ENVIRONMENTAL ENGINEERING GRUOP

EMG

EMG EnvironMental engineering Group

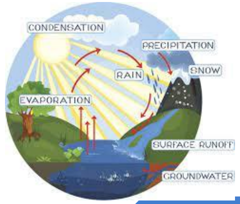
بسم الله الرحمن الرحيم

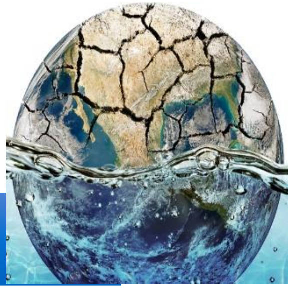
إِن يَنصُرْكُمُ اللّهُ فَلاَ غَالِبَ لَكُمْ وَإِن يَخْذُلْكُمْ فَمَن ذَا الَّذِي يَنصُرُكُم مِّن بَعْدِهِ وَعَلَى اللّهِ فَلْيَتَوَكِّلِ الْمُؤْمِنُون

أَوَلَمْ يَرَ الَّذِينَ كَفَرُوا أَنَّ السَّمَاوَاتِ وَالْأَرْضَ كَانَتَا رَتْقًا فَفَتَقْنَاهُمَا ۖ وَجَعَلْنَا مِنَ الْمَاءِ كُلَّ شَيْءٍ حَيٍّ ۖ أَفَلَا يُؤْمِنُونَ

Real Losses Detection Technique for Reducing Non-Revenue Water

9th October 2021





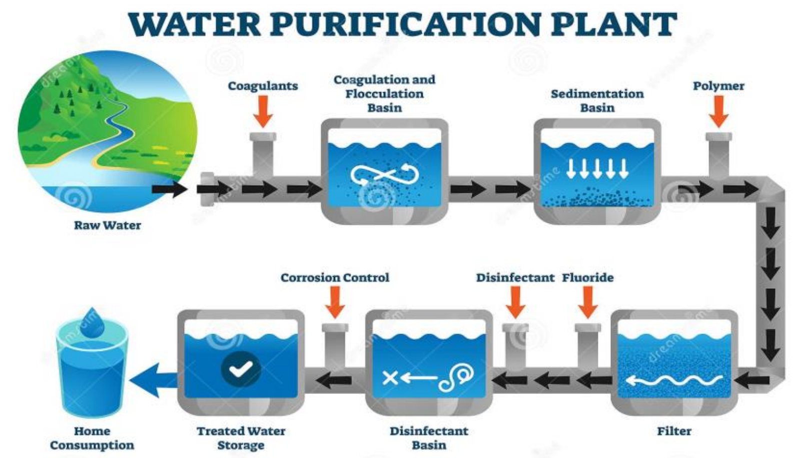
By

Dr. Ahmed El-Zayat

IWRM

EMG

ENVIRONMENTAL ENGINEERING GRUOP



Scholar Researcher Biography

Ahmed Salah El-Dien El-Zayat

Consultant

Environmental Engineering (Water & Wastewater Treatment)

B. Sc. of Civil Engineering, Cairo University, Giza, 1987

Environmental & Sanitary Engineering Diploma of Higher Studies, Cairo University, Giza

Environmental & Sanitary Engineering Master of Science, Cairo University, Giza

Doctor of Philosophy Degree
Co-Referee Ruhr University-Bochum-Germany

ASCE, AWWA, EWRI, DWA International Organizations Membership

Certified Consultant from the Egyptian Syndicate of Professional Engineers, Cairo

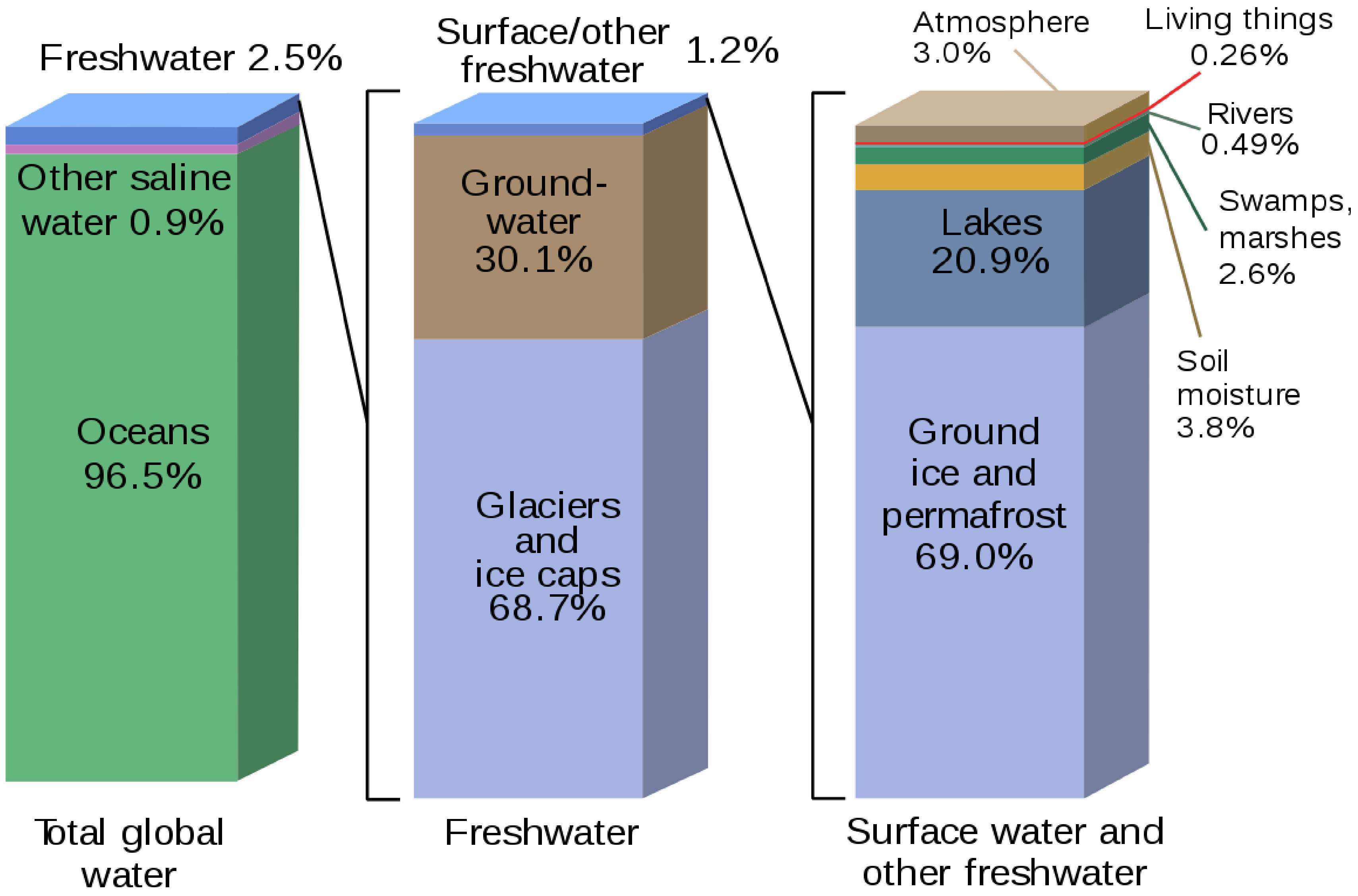
German Technology Know-How Expert in Dynamic Simulation and Experimental Modeling for Wastewater Treatment Plants, Hydraulic & Mathematical Modelling, and 3D-CFD Techniques.

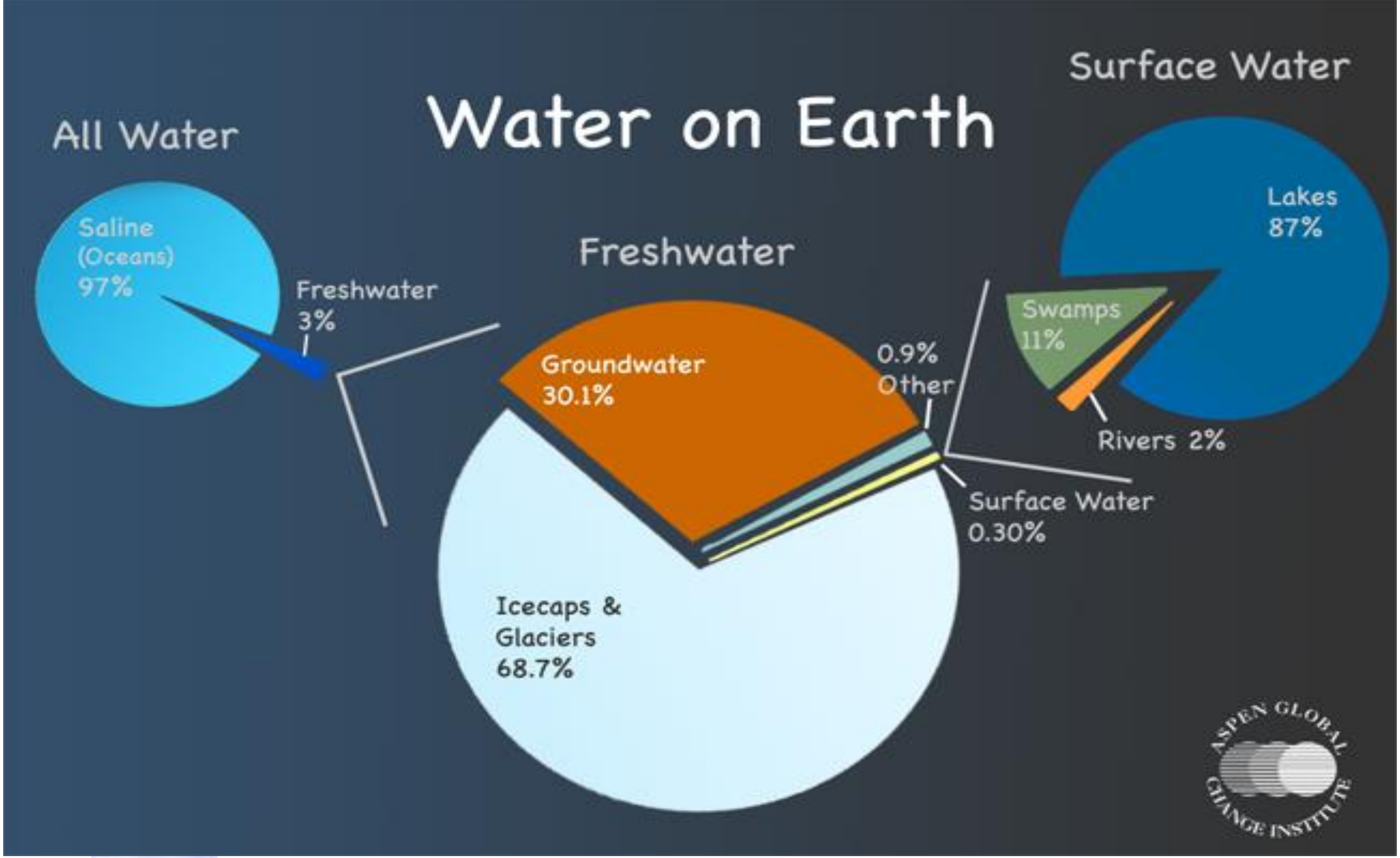
Presentation Outline

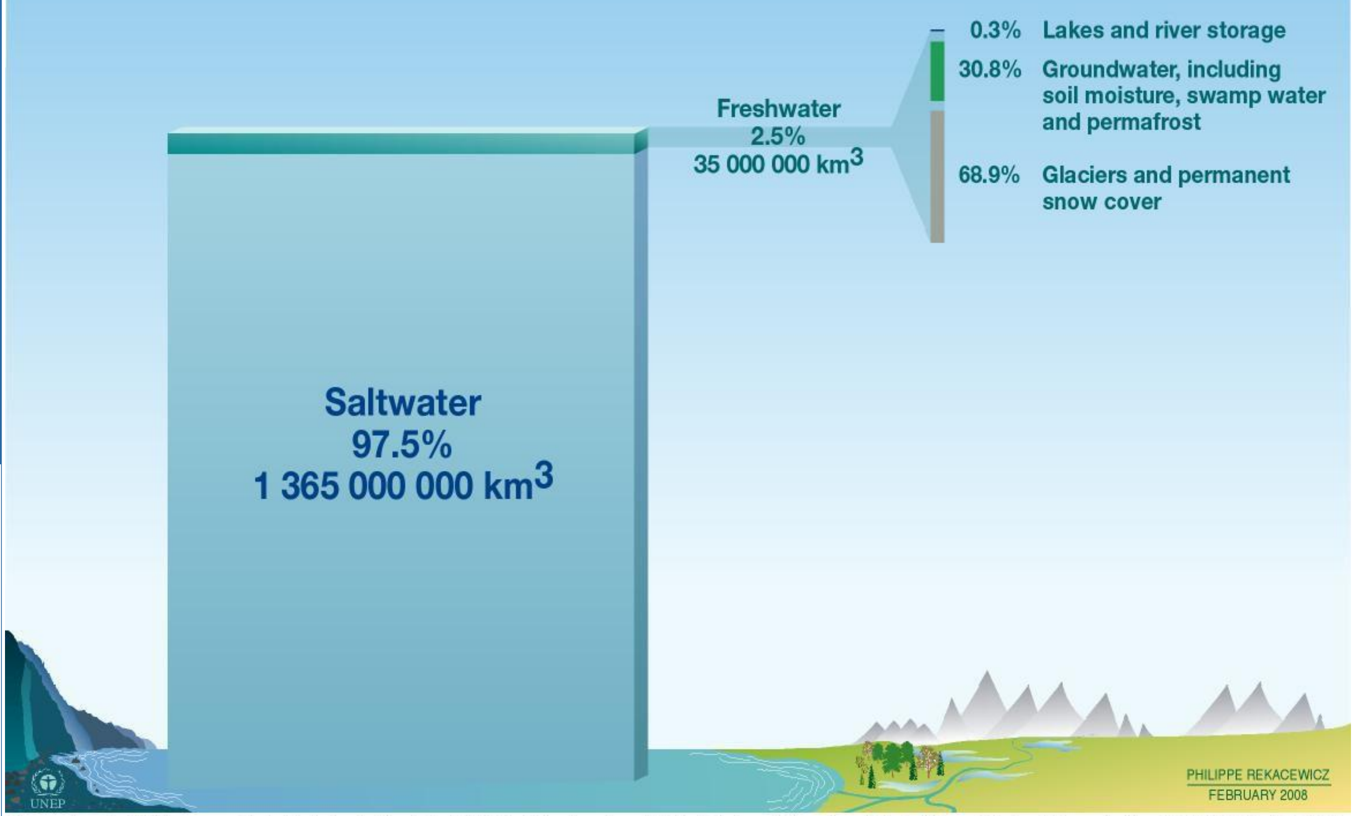
1. Water Utility Service Regime
2. Strategic Business Units
3. Key Operational Functions
4. Standard Terminologies
5. Unaccounted-For-Water Definition
6. Non-Revenue-Water Definition
7. Losses Analysis
8. Reduction and Control of UFW
9. Losses Management
10. Policy issues for sustainable O&M
11. Possible options for reform
12. Management Options
13. Case Study

WATER SCARCITY

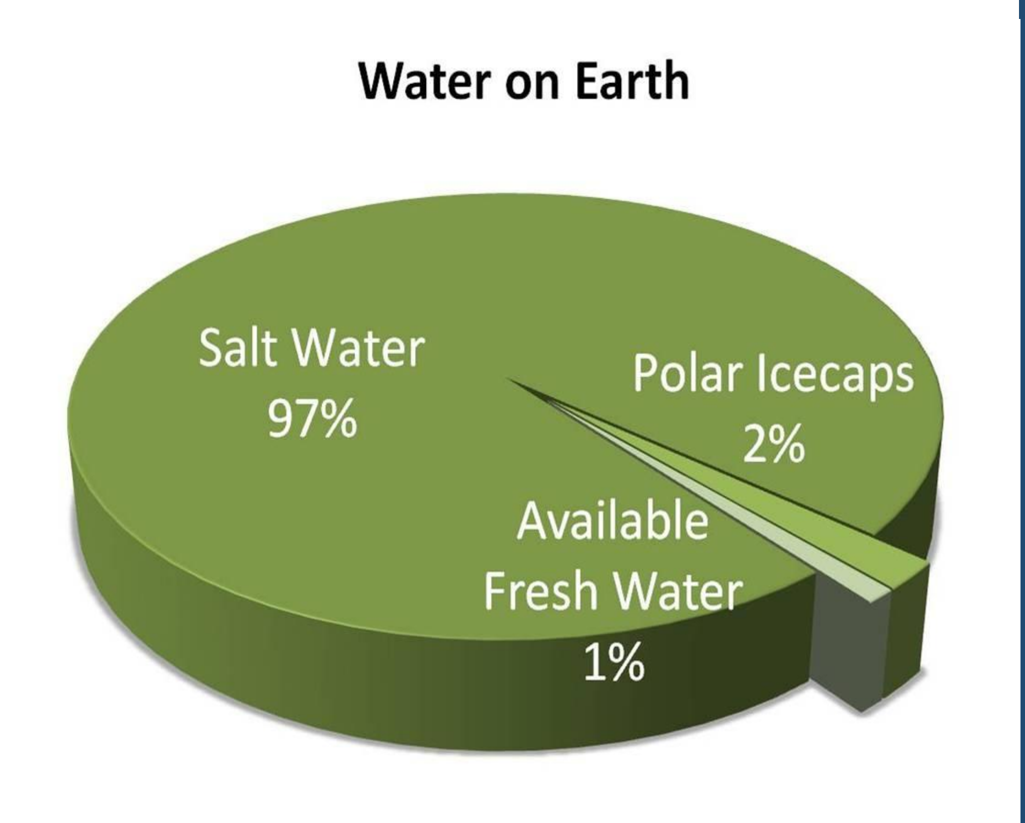
Where is Earth's Water?

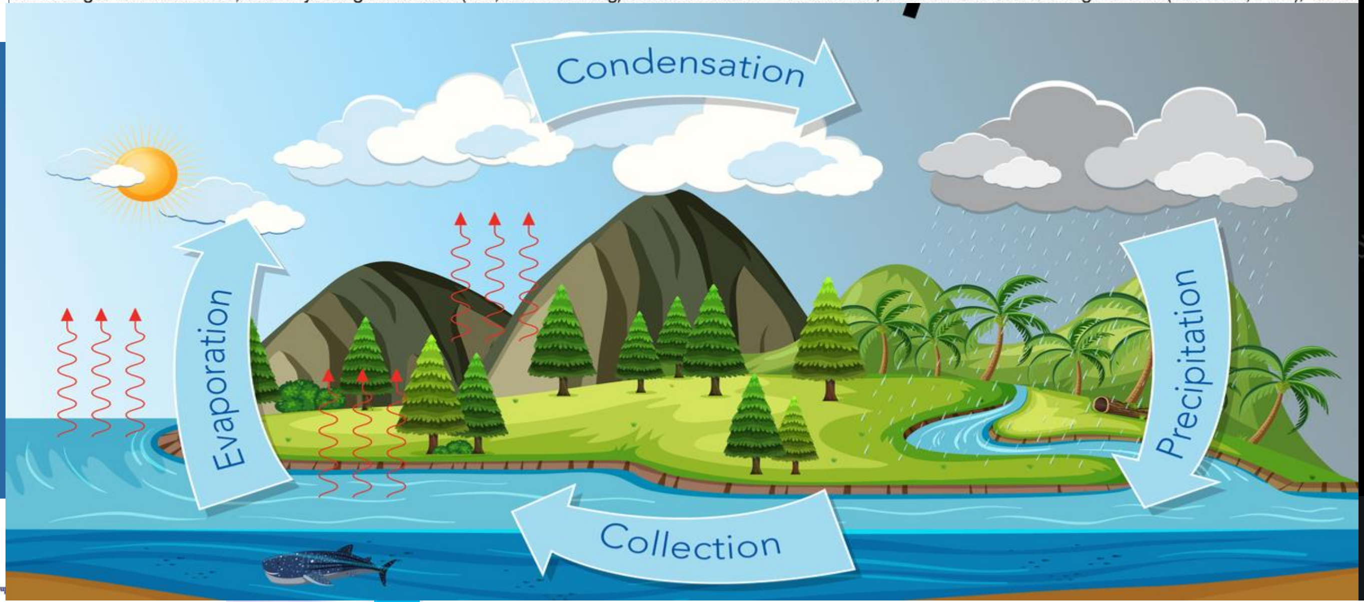



Water on Earth
All Water
Saline (Oceans) 97%
Freshwater 3%
Freshwater
Groundwater 30.1%
0.9% Other
Icecaps & Glaciers 68.7%
Surface Water 0.30%
Surface Water
Lakes 87%
Swamps 11%
Rivers 2%
ASPEN GLOBAL CHANGE INSTITUTE



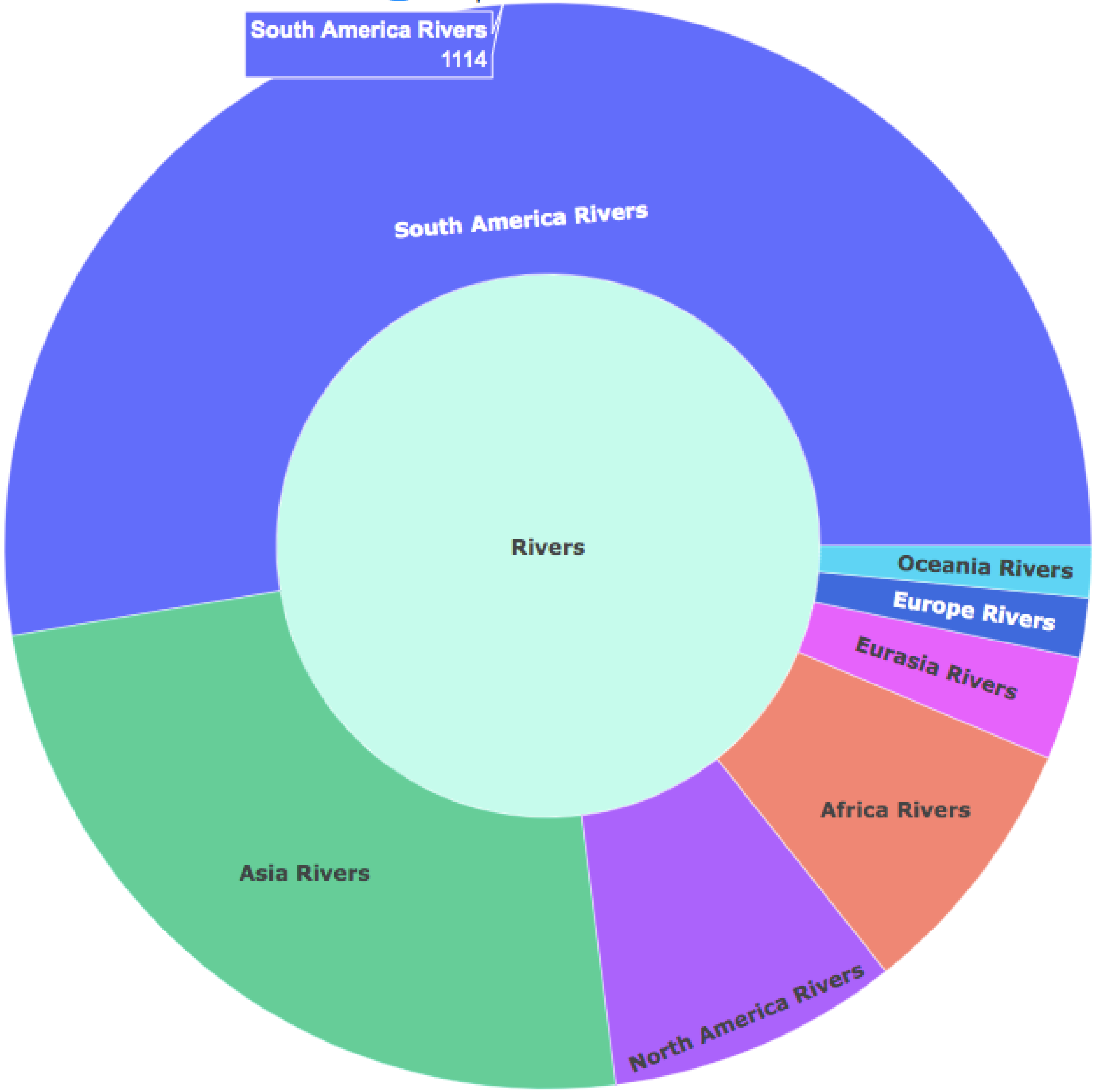
Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational, Scientific and Cultural Organisation (UNESCO, Paris), 1999.





