water and sanitation

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Water and Sanitation
REPUBLIC OF SOUTH AFRICA

Guideline for the preparation of an IWA water balance to determine Non-revenue Water and Water losses

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbol or abbreviation	Definition
DWS	Department of Water and Sanitation
ILI	Infrastructure Leakage Index
IWA	International Water Association
KPI	Key Performance Indicator
NRW	Non-Revenue Water
SIV	System Input Volume
UARL	Unavoidable Annual Real Losses
CARL	Current Annual Real Losses
UFW or UAW	Unaccounted for Water
WC/WDM	Water Conservation and Water Demand Management
Consumer	A **consumer** is a person or group of people (household) that are the final users of products and or services generated within a social system.
Customer	A **customer** (also known as a client, buyer, or purchaser) is the recipient of a good, service, product, or idea, obtained from a seller, vendor, or supplier for a monetary or other valuable consideration.
Deemed or flat rate consumption	**Deemed or flat rate consumption** is an unmetered fixed volume of water sold to a customer on a monthly basis. Customers are deemed to use this volume of water but the actual consumption may be more or less.

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INTRODUCTION

Background

The National Development Plan (NDP) makes reference to the need for vigorous Water Conservation and Water Demand Management (WC/WDM) programmes to ensure that the national and regional water loss reduction targets are met in view of the water scarcity challenges facing the country. These challenges are multi-dimensional in nature ranging from limited resource availability to limitations in access due to inappropriate infrastructure management and maintenance. Furthermore the NDP makes mention of the need for a dedicated national WC/WDM programme which will assist in setting progressive water loss reduction targets for 2017 and 2022, thus highlighting the critical requirement of sound management information upon which to make prudent decisions regarding the future and strategic options for sustainable water supply in the country.

The South African Water Services Act (Act 108 of 1997) requires all spheres of Government to ensure water services are provided in an efficient, equitable and sustainable manner which is sufficient for subsistence and sustainable economic activity. This can only be achieved through a proper understanding of the system input volume, authorised consumption, water losses and non-revenue water of all urban and rural potable water distribution systems.

It is against this backdrop that Non-Revenue Water management and its emergent fiscal implications take centre stage in order to ensure water availability for the required socio-economic development, which will aid in alleviating poverty, improving the economy and job creation whilst simultaneously achieving environmental sustainability as set out in the core objectives of the National Water Resources Strategy (NWRS 2). The management of water resources, and in particular potable water, is however a cross cutting function which is as much about technical and operational capacity as it is about healthy fiscal decision making processes and consumer sentiment. NRW management thus becomes a crucial and telling indicator of the state and health of municipalities which have been given the mandate to manage and take responsibility for the provision of services. As autonomous institutions, municipalities are also required to be self-sustaining and to operate on firm business principles whilst making provision for poor and vulnerable communities. The institutionalisation, measurement and standardisation of NRW management is therefore aimed at helping to achieve the overall objective of self-sufficient municipalities which have the financial, technical and resource capacity to provide good quality water services.

The International Water Association (IWA) has developed the standard water balance to evaluate the performance of water distribution systems and it is being promoted across the world as best practice. The IWA standard water balance was slightly modified for South Africa to allow for free basic water. The modified IWA water balance is shown in **Figure 1**.

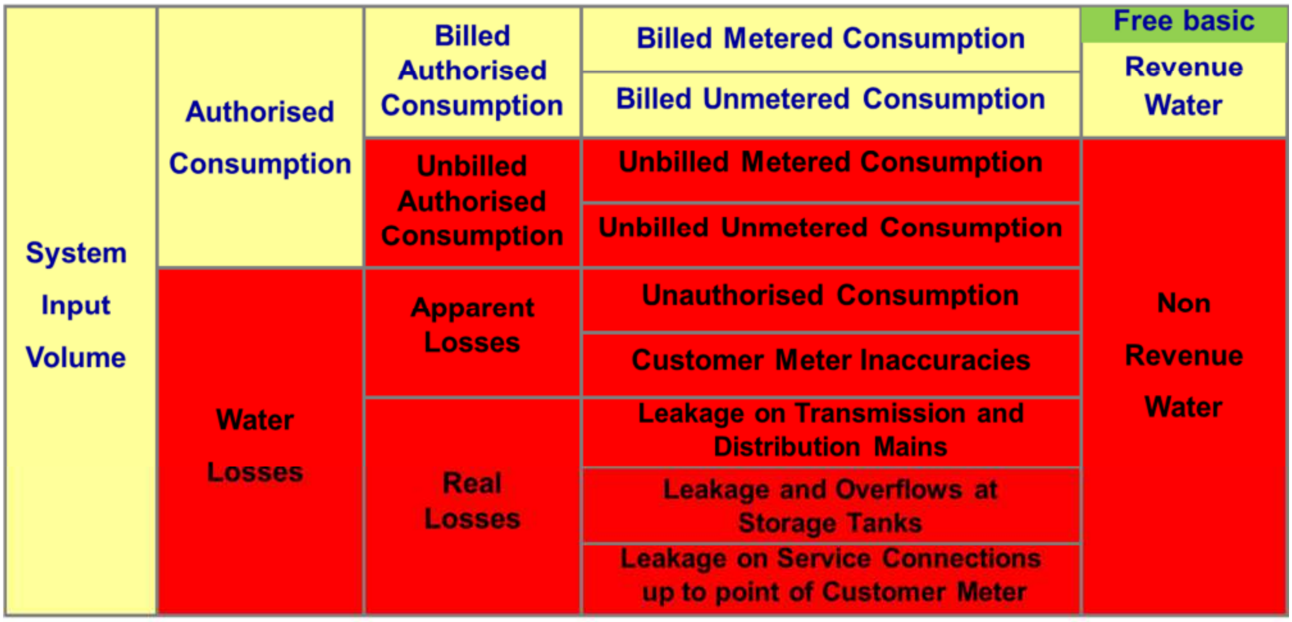


Figure 1: Modified IWA water balance

Although the IWA has gone to great extents to standardise the water balance calculations and terminology, there still remains considerable confusion and opinions on how to deal with certain aspects of the water balance calculation. The purpose of this guideline is to provide a clear understanding on the water balance calculations and terminology in order that all municipalities could be benchmarked on the same grounds.

Considerable effort has been made to establish long term partnerships and effective channels of communication between departments responsible for water management in all its facets at the national, provincial and local government levels. The financial management and viability of water service provision features prominently in these endeavours as a key component of the IWA NRW water measurement methodology. National Treasury has in recent years become increasingly vocal and concerned about municipal budget expenditure and management when it comes to water and is introducing measures to be implemented in the near future on budgeting methodologies and auditing approach. The introduction of the Standard Charter of Accounts (SCOA) by National Treasury is in the horizon for all municipalities and is based on a transparent and auditable budgeting. National Treasury is unequivocal and non-ambiguous on its stance that municipalities must implement proper budgeting methodologies which have a clear link to the IDPs and other standard reporting requirements and demonstrate consistency and coherence in the figures presented in all municipal financial documentation. More importantly National Treasury insists on the expenditure of funds on the items for which the funds are allocated and that this expenditure be substantiated or justified by concrete auditable outcomes and outputs. It is the clear intent of this department to become the custodian of all municipal financial information and this information will form the foundation upon which the NRW management specifically the billed consumption (revenue water) information will be derived.

