for DMA selection	15		
2. Network information	15		
3. Defining and isolating a DMA	15		
4. House-to-house consumer and meter survey	16		
II. GIS - Mapping of the pilot DMA	17		
1. Setting up a GIS system	17		
2. Managing a GIS system	18		
III. Establish the NRW baseline value	18		
1. Initial calculation of water losses	18		
2. Initial analysis of water losses	19		
3. DMAs and water quality	21		
4. Steps to reduce and manage NRW	21		
1. Verify the customer database	21		
2. Repair broken water meters and visible leakages	22		
3. Testing and calibrating production and district meters	22		
4. Testing customer meters	23		
5. Active leakage management	23		
6. Improve the quality of materials, installations and repairs	24		
7. Pressure management	25		
8. Asset management	25		
9. Reducing unauthorized consumption	25		
10. Managing authorized unmetered consumption	26		
11. Reducing data handling errors	26		
12. Collection efficiency and debt management	27		

1. Introduction

I. Non-Revenue Water

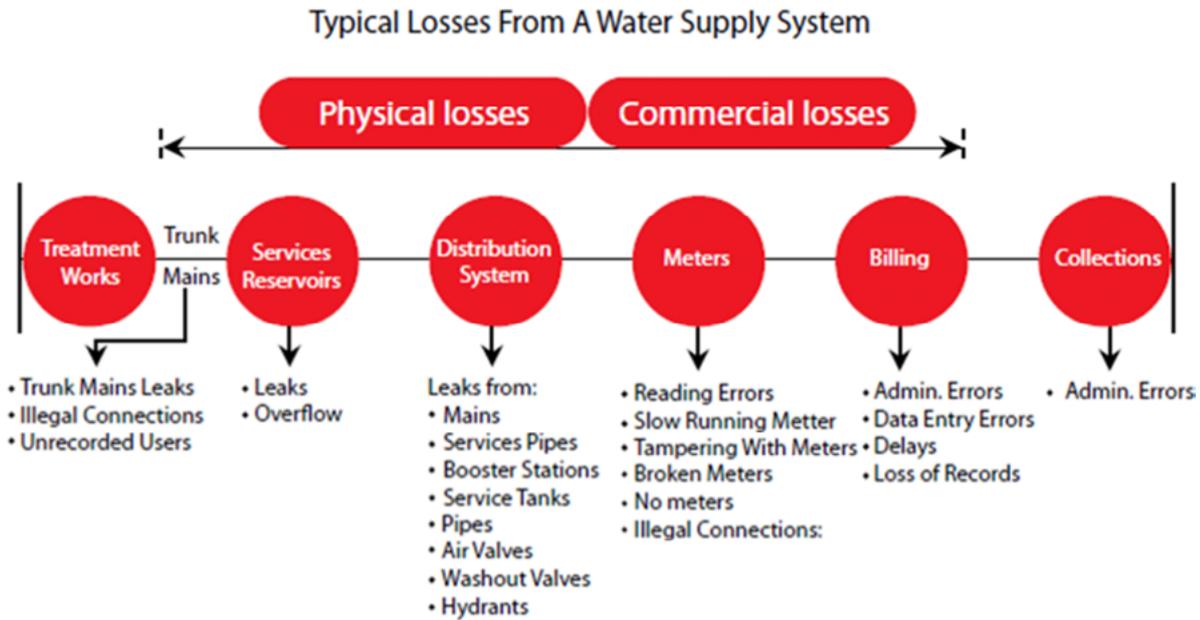
Non-revenue water is an important topic for drinking water companies, as it influences the financial sustainability, serviceability and the management of precious water resources to a large extent. According to the World Bank, in developing countries, roughly 45 million cubic meters of water are lost daily with an economic value of over US\$3 billion per year.

The International Water Association's (IWA) definition of Non-Revenue Water (NRW) is the difference between the cubic meters of water that are distributed into the water distribution network and the cubic meters that are invoiced with the customer. **Figure 1** presents the IWA water balance, the most widely accepted framework for understanding NRW. As shown in the table, NRW includes real losses (physical losses, such as leakages), apparent losses (commercial losses, such as illegal water connections) and unbilled authorized consumption (such as water used by fire fighters, or for the watering of public parks). **Figure 2** below elaborates on different components of physical and commercial losses. Losses at treatment works and during the collection process are not taken into NRW.

Figure 1. IWA water balance

Total System Input Volume	Authorised consumption	Billed authorised consumption	Billed metered consumption	Revenue water
			Billed unmetered consumption	
		Unbilled authorised consumption	Unbilled metered consumption	Non-revenue water
			Unbilled unmetered consumption	
	Water losses (UFW)	Apparent losses (Commercial losses)	Unauthorised consumption	
			Metering inaccuracies	
		Real losses (Physical losses)	Leakage in transmission and distribution lines	
			Leakage and overflows at storage tanks	
			Leakage on service connections up to customer meters	

Figure 2. Components of physical and commercial water losses



However, in most developing countries, the billing/collection efficiency should be taken into account when looking at NRW water. It may be that not all invoices are delivered to the consumers, or that fees are not collected for all issued bills. In contrast to developed countries, in many developing countries this may prove a significant factor in missed revenues. Therefore, one should count only the water that is paid for as revenue water. An adjusted water balance is shown in **Figure 3**. Improving the billing and collections practices will form a key point in solving NRW and should also be taken into account when setting up the business case.

Figure 3. Adjusted water balance for developing countries

Total System Input Volume	Authorised consumption	Billed authorised consumption	Paid billed metered consumption	Revenue water
			Paid billed unmetered consumption	
			Unpaid billed metered consumption	Non-revenue water
			Unpaid billed unmetered consumption	
	Water losses (UFW)	Unbilled authorised consumption	Unbilled metered consumption	Non-revenue water
			Unbilled unmetered consumption	
		Apparent losses (Commercial losses)	Unauthorised consumption	
			Metering inaccuracies	
		Real losses (Physical losses)	Leakage in transmission and distribution lines	
			Leakage and overflows at storage tanks	
Leakage on service connections up to customer meters				

NRW is very often still expressed in percentages, which is easily calculated and seems very intuitive. However, expressing NRW as a percentage of system input volume is a misleading and imprecise method, particularly in systems with intermittent supply and very low operating pressures, as is the case in many developing countries. This is exemplified in **Figure 4**, where you can see that utilities with a lower percentage of NRW might be doing worse than a utility with a higher percentage of NRW, when the losses are expressed in [liter/connection/day]. It is this unit that IWA has set as the international standard performance indicator for NRW. In Chapter 2 we will elaborate on how to make a first assessment of NRW.

Percentages, however, may be used when looking internally at the improvements made throughout a project.

Figure 4. Water loss performance indicators in 6 example systems.

		System A	System B	System C	System D	System E	System F
		Developed Country	Developing Country				
Population		2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	25,000
Service connections	number	150,000	400,000	250,000	300,000	300,000	6,000
Average pressure	m	50	30	20	15	15	40
System input volume	m ³ /day	460,000	255,000	490,000	375,000	420,000	3,500
Per capita consumption	l/c/d	150	80	130	100	100	80
Domestic consumption	m ³ /day	300,000	160,000	260,000	200,000	200,000	2,000
Commercial consumption	m ³ /day	100,000	20,000	150,000	100,000	100,000	200
Commercial losses	m ³ /day	10,000	18,000	20,000	30,000	30,000	150
Physical losses	m ³ /day	50,000	57,000	60,000	45,000	90,000	1,150
Total NRW	m ³ /day	60,000	75,000	80,000	75,000	120,000	1,300
NRW	% of system input volume	13	29	16	20	29	37
First impression of NRW level		LOW	HIGH	LOW	MEDIUM	HIGH	HIGH
Daily supply time	hours	24	24	24	12	24	24
Commercial losses	% of authorized consumption	3	10	5	10	10	7
Commercial loss level		LOW	MEDIUM	LOW	MEDIUM	MEDIUM	LOW
Physical losses	l/conn./day (when the system is pressurized)	333	143	240	300	300	192
Physical losses Performance category		C	A	C	D	D	A
Physical loss level		Relatively HIGH	LOW	Relatively HIGH	Very HIGH	Very HIGH	LOW

Source: Water Supply and Sanitation Sector Board Discussion Paper Series, Paper No. 8, December 2006

NRW reduction and management is a major challenge; it needs vision and commitment from management, contributions from many departments and intensive collaboration between employees. Also, the challenge to reduce NRW includes technical, cultural and organizational changes. Usually, quick-wins can be achieved within 2-3 months but sustainable results can only be achieved after several years of efforts, when structural changes are implemented.

NRW does not have to be only the result of an underperforming utility, another cause can be a lack of investments that are sometimes out of the scope of a water utility.