South America Rivers: 1,114 cubic km of water
0.0000804% of all water on Earth.
and 52.6% of all Rivers on Earth

☑ Group Rivers and Lakes



THE WORLD BANK

UNESCO-IHE

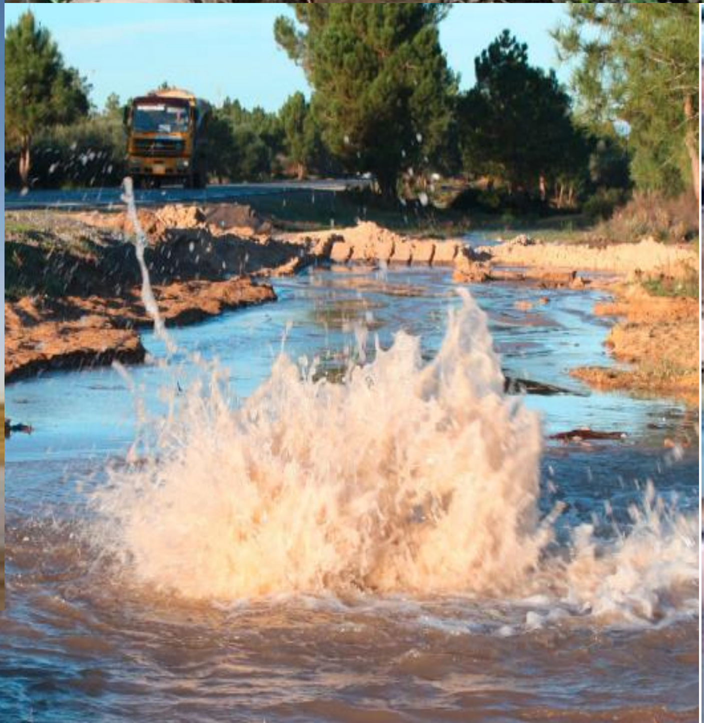
IWA

WATER CRISIS FOR BIG CITIES AROUND THE WORLD


ONE DROP WASTED IS A DROP TOO MUCH!
DISHES & LAUNDRY (2 SINKS)
18 litres
90 SEC SHOWER
15 litres
1 TOILET FLUSH
9 litres
DAILY HYGIENE
3 litres
COOKING
2 litres
DRINKING WATER
2 litres
1 DOG BOWL
1 litre
= 1 litre
EWN

EMG

ENVIRONMENTAL ENGINEERING GRUOP



EMG EnvironMental engineering Group

THE WORLD BANK

UNESCO-IHE

European Union European Regional Development Fund

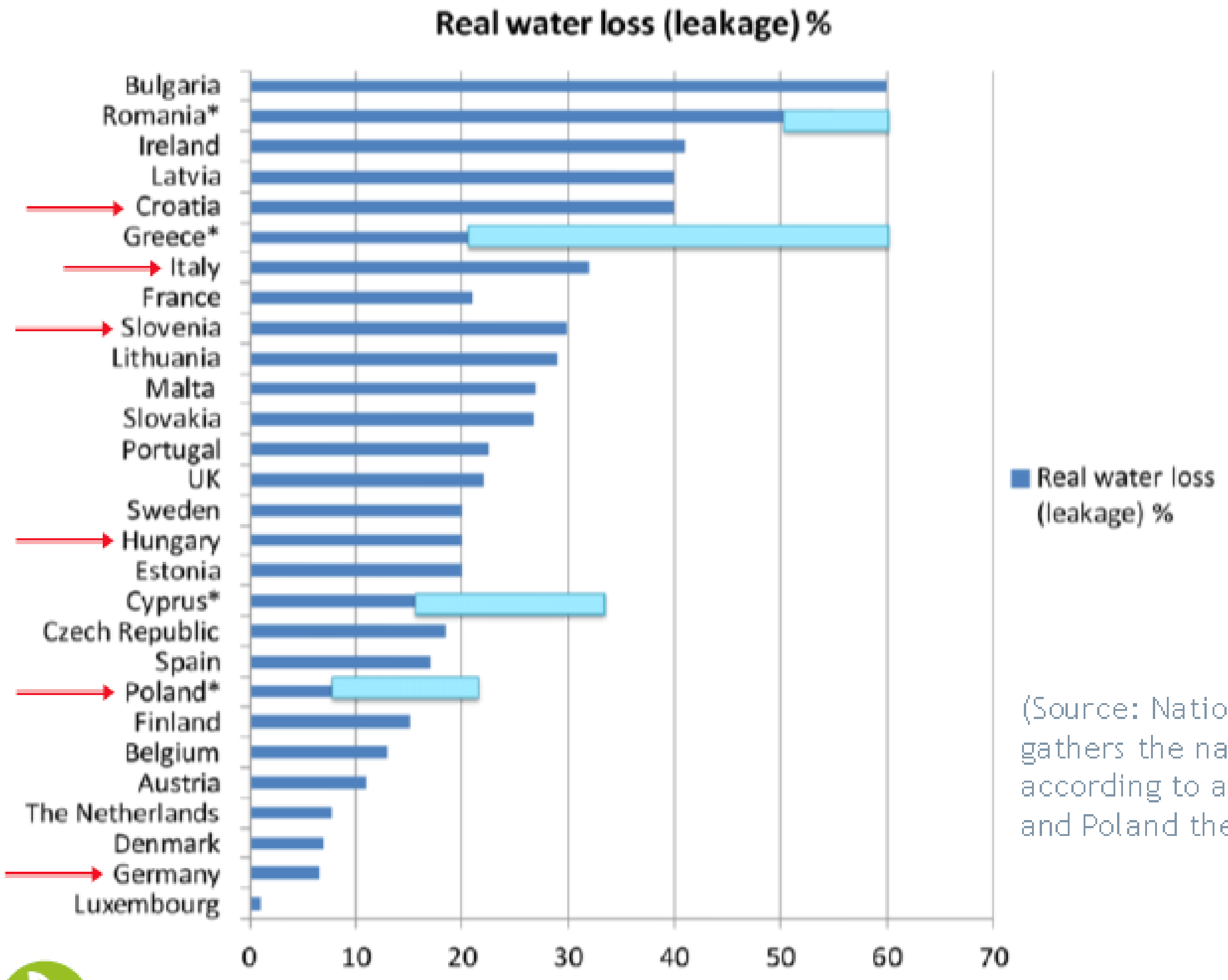
IWA

Importance of water loss reduction

- Ecological aspects
- Hygienic aspects
- Economic aspects (water export, production costs)
- Security of supply:
  (for example, a 5 mm hole and 5 bar pressure can induce 32,000 litres of daily water losses. This corresponds to a daily drinking water demand for 266 persons at an average consumption of 120 l/P*d)

FIELD INVESTIGATIONS

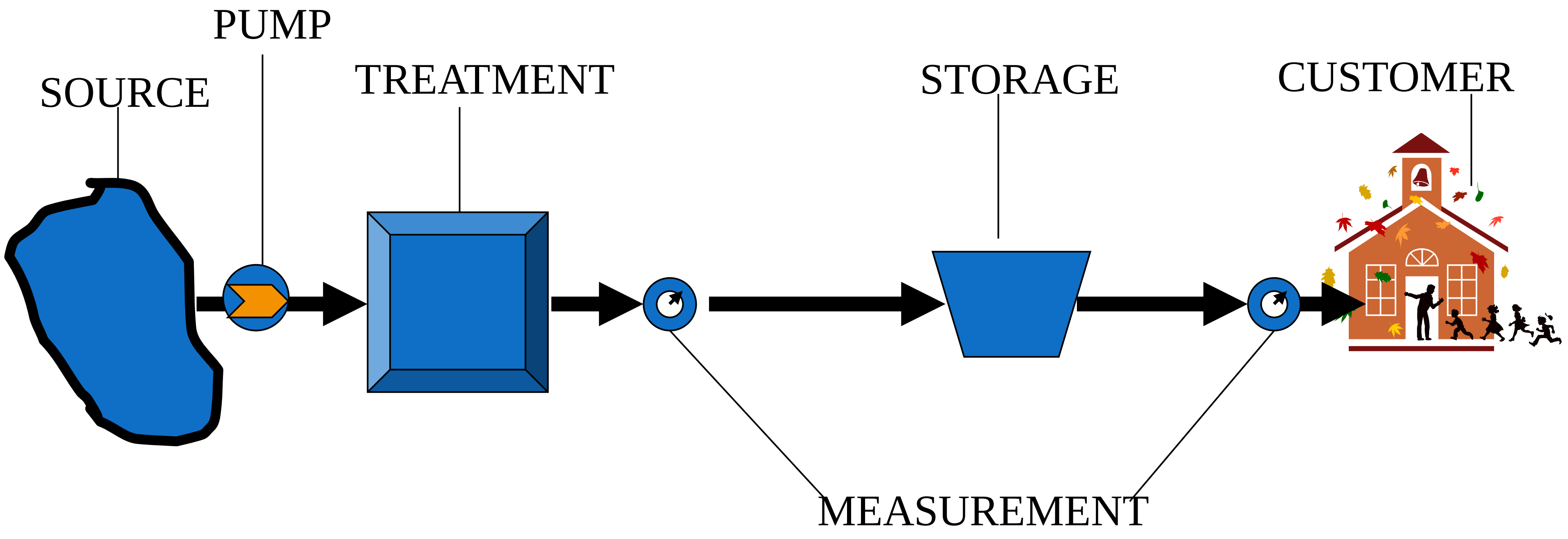
Water losses of water supply networks in the EU (%) (as averages of volume supplied)



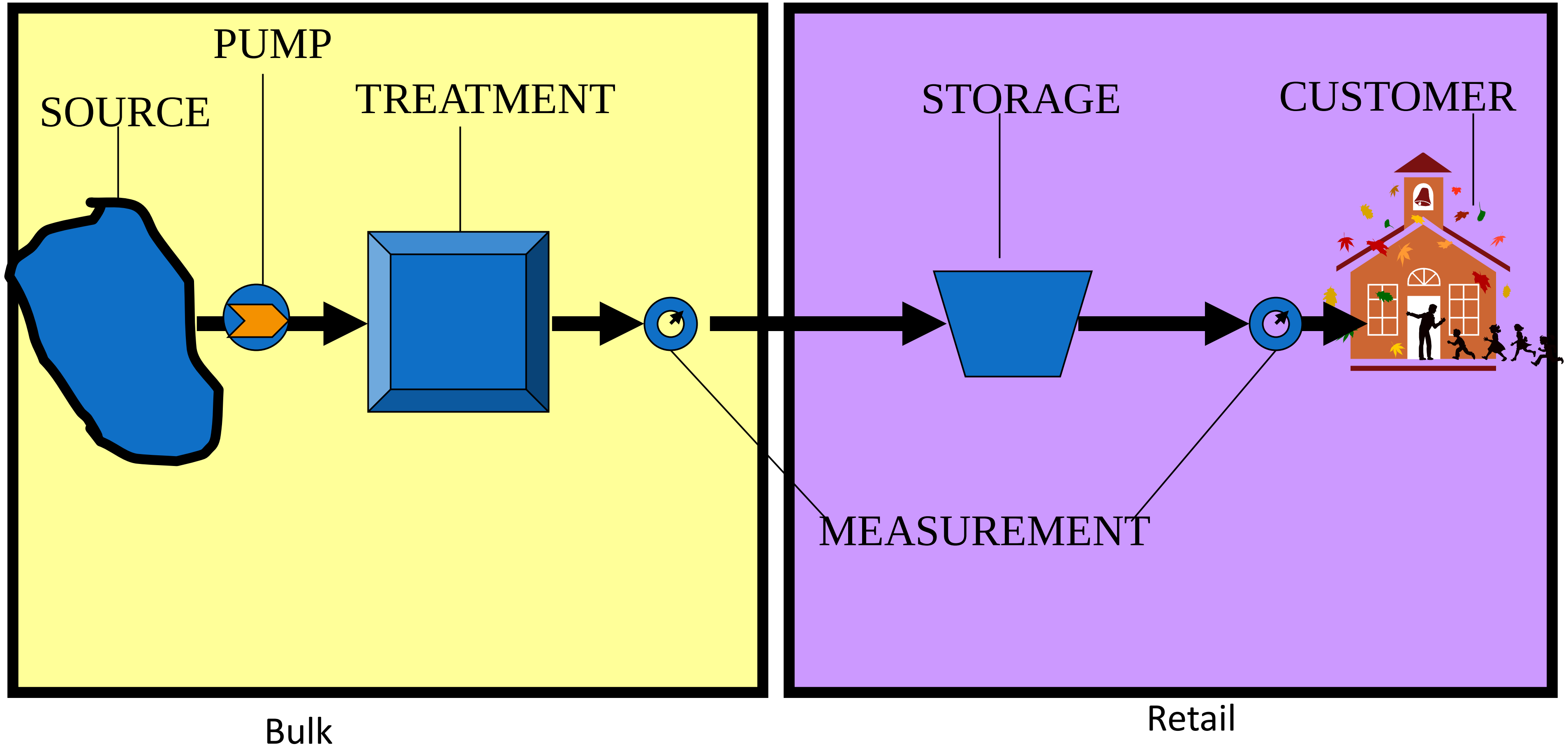
(Source: National sources (Country Fiches). This figure gathers the national data available for different years, according to availability. * For Romania, Greece, Cyprus and Poland the figure presents average ranges)

TAKING COOPERATION FORWARD 6

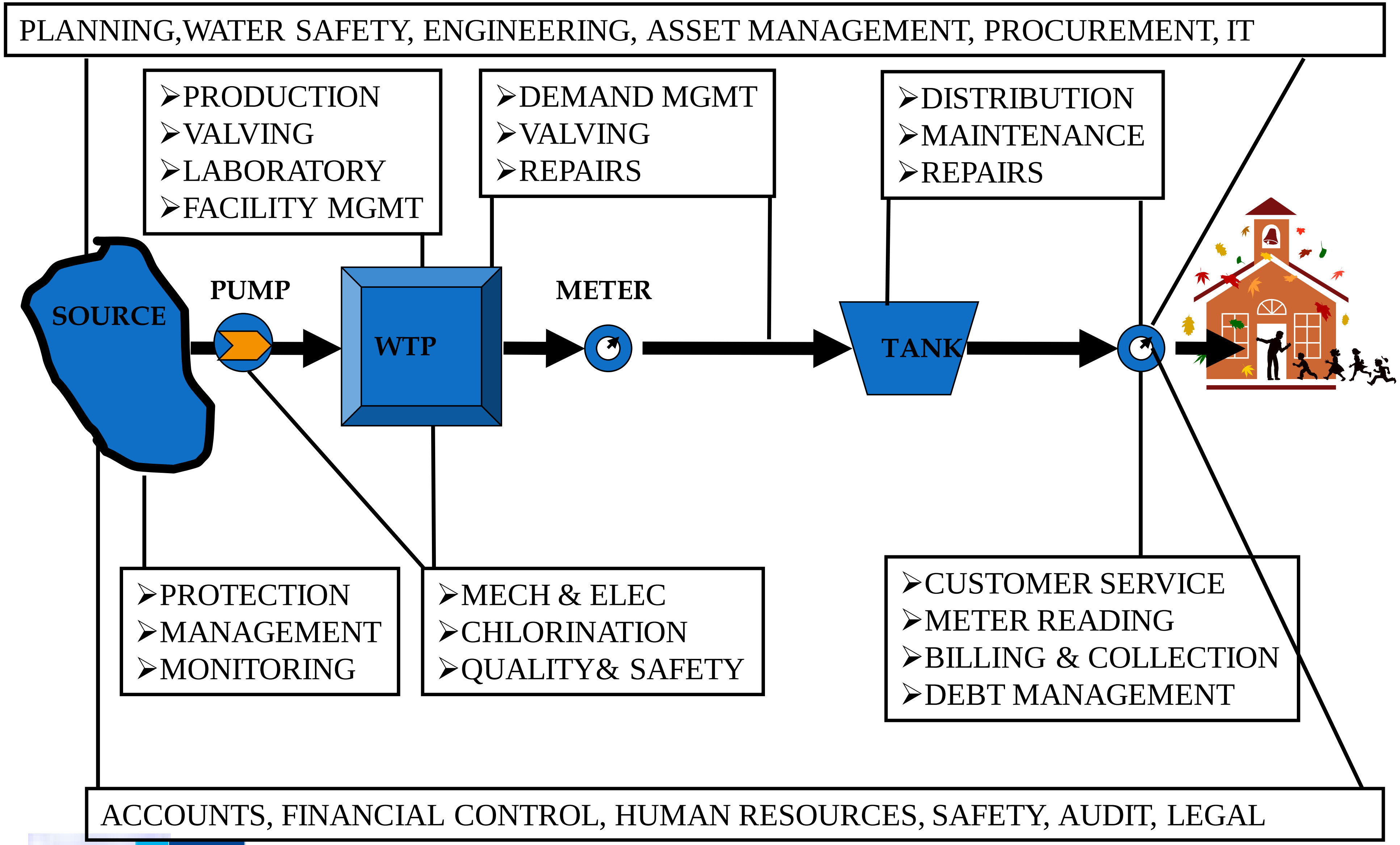
Water Utility Service Regime



Strategic Business Units



Key Operational Functions



Standard Terminologies

Source: IWA (2000)

System Input Volume	Authorised Consumption	Billed Authorised Consumption	Billed Metered Consumption (including water exported)	Revenue Water
			Billed Unmetered consumption	
		Unbilled Authorised Consumptiion	Unbilled Metered Consumption	Non-Revenue Water
			Unbilled Unmetered Consumption	
	Water Losses	Apparent Losses	Unauthorised Consumption	
			Metering Inaccuracies	
		Real Losses	Leakage on Transmission and/or Distribution Mains	
			Leakage and Overflows at Utility's Storage Tank	
			Leakage on Service Connections up to point of Customer Metering	

All quantities in m^3/year

What is Unaccounted-For-Water?

Definition

Unaccounted-for water (UFW) represents the difference between "net production" (the volume of water delivered into a network) and "consumption" (the volume of water that can be accounted for by legitimate consumption, whether metered or not).

UFW = “net production” – “legitimate consumption”

Non-Revenue Water

Non-revenue water (NRW) represents the difference between the volume of water delivered into a network and billed authorized consumption.

NRW = “Net production” – “Revenue water”

= UFW + water which is accounted for, but no revenue is collected (unbilled authorized consumption).

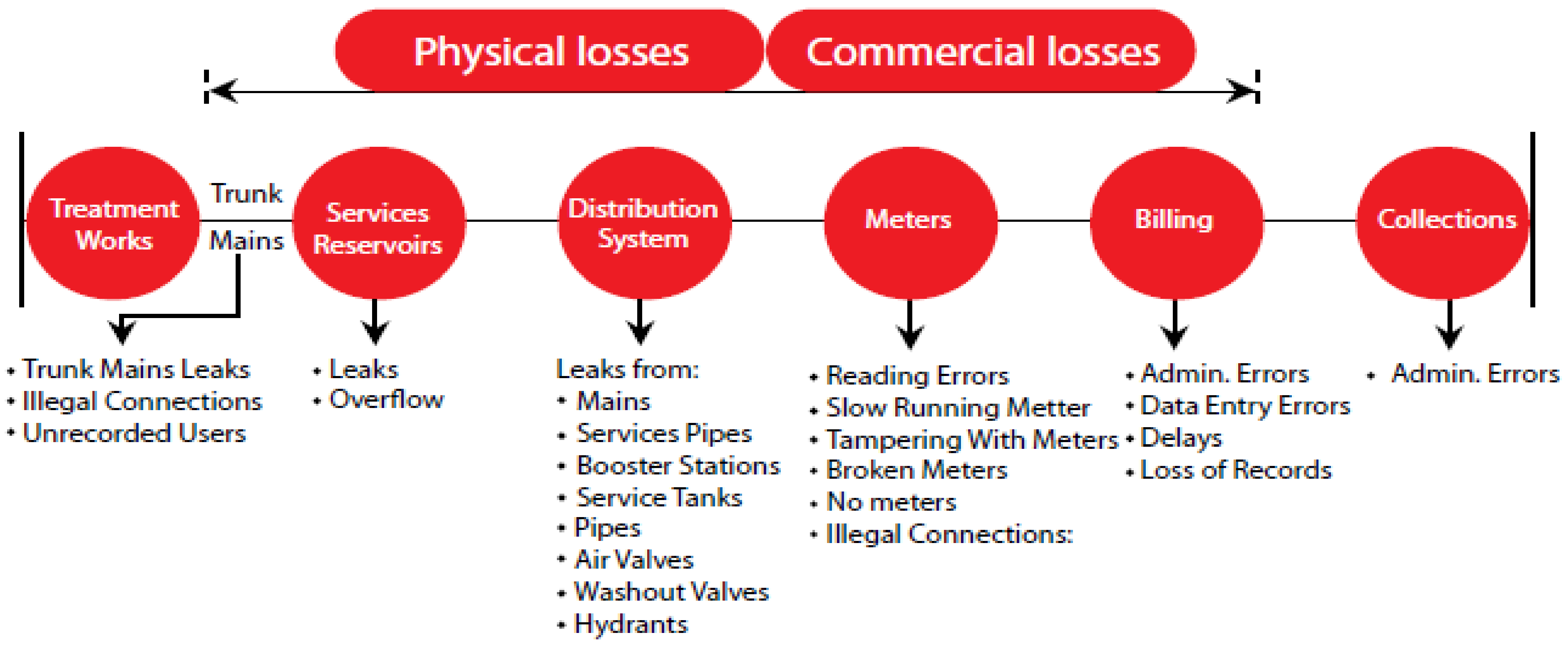
Components of Unaccounted-For Water (UFW)

- Unaccounted-for water
  - Physical loss (Real loss)
    - Pipe breaks and leaks
    - Storage overflows
    - House connection leaks
  - Commercial loss (Apparent loss)
    - Metering Errors
    - Water Theft
    - Billing Anomalies

Non-Revenue Water (NRW)

- Real loss (physical loss)
  - Leakages and pipe breaks
  - Storage overflows
  - House connection leaks
- Apparent loss (commercial loss)
  - Inaccurate metering
  - Data handling errors
  - Illegal tapping
- Unbilled authorised consumption
  - Unbilled metered consumption
  - Unbilled unmetered consumption

Typical Losses From A Water Supply System



Source: Ranhill

Internationally recognised best practice approach to calculate water balance according to IWA

System Input Volume Q_i	Authorised Consumption Q_A	Billed Authorised Consumption Q_{BA}	Billed metered consumption (including water exported)	Revenue Water
			Billed unmetered consumption	
		Unbilled Authorised Consumption Q_{UA}	Unbilled metered consumption	Non-Revenue Water (NRW)
			Unilled unmetered consumption	
	Water Losses Q_L	Apparent Losses Q_{AL}	Unauthorised consumption	
			Customer metering inaccuracies and data handling errors	
		Real Losses Q_{RL}	Leakage on transmission and/or distribution mains	
			Leakage and overflows at utility's storage tanks	
			Leakage on service connections up to point of customer metering	

(Source: Lambert, A. and W. Himer, 2000)

Terminology

- Real Losses cannot be eliminated totally. The lowest technically achievable annual volume of Real Losses for well-maintained and well-managed systems is known as **Unavoidable Annual Real Losses** (**UARL**)
- UARL is the most reliable predictor yet of „how low could a utility go“ with real losses for a specific system
- Each system has a different UARL base level, which varies widely depending on density of connections, length of connections (main to meters) and average pressure
- Using the four recommended strategies of leakage management, Real Losses can be controlled <u>but</u> cannot be reduced any further than the URAL (at the current operational pressure)
- The difference between the UARL (small rectangle) and the **Current Annual Real Losses** (**CARL**) is the **Potentially Recoverable Real Losses**

Infrastructure Leakage Index (ILI)

- The ratio of the Current Annual Real Losses (CARL) to the Unavoidable Annual Real Losses (UARL) is the **Infrastructure Leakage Index (ILI):**

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

- The International Water Association (IWA) uses ILI as a **performance indicator** for leakage which adjusts the measured loss, taking into account the service pressure and the length of the network
- ILI, is the current annual real losses expressed as a multiple of each system's specific UARL
- ILI measures how effectively the infrastructure activities such as repairs, active leakage control and pipeline/assets management are being managed at current operating pressure

PERFORMANCE INDICATOR FOR WATER LOSS

Physical loss assessment matrix

A simple matrix was published in 2005 which provides insight into typical ILI values for different situations. This approach can be used to classify the leakage levels for utilities in developed and developing countries into four categories:

- **Category A:** Further loss reduction may be uneconomic unless there are shortages; careful analysis needed to identify cost-effective improvement
- **Category B:** Potential for marked improvements; consider pressure management; better active leakage control practices and better network maintenance
- **Category C:** Poor leakage record; tolerable only if water is plentiful and cheap; even then, analyse level and nature of leakage and intensify leakage reduction efforts
- **Category D:** Highly inefficient; leakage reduction programs imperative and have high priority

PERFORMANCE INDICATOR FOR WATER LOSS

Physical loss assessment matrix

Technical Performance Category		ILI	Litres/connection/day (when the system is pressurised) at an average pressure of:				
			10 m	20 m	30 m	40 m	50 m
Developed Countries	A	1 - 2		< 50	< 75	< 100	< 125
	B	2 - 4		50-100	75-150	100-200	125-250
	C	4 - 8		100-200	150-300	200-400	250-500
	D	> 8		> 200	> 300	> 400	> 500
Developing Countries	A	1 – 4	< 50	< 100	< 150	< 200	< 250
	B	4 – 8	50-100	100-200	150-300	200-400	250-500
	C	8 - 16	100-200	200-400	300-600	400-800	500-1000
	D	> 16	> 200	> 400	> 600	> 800	> 1000

(Source: R. Liemberger and R. McKenzie, 2005)

Infrastructure Leakage Index (ILI)

Calculating Water Loss

Water loss is expressed as

- a percentage of net water production (delivered to the distribution system)
- as m^3/day/km of water distribution pipe system network (specific water loss)
- Others
  - m^3/day/connection
  - m^3/day/connection/m pressure

- Water loss as % of net water production is the most common.
- It could be misleading for systems with different net productions with same amount of real & apparent losses.