The purpose of this guideline document is not to discuss all the technicalities of the water balance calculation but rather to standardise the water balance calculation for the whole country and provide a guideline which can be used and understood by politicians, municipal officials and customers. Section 1 provides guidelines on the information required and theory behind the water balance whereas Section 2 provides practical examples of differing complexity.

Water services authorities are encouraged to prepare a water balance that best reflects their current water loss and non-revenue water situation. Preparing a water balance that looks good on paper should at all costs be avoided as problems cannot be addressed if they are "hidden" somewhere in the calculations.

Implications of water demand management and the water balance

Water conservation and water demand management could influence the:

- Available water resources that are under pressure and are highly influenced by population growth, short and long term climate change, economic trends, water quality, environmental considerations and huge cost to develop, operate and maintain new infrastructure;
- Financial sustainability of the water utility if proper metering, billing and cost recovery is not properly implemented;
- Water security if the water demand exceeds the reliable supply;
- Excessive leakage often results in deteriorating and inequitable level of service. The result of such leakage is usually intermittent supply and rationing as the water authority cannot pressurise the bulk supply. Intermittent supply can result in water borne diseases as contaminants are sucked into the pipeline during drainage.

Repairing leaks will reduce physical losses

- Water supply infrastructure assets which are not maintained will result in poor service delivery and increased leakage;
- Impacts on the micro environment by creating unnatural wetlands, breeding ground for mosquitos and health hazards to the community;

- Impacts on the macro environment by having to construct augmentation schemes such as large dams;
- Reduced production, pumping, pipe failure and chemical costs with subsequent reduced greenhouse gasses; and
- Reduce the impact of severe droughts and climate change.

The water balance gives a clear indication of the water supply and demand of a system. The supply is the volume of potable water supplied to the system while the demand is the volume authorised consumption which could either be metered or unmetered and billed or unbilled. The difference between the supply and demand provides an indication of the water losses and non-revenue water of a water distribution system.

Legal requirements

Non-revenue water and water loss calculations are required under the Regulations relating to Compulsory National Standards and Measures to Conserve Water (R509 of 2001) under the Water Services Act (Act No. 108 of 1997). The aforementioned regulations require the following:

- Clause 10 states that a water services authority must include a water services audit in its annual report on the implementation of its water services development plan required in terms of section 18(1) of the Act;
- Clause 11 states that a water services institution must prepare a water and effluent balance analysis and determine their water losses by comparing the measured quantity of water provided to each supply zone with the total measured quantity of water provided to all user connections within that supply zone; and
- Clause 13 states that a water services institution must, within two years after promulgation of these Regulations, fit a suitable water volume measuring device or volume controlling device to all user connections provided with water supply services.

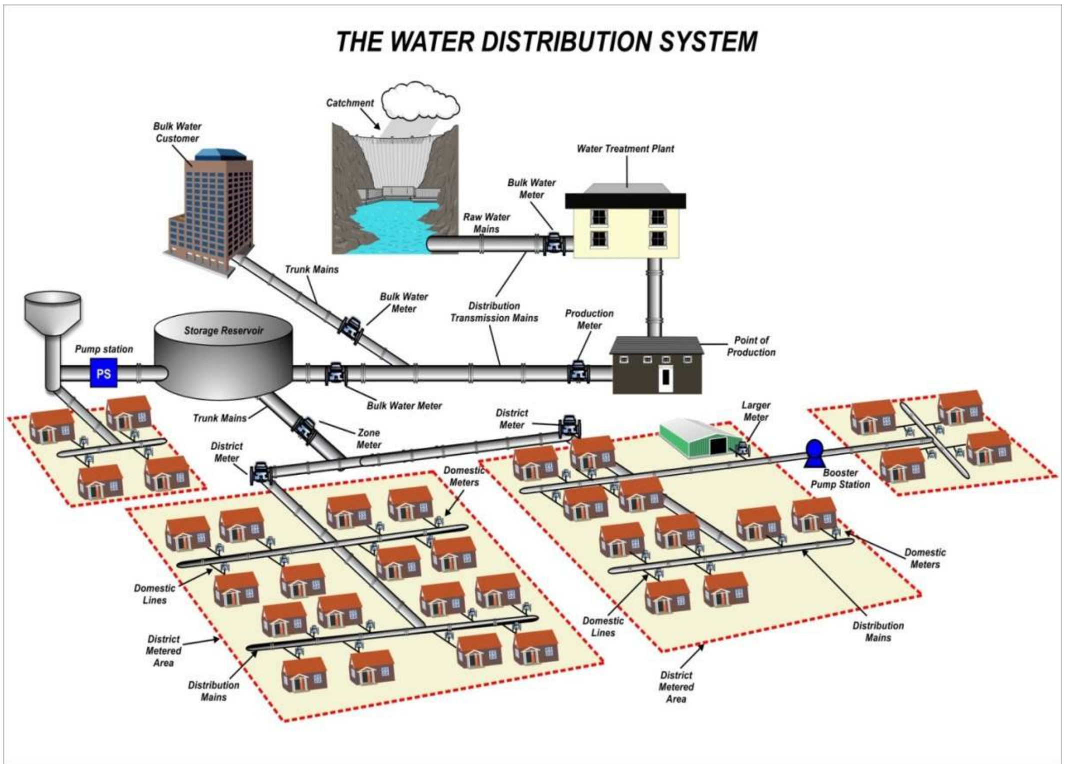
The Regulations Relating to Compulsory National Standards and Measures to Conserve Water (R509 of 2001) are included in the Department's No Drop incentive based regulatory system to improve service delivery and water security and to reduce water losses and non-revenue water.

Water Distribution System Terminology

Key components of the water distribution system are shown in the figure below.

- **Water sources** include springs, wells, boreholes, rainwater, surface water – rivers and dams, bulk-supply pipelines or a combination of these;
- **Water treatment plants** are used to treat raw water to acceptable standards for domestic and non-domestic consumption.

- **Bulk water transmission main systems** are used to transmit raw or potable water, are often long and of large diameter and are designed to supply water at the average demand flow rate. Usually there are no consumer connections on a bulk water transmission pipeline.
- **Storage reservoirs** provide balancing storage to meet daily demand, emergency storage for interruptions in bulk supply and firefighting.
- **Storage towers** serve high-lying areas adjacent to the reservoir, provide emergency storage for interruptions in supply and balancing storage for pump operation.
- **Pump stations** are required to boost pressures in transmission mains and to supply towers when natural pressures are too low.
- **Bulk distribution mains** feed from reservoirs into the reticulation and are usually the biggest pipes in the system because they are sized for peak flows.
- **Reticulation** is the network of pipes (150 diameter and smaller) which connects the system to individual consumers, the network has service valves for maintenance and hydrants as required for firefighting.
- **District metered areas** are setup to enable effective management and monitoring of system losses.
- **Consumer connections** are subject to a Service Agreement between the consumer and the utility. The connection (saddle, lead, stop tap and meter) is part of the reticulation system and belong to the utility whereas fittings on properties (after the meter) belong to the consumer and are their responsibility.