II. Roadmap to NRW Reduction and Management

The presented roadmap serves as a guiding framework for the long-term NRW management process. The main goals of the approach are: reduction of NRW, long-term management of NRW, improved customer satisfaction, improved collection, effective debt management, and the affordability of water for the poorest part of the population. The roadmap to Non-Revenue Water Reduction/Management can be summarized by three key components:

1. How to create a NRW reduction and management plan (Chapter 2), including obtaining an initial picture of the NRW problem, raising company-wide awareness and support, and creating a guiding team
2. How to divide the NRW problem into manageable pieces for undertaking (measurable) NRW reduction measures, and calculate and analyze NRW in more detail (Chapter 3).
3. Steps to reduce and manage NRW, both physical and commercial (Chapter 4)

As an annex to this document comes a guide “Practical Tools for NRW Reduction and Management”. This document contains practical tools, such as a NRW self-assessment matrix, a checklist for DMA creation, a customer survey interview sheet, an overview of a proposed NRW task team, a checklist for a coordination plan for NRW reduction pilots and timelines for the NRW reduction approach. The practical guide can be used as an independent document, a more hands-on help for running a NRW program.

Furthermore, the NRW Community of Practice within the WaterWorX program will be continuously updating a document to share Best Practices regarding everything that has to do with NRW reduction and management, including starting/running project and giving training abroad.

2. NRW Reduction and Management Plan

In reducing NRW, there is a tendency to aim for project-based interventions that quickly yield result. However, in order to sustain NRW at low levels, NRW management requires long-term embedding of these interventions in the utility organization. Therefore, an important step in NRW reduction and management is to write a comprehensive NRW multi-year strategy. A NRW strategy consists of setting targets, planning interventions and creating budgetary and organizational support. To be able to implement measures to reduce/manage NRW it is key to raise company-wide awareness on the (size of) the problem and the gains that can be made by managing it, as without incentives to tackle NRW it will be difficult to find the support needed to make any activity effective. To convince the management to work on a response strategy, one should first acquire insight in the size and underlying causes of the NRW problem as a basis for a convincing business case.

In this section, strategies to create company-wide awareness and support, necessary organizational measures and a framework for a multi-year NRW strategy are considered. Together with an understanding of DMAs (Chapter 3) and NRW reduction activities (Chapter 4), a more detailed strategy can be created.

I. Get buy-in from the management team

It is important that the management team appreciates the size of the problem and the need to do something about it to sustain company operations. Without support from top level management, experience has shown that (pilot) activities are left to individual staff members to struggle with, with a lack of due support from other team members, mid - and top-level managers. This is especially the case in highly hierarchical organizations where bottom-up initiatives are not usually initiated or supported. Buy-in can be strengthened through workshops and trainings targeting managers. In order to convince the management team it is important to highlight the size of the NRW problem as a whole:

- Use the international IWA assessment matrix as support
- Include concrete examples of physical and commercial losses, and unbilled authorized consumption (NRW), such as:
 - Volume percentage billed based on meter readings (m³ lost per year/month/day)
 - \$ percentage billed based on meter readings (\$ lost per year/month/day)
 - Total number of bursts/leaks repaired per km² of distribution network
- Make a business case, showing not only the financial gains that can be made through NRW reduction, but including gains pertaining to all five principles of de FIETS sustainability (Financial, Institutional, Environmental, Technological and Social)

1. Obtain an initial picture of the NRW problem

In order to prepare an initial NRW water balance (see **Figure 5**) the following set of data should be known [source: Recommendations for Initial NRW Assessment, IWA Water Loss 2010]:

- Annual system input volume
 - The volume of water supplied can be derived from the readings of bulk water meters on the supply lines going out of the production facilities. If records are kept and the water meters are working (this may have to be verified) this is a simple exercise. If not 100% of the outgoing pipelines of the production facilities are measured, it will be difficult to reliably calculate the level of NRW and estimations should be made. In that case, it is required to undertake temporary measurements (weekly/monthly) with temporary meters
- All elements of authorized consumption
 - Data of billed as well as unbilled metered consumption (to the extent it is known) should be ready at hand if meter readings are properly recorded. Then, analysis and estimation of the billed and unbilled unmetered consumption is required
- Estimation of commercial losses. Elements of commercial losses:
 - Customer meter accuracy: to be estimated by using data on the age of the customer meters (if available) (see **Figure 6**, note that with an average flow rate a relation can be made between meter age and cumulative volume: $\text{age} = \text{cumulative volume} / \text{flow rate}$)

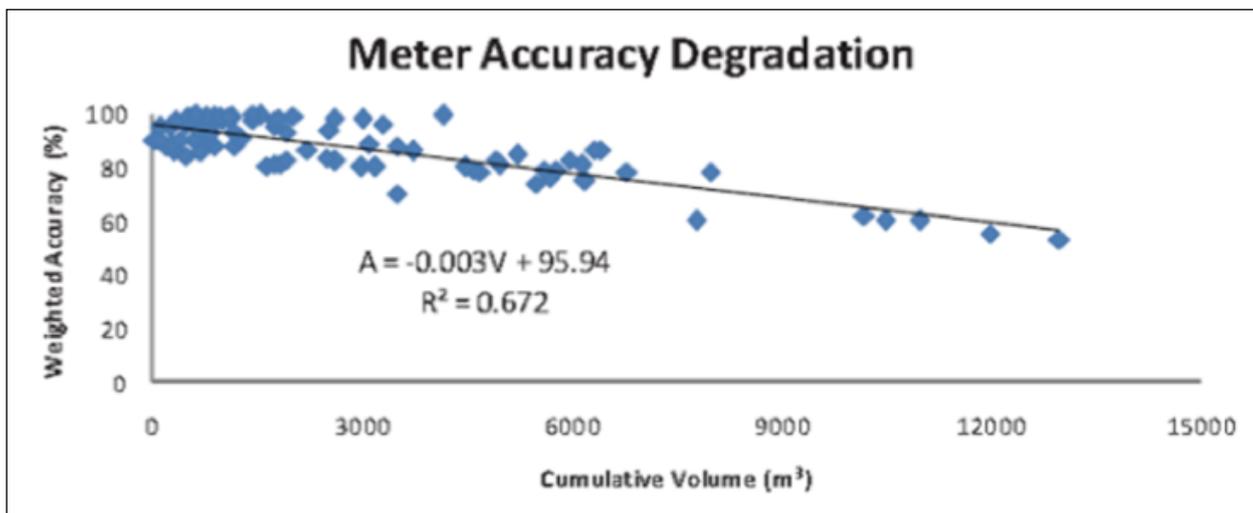
- Meter reading, data handling and billing errors: can be estimated based on a thorough process analysis and analysis of billing data
- Volume of physical losses
 - The physical losses can be calculated by subtracting the authorized consumption and commercial losses from the input volume

Although many estimates have to be made for the above calculations, this will be a good step toward a first impression of 'where the water flows'. Gradually the water balance can be improved with data that will become available during the course of the NRW project.

Figure 5. Initial water balance

Total System Input Volume	Authorised consumption	Billed authorised consumption	Paid billed metered consumption	Revenue water
			Paid billed unmetered consumption	
		Unbilled authorised consumption	Unpaid billed metered consumption	Non-revenue water
			Unpaid billed unmetered consumption	
	Water losses (UFW)	Apparent losses (Commercial losses)	Unbilled metered consumption	Non-revenue water
			Unbilled unmetered consumption	
		Real losses (Physical losses)	Unauthorised consumption	
			Metering inaccuracies	
			Leakage in transmission and distribution lines	
			Leakage and overflows at storage tanks	
Leakage on service connections up to customer meters				

Figure 6. Relation between metered volume and meter accuracy degradation (IHE Delft)



2. International NRW Assessment

To evaluate the water utilities' performance regarding water losses, the IWA assessment matrix can be used. With this tool, the utility can be put in a NRW management performance category, which will indicate the urgency of undertaking NRW reduction measures.

To make the initial NRW assessment, one needs to know:

- Daily volume of NRW
 - Daily volume of water supplied
 - Daily volume of water paid
- Average supply time (in case of intermittent supply)
- Number of service connections
- Average pressure

Expressed in [liter/connection/day], NRW can be calculated through:

$$NRW \left[\frac{\text{liter}}{\text{connection}} \right] / \text{day} = \frac{(\text{liter water supplied})/24h - (\text{liter water paid})/24h}{\# \text{ connections}} = \frac{(\text{liter NRW})/\text{day}}{\# \text{ connections}}$$

In case of intermittent supply (system not pressurized 24 hours), the daily amount of water supplied and paid have to be corrected. If this is not done it may seem there is only a small daily water loss when in fact there is just little water supplied. The correction factor is calculated by:

$$\text{correction factor intermittent supply} = \frac{24h}{\text{average daily supply time}}$$

And thus:

$$(\text{liter water supplied})/24h = (\text{liter water supplied})/\text{day} * \frac{24h}{\text{average daily supply time}}$$

House connections (including yard taps) as well as public standpipes should be taken into account when counting the number of connections. Strictly spoken, as supply time is corrected for intermittent supply, the number of connections should be corrected for rationing. For example, if of a total of 40.000 connections on average only 30.000 connections are supplied daily, the number of 30.000 should be used in the calculations instead of 40.000. However, we choose not to include this factor in the formula, because NRW calculations cannot turn out lower when this correction is not made and, as such, the unused length of the network should also be taken out.