Magnitude of Water Losses

- Water loss levels (UFW or NRW) vary widely per country and within one country per city.
- UFW values ranging from 6% to 63% have been reported (*Source:* Water and Wastewater Utility Data – 2nd edition 1996)
- A certain level of water losses can not be avoided from a technical point of view and /or is considered acceptable from an economic point of view.

What is an Acceptable Water Loss?

1. It is a compromise between the cost of reducing water loss and maintenance of distribution system and the cost (of water) saved.

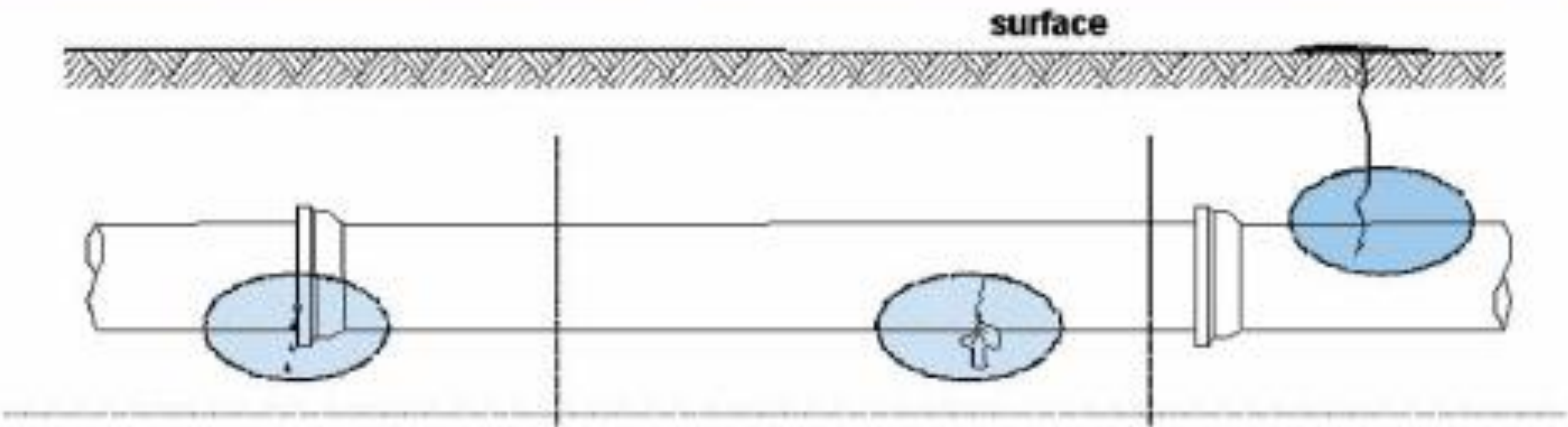
2. AWWA Leak detection and Accountability Committee (1996) recommended 10% as a benchmark for UFW.

3. UFW levels and action needed

< 10%	Acceptable, monitoring and control
10-25%	Intermediate, could be reduced
> 25%	Matter of concern, reduction needed

Unavoidable Annual Real Losses (UARL)

- The UARL is computed based on Background and Burst Estimates (BABE) concept.



Background leakage	Un-reported leakage	Reported leakage
Un-reported and un-detectable using traditional accoustic equipment.	Often does not surface but is detectable using traditional accoustic equipment.	Often surfaces and is reported by the public or utility workers

UARL – Background (1)

- Based on a statistical analysis of international data, including 27 diverse water supply systems in 19 countries, a method of predicting UARL has been developed and tested for application to systems with:
  - average operating pressure of between 20 and 100 metres;
  - density of service connections between 10 and 120 per km of mains;
  - customer meters located 0 and 30 metres from the edge of the street.

Unavoidable Annual Real Losses (UARL)

UARL (L/day) = (18 x Lm + 0.80 x Nc + 25 x Lp) x P

where

Lm = Length of mains in km

Nc = Number of service connections

Lp = Total length in km of underground connection pipes (between the edge of the street and customer meters)

P = Average operating pressure in m

UARL in litres/service connection/day for customer meters located at edge of street

Density of of Connections Nc/Lm (per km mains)	Average Operating Pressure (P) in Metres				
	20	40	60	80	100
20	34	68	112	146	170
40	25	50	75	100	125
60	22	44	66	88	110
80	21	41	62	82	103
100	20	39	59	78	98

Unavoidable Annual Real Losses (UARL)

Generalised Equation

$$\text{UARL (L/day)} = (A \times Lm + B \times Nc + C \times Lp) \times P$$

where

A = specific real losses for mains (L/day/km/m pressure)

B = specific real losses for service connections (L/connection/m pressure)

C = specific real losses for underground service pipes (L/day/km/m pressure)

The Infrastructure Leakage Index (ILI)

- A better indicator
- Describes the quality of infrastructure management
- Is the ratio of *Current Annual Real Losses* to *Unavoidable Annual Real Losses*

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

World Bank Institute Banding System to Interpret ILIs

- ILI is classified into Bands A to D
- Different limits for developed & developing countries
- Each Band has a general description of performance
- Each Band suggests a range of recommended activities

WBI Banding System to Interpret ILIs

Developing countries	Developed countries	BAND	General description of real loss performance management categories
ILI Range	ILI Range		
< 4	< 2	A	Further loss reduction may be uneconomic unless there are shortages; careful analysis is needed to identify cost effective improvement
4 to <8	2 to <4	B	Potential for marked improvements; consider pressure management, better active leakage control practices, and better network maintenance
8 to <16	4 to <8	C	Poor leakage record; tolerable only if water is plenty and cheap; even then analyze level and nature of leakage and intensify leakage reduction efforts
16 or more	8 or more	D	Very inefficient use of resources; leakage reduction programs imperative & high priority

WBI Recommended Activities

WBI Recommendations for BANDS	A	B	C	D
Investigate pressure management options	Yes	Yes	Yes	
Investigate speed and quality of repairs	Yes	Yes	Yes	
Check economic intervention frequency	Yes	Yes		
Introduce/improve active leakage control		Yes	Yes	
Identify options for improved maintenance		Yes	Yes	
Assess Economic Leakage Level	Yes	Yes		
Review burst frequencies		Yes	Yes	
Review asset management policy		Yes	Yes	Yes
Deal with deficiencies in manpower, training and communications			Yes	Yes
5-year plan to achieve next lowest band			Yes	Yes
Fundamental peer review of all activities				Yes

Comparison of real loss performance indicators

Source: Liemberger and McKenzie (2005)

Indicator	Vietnam	Indonesia	Sri Lanka
L/conn./day	866	430	519
L/conn./day/m pressure	72	38	48
ILI	79	31	39
NRW (%)	42%	40%	46%

The % losses do not reflect the huge difference in leakage performance of three systems.

Suggested apparent loss percentages for a typical water distribution system in South Africa

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

Source: Seago *et al.* (2004)

Thumb rule = apparent losses is 20% of total water losses

The Apparent Loss Index (ALI)

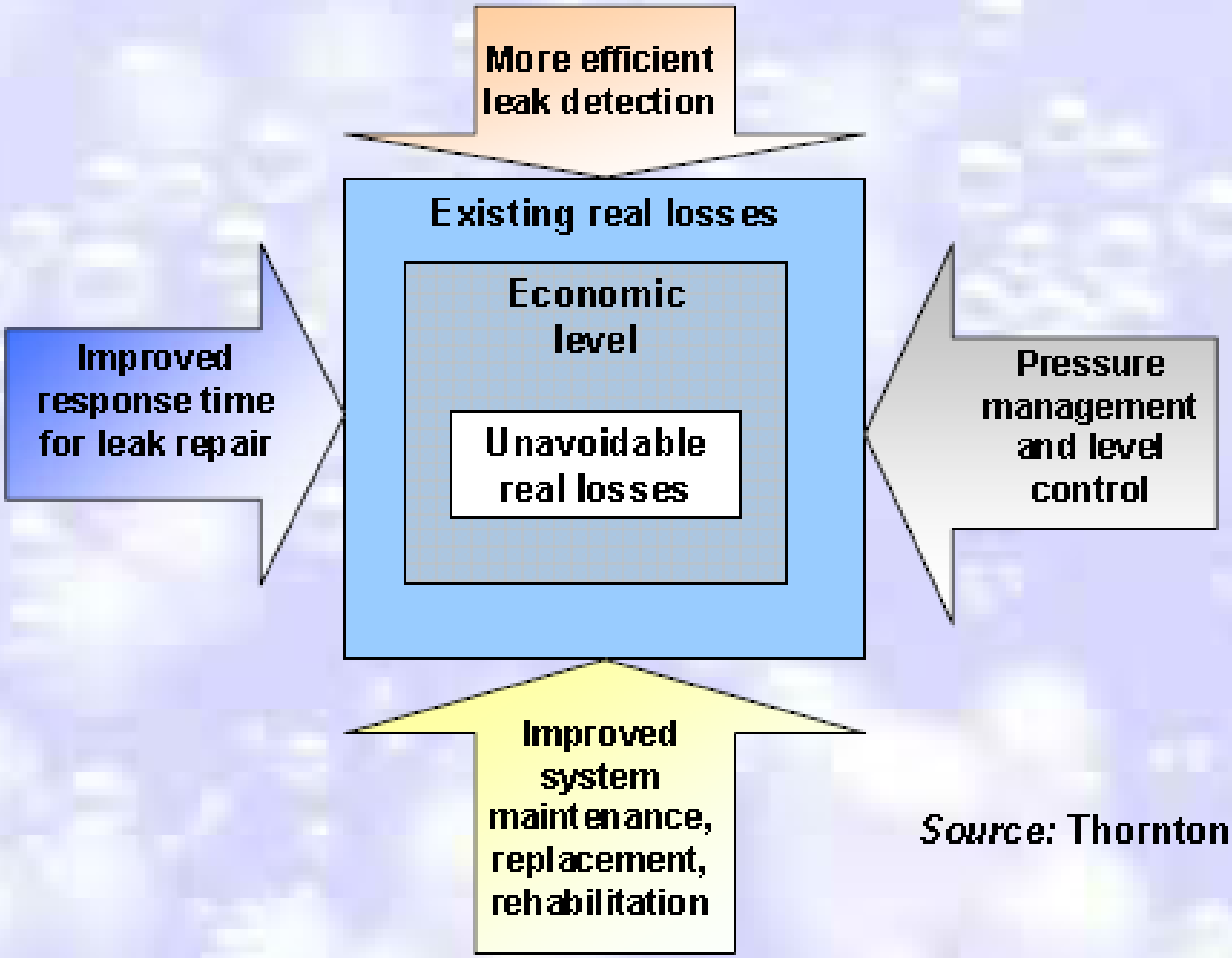
- Similar to the concept of ILI, a index for apparent loss has been recommended by IWA task force.

$$\text{Apparent Loss Index (ALI)} = \frac{\text{Apparent Loss}}{\text{5\% of Water Sales}}$$

Controlling Water Loss

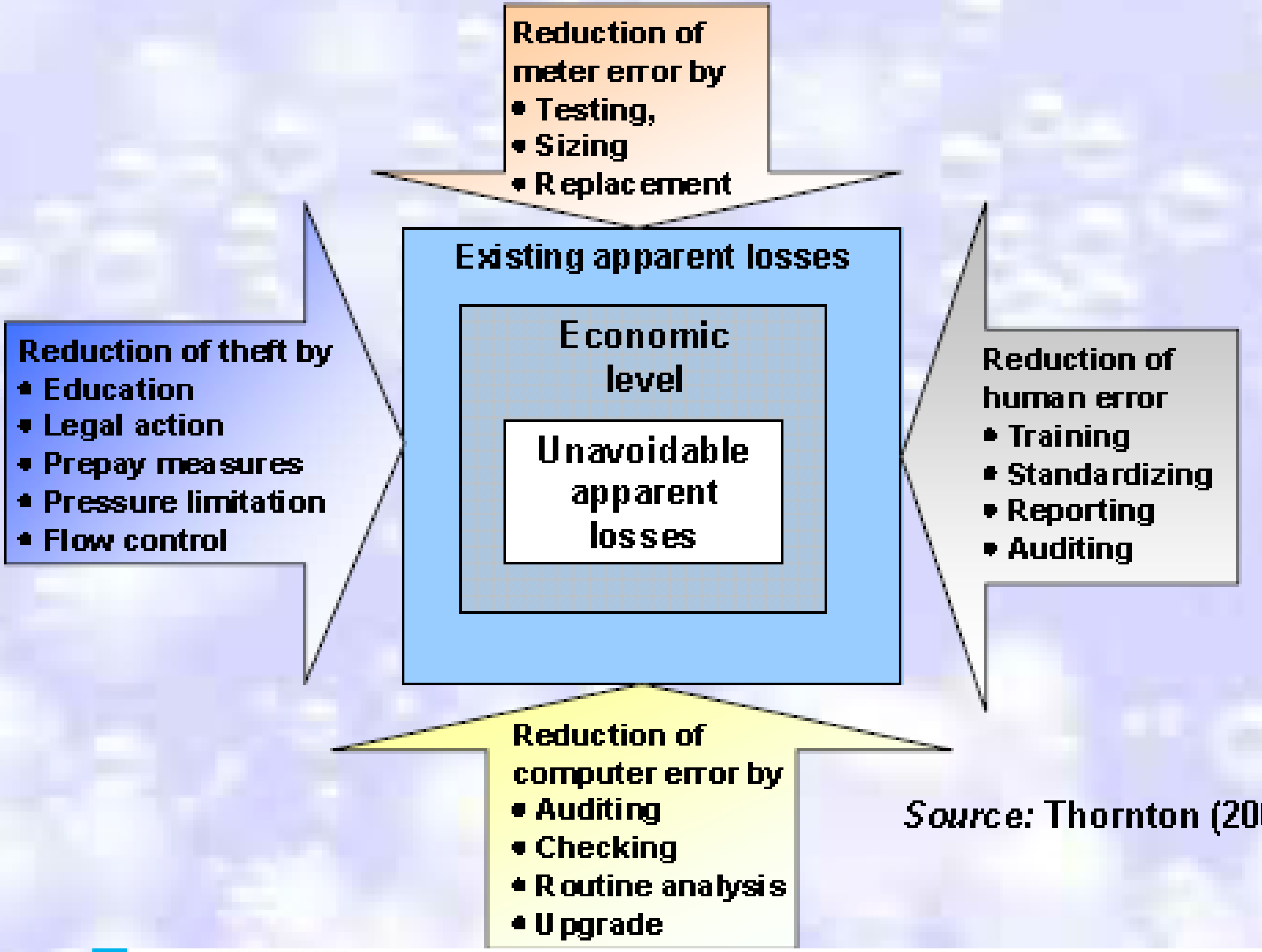
- Water audit or Water balance
- Meter testing and repair/replacement, improving billing procedure
- Leak detection and control program
  - network evaluation
  - leak detection in the field and repair
- Rehabilitation and replacement program
- Corrosion control
- Pressure reduction
- Public education program; Legal provisions
- Water pricing policies encouraging conservation
- Human resources development
- Information system development

Four components of an active real loss management program



Source: Thornton (2002)

Four components of an active apparent loss management program



Source: Thornton (2002)

IWA recommended performance indicators

Function	Level	Performance Indicator	Remarks
Financial: NRW by volume	Basic	Volume of NRW as % of system input volume	Can be calculated from simple water balance
Financial: NRW by cost	Detailed	Value of NRW as % of annual cost of running system	Allows different unit costs for NRW components
Inefficiency of use of water resources	Basic	Real loss as % of system input volume	Unsuitable for assessing efficiency of management of distribution system
Operational: Real losses	Basic	m^3/service line/day, when system is pressurized	Best "traditional" basic performance indicator
Operational: Real losses	Detailed	Infrastructure Leakage Index	Ratio of CARL to UARL

Source: Adapted from Thornton (2002)

Guideline for Water Loss Level

- **For systems with per capita consumption of less than 150 l/day the general rule for water loss level is:**

Good condition of system	< 250 Litre/connection /day
Average condition	250 - 450 Litre/connection/day
Bad condition of system	> 450 Litre/connection/day

- **Another guideline for the water loss level is the "Benchmark" Litre/km mains/day:**

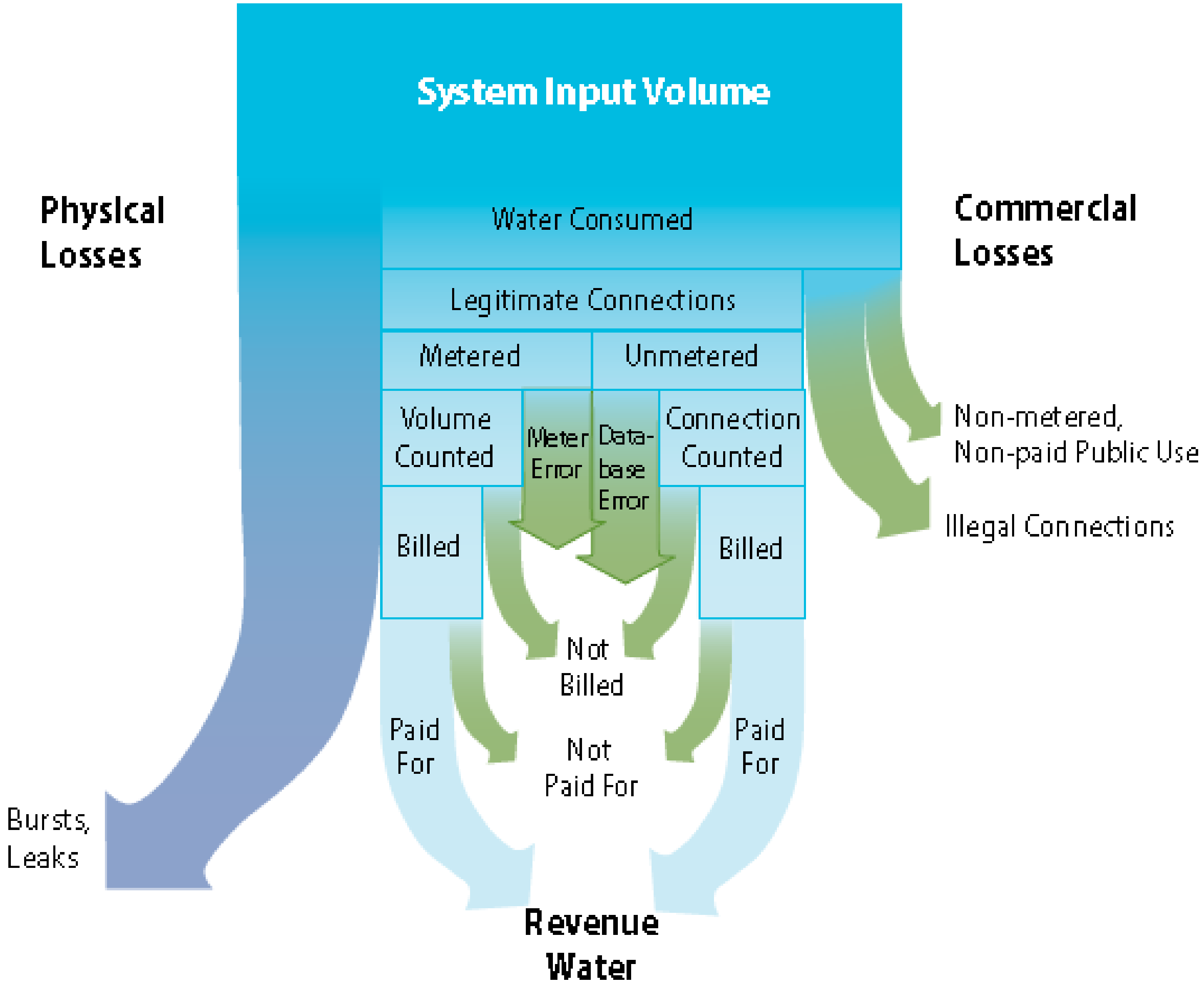
Good condition of system	< 10,000 Litre/km main/day
Average condition	10,000 – 18,000 Litre/km main/day
Bad condition of system	> 18,000 Litre/km main/day

Source: Gerhard Zimmer (Experiences from Kfw funded programs)

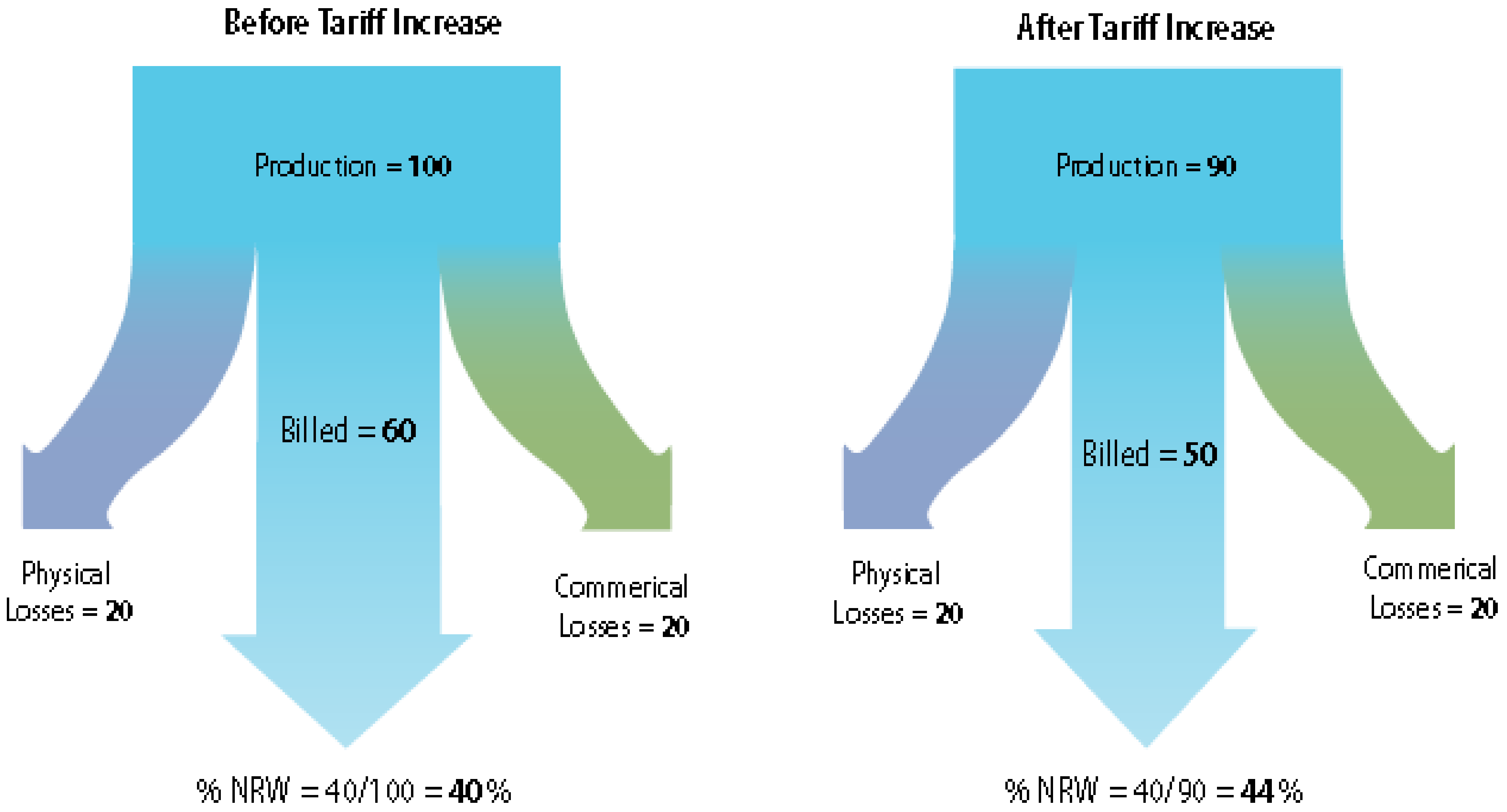
Leak detection methods and their suitability for types of mains