WATER BALANCE BASIC INFORMATION REQUIRED

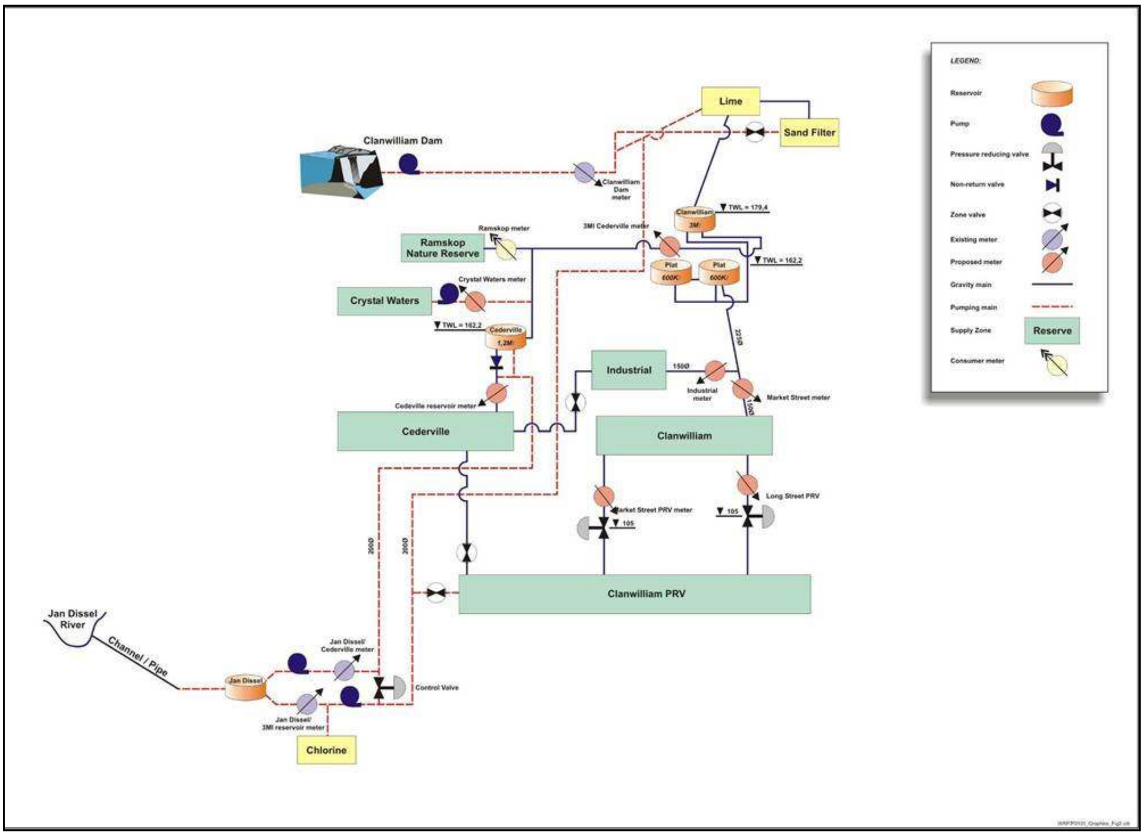
Certain basic information is required to prepare a water balance. Most of the information required should be provided by the engineering and finance departments of the municipality and it is important that these departments work together to develop a single water balance which accurately reflects the volumes of water distributed to the consumers and not a department specific water balance which gives different answers. Information used in the water balance should be the same as presented in the Integrated Development Plan (IDP), Water Services Development Plan (WSDP), annual report, and other official documents.

The water balance calculation should be based on traceable and credible information which could be verified during an audit. Credible and verifiable information includes monthly bulk or consumer meter readings and official reports from the municipal billing system to justify billed metered and unmetered consumption.

Supply area and schematic

A water supply system is defined as an area with defined physical water infrastructure including but not limited to pipes, valves, meters and potable water storage facilities such as reservoirs or boreholes, for which the system input volume and authorised consumption could be measured and a water balance prepared. A water supply system could be any size and made up of several smaller water supply systems. The sum of several smaller water supply systems should add up to the water balance for the whole water services provider's (WSP) or water services authority's (WSA) supply area.

To enable management of these systems, the engineering department should develop a layout drawing of the supply area supported by a schematic layout. The infrastructure should be recorded in a comprehensive asset register which can provide information pertaining to the age of infrastructure, replacement due dates and the replacement value of the infrastructure.



Typical schematic layout drawing

Population, households and properties served

The population and households served should be obtained from a reliable source such Statistics South Africa (StatsSA) Census 2011 data. StatsSA data is considered the official source of demographic information by the Department of Water and Sanitation, and any deviation from StatsSA data must be verified.

The number of properties should be equal to the number of registered properties on the cadastral CAD or GIS system. It is accepted that many municipalities do not have updated cadastral information but do have a list of registered properties which can be audited. For the purposes of a water balance calculation both households and properties are important data elements which aid in providing a holistic picture in terms of the functioning of the water system.

Number of connections

Billed metered and unmetered connections

Double meter box considered as two connections

A billed metered or billed unmetered connection is defined as a connection which may or may not have a meter, for which an account is issued by the water services utility based on actual metered or deemed (flat rate) consumption. It is accepted that there might be more than one consumer on a property, multiple connections per account or a connection which supplies more than one property, however this should not have a significant impact on the overall result. A townhouse development is a good example of a single account and water connection. Taking into consideration the physical complexities of connections in differing water supply systems, for the purposes of this document, the number of water accounts has been adopted as the auditing tool to determine the number of connections as this can easily be audited and obtained from the municipal billing system.

If there is an informal township development, the number of connections should be equal to the number of yard connections or public standpipes. The number of yard and public standpipe connections should be obtained from the engineering section and audited during field investigations. These connections receive free basic water and form part of billed metered or unmetered consumption (billed at a zero rate) although it is accepted that the municipality will not send out bills for zero rand.

Unbilled metered and unmetered connections

An unbilled metered connection is defined as a connection on which a meter has been fitted and read or estimated at the intervals determined by the utility for which no bills are produced. Ideally any metered connection whether billed or unbilled should be read consistently on a monthly basis in order to establish a solid and accurate management information foundation upon which to calculate the water balance.

A unbilled unmetered connection is defined as a water connection installed for a consumer, which is not metered or billed by the utility. In an efficient system with a high level of service, these connections should be very few or negligible as they contribute significantly to NRW if allowed to increase by the utility.58

Length of mains

The length of mains, measured in kilometres, is the total length of pipe that supplies potable water to customers and is obtained from the municipal asset register, GIS or CAD systems or as-built drawings.

Long sections of transmission mains should be excluded from the length of reticulation

If the length of mains is not available, it can be estimated by dividing the average number of connections per kilometre with the total number of connections. In South Africa there is an average of 50 connections per km of mains for most urban areas. The estimated number of connections per km can also be calculated using the formula below.

$$Estimated\ number\ of\ connections\ per\ km = \frac{1000 * 0.9 * 2}{Average\ length\ of\ property\ street\ front\ (m)}$$

Using the formula above will provide the following results:

Average property size (m^2)	350	1000	2000	3000
Average length of property street front (m)	15	25	36	45
Expected number of connections per km	120	72	50	40

Some municipalities are supplied from boreholes which are long distances away from the main distribution area. If these transmission mains are more than 20% of the total length of mains, it should be excluded from the length of mains as it has no connections and distorts the key performance indicators. These long truck mains should rather be analysed separately to determine bulk transmission losses. This can be done by subtracting the flow on the outlet meter at the potable water supply source and the inlet meters to the zones supplied by the trunk mains.