The daily volume of water supplied can be derived from the monthly reading of bulk water meters on the supply lines going out of the production facilities and the monthly billing data. The daily volume paid should be abstracted from the companies' commercial system.

When making the NRW assessment, also the pressure is considered, as the amount of physical water loss depends highly on the pressure of water in the network (on about a 1:1 scale). For this initial assessment, an average pressure can be determined by measuring several points in the network (not only at the outlet of pumping stations as this will yield an overestimation) averaged over 24 hours (including nighttime pressure, to avoid underestimation).

With all this data NRW can be calculated in [liter/connection/day] and, together with the average pressure, the NRW management category can be determined using the International NRW Assessment Matrix as shown below in **Figure 7**.

Figure 7. International NRW Assessment Matrix (Recommendations for Initial NRW Assessment, IWA Water Loss 2010)

NRW Management Performance category		Non-Revenue Water in Litres/connection/day when the system is pressurized at an average pressure of:				
		10 m	20 m	30 m	40 m	50 m
High Income Countries	A1		< 50	< 65	< 75	< 85
	A2		50-100	65-125	75-150	85-175
	B		100-200	125-250	150-300	175-350
	C		200-350	250-450	300-550	350-650
	D		> 350	> 450	> 550	> 650
Low and Middle Income 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	520-1000	620-1200
	D	> 400	> 600	> 800	> 1000	> 1200

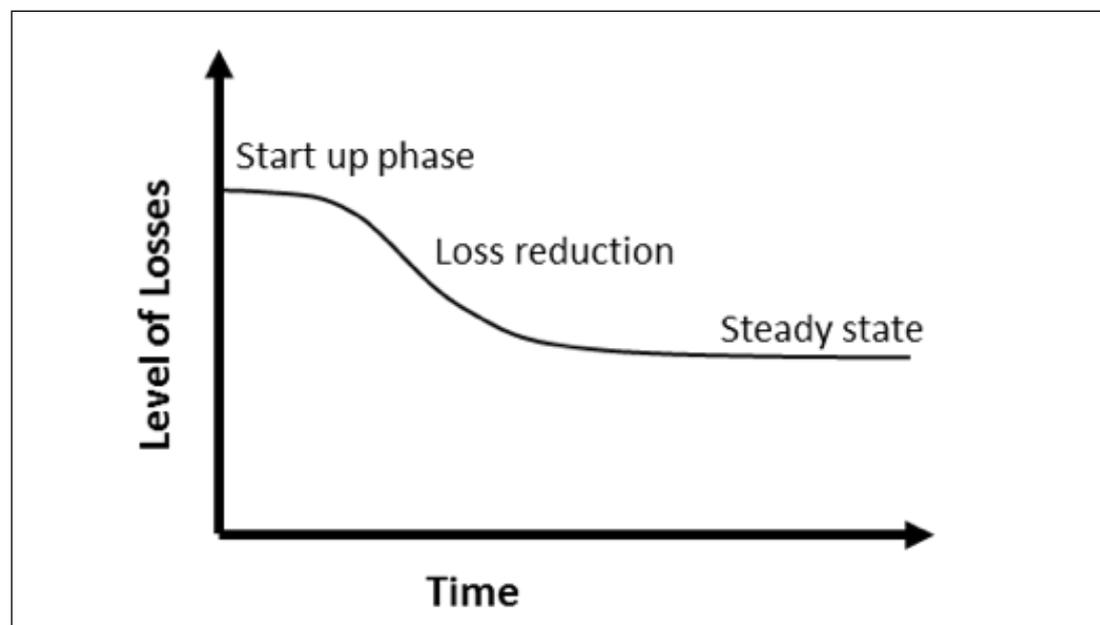
Per category, the urgency of undertaking NRW interventions is summarized by [Recommendations for Initial NRW Assessment, IWA Water Loss 2010]:

- Category A1: World class NRW management performance; the potential for further NRW reductions is small unless there is still potential for pressure reduction or accuracy improvement of large customer meters
- Category A2: Further NRW reduction may be uneconomic unless there are water shortages or very high water tariffs; a detailed water audit is required to identify cost-effective improvements
- Category B: Potential for marked improvements; establish a water balance to quantify the components of NRW; consider pressure management, better active leakage control practices, and better network maintenance; improve customer meter management, review meter reading, data handling and billing processed and identify improvement potentials
- Category C: Poor NRW record; tolerable only if water is plentiful and cheap; even then, analyze level and causes of NRW and intensify NRW reduction efforts
- Category D: Highly inefficient; a comprehensive NRW reduction program is imperative and high-priority

3. NRW target level

Usually, reduction measures will cause NRW levels according to a curve as shown in **Figure 8**: gradually decreasing water losses until a steady state is reached (if NRW is managed well and does not go back up).

Figure 8. Start-up, transition and steady state phase losses

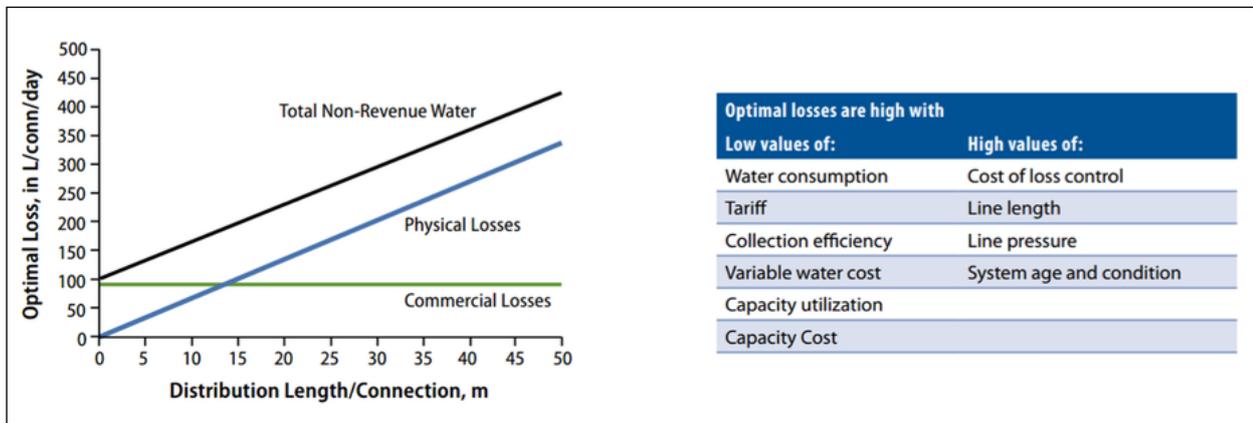


The Netherlands holds a global record low NRW of about 22 liter/connection/day (6%; 1.5 m³/km/day), but for instance in England, the level lies around 149 liter/connection/day (20%; 10 m³/km/day). For the English, considering the investments that should be made to lower that level and the financial gains that would be made by selling more water, it is not worthwhile to invest in NRW reduction measures. In other words, when considering a target level of NRW, one should look at the economic level of losses. The NRW target should be based on:

- Unavoidable Annual real Losses
 - The magnitude of leakage that is considered undetectable will depend on the available detection technologies, availability of staff, pressure of water in the network, type of soil, etc.
- Economic level of Leakage
 - The benefits of leak detection and repair depend on the amount of leakage (burst rate, flow rate), the water tariff, the cost of replacement of pipes, and the operational cost of loss-control (detection and repair)
 - Furthermore, in countries dealing with a water deficit there is also a humanitarian and environmental dimension to the value of water. This might come in as a factor through the water tariff
- Economic level of Commercial Losses
 - The benefit of commercial loss control activities depend on the height of commercial loss and the cost of meter replacement and repair, programs to uncover illegal connections, and programs to verify meter reading, billing and collection data transfer quality
- Current Annual Real Losses
 - The target level of NRW within a project should also depend on the current status of losses and the time available for the project

Most of the research on these economic levels have been performed in developed countries, making it harder to make a quick estimation of what those levels would be in developing countries. Studying the available literature for developing countries, Wyatt (Non-Revenue Water: Financial Model for Optimal Management in Developing Countries, RTI Press publication, 2010) made a generic model to assess the optimal losses (physical and commercial) for different lengths of network in developing countries. **Figure 9** shows the optimal losses for a range of distribution line lengths per connection. As expected, as pipe length per connection increases, optimal physical losses (L/connection/day) rise linearly while commercial losses hold steady. It is interesting to note that when pipe length per connection is short (i.e. densely settled areas), physical and commercial losses are around equal value (in terms of L/connection/day). Wyatt et al. also assessed the influence of different parameters on the level of economic loss as depicted in the table in **Figure 9**. It shows that for example: a low tariff would mean that aggressively controlling commercial losses would have a low return resulting in high optimal commercial losses; and if the variable cost of water production is low, the return from physical loss control would be small and so the optimal physical losses high.