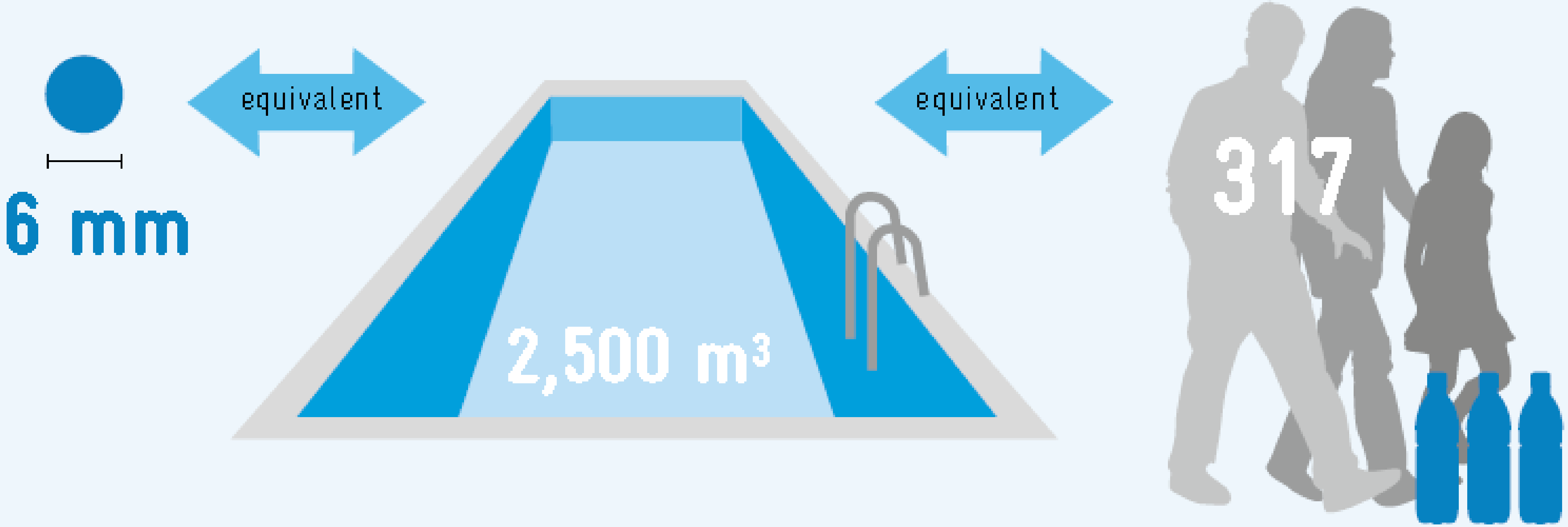
Leak detection methods		Suitability for		
		Service pipes	Distribution mains	Trunk mains
Acoustic techniques	Basic Listening stick	Yes	Yes	
	Electronic listening stick	Yes	Yes	
	Leak noise correlator		Yes	Yes
	Noise loggers		Yes	
	Multi acoustic sensor strip	Yes	Yes	
	In pipe sounding			Yes
Non-acoustic techniques	Gas injection	Yes	Yes	
	Ground penetrating radar	Yes	Yes	Yes
	Infrared photography			Yes
	In pipe hydraulic plug	Yes		

(Source: EU Reference document good practices leakage management WFD CIS WG PoM)



Physical Losses and Commercial Losses = Non-Revenue Water


Before Tariff Increase
Production = 100
Billed = 60
Physical Losses = 20
Commerical Losses = 20
% NRW = 40/100 = 40%
After Tariff Increase
Production = 90
Billed = 50
Physical Losses = 20
Commerical Losses = 20
% NRW = 40/90 = 44%



Hole ø = 6 mm
Pressure = 50 m
» Leakage = 43.2 m³/d

Olympic size swimming pool
V = 2,500 m³
» Filled in less than 2 months

Per capita consumptions = 136 l/cap/d
Q = 317 x 136 l/cap/d = 43.2 m³/d
» Water for 317 persons

calculating the change in leakage flow for a small pressure increase. These results are shown in Figures 3 for the leakage exponent. The results show that the leakage exponent of a given leak is not fixed, but is higher at higher pressures and at lower pressures.

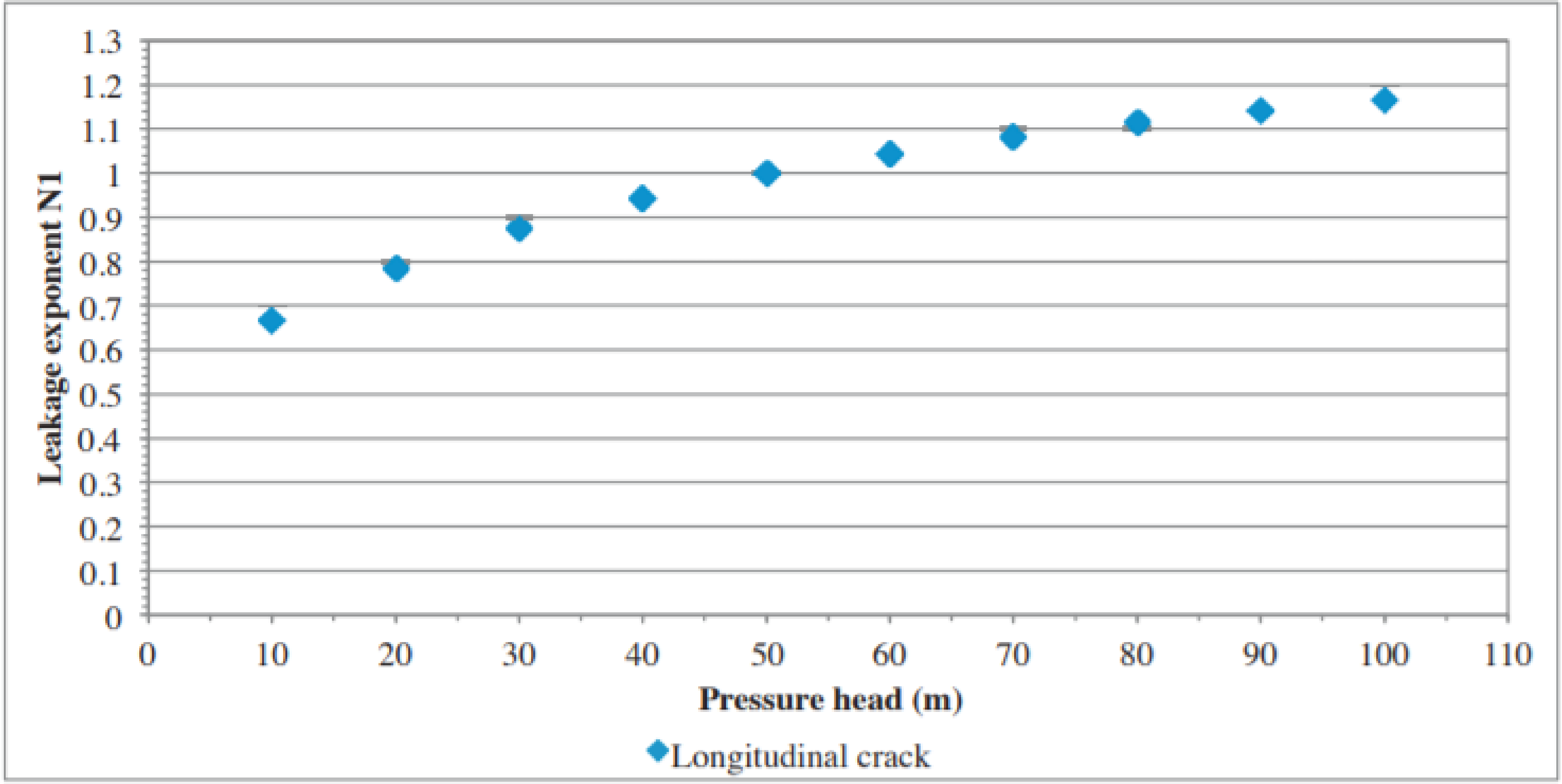


Figure 3. Leakage exponents obtained at different pressures for the h-Q curve in Figure 2

Table 2.1 Leak flow rate from a 6 mm hole for different pressures and pipe materials

Ø Hole	Pipe material	Leakage exponent	Leak flow rates at pressure of		
			50 m	40 m	30 m
6 mm	Rigid (e.g. steel, cast iron, ...)	0.5	1,800 m^3/h	1,610 m^3/h	1,394 m^3/h
6 mm	Flexible (e.g. PE, PVC, ...)	1.5	1,800 m^3/h	1,288 m^3/h	837 m^3/h

Pressure management: reduction of excess average and maximum pressures						
Conservation benefits		Water utility benefits			Customer benefits	
Reduced flow rates		Reduced frequency of bursts and leaks				
Reduced consumption	Reduced flow rates of leaks and bursts	Reduced repair costs at mains and services	Deferred renewals and extended asset life	Reduced cost of active leak-age control	Fewer customer complaints	Fewer problems on customer plumbing and appliances

Figure 3.2 Relationship between leakage rate (Q) and runtime (t) of leaks [22] [77]

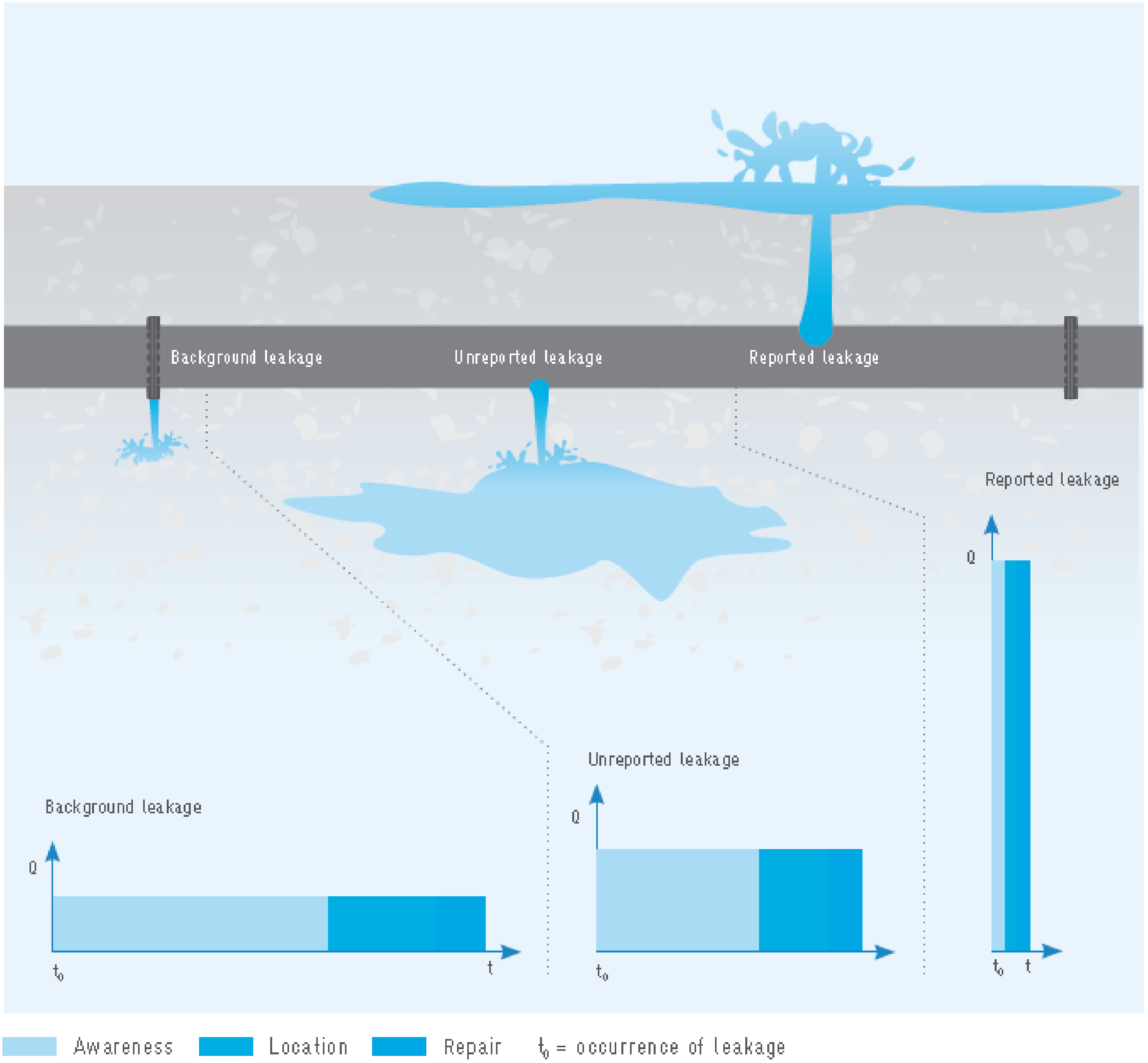


Figure 5.1 Interactions between various GIS-based information systems

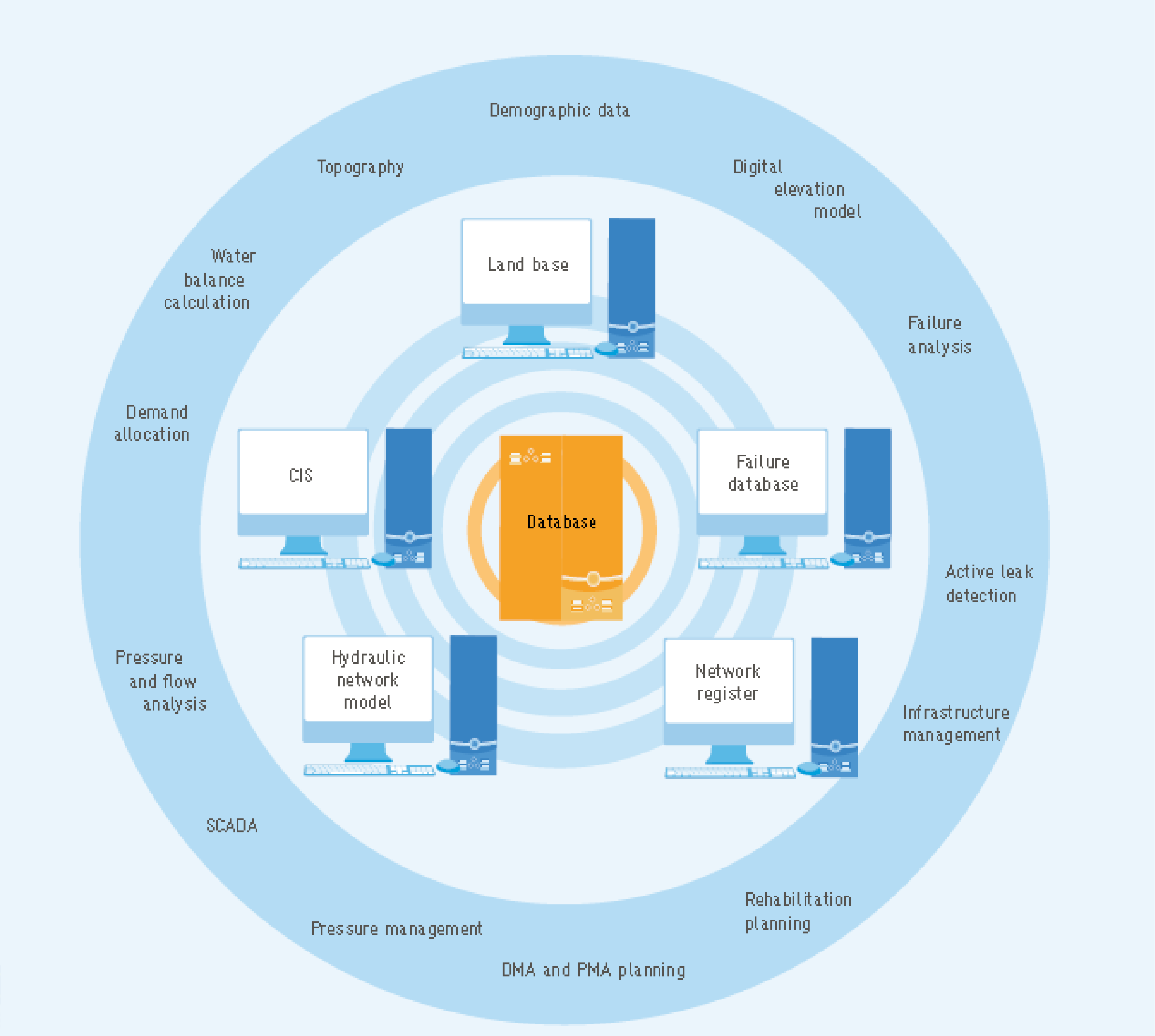


Figure 5.4 Structure of a GIS based on databases, data sets and single object classes [93]