Bulk water supply

The bulk water supply is the total volume of potable water supplied to the system from rivers, dams, springs, boreholes and bulk water service providers. All these supply points should be metered and monitored on a continuous basis.

Metered consumption

Metered consumption is the total volume of potable water supplied to consumers based on actual meter readings or estimated consumption at accepted intervals determined by the utility. Meter readings are usually managed by the finance department, and ideally performed on a monthly basis and captured on the municipal billing system. Metered consumption is calculated by subtracting the meter reading for this month from the previous month or estimating consumer consumption based on patterns of historical consumption. Metered consumption is considered billed whenever the municipality prepares an invoice for payment.

Unmetered consumption

Unmetered consumption is the estimated total volume of potable water supplied to a consumer based on a predetermined deemed consumption. This can also refer to RDP level of service where a utility provides communal connections at distances of 200m or less from the dwellings or properties. Billed unmetered consumption is managed by the finance department and is based on the predetermined deemed consumption. In a best practice scenario, the deemed consumption should be measured at a zone meter and divided by the number of households in the zone in order to determine accurate deemed volumes. The deemed volume should also be clearly communicated to consumers and recorded in service level agreements in order to control and manage these volumes and prevent them from unreasonable escalation. It has been found that in areas where water use is not metered or is billed based on deemed consumption, the volumes used far exceed the estimated consumption. Whilst it is accepted that in certain systems, it is not feasible to meter and bill each connection, some alternative form of volume control is necessary in order to ensure sustainable water supply. Such control mechanisms can vary wide and can include volume restrictors, or extensive education and awareness as a first step to make people aware of the need to save water.

Average system pressure

The average system pressure is the average operating pressure of the reticulation network. The average operating pressure could be obtained from a hydraulic network analysis, logging results, or spot pressure readings. In a well managed system, the operating pressures can be obtained from the utilities water master plan. In the absence of such a management system, the engineers should at least be able to provide schematics or some form of pressure monitoring records.

Intermittent supply and time pressurised

Water distribution systems should at all times be pressurised but if this is not the case, the system input volume and authorised consumption must be adjusted accordingly to ensure key performance indicators are not distorted. For example, the table below illustrates the impact of supplying 10million m^3/annum to a population of 100 000 over 365 days (100%) and 200 days (60%) respectively.

System input volume (m^3/annum)	% time pressurised	Population served	Litres / capita / day
10 000 000	100% (365 days)	100 000	274
10 000 000	60% (200 days)	100 000	475

Intermittent supply should at all costs be avoided for the following reasons:

- During system drainage, negative pressures inside the pipeline will damage the pipe seals which were designed for positive pressures. Continuous negative and positive pressure fluctuations will damage pipe seals to such an extent that they can only be repaired by total replacement of the network.
- During system pressurisation, the air in the pipelines dissipates through the consumer water meters. Air passing through a water meter will damage the mechanism, as the air causes the meter to spin excessively which exceeds the maximum flow rate of the meter. The air passing through the meter also distorts the meter readings as the consumption is in actual fact air.
- The negative pressures inside the pipeline, during system drainage, will suck any contaminants (sewer, soil, storm water, chemicals, etc.) into the pipeline which can cause water borne diseases such as cholera and typhoid.
- Water distribution systems are designed for stable pressures and continuous drainage, and pressurisation will increase burst pipes, operational problems, overtime claims, consumer dissatisfaction and general disruption in supply.
- Isolating valves in water distributions systems are not designed for daily operation and will inevitably get damaged over time when improperly operated.. This will increase maintenance cost.
- If the water supply becomes uncertain, consumers will start leaving taps open and wait for the water to fill buckets, baths and tanks. Once consumers start leaving taps open, it becomes increasingly difficult for the water services teams to fill reservoirs and pressurise the system.

  Service delivery will become worse with an increasing reluctance to pay for services.

Isolating valve which had to be replaced after continuous opening and closing

Non-revenue water management has become a regulatory requirement which has inspired the development of the DWS No Drop System. As such, the information supplied must come from credible verifiable sources of information in order to protect the integrity of the information used for decision making purposes. Table 1below summarises the data elements required as inputs into the water balance calculations and the audit requirements for each element. These sources should be continuously updated and maintained in order to make it easy to compile the water balance on an annual or monthly basis.

Table 1: Summary IWA water balance information input requirements

Water Balance Input Information Requirements	Definition	Information Sources/ Audit Requirements
Demographics (Population + Households)	Population and households served with potable treated water	StatsSA Census data
Number of properties	Number of registered properties.	CAD/ GIS system
Number of connections	Number of connections installed and registered by the municipality. 1 connection = 1 customer =1 account	Record customer connections on municipal billing system
Length of mains	Total length of distribution pipe that supplies potable water to customers	Length of mains as captured on Municipal Asset register/ GIS/ CAD system or as built drawings.
Average system Pressure	Average operating pressure of the network	Municipal water master plan/ reticulation drawings
System input volume	Total volume of potable water supplied to the system from rivers, dams, springs, boreholes and bulk water service providers	Record of monthly bulk meter readings taken from the outlet of water treatment plants.
Billed metered consumption	Water connection fitted with a meter and linked to a customer account which is billed. Account can be based on actual or deemed consumption	Municipal billed accounts. Periodic customer meter audit verification is also recommended.
Billed unmetered consumption	Fixed volume of water for which a bill is issued by the utility. This can refer to deemed consumption and/or free basic water.	Volume of billed consumption captured on the municipal billing system as fixed volume charge accounts.
Unbilled metered consumption	Volume of water used for municipal parks, road islands, fire-fighting, municipal gardens and public facilities.	Unbilled metered accounts recorded on the municipal billing system
Unbilled unmetered consumption	Volume of water used for fire-fighting, flushing of mains and maintenance of water infrastructure	Field investigation documentation with expected volumes used in each of the listed activities.

BASIC COMPONENTS OF THE WATER BALANCE

IWA water balance

The modified IWA water balance, with the free basic water component included, is shown in **M**, and is described in the following paragraphs. The water balance calculations are very easy if the system input volume and authorised consumption volumes are known. Once these two values have been determined, any of the other indicators can be calculated through simple arithmetic.