Figure 9. Generic optimal physical and commercial losses, and total NRW; Influence on key parameters (Wyatt)



4. Develop a business case

As mentioned above, a business case does not have to relate to finance only. NRW reduction will cause improvements on all five principles of de FIETS sustainability approach.

Financial

To convince the management that reducing NRW will increase the revenue of the company significantly¹, a positive (financial) business case is crucial. The initial business case is made by comparing the amount of revenue that is currently lost to NRW to what would be lost if NRW targets are met. The calculation should include an estimation of the investment - as well as operational costs of the means needed for in materials and man hours. The business case can also include prospects on income from new service extensions enabled through increased revenues and the extra water that will become available.

After a first pilot project has been performed and a scaling-up approach can be worked out, a more detailed business case can be set up.

1. Suppose all reduced NRW will be consumed and invoiced, than for example a 10% reduction of NRW will give a 10%* $\frac{\text{Volume Produced}}{\text{Volume Billed}}$ increase of Billed Volume (in %).

Institutional

To manage NRW, a water utility needs to be well organized. If the steps proposed in this Roadmap are followed, the utility will have better internal cooperation (between different departments). This will not only benefit the reduction of NRW, but will help to tackle any other large problem that the utility may have and increase general communication and efficiency.

Furthermore, reducing NRW will improve customer satisfaction, as the customers will experience fewer interruptions in water supply, higher pressure and better water quality (Section 3.III.3), which may again lead to better payment by customers.

Environmental

Less NRW will increase climate resilience (less stress on water resources), decrease carbon footprint (with less leakages, pumping can be decreased) and decrease use of chemicals (fewer service interruptions and fewer ruptures in pipes leads to improved water quality).

Technological

An important part of NRW management is the managing of assets. Asset maintenance plans will increase the lifetime of assets and thereby increase overall technological sustainability.

Social

Managing NRW will increase social sustainability, as by increasing the companies' revenues and making more water available through the reduction of physical water losses, customers can receive more water and new service extensions can be made.

II. Organizational measures

Only theoretical knowledge of what needs to be done will not result in the desired outcomes. It is the planning and organization of a change process that will determine whether or not the prioritized NRW reduction/management activities will yield fruit. Organizational measures that positively contribute to the achievement of any overall objective, including NRW, are presented below. As every organization is different, the organizational measures will be different for each individual company too.

1. Steering committee

To be able to integrate NRW activities in the organizational structure of the company, it is useful to have a well-established 'steering committee' consisting of people from the management team. They can drive, accelerate and check the work that is done and therefore the results that are achieved. The steering committee should contain people that are in direct contact with the employees and they should drive the task team(s). Being part of a steering committee gives management a sense of responsibility, as well as create opportunities for the most influential people to get together on a regular basis to discuss NRW. One should look closely at the existing management structure to decide who should be represented in the steering committee, and what role each member should play.

2. NRW task team

In principle, everyone within the water company works on managing NRW, however, it may help to appoint a NRW task team to have tasks and responsibilities well defined and create contact points, for managers as well

as other employees. Forming a NRW task team consisting of commercial and technical department staff, is a way to get buy in and raise the feeling of ownership through all departments and levels of the company. The NRW task team should be coordinated by an experienced NRW 'caretaker', who can write/update the NRW management plan, initiate, drive and monitor NRW management activities and report back to management. Functions, corresponding tasks and responsibilities should be well-defined for all members of the team. An open-door policy by top and mid-level managers further allows lower cadre staff to voice their opinions and provide suggestions based on experience on the ground. It is also the responsibility of the NRW task team that all stakeholders working in the DMA should be made aware of the pilot project that is running and have regular catch up meetings, so that plans are aligned and different activities do not interfere.

See Toolbox for examples of functions and corresponding tasks for the task members.

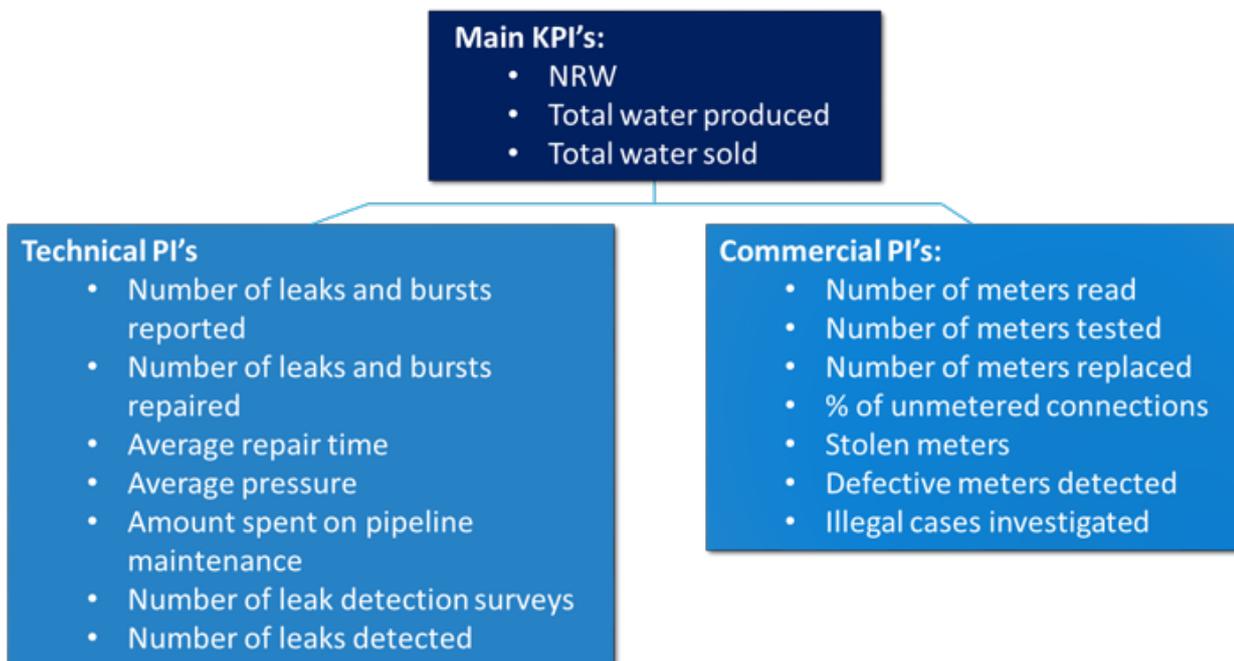
3. KPIs

Key Performance Indicators (KPIs) are measurable indicators that help a utility to:

- Better understand water losses
- Define and set targets for improvement
- Measure and compare performance
- Develop standards
- Monitor compliance
- Prioritize investments

It is important to define KPIs upon that can serve as a baseline and with which performance can be measured. Useful KPIs are summarized in **Figure 10**.

Figure 10. Useful KPIs for NRW management



4. Performance management of non-managerial staff

The execution of most of the work of a water utility is performed by lower cadre staff, such as plumbers and electricians, meter readers and commercial field officers. For them, the motivation to reduce NRW will come from somewhere else than it would for managerial staff. Non-managerial employees in different departments should also be trained to understand NRW, but the general performance of the company will not be something they care too much about and they will need different incentives to make their vital contribution to the goals. To develop a strategy on how to manage the performance of these employees, it is important to understand the local context. Incentives could come from benchmarking between different zones: employees could receive a bonus or salary increase when the zone they work in increases its performance more than others, or more than a certain target.

5. Planning, reviewing, documentation and reporting

Weekly team meetings help to keep staff focused and provide a platform to discuss progress and emerging issues, based upon which plans can be adjusted. Documentation of the process and results is crucial to:

- Increase the understanding of the main causes and contributions of commercial and physical losses to the total volume of water and money lost
- Refine the response strategy based on emerging evidence as to what works and what does not
- Future up-scaling efforts

III. Framework for a multi-year NRW strategy

The following steps present a framework for a multi-year NRW strategy. The longer the project is running the clearer things will become in terms of best practices and appropriate up-scaling strategies.