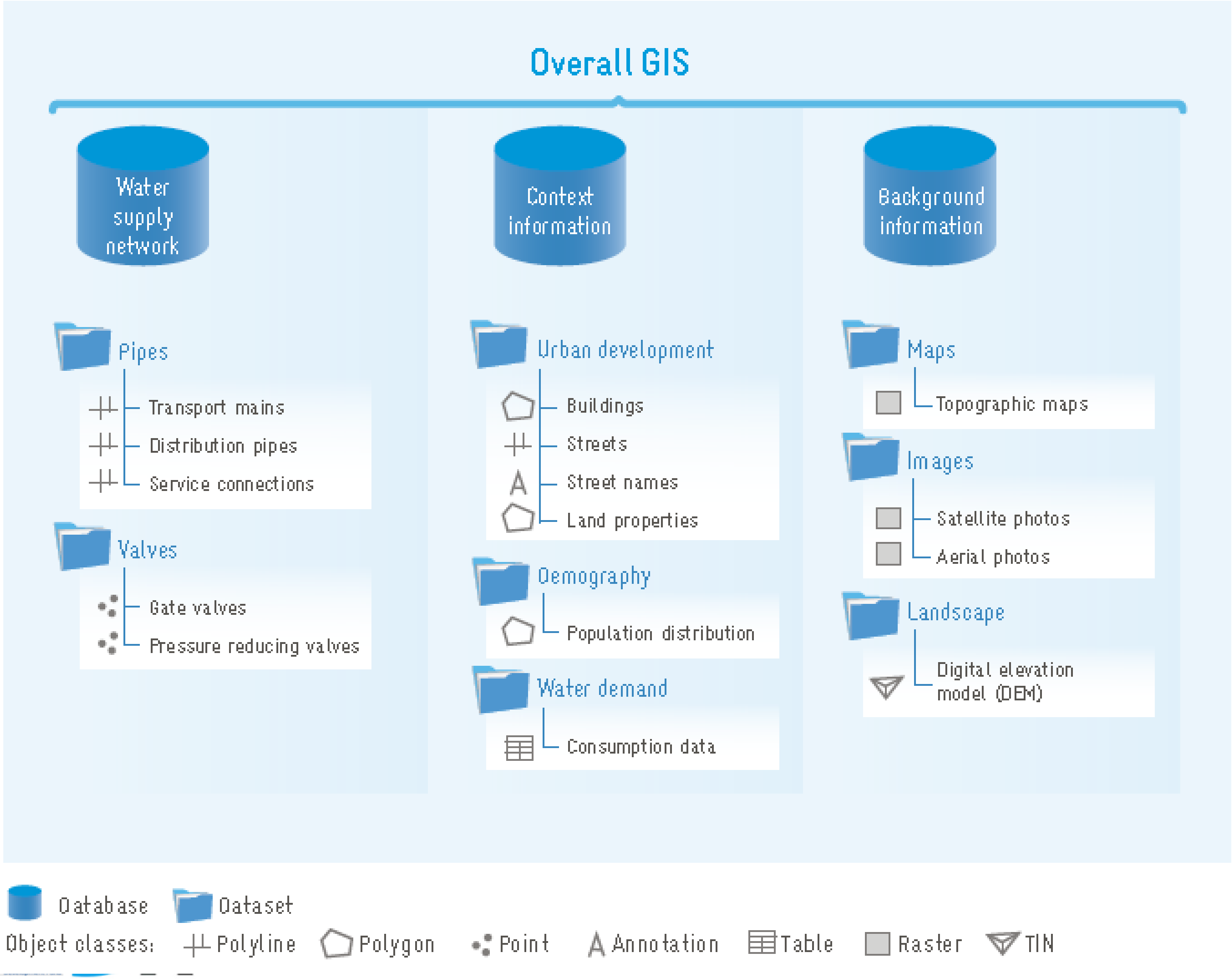


Figure 5.6 Linking the hydraulic network model to the network register

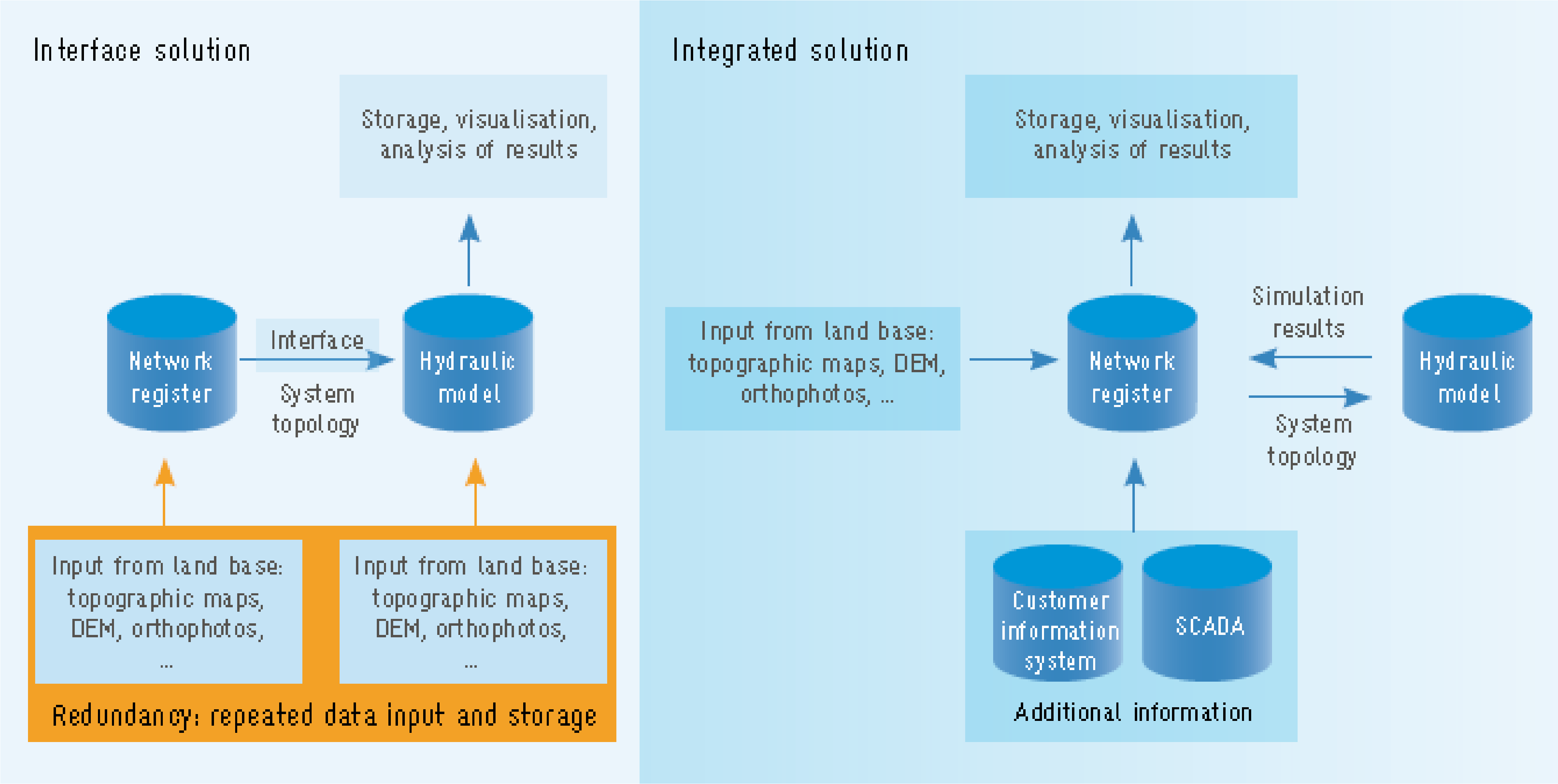
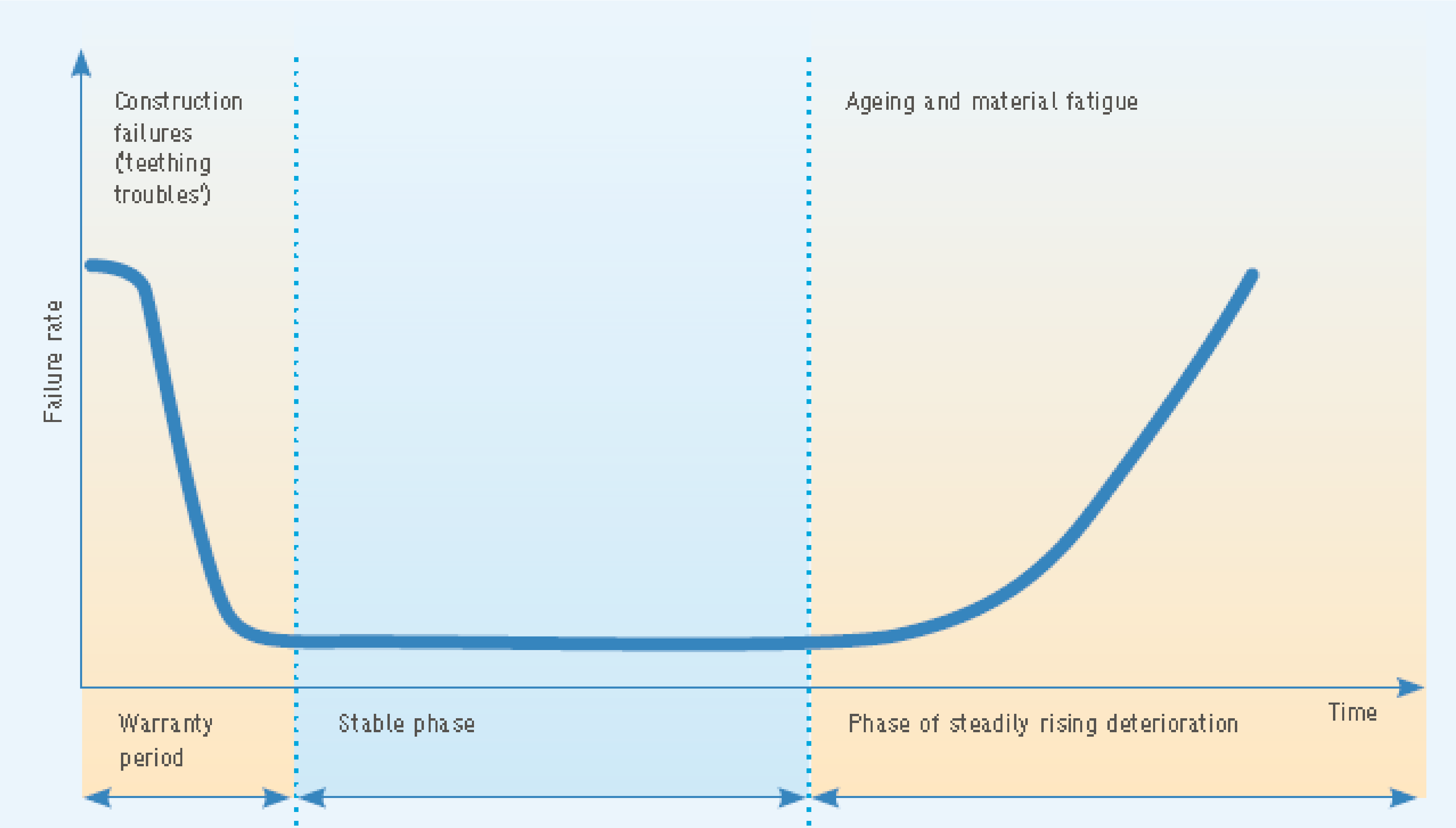


Figure 5.9 Typical behaviour of the failure rate in pipes, based on [43]



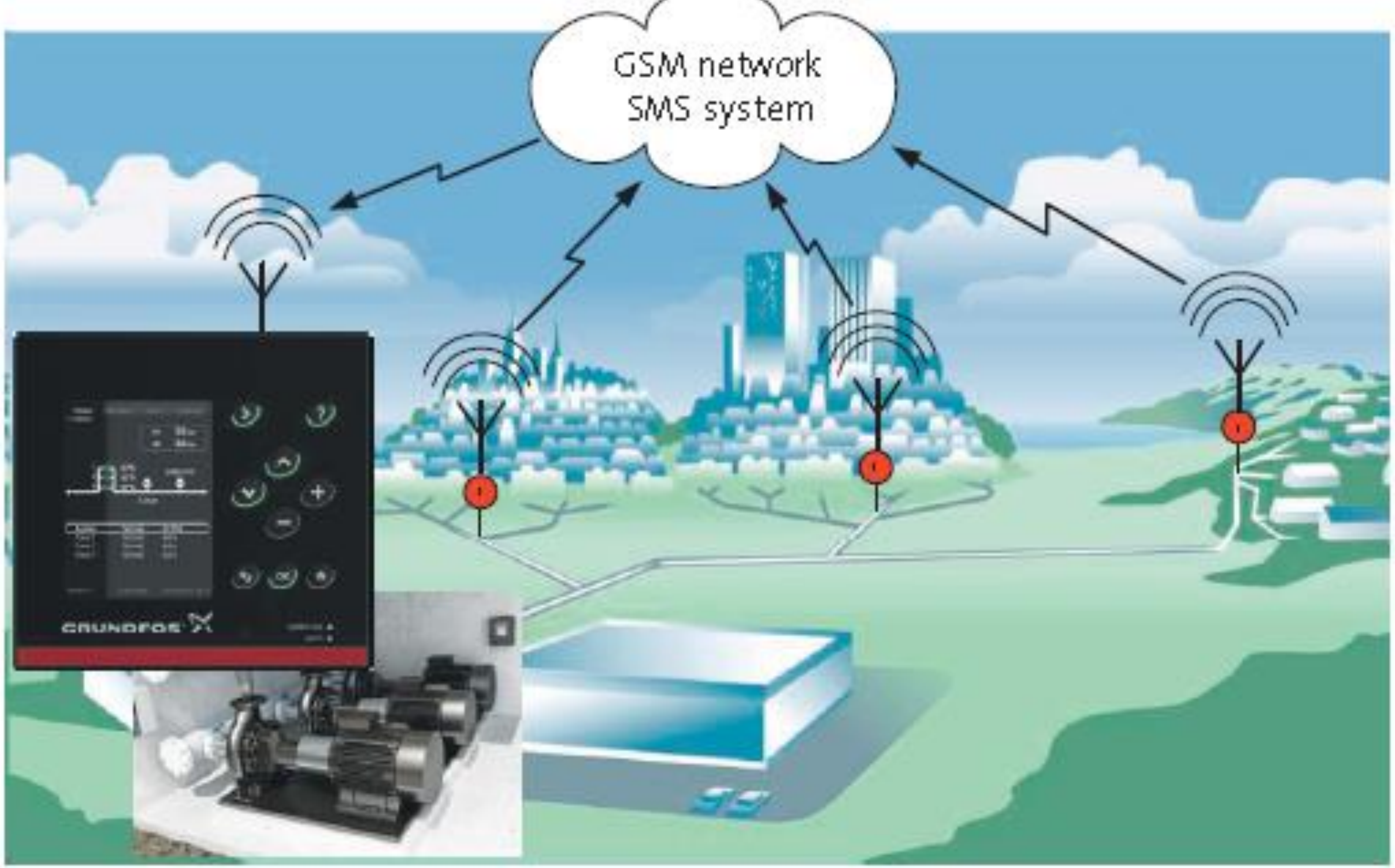
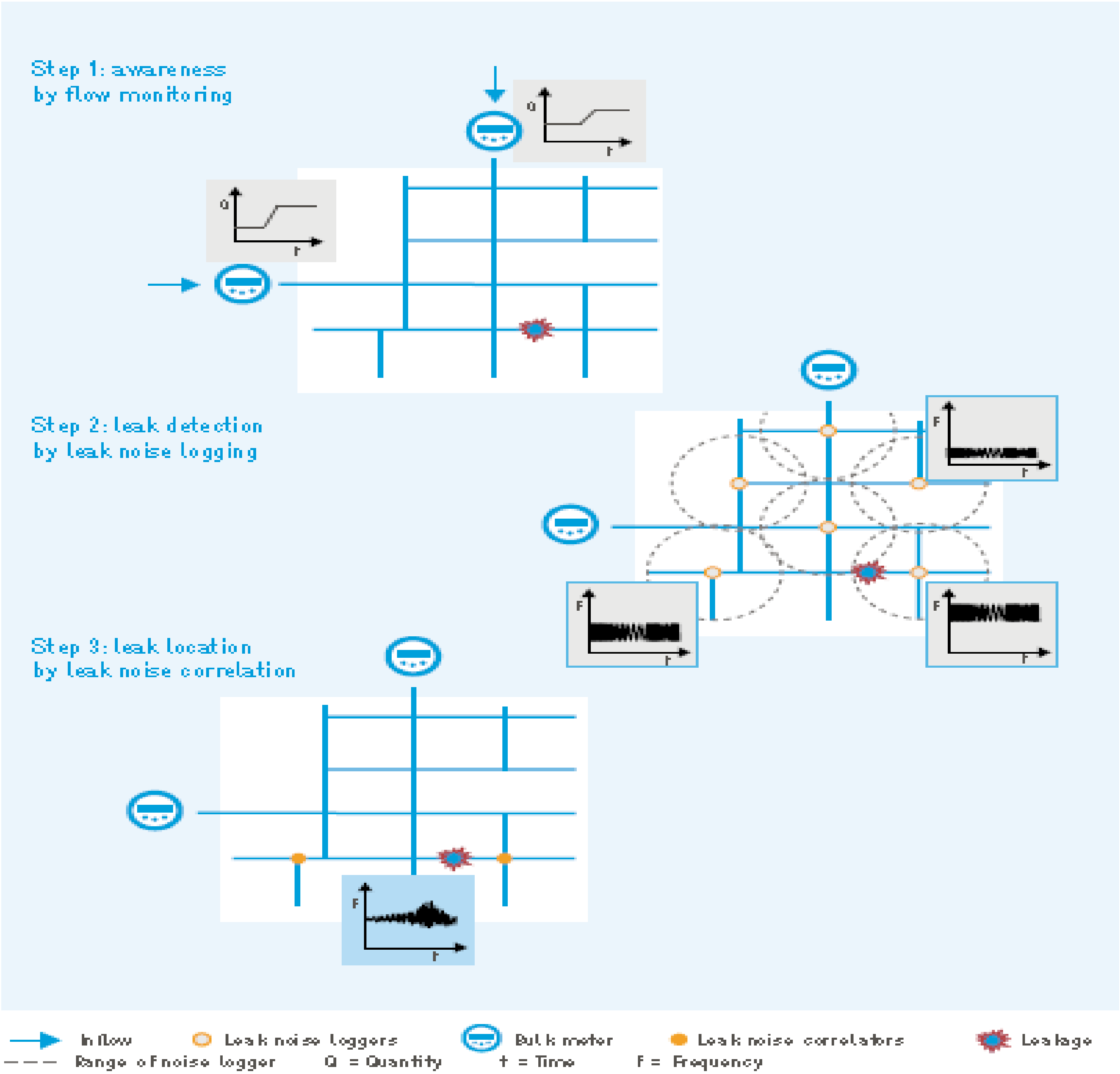


Figure 5: The Demand Driven Distribution controller connected to network pressure sensors via the GSM network allows control of the pumps in accordance with the logger data via a smart adaptive control algorithm

	PROBLEMS FACING WATER UTILITIES, AND BENEFITS WITH DIFFERENT MODES OF OPERATION		
	INTERMITTENT SUPPLY: (NOT "24/7" OPERATION)	CONTINUOUS SUPPLY: (EXCESS PRESSURE)	OPTIMAL PRESSURE MANAGEMENT: (DEMAND DRIVEN DISTRIBUTION)
NRW – HIGH LEAKAGE COMPONENT	Leakage flow rates reduction due to limited time of pressurisation. Very high burst frequencies on mains and services. Big risks of contamination when the pipes are not pressurised.	High burst frequencies due to higher than required maximum pressures for much of the time. High leak flow rates due to higher than required average pressures.	10 % reduction of average pressure produces 10 % to 20 % reduction in annual leakage (depends on pipe materials and type of leaks)
ENERGY EFFICIENCY	High energy costs for pumping as higher flow rates are imposed to move the same volume.	Excess energy costs due to excess pressurisation from pumping.	10 % reduction of excess average pressure produces around 10 % decrease in energy costs from pumping.

OPERATION AND MAINTENANCE	High manpower costs for valving operations. High repair costs.	High repair costs High liability costs	10 % reduction of average pressure decreases economic intervention costs of active leakage control by 10 %.
	Active leakage control is difficult due to insufficient pressure.	High active leakage control costs due to higher rate of rise of unreported leaks.	10 % reduction of average pressure decreases economic intervention costs of active leakage control by 10 %.
	Short asset life time due to poor operation and pressure transients.	Short asset life time due to excess pressure.	Deferred renewals, residual asset life extension. This benefit can be very substantial; prediction methodology for pressure reduction being developed.



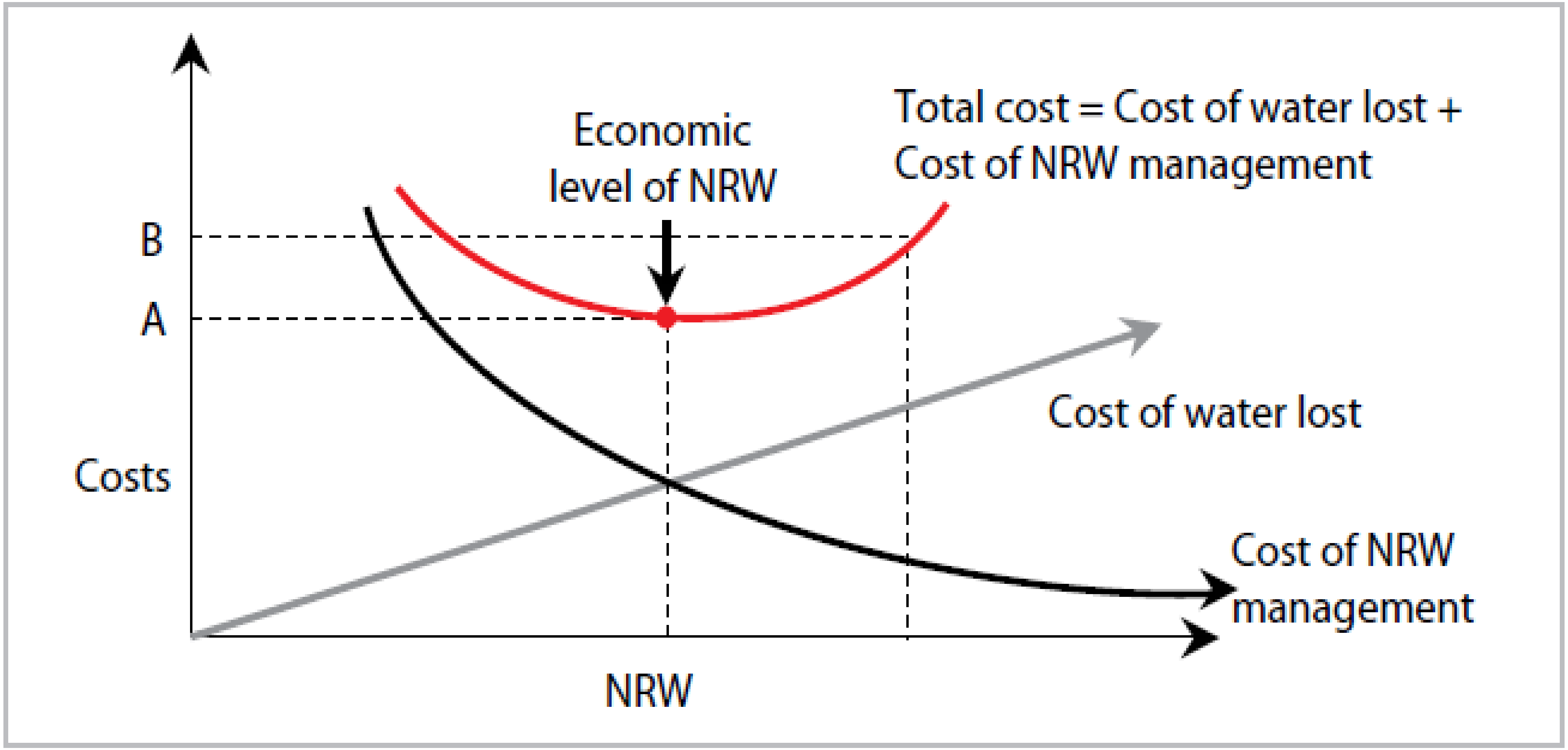
Step 1: awareness
by flow monitoring
Step 2: leak detection
by leak noise logging
Step 3: leak location
by leak noise correlation
Inflow
Leak noise loggers
Bulk meter
Leak noise correlators
Leakage
Range of noise logger
Q = Quantity
t = Time
F = Frequency

Production Meter Accuracy

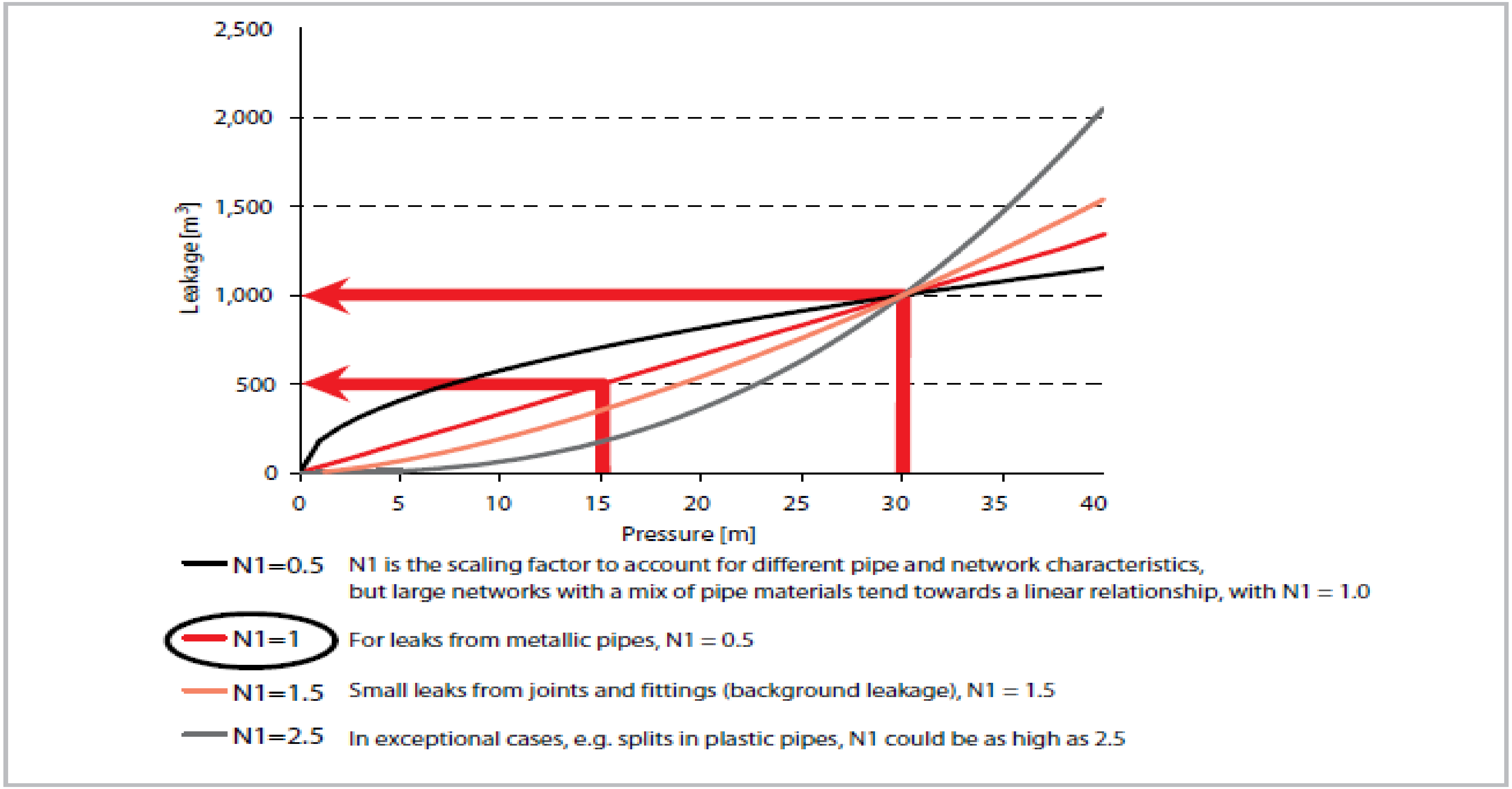
Equipment/Method	Approximate Accuracy Range
Electromagnetic Flow Meters	<0.15 -0.5%
Ultrasonic Flow Meters	0.5 - 1%
Insertion Meters	<2%
Mechanical Meters	1.0 - 2%
Venturi Meter	0.5 - 3%
Meas. Weirs in open channels	10 - 50%
Volume calculated with pump curves	10 - 50%
Note: Actual meter accuracy will depend on many factors (like flow profile, calibration, meter installation, maintenance) and has to be verified case by case	

Source: World Bank Institute, 2007

NRW Economic Level Identification



Pressure Leakage Relationship



Source: World Bank Institute

Reduction and Control of UFW

- Substantial savings can be achieved, and requirement of extension water supply facilities can be avoided or minimised by reducing unaccounted-for water. (specifically, leakage detection and control)
- By reducing UFW water agency will be in better financial situation and will be stronger position to achieve its financial self-sufficiency and long-term sustainability.
- A low rate of unaccounted-for water is one of the best overall indicators that a water utility is successful.