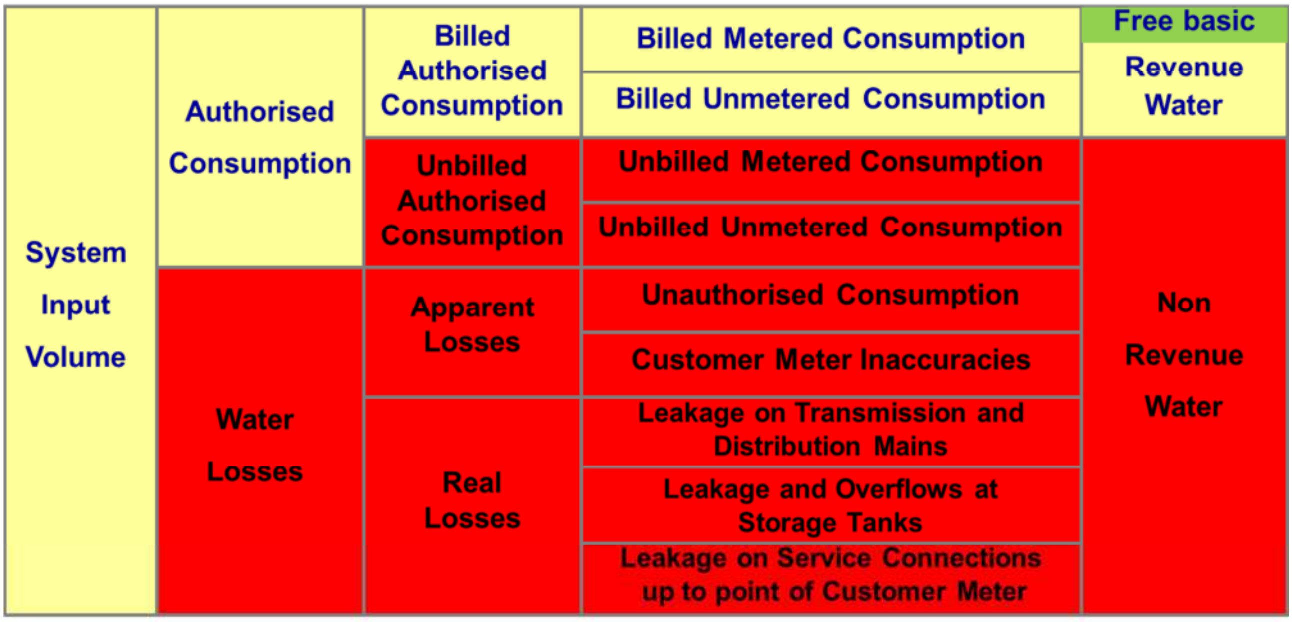


Figure 2: Modified IWA water balance

Key considerations

The following key issues should be taken into consideration during the water balance calculation:

- The water balance is based on the potable water supplied to the system and does not make allowance for water treatment losses. Water treatment losses are typically between 5 and 10% of system input volume and must not be included in the water balance.
- Free basic water is considered billed metered or unmetered consumption, billed at a zero rate, and forms part of the billed consumption and revenue water. Care must be taken not to duplicate free basic water where it has already been included in the billed consumption.
- Billed consumption is considered to be the consumption for which an invoice is issued by the municipality to the consumer. Revenue water refers to the volume of water for which revenue should be received, and can be “Billed Metered” as well as “Billed Unmetered” water. The issue of payment of the bill is not addressed under the water balance as this is considered to be a cost recovery (legal) issue and not a technical water balance issue.

- NRW water is becoming the standard term replacing unaccounted-for water (UFW or UAW) in the water balance calculation and is the term recommended by the International Water Association in preference to UFW. It is a term that can be clearly defined, unlike the unaccounted-for water term which often represents different components to the various water suppliers.

System input volume

The system input volume (SIV) is the volume of potable water supplied to the water supply system and is calculated as follows:

System input volume =

Potable supply from water treatment plant (sum of meter/s on plant outlet)

+ supply from bulk or other water services providers (sum of meter/s used for billing purposes)

+ supply from boreholes, springs, fountains if not supplied through water treatment plant (meter/s on each borehole or bulk supply point)

The system input volume should be obtained from the engineering department.

Authorised consumption

Authorised consumption is the volume of metered and unmetered water used by registered customers, the water supplier and others who are implicitly or explicitly authorised to do so by the water services authority, for residential, commercial and industrial purposes. Authorised consumption can only be metered or unmetered and billed or unbilled. All consumption within the municipal system must fall within one of these four categories otherwise it should be considered part of water losses. Authorised consumption is determined as follows:

1. Does the consumer have an official water connection or access to a public standpipe?

   Yes = Authorised consumption → Metered or unmetered connection
   No = Unauthorised consumption → Commercial losses (provided consumers have some form of formal access to water available)

2. Is the connection point metered?

   Yes = Metered connection → Provide monthly meter readings/ estimated consumption on billing system on each account
   No = Unmetered connection → Provide monthly deemed consumption figures

3. Does the consumer receive a water bill?

   Yes = Billed consumption → Provide monthly bills distributed to consumers
   No = Unbilled consumption → Consumer does not receive a monthly bill

Table 2 shows three examples of how to assess whether it is authorised consumption.

Table 2: Examples to assess authorised consumption

Scenario	Metered standpipes installed by the WSA (RDP level of service).	Unmetered house connection installed by the WSA. Deemed / flat rate consumers.	Metered house connection installed by the WSA but not captured on billing system.
Authorised connection?	Yes and the consumer is authorised to use the total free basic water allowance, for example, 6kl/month.	Yes and the consumer is authorised to use a deemed consumption of, for example, 20kl/month.	*Yes.
Metered	Yes	No	Yes but not read
Billed	Yes. Free Basic Water is billed at a zero rate but the WSA is most probably not going to send a zero bill to its customers.	Yes. Consumer is billed 20kl/month irrespective if it is used or not.	No. Consumer not captured on billing system.
Water Balance Category	Billed metered consumption. Any consumption in excess of the 6kl/month is considered unauthorised consumption and should form part of the water (commercial) loss provided that this fixed authorised consumption is communicated and captured in a service level agreement. If not, it forms part of unbilled unmetered consumption.	Billed unmetered consumption. Any consumption in excess of the 20kl/month is considered unauthorised consumption and should form part of the water (commercial) loss provided that this fixed authorised consumption is communicated and captured in a service level agreement. If not, it forms part of unbilled unmetered consumption.	*Commercial losses The intension was to meter and bill the consumer. If this does not materialise, it is considered metering and billing inaccuracies and forms part of water losses.

Billed metered consumption

The billed metered consumption volume is the actual metered volume of water provided to the customer, through a metered connection which should be read and billed on a monthly basis. This volume will already include the free basic water component and should not be added again.

Water exported to neighbouring municipalities' forms part of billed metered consumption as these consumers are authorised to use the water, supplied through a metered connection which should be read and billed on a monthly basis.

Water used by municipalities for parks, swimming pools, etc. which is metered and billed internally between departments is also considered billed metered consumption although payment will happen through journal entries. These departments are expected to budget and "pay" for water.

The billed metered consumption is obtained from the municipal billing system.

Domestic metered connection

Billed metered consumption =

Metered water supply and billed to consumers inside the municipal supply area

\+ Metered water supply and billed to customers outside the municipal supply area (if applicable)

\+ Metered water supply and billed to internal municipal departments (if applicable)

Billed unmetered consumption

In formal areas, the billed unmetered consumption volume is the deemed volume of water which the consumer is authorised to use, supplied through an unmetered connection which cannot be read on a monthly basis, and the consumer is billed based on a deemed consumption. Flat rate or deemed consumption will already include free basic water and should not be added again. Ideally, areas billed on deemed consumption should be monitored through zone meters and the estimated consumption should be based on the supply going into the zone as opposed to a purely theoretical estimate.

In informal areas, the billed unmetered consumption volume is the deemed volume of free basic water supplied to customers which includes yard and public standpipe connections. Although it is accepted that bills are not usually sent to these customers, they are still entitled to free basic water and technically the municipality should send them a zero bill for their free basic water component.

Leakage from an uncontrolled public standpipe

The billed unmetered volume supplied to formal areas is obtained from the municipal billing system while the volume supplied to informal areas is usually calculated based on information obtained from the engineering department.