4. Leadership, information and employee involvement

Strong and visible leadership and management skills are required to address NRW. Describe the way leadership needs to be, how the information process will be managed and how employees will be involved. For example:

- Organize discussions to hear opinions (of different departments and cadres of staff) on current operations, previous NRW reduction projects, existing NRW management schemes and ideas on how to plan and run the current project
- Create due awareness
- Create a guiding team
- Training on NRW management (for all departments and cadres of staff) following a training needs assessment

5. Community, stakeholder and customer involvement

A participatory approach on different levels and with different stakeholders is required to make NRW reduction a success and NRW management sustainable. In particular, the interests of customers and (low-income) communities should be involved to increase sustainability and effectiveness of the programs. The inclusion of low-income groups/customers is not only important from a social perspective (access to drinking water and sanitation is regarded as a basic human right), it also acknowledges that customer/community involvement is a step towards an integrated approach that could reduce NRW and increase the financial sustainability of water utilities. Supportive actions for community and stakeholder involvement:

- Stakeholder mapping: find out what organizations (community or in the wider catchment) are active and what role they play
- Write an involvement strategy in NRW reduction activities
- Awareness campaigns and promotional activities

6. NRW reduction activities

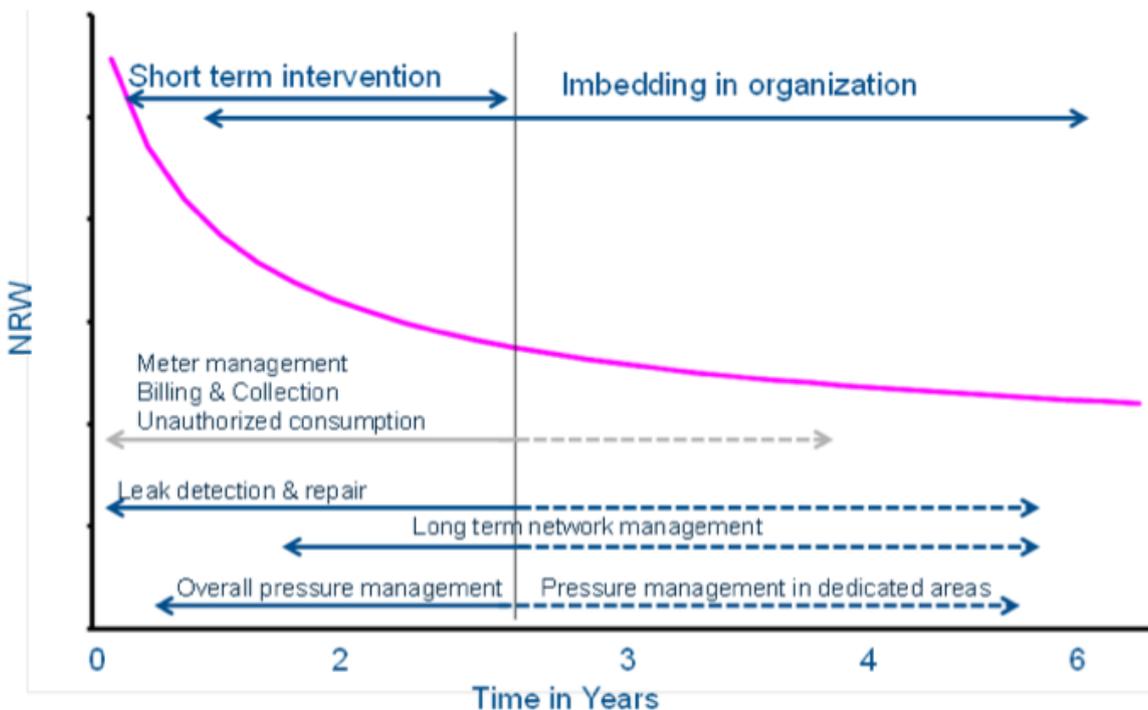
Describe the strategy of NRW reduction, including training approach, short term intervention, long term intervention, etc. **Figure 11** shows general time-frames for the approaches. See Chapter 4 for a more detailed approach.

7. Monitoring

Describe how NRW will be monitored and reviewed. Including:

- Set/prioritize targets considering available human resources and budget; define (key) performance indicators
- Develop a reporting system
- Define responsibilities for measuring, reporting and analysis of data
- Measure results according to performance indicators; collect best practices
- Develop Business Case on NRW reduction activities

Figure 11. Time-lines for NRW reduction and management interventions



3. District Metered Areas

To be able to analyze the level of NRW, the problem should be divided into manageable pieces. This is often done by creating District Metered Areas (DMAs): hydraulically isolated sections of the complete water network in which NRW can be analyzed in more detail and in which the effect of NRW reduction measures can be monitored.

I. Creating a DMA

For the creation of DMAs, the water distribution network should be sectioned in hydraulically isolated and separately measured zones. Then, if the customers connected in this area are known, accurate balances can be set up between the incoming water and the water sold.

For some tools to support with setting up a DMA, see Chapter 2 of the Practical Tools for NRW Reduction and Management.

1. Criteria for DMA selection

Important criteria for selecting a pilot area include:

- 'High NRW' area (commercial and/or physical losses)
- Not too big, not too small, generally between 500 and 3000 connections
- A 'logical' zone, with clearly visible topographical points that can serve as boundaries for the DMA, such as rivers, roads, railway tracks, drainage channels, etc. This helps to:
 - Save in investment costs for network changes needed for the isolation of the zone as well as the number of district meters that need to be installed for its metering
 - Make it easier to identify the customers connected in the zone
- Ideally, water availability 24/7 and good pressure. A lack of water and low pressure levels undermine the reliability of the meter readings and - subsequently - water balance calculations and night flow measurements
- No plans to increase capacity and/or expand the network. It is not practical to select an area for a pilot project where in the near future changes will be made to the network

2. Network information

In many countries in development, the network's assets (pipes) are poorly registered, making it difficult to investigate the quality of the network and model water flows. To obtain better insight, a necessary first step is to collect and register data on the network, such as the location of pipes, water reservoirs, valves, etc. For a broader introduction on the use of GIS, see Section 3.II.

3. Defining and isolating a DMA

With the DMA selection criteria and network information (GIS), an appropriate zone can be selected. To isolate the DMA, it is required to:

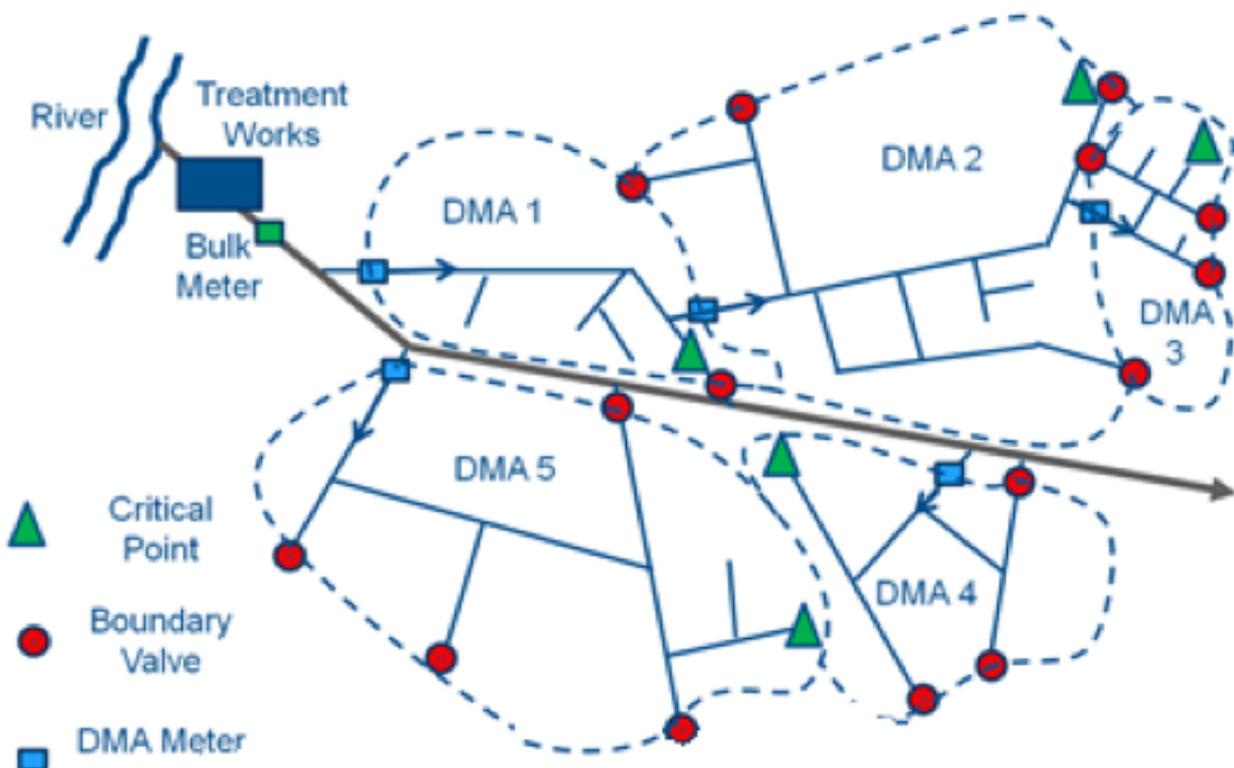
- Install meters and valves in tamper-proof chambers on all incoming and outgoing lines

- Verify which consumers are (not) supplied by the incoming lines and deliberately in - or excluding them in the DMA water balance calculations

It is important that a DMA is hydraulically separated. All in - and outgoing flows should be known and well-measured. Preferably, a DMA has only one incoming line and no outgoing lines, but with a 'spaghetti' network this is often not realistic. When a 'logical' DMA is too large, it can be sectioned by making by-passes and/or installing new measuring points in the network with valves and water meters. Any new assets installed for the zone's isolation should be taken up in the GIS. See **Figure 12** for an example of a sectioned network.