Policy issues for sustainable O&M

Governance

- Operational autonomy
- Ability to manage staff
- Flexibility in decision making
- Transparent subsidies

Management

- Responsiveness to consumers
- Efficiency
- Commercial viability
- Capacity to grow and transform

Possible options for reform

(A) Integrated Municipal Management (IMM)

(B) Municipal Water Company (MWC)

A. Integrated Municipal Management

Advantages

- Simple to administer
- Managerial control with Municipal Commissioner
- Customers can deal with one agency for all services
- Democratization at the grass-root level

Weaknesses

- Low accountability
- Key staff
- Difficult to link tariffs to service delivery
- Less focus on water
- Councilor and operator conflicts

B. Municipal Water Company

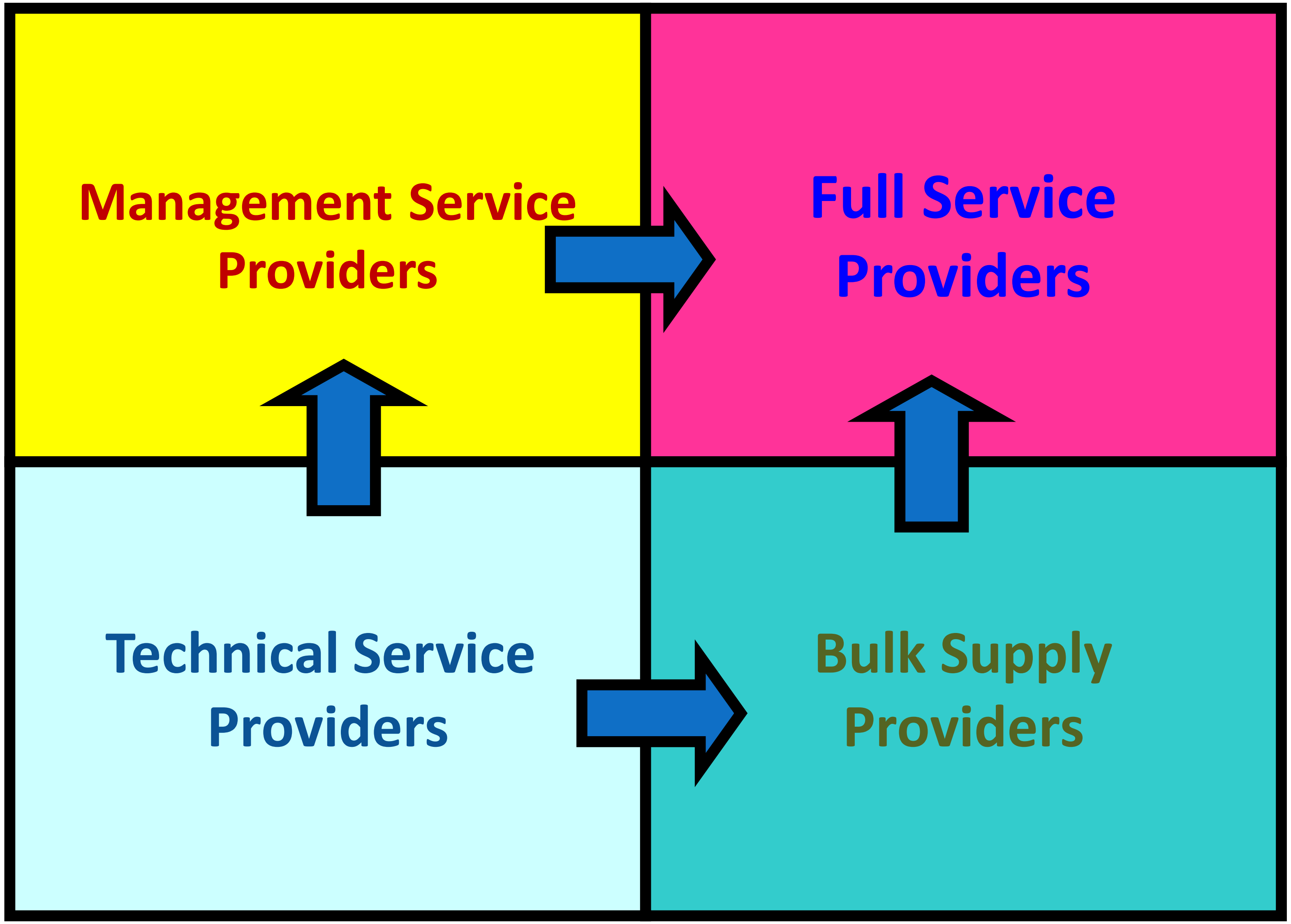
Advantages

- Protected from daily interference from policy makers
- Civil society can be included in management
- Tariffs and service delivery can be linked
- Better financial planning and management

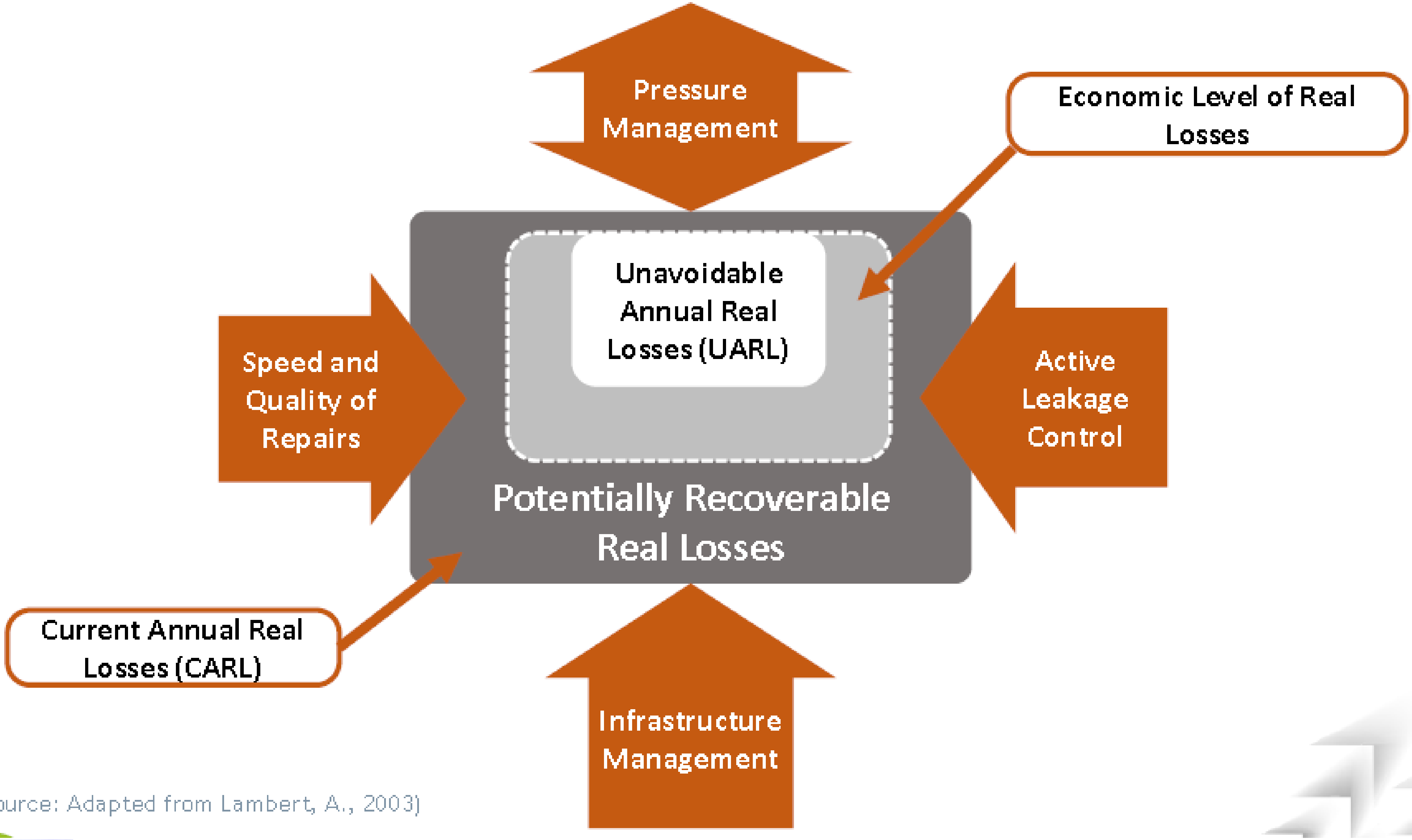
Weaknesses

- Require detailed initial planning and preparation
- Staff who are deputed may be unwanted by the parent agency
- Require elaborate training to induce corporate culture
- Councilors involvement low hence they may resist

Management Options



IWA intervention strategies to reduce water losses



(Source: Adapted from Lambert, A., 2003)

What is Water Loss Management?

Strategies and tools to assist water utilities in their important goal of reducing non-revenue water. Water Loss Management is integral to the good management of any water supply system.

Leak Detection Equipment for finding Real Losses

Strategies and tools for Managing Real Losses

Terminology

Non-Revenue Water Consists of:

<u>Real Losses</u>

- Service Leaks
- Weepers (Undetectable)
- Reservoir leakage
- Main Leaks
- Major Ruptures / Failures

<u>Apparent Losses</u>

- Meter Under-Registration
  - Mechanical Wear
  - Over-sized meter
- Authorized Unbilled consumption
- Billing Errors
- Theft

What's a Normal Amount of Water Loss?

Depends on the size of the system

Benchmark to a systems theoretical minimum level of water loss (UARL).

- 1 – 2 times the UARL = very well managed system
- 2 – 3 times the UARL = doing pretty good
- 3 – 4 times the UARL = average performer
  (some easy reductions with leak detection may be possible)
- 4 – 5 times the UARL = definite room for improvement
- > 5 time the UARL = Leak detection easily justified

SYSTEM	Lm (km)	Nc (#)	Lp (km)	P (mH)	UARL (L/s)	Current Losses (L/s)	ILI Est.
Sooke	132	4,415	44	50	4	10	2.5

Leak Sizes

< 0.1 L/s (pinhole leak)

0.1 L/s – 0.2 L/s (small leak)

0.25 L/s – 0.5 L/s (medium leak)

1 – 3 L/s (large service leak)

3 – 6 L/s (very large leak)

> 6 L/s (pressure loss)

EMG
ENVIRONMENTAL ENGINEERING GROUP
THE WORLD BANK
UNESCO-IHE
IWA

Managing Non-Revenue Water

What Should We Do at Minimum

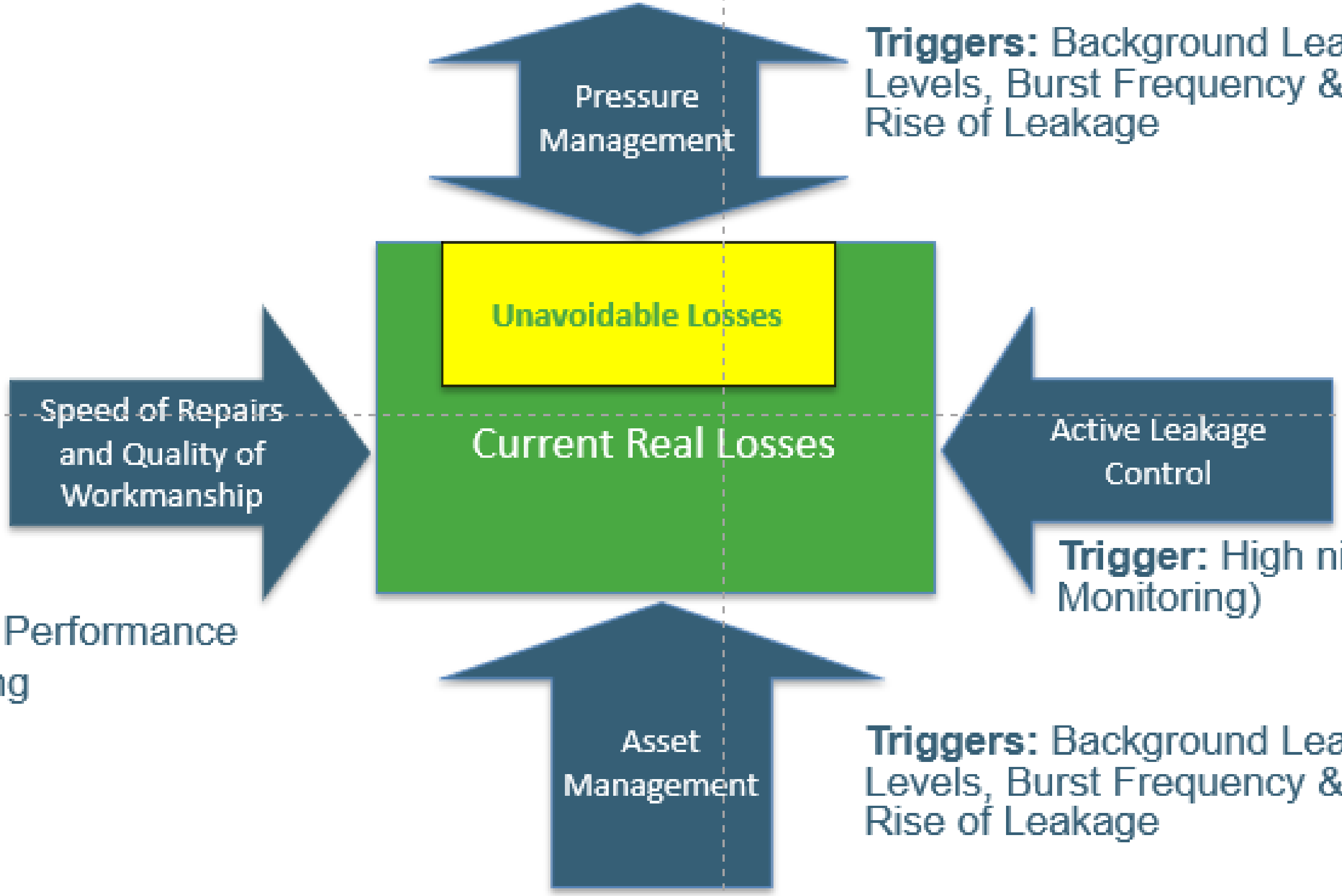
Managing Real Losses

- Source meter with good low flow capability. Ability to data-log hourly flow.
- Monitor source meter data (review night flows and track)
- Track break locations, materials and failure type
- Replace pipe with high break frequency
- Integrate water loss testing with other operational tasks
- Reduce pressures where possible
- Hire competent pipe installers and designers, use good materials.

Managing Apparent Losses

- AWWA M36 Water Audit
- Get to know your customer data - Flag low billing volumes and oversized meters
- Replace residential meters approx. every 20-25 years
- Right size meters for large customers
- Test/Replace large customer meters (more frequently than residential meters)

Managing Real Water Loss



Triggers: Background Leakage Levels, Burst Frequency & Rate of Rise of Leakage

Trigger: High night flow (Flow Monitoring)

Trigger: Performance Monitoring

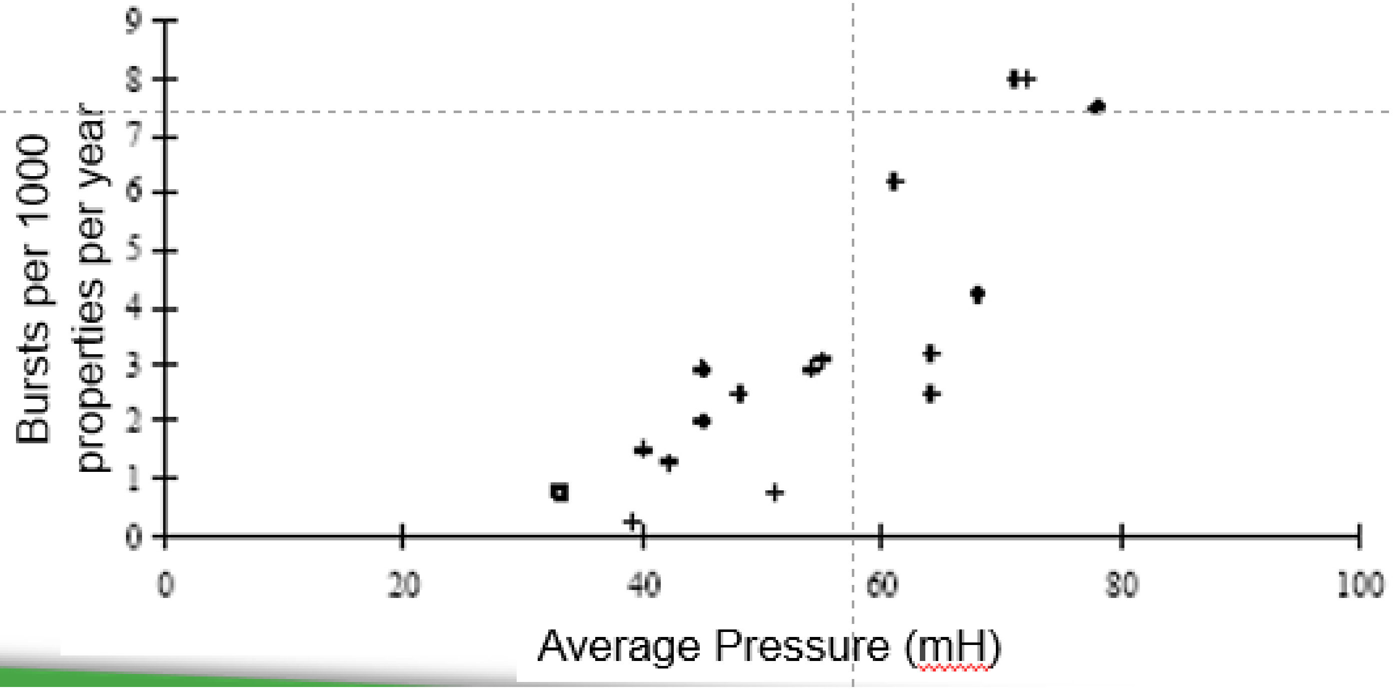
Triggers: Background Leakage Levels, Burst Frequency & Rate of Rise of Leakage

PRESSURE MANAGEMENT

LOWERING SYSTEM PRESSURES

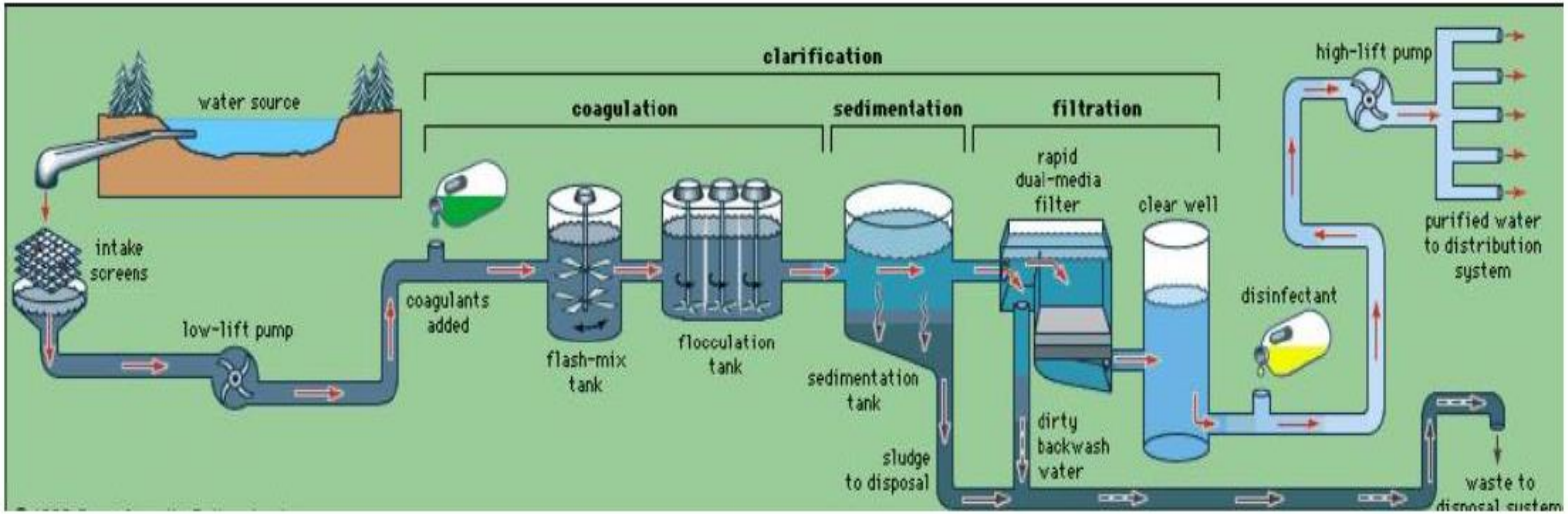
- Pressure reduction : leakage relationship is 1:1
  (20% pressure reduction = 20% leakage reduction)

- Reduced burst rate & reduced maintenance costs



Treatment & Distribution Cost

Surveys of utilities have revealed treatment and distribution costs ranging from $1.00 - $4.00 / 1,000 gallons (higher for consecutive systems)



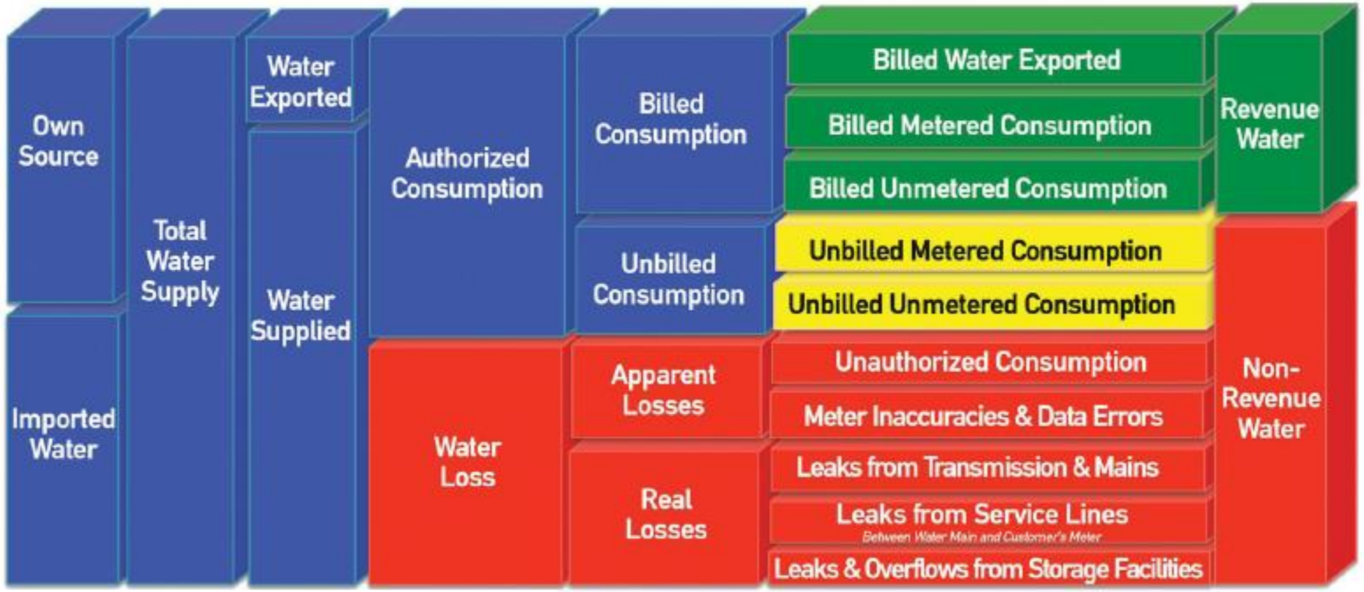
Water Audit

- System owner must quantify water loss

AWWA M36

Water Audits and
Loss Control Programs

4th Ed. (2016)

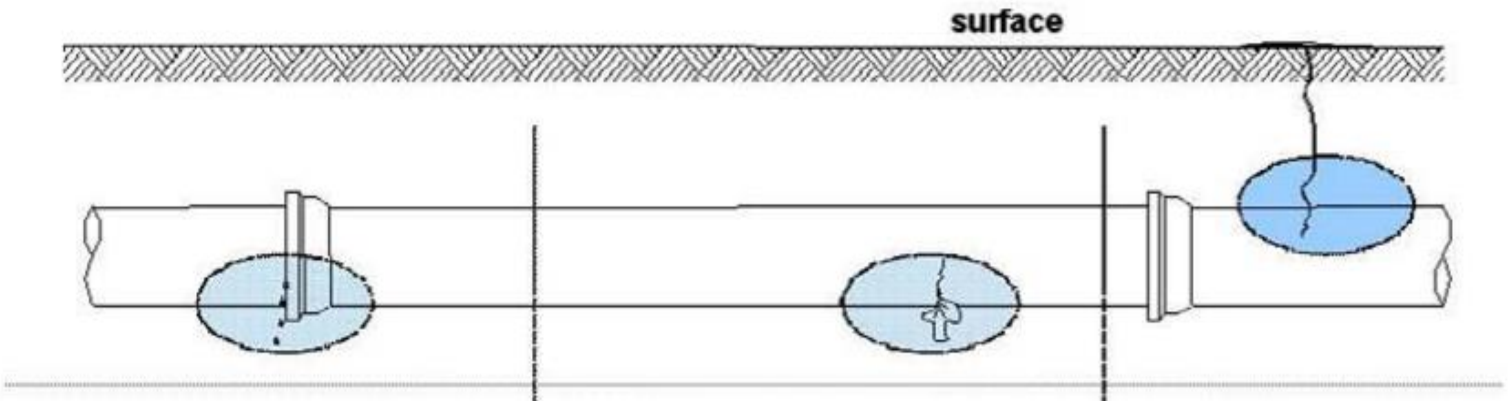


How Do We Eliminate The Loss ?