Billed unmetered consumption =
  Unmetered and billed deemed water supply to consumers in formal areas
+ Unmetered and billed deemed water supply to consumers in informal areas

Unbilled metered consumption

The unbilled metered consumption volume is the volume of water which the consumer is authorised to use, supplied through a metered connection which is read or estimated on a monthly basis but consumers do not receive a bill. These consumers typically include the municipality's own use such as parks, buildings and swimming pools.

This volume is obtained from the municipal billing system.

Unbilled metered consumption =
  Metered water supply and unbilled to consumers inside the municipal supply area
+ Metered water supply and unbilled to customers outside the municipal supply area (if applicable)
+ Metered water supply and unbilled to internal municipal departments (if applicable)

Unbilled unmetered consumption

Unbilled unmetered consumption typically includes fire-fighting and training, flushing of mains and sewers, street cleaning, watering of municipal gardens, public fountains, building water, etc.

Water used for firefighting is generally much less than expected if it is considered that the average fire truck carries approximately 5000 litres of water which is more than sufficient to extinguish the average residential fire. If the municipality responds to one call per week then the total volume of unbilled unmetered consumption will be only $5m^3 \times 52 = 260m^3$/annum. This is less than the average household water use of approximately 360kl/annum.

The same applies to water used for maintenance and flushing. A 1km x 250mm diameter pipe holds approximately $50m^3$ of water. If the municipality drains 50km of mains per annum, which is substantial, then the unmetered unbilled consumption will be only 5 $000m^3$/annum.

Unbilled unmetered consumption should therefore form a very small portion of the overall water balance as all water supplied should preferably be billed or metered. Unmetered unbilled consumption is not expected to be more than 0.1 and 0.2% of system input volume for large and small municipalities respectively. If this component ends up being more than the parameters stated above, it will be important for the municipality to undertake investigations to establish the cause of the escalation in this element of NRW as it spells trouble for the sustainability of the water supply.

Unbilled unmetered consumption =
Unmetered unbilled water used for firefighting, mains flushing, parks, buildings, etc.

Water losses

Water losses are calculated as the difference between the system input volume and the authorised consumption. Water losses are broken down into commercial or apparent and physical or real losses. Commercial losses are not visible, except for unauthorised use, and are usually as a result of poor or lack of metering. Physical losses are visible losses and are usually as a result of burst pipes, overflowing reservoirs and leaking connections.

Burst pipes contribute to physical losses

Water losses = System Input Volume – Authorised Consumption
where Authorised Consumption = Billed metered + billed unmetered +unbilled metered + unbilled unmetered

Commercial or apparent losses

Commercial or apparent losses are made up of unauthorised connections (theft), unauthorised consumption, plus all technical and administrative inaccuracies associated with customer metering and billing. If commercial losses are reduced, generally more revenue will be generated by and for the water services institution.

Unauthorised water connections

Traditionally, commercial losses were accepted as 20% of water losses but this assumption was revised in the WRC Report TT300/07 (WRC, Jan

2007) as shown in **Table 3**, which provides a more pragmatic approach to calculating commercial losses.

The percentage unauthorised connections, meter error and data transfer errors should be added together to obtain the total percentage of commercial loss. The volume of commercial losses is then calculated as a percentage of the total water losses.

Table 3: Percentage commercial loss guideline

Illegal connections	%	Meter age and accuracy	Good water	Poor water	Data transfer	%
Very high	10%	> 10 years	8%	10%	Poor	8%
High	8%					
Average	6%	5- 10 years	4%	8%	Average	5%
Low	4%					
Very low	2%	< 5 years	2%	4%	Good	2%

*Source: WRC Report TT, 2007

% Commercial losses = % Illegal Connections + % Meter Error + % Data Transfer Error

Volume commercial losses = Water losses x % Commercial losses

Advanced commercial or apparent loss calculations

Table 3 generally provides a very conservative approach to calculating commercial losses but is a good start. It is recommended that municipalities that are at an advanced stage of water balance calculations should adopt a more detailed approach as described in the following sections.

Excluding the x10 factor on bulk meters increases commercial losses (Meter reading = 583849 x 10 = 5838490)

Unauthorised connections (theft)

An unauthorised connection is defined as a water connection to a consumer which was not installed by the water utility or a water connection which has deliberately been tampered with to reduce or eradicate the metered consumption. The percentage number of illegal connections is determined by dividing the number of illegal connections by the total number of connections. 10% illegal connections therefore mean 10 illegal connections for every 100 connections whereas 2% illegal connections mean 2 illegal connections for every 100 connections.

$$\%\ Unauthorised\ connections = \frac{Number\ of\ unauthorised\ connections}{Total\ number\ of\ connections}$$

Volume lost due to illegal connections is calculated as

V_{Theft} (m^3) = number of unauthorised connections x average consumption

Meter error and under registration

Metering inaccuracies differ significantly from municipality to municipality and depend on the water quality, class of meter, type of meter, meter sizing, installation requirements and air surges.

The WRC study on Apparent Water Losses Related to Municipal Metering in South Africa (WRC Report No. 1998/1/12, Aug 2012) suggests the following formula to calculate the percentage meter error for small meters (≤25mm diameter) between 5 and 25 years old.

$$\%\ Meter\ error = -0.36 \times Average\ meter\ age\ in\ years + 1$$

The average 10 year old meter therefore under records the total consumption by -2.6% (-0.36 x 10 years + 1). The formula shows that the meter error is negligible in the first 5 years of operation as new meters tend to over register in the first 2 to 3 years.

The error on larger meters could be as high as 20% due to oversized meters, unmetered fire connections inside consumer properties, incorrect meter installations and theft (WRC Report No. 1998/1/12, Aug 2012).

Debris caught in the meter mechanism will cause meter error

Volume lost due to meter error and under registration is calculated as follows:

V_{error} (m^3) = % meter error x total domestic metered consumption +
% meter error x total non-domestic metered consumption

Data transfer and management errors

Data transfer and management errors are the difference between the actual metered consumption and the metered consumption billed. Data transfer and management errors typically occur as a result of data entry errors, estimated readings, meters not captured on the billing system, meter factor errors and financial billing corrections without volume corrections.

It is accepted that many municipalities do not read their meters on monthly basis and work on estimated readings. In this case the data transfer error will be high on estimated months but is expected to be reconciled once the meters have been read.

The percentage data transfer error is difficult to estimate but can be determined through sample testing and calculated as follows:

$$\%\ Data\ transfer\ error = \frac{Consumption\ on\ billing\ system - Actual\ consumption}{Actual\ consumption}$$

The volume (V_{data}) water lost as a result of data transfer and management errors is calculated as follows:

$$V_{data}\ (m^3) = \%\ \text{Data transfer and management error x metered consumption}$$

The total volume $V_{commercial\ losses}$ (m^3) commercial losses is then calculated as follows:

$$V_{commercial\ losses}\ (m^3) = V_{Theft}\ (m^3) + V_{error}\ (m^3) + V_{data}\ (m^3)$$

Current Annual Physical or Real Losses (CARL)

Physical or real losses are the physical water losses from the pressurised system, up to the point of measurement of customer use. Real losses include leaking mains, reticulation pipes, connection pipes, overflowing reservoirs and bursts.

Physical water losses

Physical losses are calculated as the difference between the total losses and commercial losses. If real losses are reduced, more water will be available for distribution to customers or the total system input volume will reduce.