By closing the valves on incoming lines and verifying whether or not customers still receive water, it can be determined who is located in - and who is outside of the DMA. This exercise can also reveal any incoming lines that were missed in previous mapping and that should be metered (and put in GIS). Results from water balance calculations can also indicate (for instance by showing particularly high or low NRW) incoming or outgoing lines that were left out and still need to be disconnected or metered.

Figure 12. Sectioning of a network



4. House-to-house consumer and meter survey

Undertaking a house-to-house survey of all customers (in the field as well as the database) serves to confirm/update the customer database as well as to record the first technical issues in the field:

- Establish the complete consumer database of the DMA
- Find out customers that are not registered in the database
- Find out customers that do not receive invoices
- Clean up double or 'ghost' entries in the database

- Confirm/update consumer data in the field with billing data (name, telephone number², email, and meter brand, type, size, material, date installed, serial number, GPS coordinates³) details
- Identify and address potential meter by-passes and illegal connections
- Problems such as not working water meters, leaking or incomplete installations

Without even undertaking any technical work, updating the customer database after this first survey can already lower the NRW by following up on unregistered or unbilled customers.

For an example of an interview sheet for a customer survey, see Chapter 3 of the Practical Tools for NRW Reduction and Management.

II. GIS - Mapping of the pilot DMA

GIS (Geographical Information System) mapping is important to represent the water pipe infrastructure and to identify all infrastructure components i.e. incoming/outgoing DMA meters, primary and secondary distribution network, consumer meters, service connections (if known), valves etc. Having an up to date GIS with GPS locations of all assets is of great help with managing the network.

1. Setting up a GIS system

The development of a GIS system requires the implementation of a complete process. The following step-by-step approach is suggested:

- For every water utility an introduction to GIS should be given and the importance of GIS recognized
- An inventory of the available information should be made. One can think of:
 - Available (network) maps
 - Information on the network that is available from other information systems, for instance from a maintenance or invoicing perspective
 - Available software packages and (desirable) connections with other software packages and user purposes
- The people and resources should be made available to set up the GIS
 - GIS specialist
 - Availability over GPS devices
 - Choose a software package
 - Computers (connected to central server)
- Develop/choose a data model in which the data will be captured
- Collect data and fill the data model with information on the network, e.g. GPS location of pipes, pipe diameter, pipe material, age etc., as defined in the data model. Distinguish input between 'need to have' and 'nice to have'
- Verify the quality of data by undertaking quality checks in the field. If essential data is missing, field trips should be organized to collect additional data that is needed to obtain a complete database

2. E.g. for contacting consumers to read meters (if gate-locked), SMS-billing, updates about water rationing.

3. By projecting the GPS coordinates of consumer meters on (Google) satellite imagery, plots/houses without connections can be identified.

- To graphically represent the data, a GIS application should be selected, such as Google Maps, Arc GIS, Q-GIS (free ware). The selection will depend on the available budget and intended use. Converting information from the database to a geographical drawing requires specialist knowledge

2. Managing a GIS system

After the initial database has been filled and the GIS map is made, the GIS should be continuously updated, every extension of the network should go through the GIS specialist. Staff will have to be trained on the use of GIS. The method to increase and safe-keep the quality is a cyclical process of periodically sharing the (detail) map, undertaking check-ups, giving feedback on changes and making moderations. For this management phase, tasks and responsibilities should be divided. To let the GIS really come to life, the participation of the network keepers (pipe fitters) is necessary. Organize for instance regular sessions where all pipe fitters get updated on all the changes in the network.

III. Establish the NRW baseline value

1. Initial calculation of water losses

To establish the level of NRW in a pilot DMA in more detail, it is necessary to know the (exact) volume of water that goes into the area and the volume that is invoiced (and paid) in the area. These two values should be obtained and compared over the exact same amount of time. The water loss is calculated by subtracting the difference between the readings of all consumer meters from the difference between the readings of the bulk water meters over this period.

A way to make sure this period of time is as exact, is by closing off the valves on all supply pipes into the DMA and waiting until all water has been drained from the area. At this moment the bulk meter(s) and all customer meters can be read. These readings are called 'zero-readings'. Next, valves can be opened to supply water again in the normal way for around two weeks. Closing the main valves again and organizing another set of zero-readings on say, day 14, makes it possible to make the exact calculation of the difference between the volume of water that was supplied to the area and that was measured with the customers over these two weeks. If all customers are known, all customers have well-working water meters and all customer meters are read, the losses found in this calculation will be pure physical losses.

The zero-readings should be undertaken in as short a time as possible, not taking more than two days of cutting of the water supply as this method is very disturbing to the customers. When the DMA is an area where water is supplied only during certain days of the week, the zero-readings should be organized during the days without supply.

A slightly less accurate way to determine the level of NRW is described in Section 2.0, the difference being that valves stay open. This calculation can be made more accurate by making sure the regular meter readings within the DMA are done within as short a time-frame as possible (one or two days).

It is important to consider very well who is reading the meters: the usual meter reader may have his/her routine, including missing certain customer, whether on purpose or not. The validation of (a sample of) reported consumer meter readings, meter reading entries in the billing system, 'gate-locks', disconnected consumers and dormant connections by an NRW caretaker or other (independent) technical staff can serve to keep meter readers on their toes and minimize (potential) colluding of staff with consumers.

Just like during the house-to-house survey, whilst reading the meters, problems like connections without a (working) water meter, leaking or incomplete installations, or customers who do not receive invoices, can be registered.

For some tools to find the NRW baseline value in a DMA, see Chapter 4 of the Practical Tools for NRW Reduction and Management.

2. Initial analysis of water losses

After establishing the level of NRW, it is helpful to understand in more detail what the causes of NRW are and to make a distinction between apparent and real losses as presented in the IWA water balance.

Real losses

As mentioned above, if a very well organized customer survey and set of meter readings can be performed, a good idea of the amount of physical losses can be obtained. However, if the survey is not so reliable, a general idea of the severity of real losses can often be obtained by looking at the number of reported bursts and leakages, or by looking at unreported leakages by making tours through service areas and see if you often see water running along the roads. Analyzing the age and quality of the used pipes, and the average response time for repairs also helps to make an estimation on the status of real losses. **Table 1a** shows the flow rates for reported and unreported bursts and **Table 1b** for background losses in different parts of the network as estimated by the IWA Water Loss Task Force. Night flow measurements will give more detailed information.

Table 1a. (Source: IWA Water Loss Task Force)

Location of Burst	Flow Rate for Reported Burst [L/hour/m pressure]	Flow Rate for Unreported Burst [L/hour/m pressure]
Mains	240	120
Service Connection	32	32

Table 1b.

Location of Burst	Flow Rate
Mains	9.6 [L/km/day/m pressure]
Service Connection - main to property	0.6 [L/service connection/day/m pressure]
Service Connection - property to customer meter	16.0 [L/km of service connection/day/m pressure]

Apparent Losses

It is not straightforward to analyze the apparent losses. Below are presented four of the main causes of apparent losses.

Unauthorized consumption

To estimate the level of unauthorized consumption, one needs to separate unauthorized consumption by domestic users and by non-domestic (such as industrial) users.

To uncover unauthorized consumption by non-domestic users, one can:

- Compare the average consumption of each user to what the expected consumption of this user would be knowing their type of business
- Paying surprise visits and check for illegal connections, or water meters that are bypassed or tampered with

Next, the amount of water consumed illegally by domestic users can be estimated by comparing the amount of water that is billed to domestic consumers in the area (total billed minus what is billed to non-domestic users), to the estimated average domestic consumption in the area. The average consumption in the area will depend on:

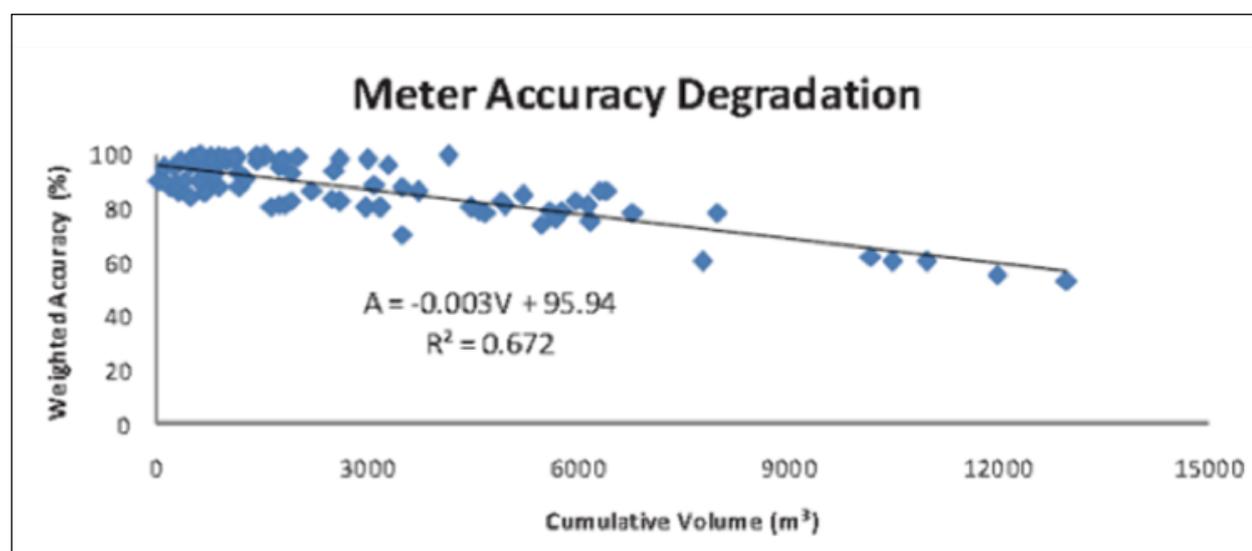
- The number of inhabitants in the area
- The average consumption per person
- Other sources that are used (are people fetching water elsewhere?)