- Identify Water Loss (Water Audit)
- Implementation of Leak Detection Program
- Pressure Management

Water Audit

- Real losses



Background leakage

Un-reported and un-detectable using traditional accoustic equipment.

Tools

- Pressure stabilization
- Pressure reduction
- Main and service replacement
- Reduction in the number of joints and fittings

Un-reported leakage

Often does not surface but is detectable using traditional accoustic equipment.

Tools

- Pressure stabilization
- Pressure reduction
- Main and service replacement
- Reduction in the number of joints and fittings
- Proactive leak detection

Reported leakage

Often surfaces and is reported by the public or utility workers

Tools

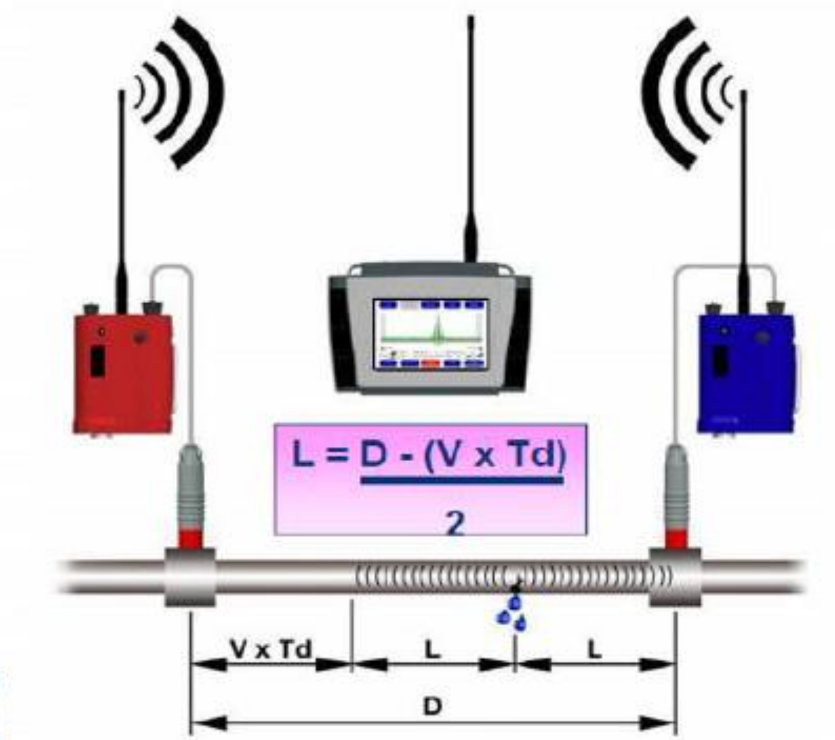
- Pressure stabilization
- Pressure reduction
- Main and service replacement
- Optimized repair time

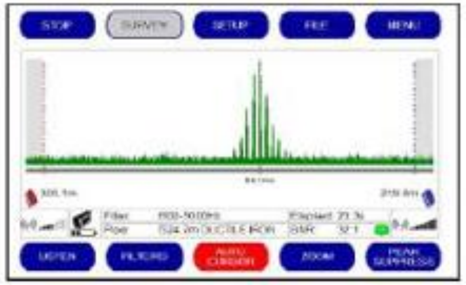
Leak Localization

- Acoustic monitoring through leak loggers
  - Capable of checking the entire distribution network multiple times per year or even daily
  - No leak detection experience required
  - No technical skills required – loggers are magnetically attached to valves

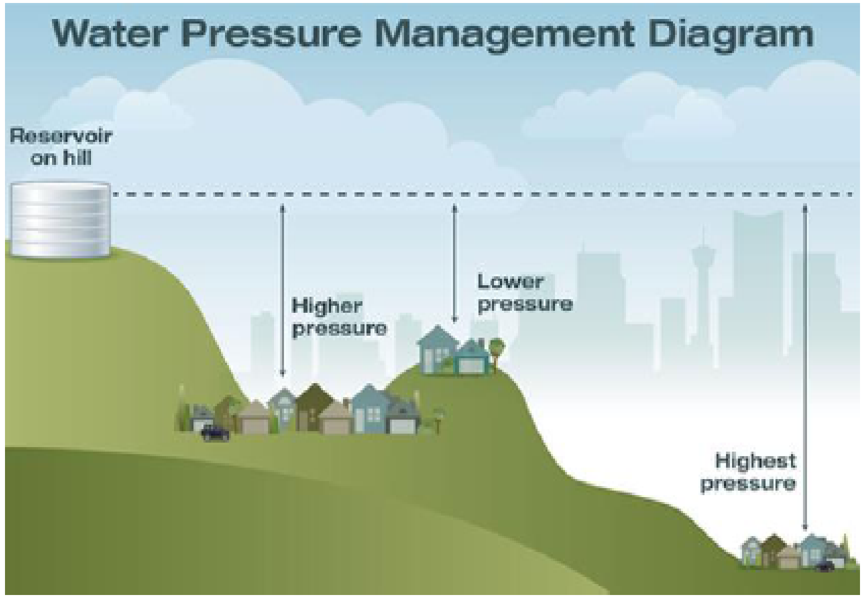
Leak Pinpointing : Correlation

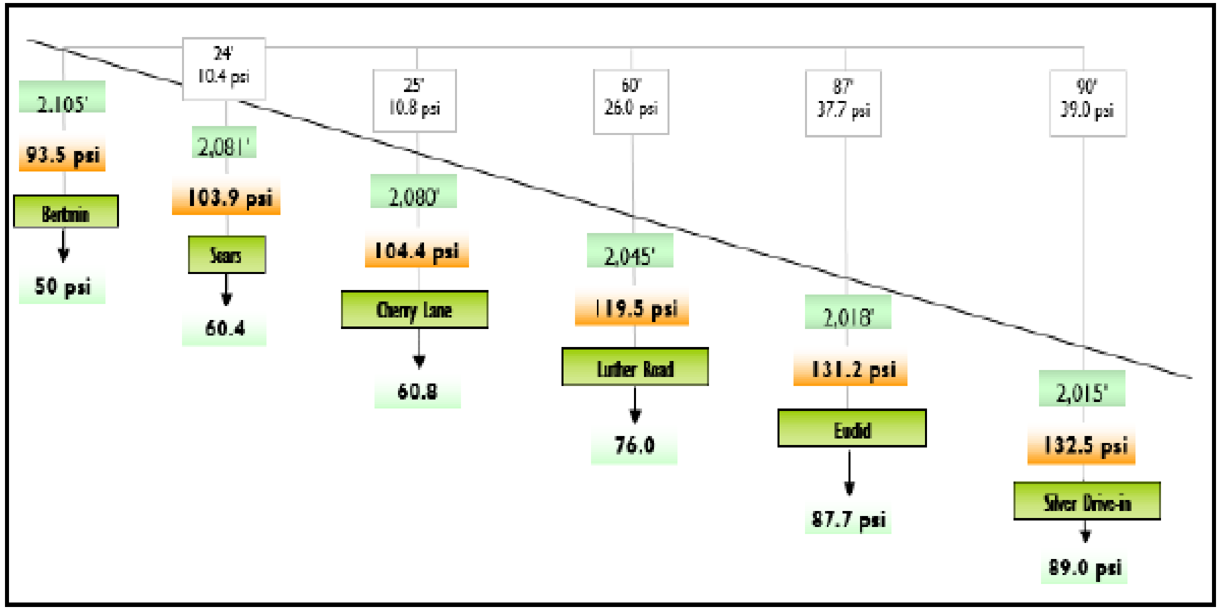
- Traditional correlation methods can be used





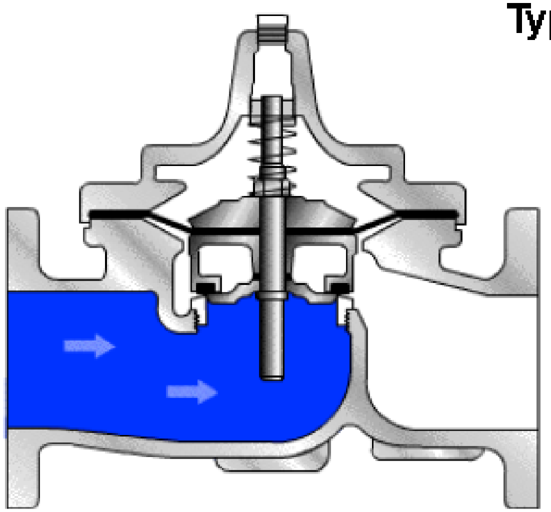
Pressure Management



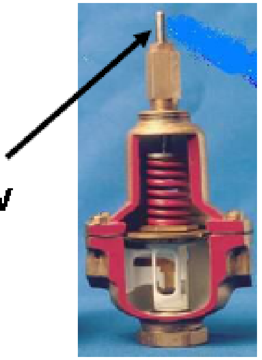


Pressure Management

- When adjusting the pilot, screw in and the PRV increases pressure on the outlet, by venting water from the PRV top chamber
  - Water in the top chamber then pushes the PRV seat down and releases the seat upwards when water is vented



Typical pilot adjusting screw

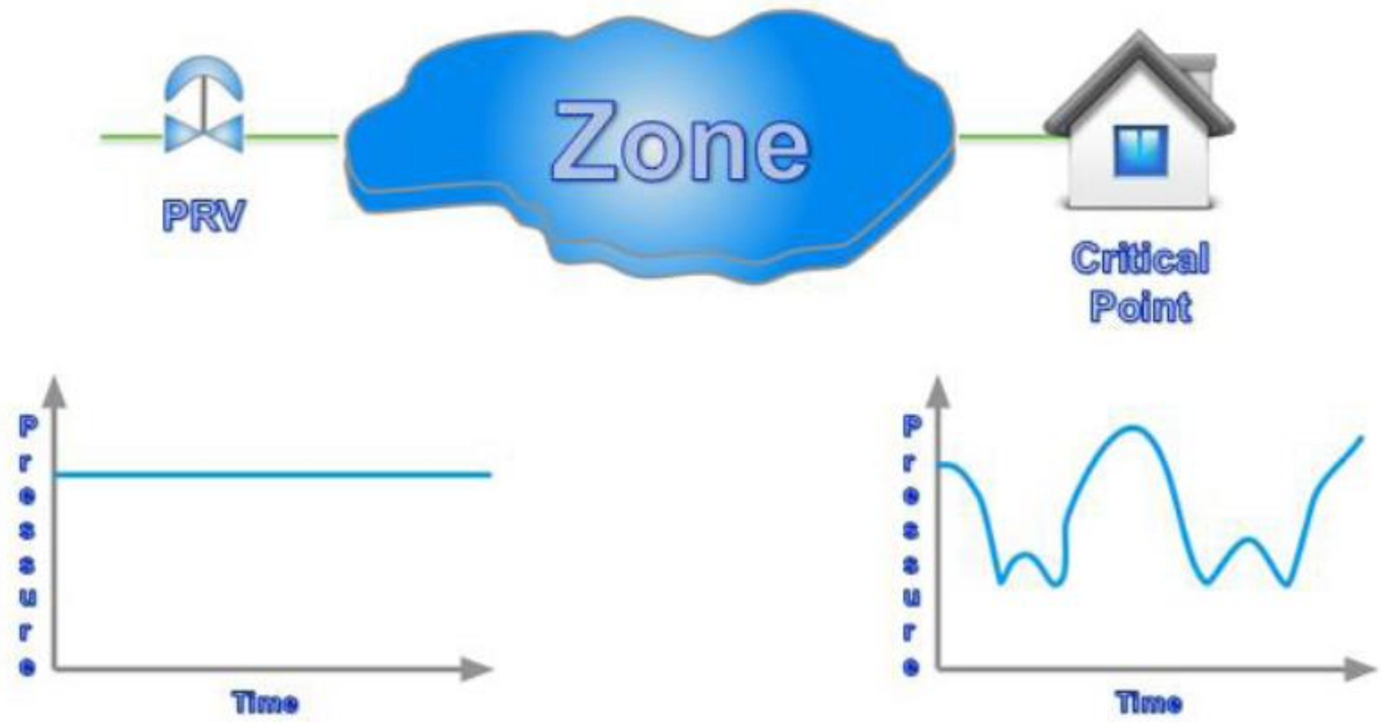


Pressure Management

- Methods of PRV Control
  - Fixed Outlet
    - Delivers constant outlet pressure.
    - Designed to give target pressure at Critical Point (CP) at peak flow.
    - Therefore also gives excess pressure at other times.
  - Time Switched Control
    - Stepped variation in PRV outlet pressure at specific times.
    - Removes excess pressure at specific time.
    - Simple and low cost.
    - Can cause pressure surges when reopening.
  - Flow Modulation
    - PRV outlet pressure varied according to through flow.
    - The Aim is to achieve flat pressure at Critical Point (CP).
    - More complex, higher cost of construction.
    - If PRV sized correctly will deal with fire demands and create a calm network.

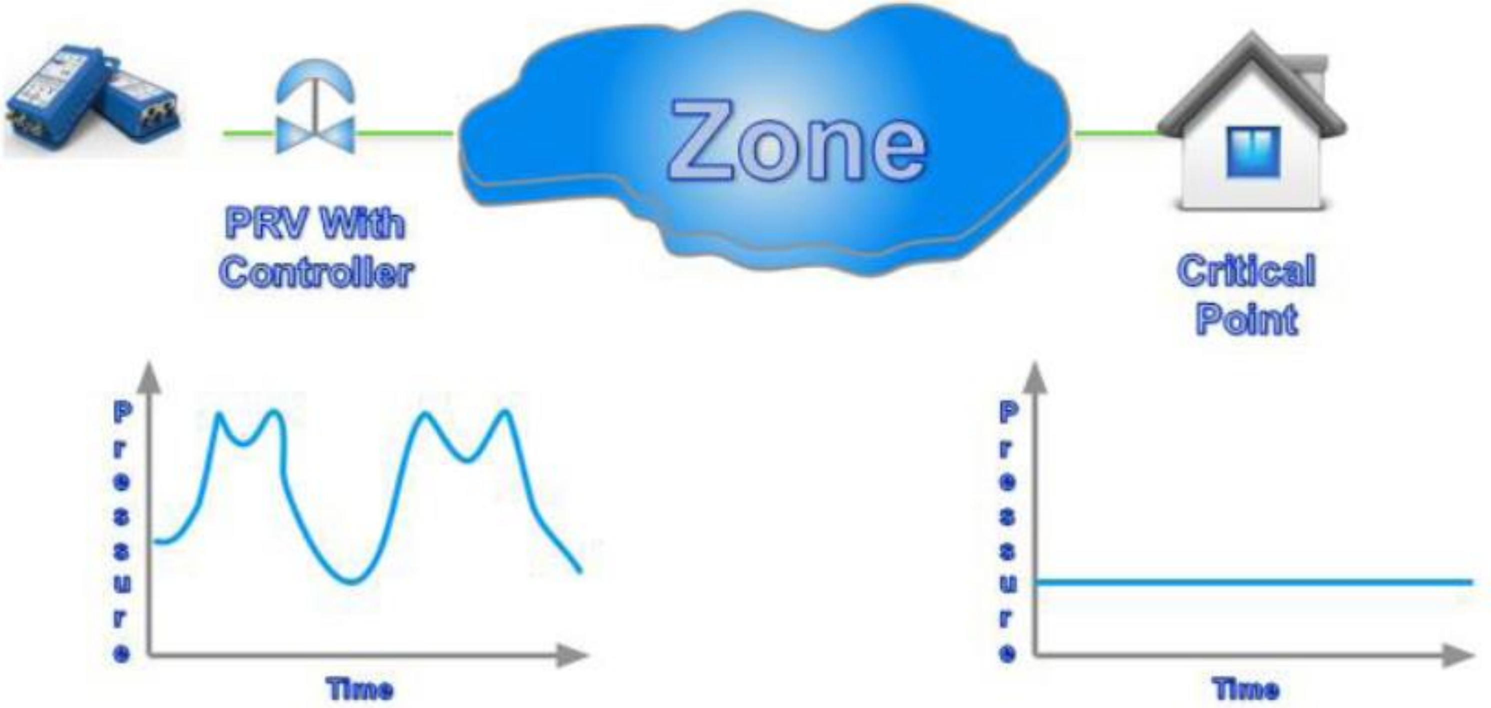
Pressure Management

Fixed Outlet PRV

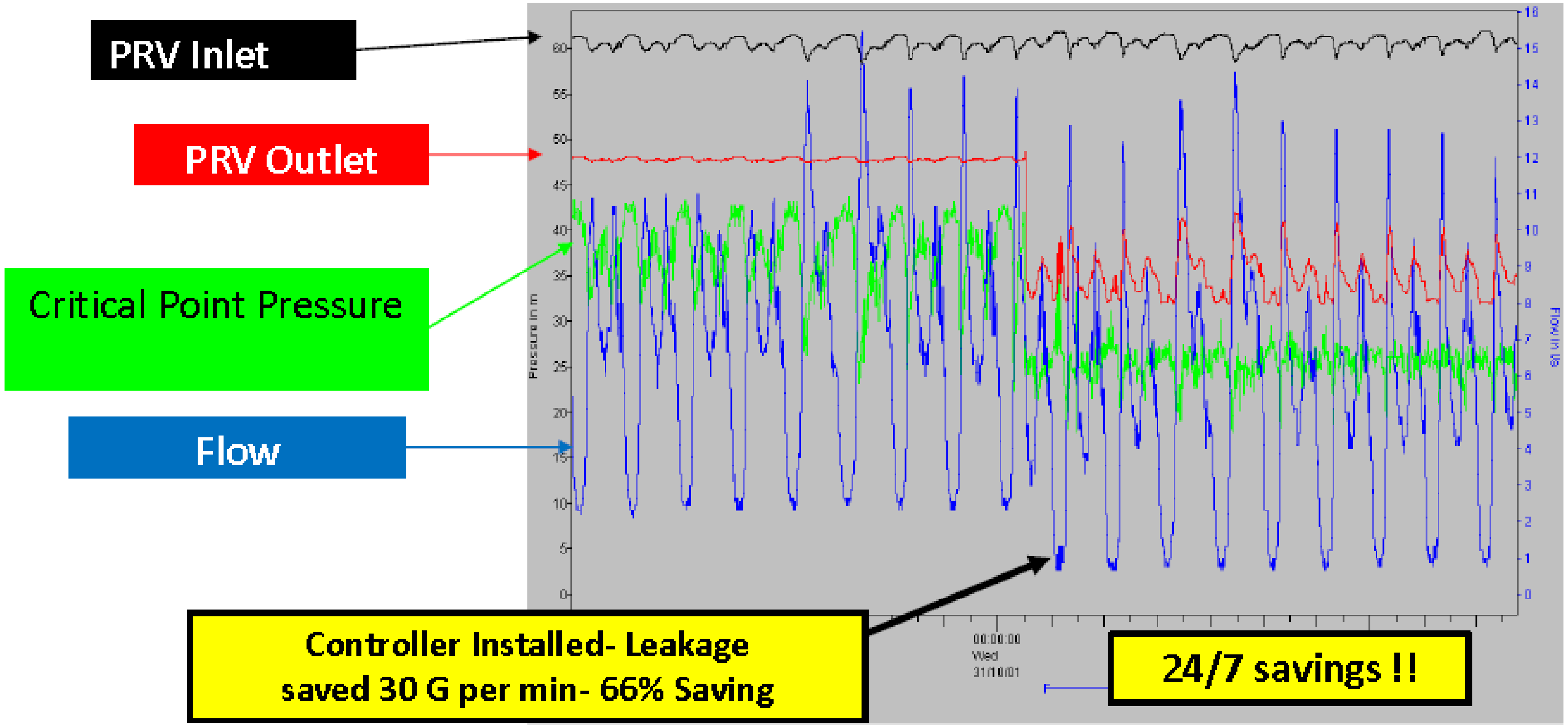


Pressure Management

Modulated



Pressure Management



Pressure Management

- Dramatic and Instant Leakage and Distribution Input Saving
- Increase in initial savings due to decrease in CP target settings
- Significant stabilization of network pressure
- Stable Pressure means reduced:
  - Bursts
  - Leakage Recurrence
  - Detect and Repair Activity
  - Cost to maintain stable leakage level
  - A calm network for Operations and the Customer
  - Number of unscheduled network events

6.3.1 Definition and purpose of DMAs

A district metered area (DMA) is defined as a discrete area of a water distribution network. It is usually created by closing boundary valves so that it remains flexible to changing demands. However, a DMA can also be created by permanently disconnecting pipes to neighbouring areas. Water flowing into and out of the DMA is metered and flows are periodically analysed in order to monitor the level of leakage. [58] DMAs can principally be categorised into three different types: single inlet DMAs, multiple inlet DMAs and cascading DMAs, as illustrated in *Figure 6.2*:

Figure 6.2 Typical layout of DMAs, based on [22]

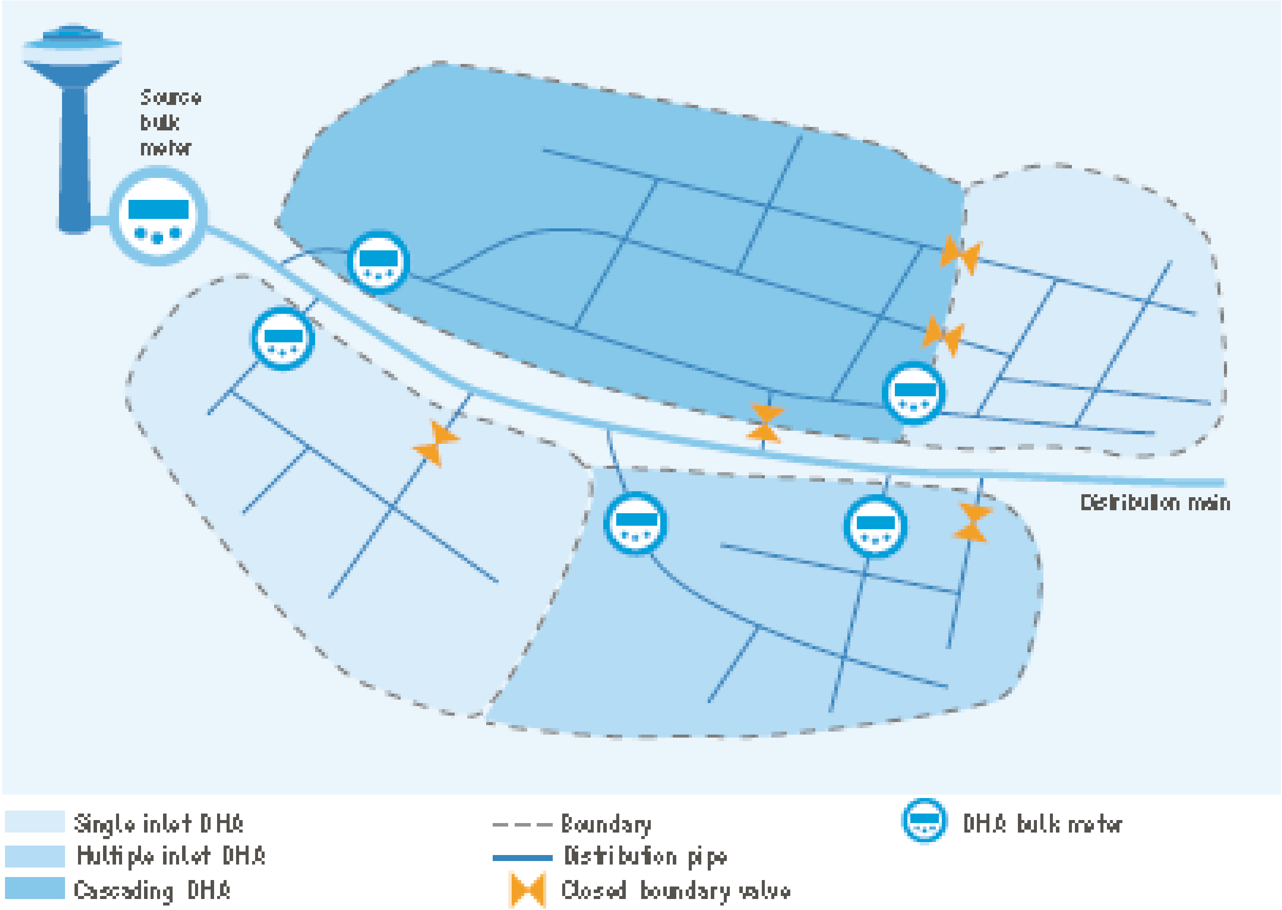


Figure 6.3 Relationship between the flow rate, pressure and leakage components, based on [58]