Physical or Real losses = Water losses - Volume Commercial Losses

Unavoidable Annual Real Losses (UARL)

Although not shown explicitly in the water balance, the Unavoidable Annual Real Losses (UARL) is the accepted minimum level of physical losses from the water distribution system. The leakage from a water distribution system can never be zero.

Unavoidable Annual Real Losses (UARL) = (18 x Lm + 0.8 x Nc + 25 x Lp) x P

Where Lm = length of mains in km; Nc = Number of connections; Lp = Length of underground Pipe in m and P = average operating pressure in m.

Lp is considered zero if the meter is on the property boundary otherwise it is length of pipe from the property boundary to inside the household where the meter is installed.

Non-Revenue Water

Non-revenue water is the volume of water for which the water utility receives no income and is calculated as follows:

Non-revenue water = System input volume – Billed (metered and unmetered) consumption

Potential real loss saving

The potential real loss saving is the difference between the Current Annual Real Losses (CARL) and the Unavoidable Annual Real Losses (UARL)

Potential real loss saving = CARL – UARL

WATER SUPPLY SYSTEM ASSESSMENT

Key Performance Indicators

Once the water balance has been calculated, various key performance indicators can be calculated to assess the performance of the water supply system. It is recommended that several KPIs are calculated and used to assess the performance of the distribution network.

% Non-revenue water (NRW)

Although the use of percentages to define water losses is not recommended by the IWA, this indicator remains widely accepted and used in most parts of the world including the South African water industry and for this reason, it has been retained although it should be used with caution in the knowledge that it can sometimes be misleading. It does however remain a useful indicator in communicating the extent of non-productive water distributed which reflects on both the technical and finance departments in the municipalities. The % NRW is calculated as follows:

$$\%\ NRW = \frac{SIV - (Billed\ Metered + Billed\ Unmetered)}{System\ Input\ Volume} \times 100$$

Unit consumption

Litres / capita / day provides an indication of the gross volume of water used per capita (person) per day. Although the calculation is based on the total system input volume (m^3/year) and not just the domestic component, it does provide a useful indicator. Care should be taken in areas where there is a large non-domestic component of water use and if necessary, it should be excluded from the calculation in order to derive a more realistic per capita consumption.

$$\ell/c/d = \frac{System\ Input\ Volume \times 1000 \div 365}{Population\ Served}$$

Real loss indicators

The use of percentages as an indicator for real losses (physical leakage) should also be discouraged although, it is again, accepted that percentages will always remain in use since few water utility managers are prepared to discard percentages completely from their list of KPIs. It is therefore important when using percentages to quantify physical leakage, to highlight the potential pitfalls and to ensure that other KPI's are also provided.

Litres / connection / day – metric units

This water loss indicator will be suitable for most systems where the density of connections is greater than 20 connections per km mains. In cases where the density of connections drops below 20 per km of mains, it is often appropriate to rather use the following indicator:

m^3 / km mains / day – metric units

Infrastructure Leakage Index

This is a useful indicator and can often be used to benchmark one system against another. The infrastructure leakage index provides an indication of the current level of leakage (CARL) versus the expected minimum level of leakage (UARL). An ILI of 5 therefore means that the current level of leakage (CARL) is five times higher than the expected minimum level of leakage (UARL).

Infrastructure Leakage Index ILI = CARL / UARL

Where:

- ILI = Infrastructure Leakage Index (non-dimensional)
- CARL = Current Annual Real Losses (litres per connection per day)
- UARL = Unavoidable Annual Real Losses (litres per connection per day)

Benchmarks

Interpreting the results from the water balance calculation and key performance indicators are critical to assess the performance of the water supply system. The results vary significantly from municipality to municipality and across the different municipal categories as categorised according to the Municipal Infrastructure Investment Framework (MIIF). The MIIF categorisation is summarised in **Table 4**.

Table 4: Municipal categories

Category	Short description	Long Description
A	Metros	Metropolitan municipalities
B1	Major cities	Secondary cities, local municipalities with the largest budgets
B2	Minor cities	Municipalities with a large town as core
B3	Rural dense	Municipalities with relatively small population and significant proportion of urban population but with no large town as core
B4	Rural scattered	Municipalities which are mainly rural with, at most, one or two small towns in their area

The following tables provide the results from various water loss / non-revenue water studies undertaken by the department and the WRC over the past 10 years. These results should only be used to assess if results are in the correct range.

Basic information

Municipal category	A	B1	B2	B3	B4
Length of mains (km)					
Connections / km					
Average system pressure					

Water balance volumes

Municipal category	A	B1	B2	B3	B4
System input volume					
NRW					

Key performance indicators

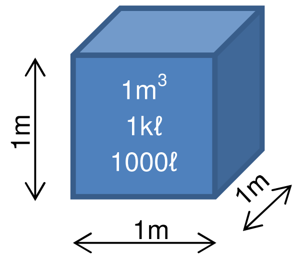
Municipal category	A	B1	B2	B3	B4
Litres / capita / day					
m^3 / connection / month					
Infrastructure Leakage Index					

COMMON MISTAKES AND RECOMMENDATIONS

Unit errors

The units used to calculate the water balance must remain consistent. The following should be kept in mind to avoid errors:

- Ensure the volumes are provided per month or per year as required.
- mega litres = Mℓ = 1 000 000 litres and is typically used to define the capacity of a treatment plant in Mℓ/day. 1 Mℓ = 1000 kℓ
- kilo litres = kℓ = 1000 litres = 1 m^3 and is typically used to calculate the water balance.
- The length of mains must be provided in kilometres (km) and not metres (m).
- The average system pressure must be provided in metres (m) where 100kPa = 1bar = 10m pressure.

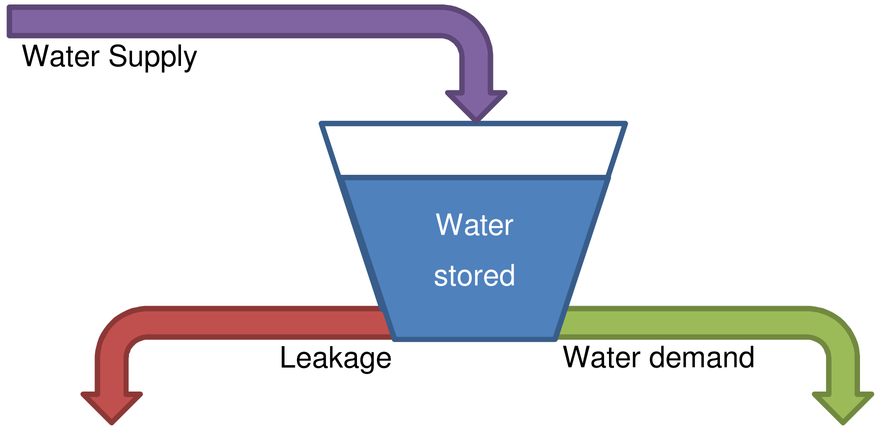


1 m^3 = 1 kℓ = 1m x 1m x 1m block of water

Storage volume included in water balance

Several water services institutions include the volume of water stored in reservoirs and pipes in the water balance. The reason for this is unclear but some institutions consider the volume of water stored in reservoirs and pipes as an asset on their asset register and therefore also include it in the water balance.

To explain this misconception, the water distribution system could be compared to a bucket full of water, where the water in the bucket is equal to the water stored in reservoirs and pipes, the inflow is equal to the water supply, the outflow is equal to the water demand and there is a hole in the bucket which is equal to the leakage.