Meter inaccuracy

Get an idea of the inaccuracy of bulk meters either by making estimations or using portable flow meters.

IHE Delft performed a study of customer water meters in Africa and found the relation between cumulative volume and meter accuracy as shown in **Figure 13**. The cumulative metered volume of a meter can be read from the meter.

Figure 13. Relation between metered volume and meter accuracy degradation (IHE Delft)



Corrupt practices meter readers

Meter readers that collude with customers (to record lower readings in exchange for money), may significantly impact a water companies billed consumption.

Data handling error and billing based on estimates

At each step between connecting and collecting revenue from the customer, data needs to be handled carefully. If a new customer is connected, the billing department needs to be informed, the customer should be added (with all correct meter and contact details) to the customer database, the reading should be recorded truthfully, the reading should be entered in the database correctly, etc. Mistakes in handling this type of data can hurt the utilities' billed consumption. When verifying consumption entries, one should pay attention for example to customers who continuously have a very low consumption, or for whom zero consumption is recorded. Analyzing this data (especially important for commercial users), can uncover faulty meters, illegal consumption, corrupt practices, or data handling errors.

Looking closely at the database in which meter readings are registered, one can find out what the rate of billing based on estimates is. It is important to check at what amount the estimates are put and how realistic they are, especially for commercial users.

3. DMAs and water quality

The creation of DMAs also helps water companies to prevent the degradation of water quality in the distribution network. By being able to close valves that border between DMAs, for instance when repairs need to be done, flow exchange and change of flow direction can be reduced. This will prevent sediment on the bottom of the pipes to be disturbed and contaminate the water. Each DMA should preferably have a water quality measuring point. Taking samples regularly and testing water quality will help to identify events or abnormalities, which will also help the asset manager to identify pipes or problem areas that need repair or replacement (for example, murky water may indicate cracks where water seeps into the pipes).

The next section presents more ways of finding out the causes of – and solutions to – NRW.

4. Steps to reduce and manage NRW

Reducing and sustaining NRW levels in the pilot DMA involves implementing activities pertaining to all categories of water losses (see **Figure 3**). The sequence of the proposed steps focusses on addressing 'quick wins' first (step 1 and 2); those entail relatively straightforward measures based on the results of the house-to-house customer survey, that can reduce NRW within a short period of time. Thereafter, some important medium – and long-term strategies are presented that are needed to meet NRW reduction objectives and that will also serve towards long term NRW management.

Look up the Best Practices document that presents methods that will help you with the planning, organization and execution of these steps.

1. Verify the customer database

After the house-to-house survey (see Section 3.1.4) has been undertaken:

- Verify all clients in the used customer database
 - Check if all customers are represented in the database and their information (such as name, address, phone number) is correct

- Correct wrong and add missing data
- Verify whether there are people in the database that are registered within the DMA but were not encountered during the survey
 - Double check these customers. Verify if (and why) they were skipped during survey
 - Clean up ghost entries
 - Inspect disconnected consumers and dormant connections.

These actions will reduce NRW by:

- Making sure all customers are known and billed
- Making sure all bills are delivered at the right address
- Minimizing water theft by verifying that disconnected customers are not consuming water illegally
- Minimizing theft by making sure dormant connections are not receiving water (again) without being reactivated in the database (and therefore not receiving bills)

2. Repair broken water meters and visible leakages

During the house-to-house survey, obvious technical problems in the field have also been reported (see Section 3.1.4), following up on that:

- Install water meters at connections without a meter
- Repair or replace meters at connections with a broken meter
- Repair installations that are leaking or incomplete (replacing or repairing valves, installing yard tap water meter constructions, etc.)
- If any other leakages (not at the consumer connections but for instance along the roads or at reservoirs) were noticed during the survey, these issues should also be solved

For most of these actions, materials should be readily available. However, this should be checked beforehand. Depending on the baseline situation (many leakages, many installations without water meter, etc.) these simple measures can cause a drop in NRW within a short timeframe.

The next few steps will require more planning and long-term thinking than the steps described above.

3. Testing and calibrating production and district meters

A key element for NRW analysis (and for all operations) is to know how much water the utility is producing and distributing. Production (outlet of production stations) and district (subdivisions of the complete network) meters should be calibrated on a regular basis (i.e. 3-monthly, 6-monthly intervals respectively). This calibration can be done using portable flow meters. Meters that are not working well should be repaired or replaced as soon as possible.

Testing and calibrating these meters does not directly reduce NRW, however, only by having reliable district meters water balance calculations can be validated and improved, and a proper NRW strategy can be adopted.

4. Testing customer meters

In Step 2, the repair or replacement of meters that are obviously not functioning has been advised. However, not all faulty meters are so easily detected. To reduce NRW further and to sustainably manage NRW, it is important to have a strategy in place on how to regularly test customer meters and repair or replace them if needed (depending on the costs). A company can decide to remove all meters that have metered over a certain amount and/or to organize regular sessions to test (old) water meters, either with portable meters or by doing a bucket test.

As faulty meters (dirty, aged, blocked) often under-register water consumption, implementing programs to actively find them out will support the management of NRW.

5. Active leakage management

Visible leakages

Active leakage management forms an important part of physical losses' management. For a water utility it makes sense to have staff active specifically as leakage surveyors. Leakage surveyors can make turns through the neighborhoods to see if they can spot any leakages themselves or find out about any through conversation with the residents. Either they can carry toolkits to make (small) repairs themselves, or they can notify the zone's technical assistance. Also customers and residents of the area can be used to gather information. A (free) phone number that people can call to report leakages (or other problems, such as illegal water use) can greatly help. In all cases, it is important that there is a good response on notifications on leakages, whether they come from utility staff or customers, so that people do not become demotivated to report.

Another simple and low cost measure to reduce and manage NRW is to check the reservoirs for overflow or leakage. Especially at night, when consumer demand drops to a minimum, reservoirs may overflow. Valves should be closed (either manually or automatically) when the reservoir has been filled.

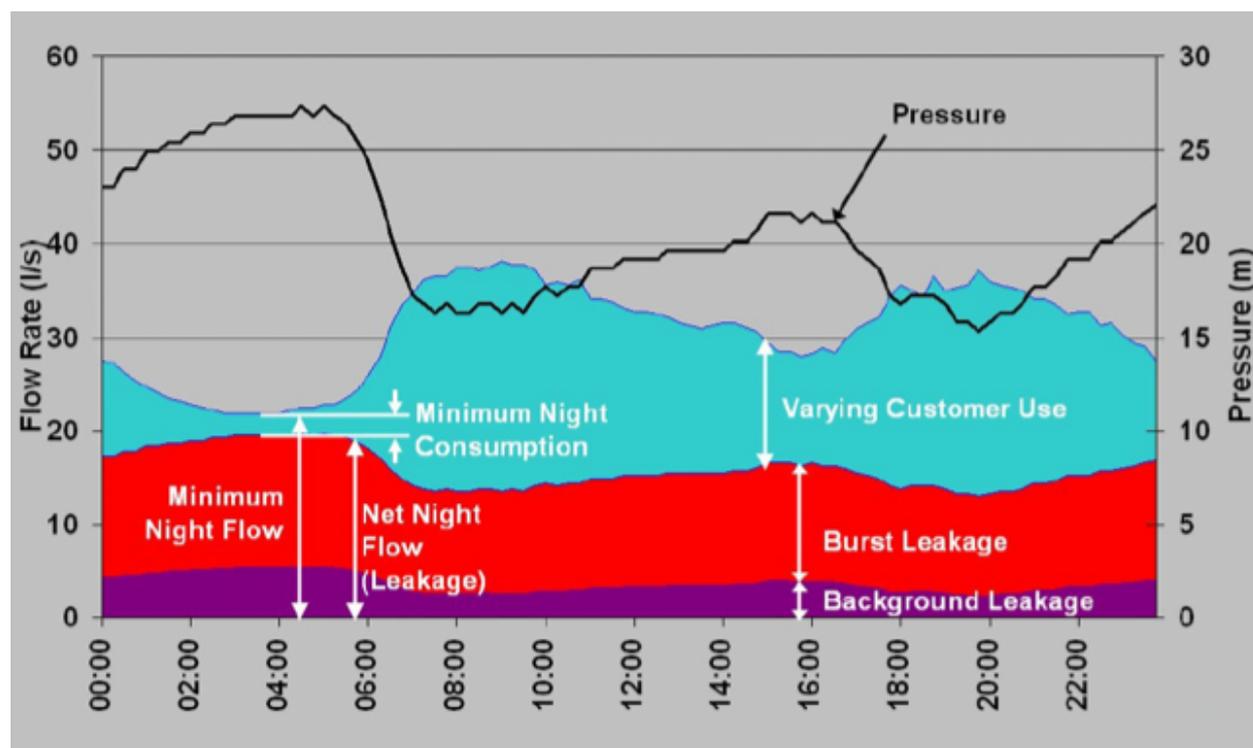
Quantifying and localizing invisible leakages (night flow measurements)