It is accepted that the water level in reservoirs fluctuates on a daily basis and pipes are drained to perform maintenance, but for all practical purposes the reservoir and pipes remain full and therefore the water level in the "bucket" or water distribution system remains the same. For the water level in the bucket to remain the same, the inflow must be equal to the outflow plus leakage and the "Water supply = Water demand + Leakage". The volume of water stored in pipes and reservoirs must therefore be excluded from the water balance calculation. Any losses from overflowing and disinfection of reservoirs, scouring of pipelines are included in the water losses.

Monthly or annual water balance

All meters readings and water balance calculations should be performed on a monthly basis to ensure discrepancies are immediately resolved. Any estimates or data changes should be properly documented to ensure institutional memory.

It is accepted that the metered consumption could fluctuate depending on seasonal changes, meter reading problems, interim estimates, meter corrections, etc. to the extent that the demand could exceed the supply in some months. To allow for these changes, it is recommended that the water balance is prepared on a 12 month rolling basis. The water balance should therefore always be based on the last 12 months of data.

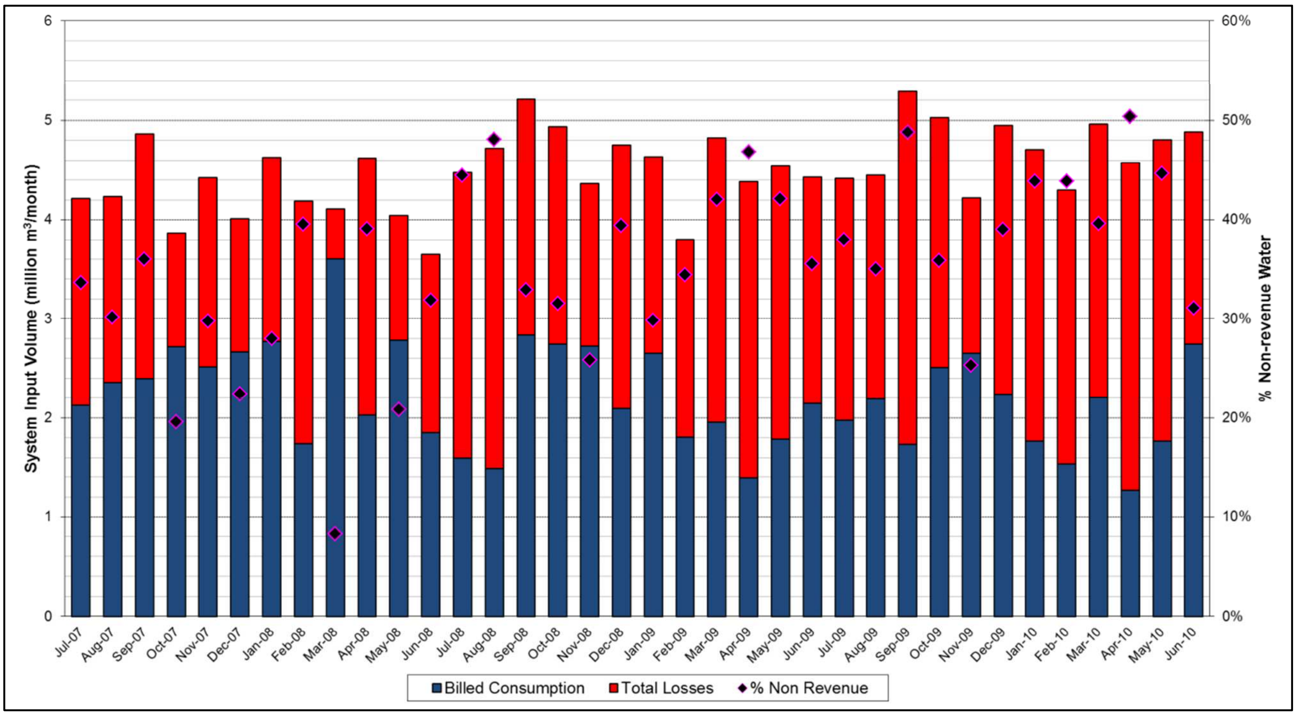


Figure 3: Monthly water balance calculation indicating huge fluctuations in NRW

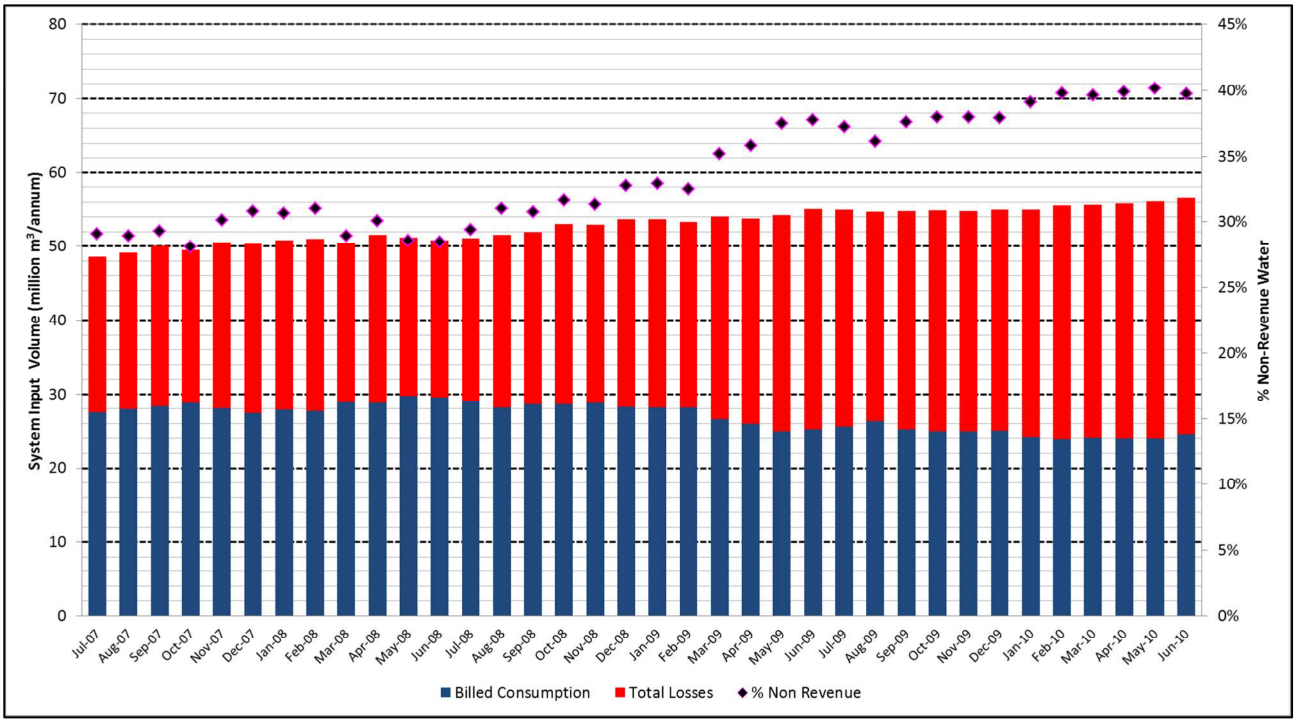


Figure 4: 12 Month rolling water balance calculation indicating gradual NRW increase