Depending on the type of soil (very permeable or not, very wet or not), water leaking from supply or distribution pipes, may or may not come to the surface and become visible for passers-by. For obvious reasons, localizing invisible leakages is more complicated than localizing visible leakages.

Undertaking Minimum Night Flow (MNF) measurements is a method used to quantify the invisible leakages. For MNF the flow into a DMA or DMA branch is measured when most consumers are asleep (i.e. between 2 and 4 a.m.) and consumption has dropped to a minimum. If the apparent water consumption in the area during that time is higher than the expected 'background flow' (i.e. usage by those few people awake and storage tanks that may be filling up), this indicates leakage. Daily monitoring of DMA consumption levels, or, if water supply is irregular, weekly consumption levels, can also serve as a leakage warning tool.

The next challenge is to then localize this leakage. There are different techniques with which this can be done:

- Step-testing: isolating portions of the network with (portable) water meters, and checking them for leaks
- Using leak noise correlators and/or ground microphones (the latter at night when there is not too much background noise) trained staff will be enabled to pinpoint leakages



Improvement of leakage registration

Another example of active leakage management is the registering of leakages. By recording installation date, time and location of leakage occurrences (for instance in GIS) helps to analyze the quality of the network and repairs. In this way, indications of too high pressure can be found (see step 7), problematic pipes can be identified that need structural replacement, and possibly uncover teams that perform installation or repair work of insufficient quality.

Preventing leakages

Besides repairing leakages, there is a lot that can be done also to prevent leakages. Some of these measures are introduced in step 6, 7 and 8.

Preventing leakages and repairing them quickly and skillfully greatly helps towards NRW reduction on the short as well as long term. Doing active leakage surveys will greatly increase the response time to leakages.

6. Improve the quality of materials, installations and repairs

(Recurrent) leakages are often caused by a combination of factors. In the sections below we will elaborate on pressure and asset management.

Quality of material

If a water company economizes on materials, they often end up with class C (or lower) PVC pipes that wear quickly and are susceptible to rupture under high pressure. However, the use of HDPE (better quality/durability than PVC and fewer fittings) is quite standard especially for service connections. It is advised to always buy materials from ISO accredited (or equivalent) manufactures

To change procurement policies and incite companies to make higher investments in their materials, a business case should be presented that compares the CAPEX and OPEX in case of high versus low quality materials.

Quality of installation

If for example an installation is made at too shallow depth or if back-filling is poorly done, pipes may be damaged by crossing traffic or erosion. Other examples are the installation of so-called spaghetti networks and not using tension-proof connections in pipe bends. For both quality of installation and repair, attention to the plumbers is needed. The plumbers should receive regular (refreshment) trainings and their work should sometimes be verified by more senior technical staff.

Quality of repair

If repairs are done without adequate materials or knowledge, they will soon reoccur. Classic examples of poor repairs include:

- Using bicycle tire to fix leakages
- Using poor quality PVC connections and/or working without appropriate fittings
- Abstaining from closing valves before doing repair work (possibly because no valves are there) and gluing under wet conditions

As mentioned above, plumbers should receive regular (refreshment) trainings and their work should sometimes be verified by more senior technical staff.

7. Pressure management

There is a close relationship between applied pressure and the leakage flow rate. Depending on the material of the pipe, the approximate relationship is about 1:1, meaning a 10% increase of pressure, will cause a 10% increase of leakage. Therefore, to reduce NRW to a minimum, it is important to gauge the pressure, see where (and when) it is higher than needed and reduce the pressure by limiting the exit pressure at pumping stations and/or by installing Pressure Reducing Valves (may be needed especially in mountainous areas).

8. Asset management

Many water utilities act according to so-called 'fire-fighting': the continuous solving of problems that occur instead of undertaking activities to avoid problems that may occur in the future. At first glance it may seem economical to only solve problems that you already have, as preventive maintenance will cost money (for time and materials). However, it is a lot more expensive to solve a problem than to prevent it. A good preventive maintenance strategy will save a utility money and work, and will improve customer satisfaction by having less interruptions in water supply and less fluctuations in water quality. Part of the asset management strategy is having a structured way in which to send out work orders to technical staff to check the status and clean assets (such as valves, meters, pumps, hydrants, measuring points) on a regular basis. There are software tools on the market that can help with assessing assets, setting up maintenance plans and distributing work orders.

For an asset management framework, see Chapter 5.II of the Practical Tools for NRW Reduction and Management.

9. Reducing unauthorized consumption

- Finding and reducing illegal connections and meter by-passes
 - Field visits and customer awareness programs
 - Meter by-passes of commercial users if suspected to be investigated on premise

- Illegal use of fire hydrants. If water gets stolen through fire hydrants, this often is done in large volumes at night, which should be detectable by the utility.
 - Customer awareness programs
 - Cooperation with local agencies to identify owners of tankers that are suspected of theft and penalizing perpetrators
- Avoiding corruption by meter readers
 - Rotation scheme

10. Managing authorized unmetered consumption

Billed unmetered consumption

The danger with billed unmetered consumption is that customers may start to sell water and therefore consume a lot more than projected. This type of practice may be discovered during surprise visits to these houses, or when checking if there are large tanks on the premise. However, best is to avoid such situations by installing water meters.

Unbilled unmetered consumption

There are some consumers that will not pay for water. These might be public agencies that water parks, fire fighters or governmental buildings. Even though these consumers remain unbilled, it is better to meter these connections as well, as it will help the understanding of where the water flows.

11. Reducing data handling errors

- Meter reading errors, either by mistake or on purpose
 - Awareness program for meter readers and data analysts on the importance of reading the meter correctly and verifying data respectively
 - Get rid of old meters that are hard to read. Awareness program for meter readers and maintenance team to report and solve such technical issues
 - Avoid corruption, for instance by putting the meter readers on a rotation scheme (changing their working area every so many months)
 - There are technologies available on the market with which meters can be read for instance with a smart phone (this will not necessarily eliminate all data errors, but will definitely make corruption more difficult)
- Billing data errors, such as wrongly transferred meter data or bills sent to the wrong address
 - Awareness program for the billing department on how to analyze and verify data
 - Awareness program for staff that goes out into the field to deliver bills to report back when people are continuously not found (on the registered address) or the gate is always locked
 - Actively keeping the customer database updated

12. Collection efficiency and debt management

As mentioned in the introduction, in many developing countries the collection efficiency plays a large role in the monthly revenue of water utilities. With collection efficiency the ratio between the amount of water billed and the amount of water paid for is meant. Although the collection efficiency is not part of the IWA definition of NRW, it is a very important issue to take into consideration when implementing a NRW strategy as cash always counts. Therefore, it is advised to actively engage with customers that are not paying and have a debt. There are a number of elements that should be looked into:

- Reach out to all customers with debt and, depending on the height of debt, how long it has been standing for and how many warning they already had, disconnect them or give them a deadline for payback
- This activity requires the team to pro-actively engage 'gate-locked' consumers through phone/SMS/email and (subsequently) disconnect non-compliant consumers
- In developing countries debt management issues may become ethical questions: is someone not unwilling but unable to pay? Ways to deal with such issues could be to:
 - Work out a payback scheme with the customer. Instead of disconnecting the customer if the debt is not paid before next month, it could be agreed the customer pays off a little bit every month over a longer period (say 6 months or a year)
 - Depending on the situation of the customer and the utilities' policy, the debt can be pardoned. This would not lower NRW but would close the case and reduce the value of VAT to be paid by the utility
- Look at the number of clients that receive bills based on estimates and see if water meters can be installed. Billing based on estimates can encourage customers to tap as much water as they like and sell it to other people
- Pre-paid meters are often expensive and many water utilities can't afford to install them to the largest part of their customers, however, with infamous clients (and especially those that are large water consumers) it might prove beneficial to install them

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