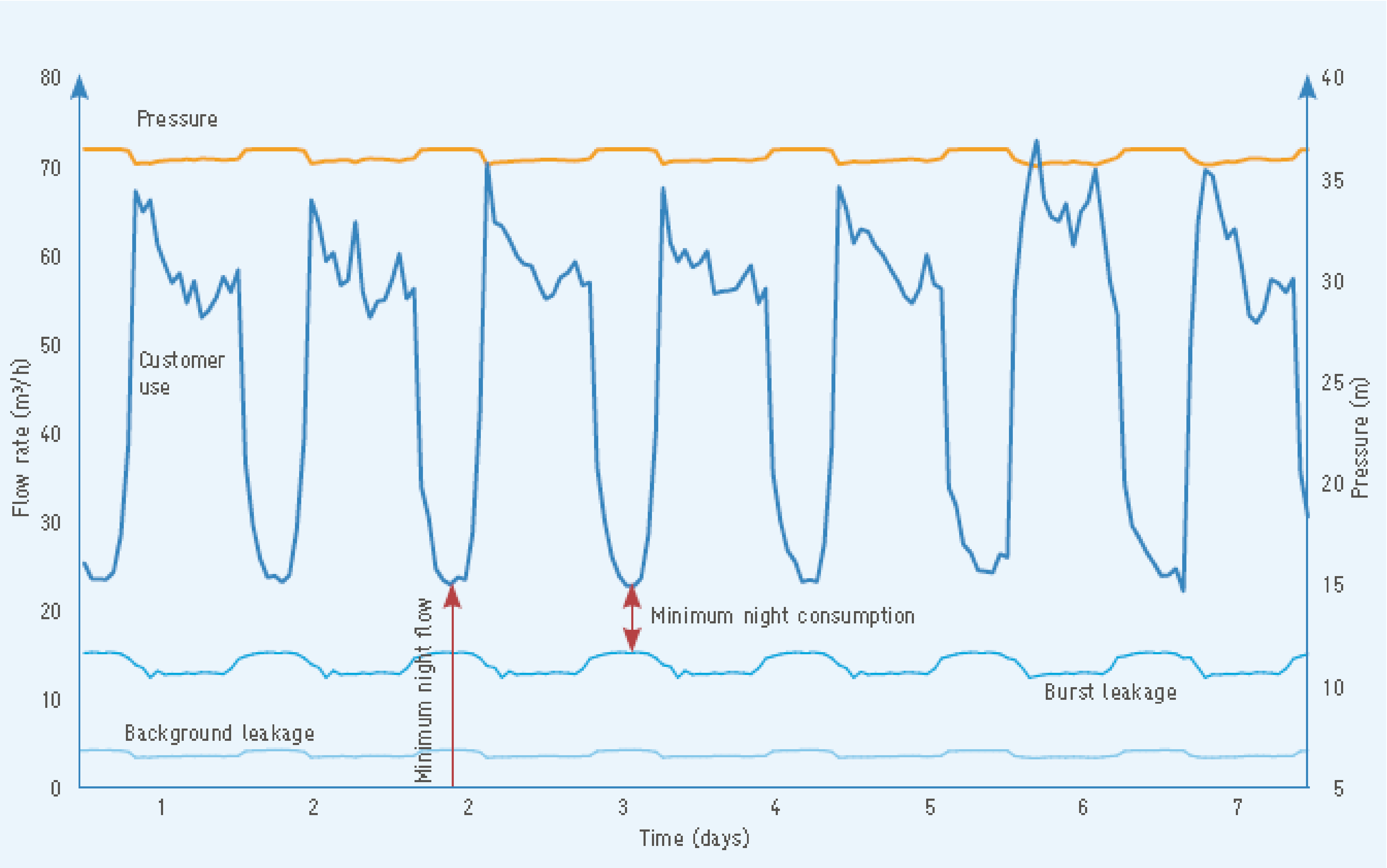
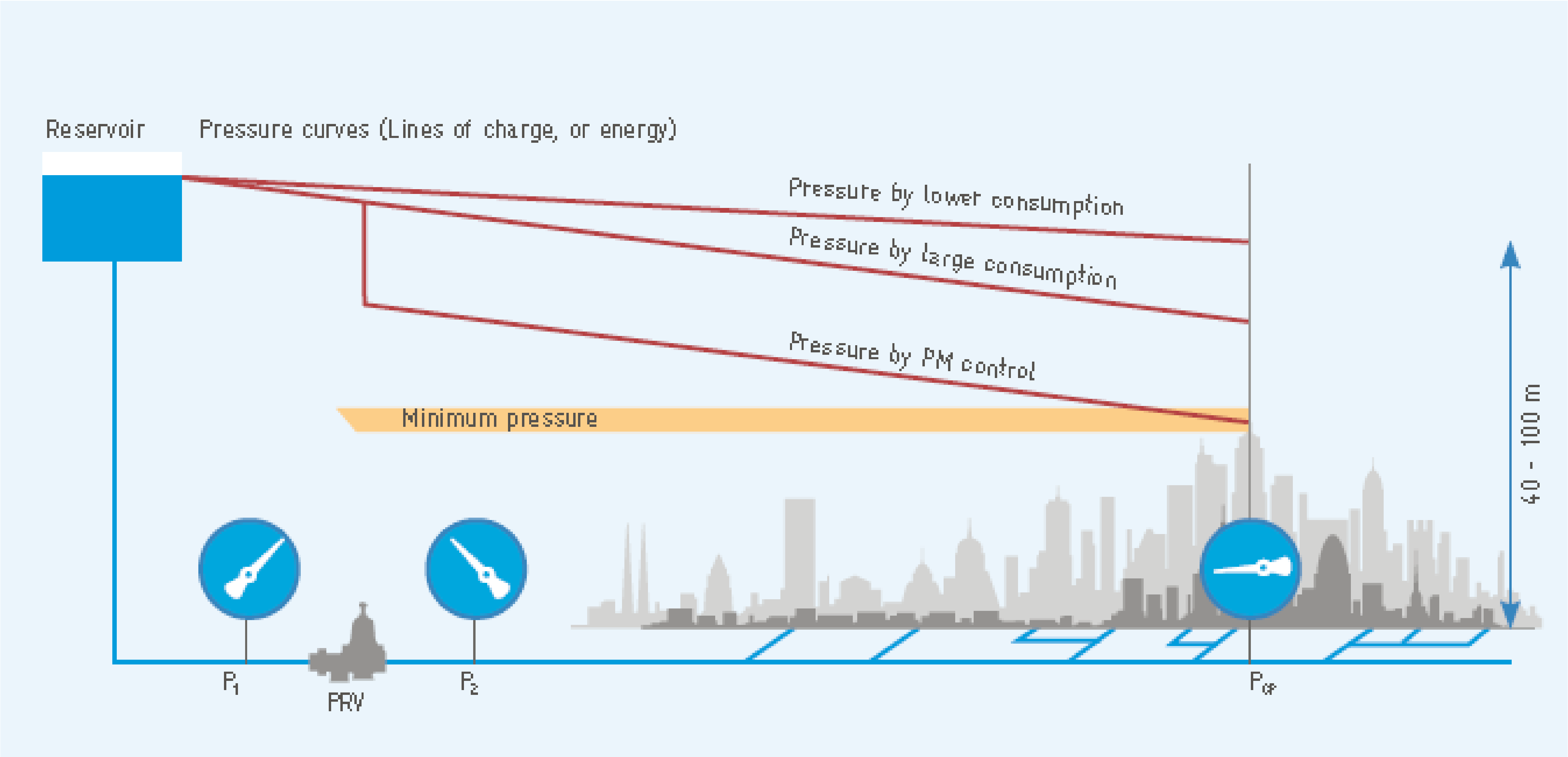
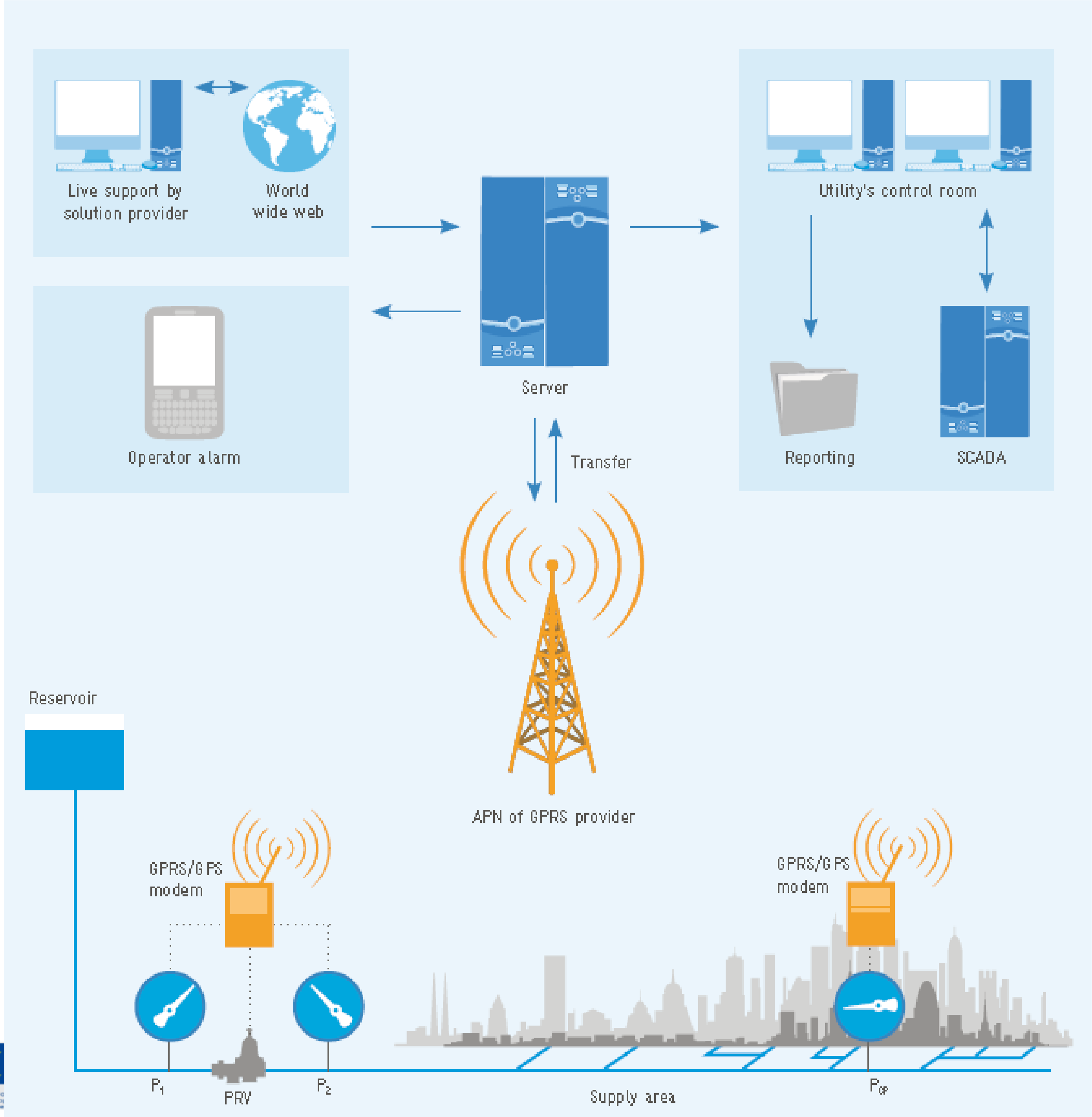


Figure 6.4 Simplified view of pressures within a distribution network





Live support by solution provider
World wide web
Utility's control room
Server
Operator alarm
Transfer
Reporting
SCADA
Reservoir
APN of GPRS provider
GPRS/GPS modem
GPRS/GPS modem
P_1
PRV
P_2
Supply area
P_{cp}

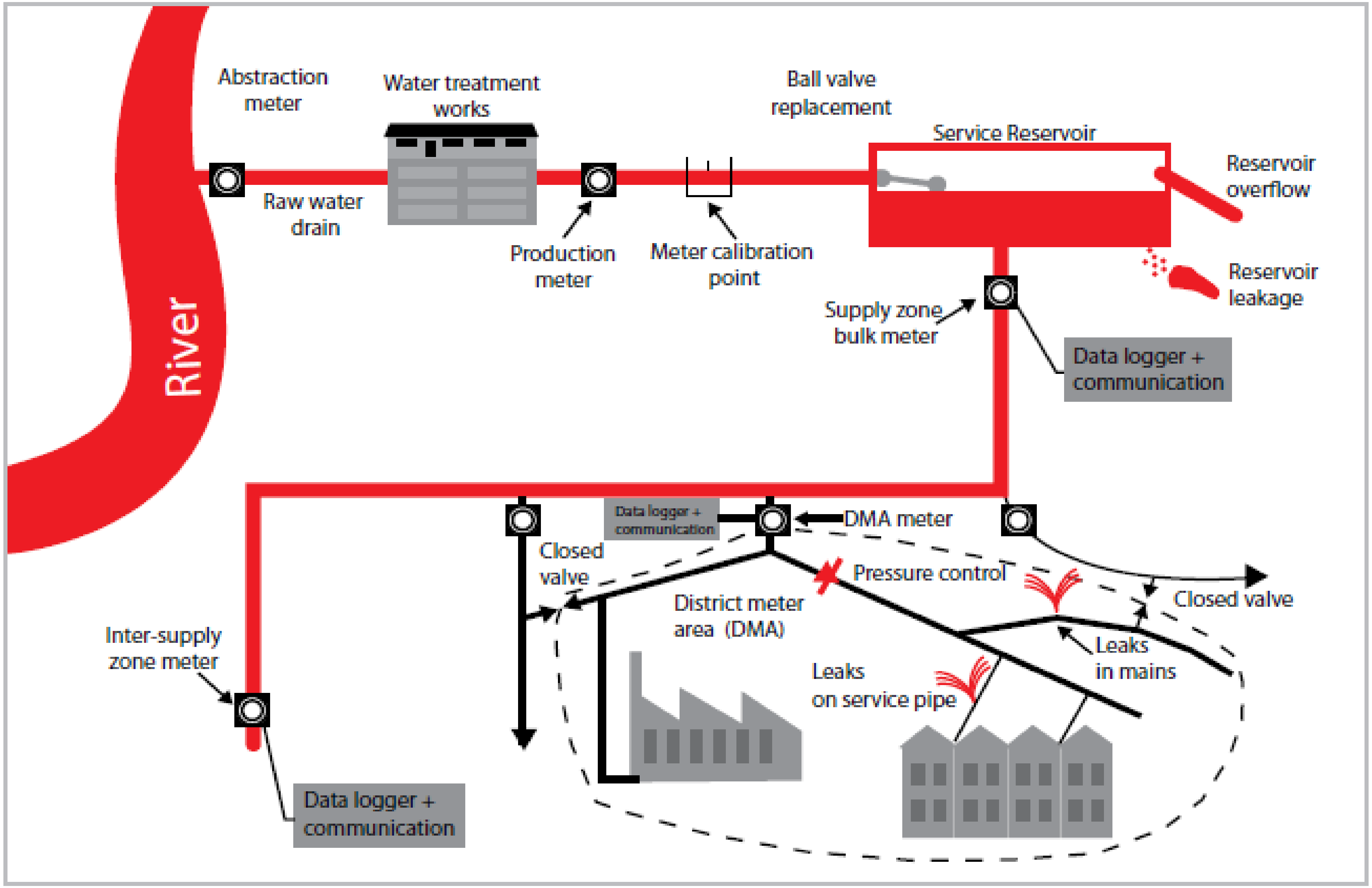
CONCLUSIONS

How to achieve and maintain a low level of NRW?

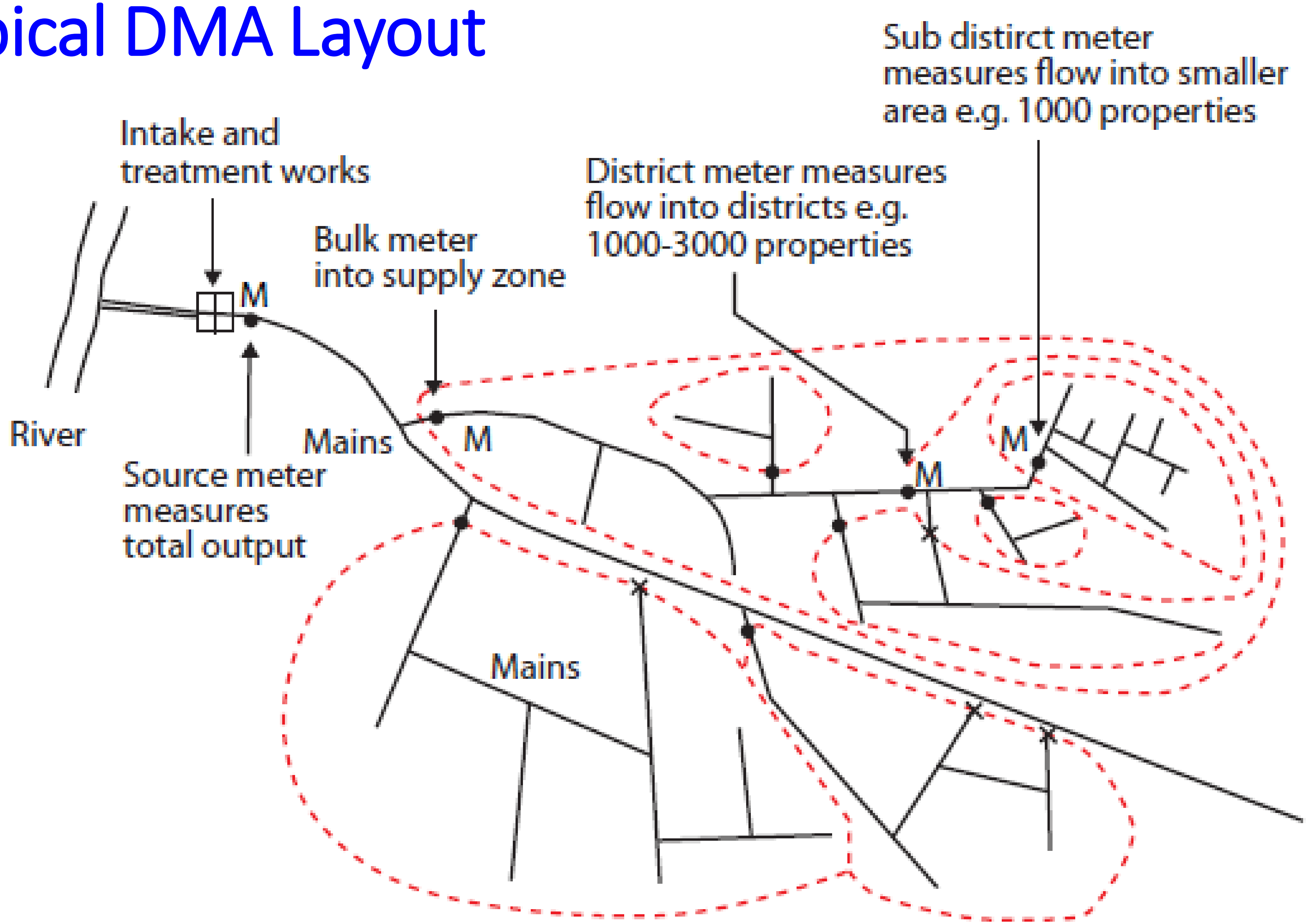
- Develop a holistic NRW master plan based on the analysis of the current NRW and the state of the water distribution network, which can serve as the basis for upcoming investment plans and their projected returns
- This is followed by a continuous focus on monitoring and optimising the water distribution to maintain a low NRW level
- Ongoing monitoring and pressure management are best carried out by breaking down the distribution system into smaller DMAs
- The quality of installed components such as valves, pumps, pipes and metres etc. also play a key factor in reducing the water loss, since operating costs and repairs are often more expensive than the product itself
- Carrying out a successful NRW programme requires commitment from all organistional levels as well as trained staff, who work continuously on keeping NRW levels low
- Capacity building at all staff levels in the utility is a key element

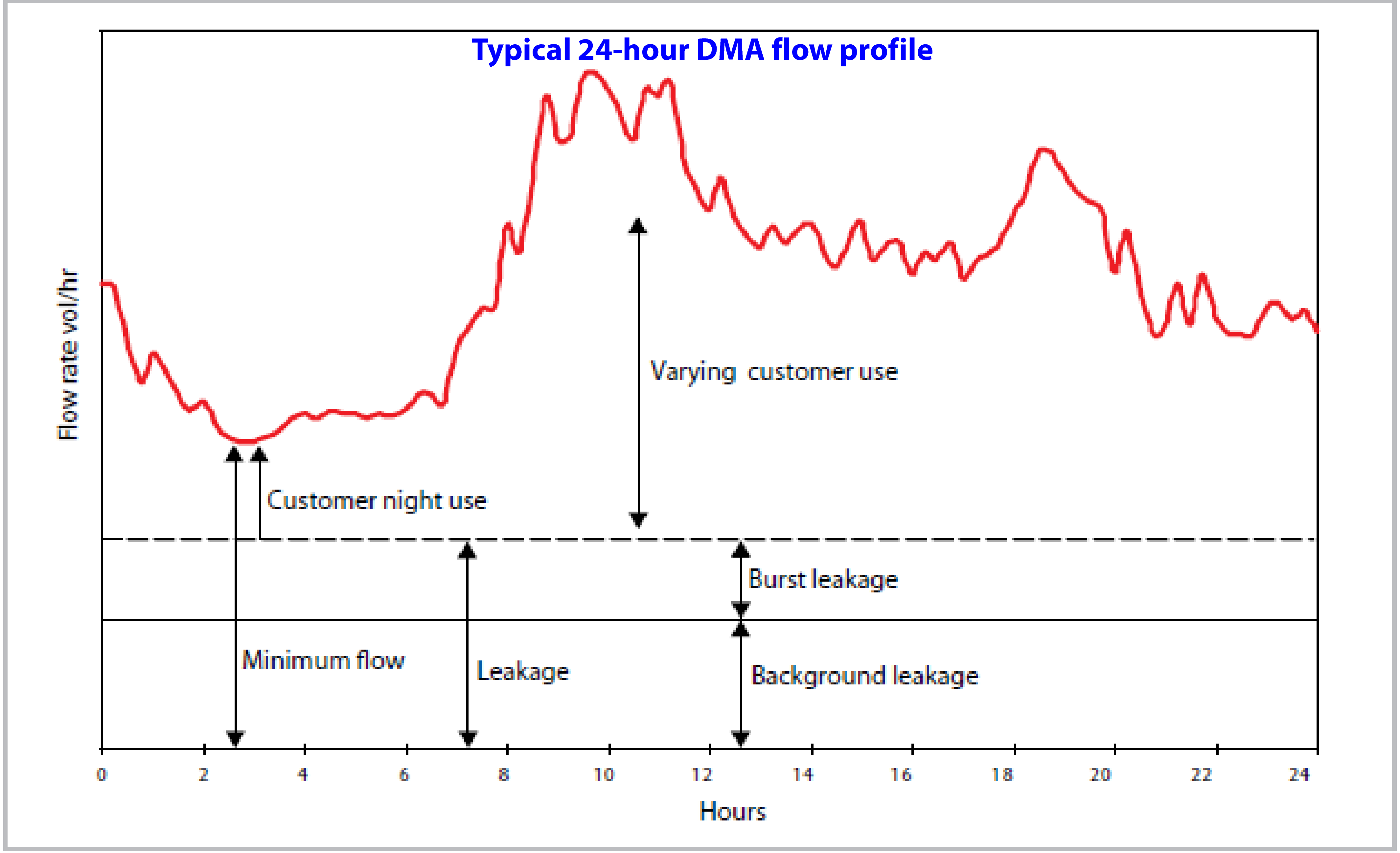
CASE STUDY

- This project is as a Case Study done by NBW using Darwin Calibrator functionality within Bentley System – WaterGems and with technical support of World bank Institute.
- Darwin Calibrator is an optimization module that uses genetic algorithms to calibrate hydraulic models of water distribution networks
- One of the operations available in this module is ‘Detect Leakage Node, which enables pinpointing of potential leak locations
- The main purpose of this project was to gain a better understanding of the practical processes involved in using hydraulic models in a dynamic way for the purposes of localising bursts for detection teams to target
- In addition, the project identified potentially closed valves and investigated the optimum number of pressure loggers required
- With each DMA analyzed, the approach became more structured and adjustments were made to the leak analysis process
- This presentation describes the final methodology developed using the experience gained and lessons learnt from this project

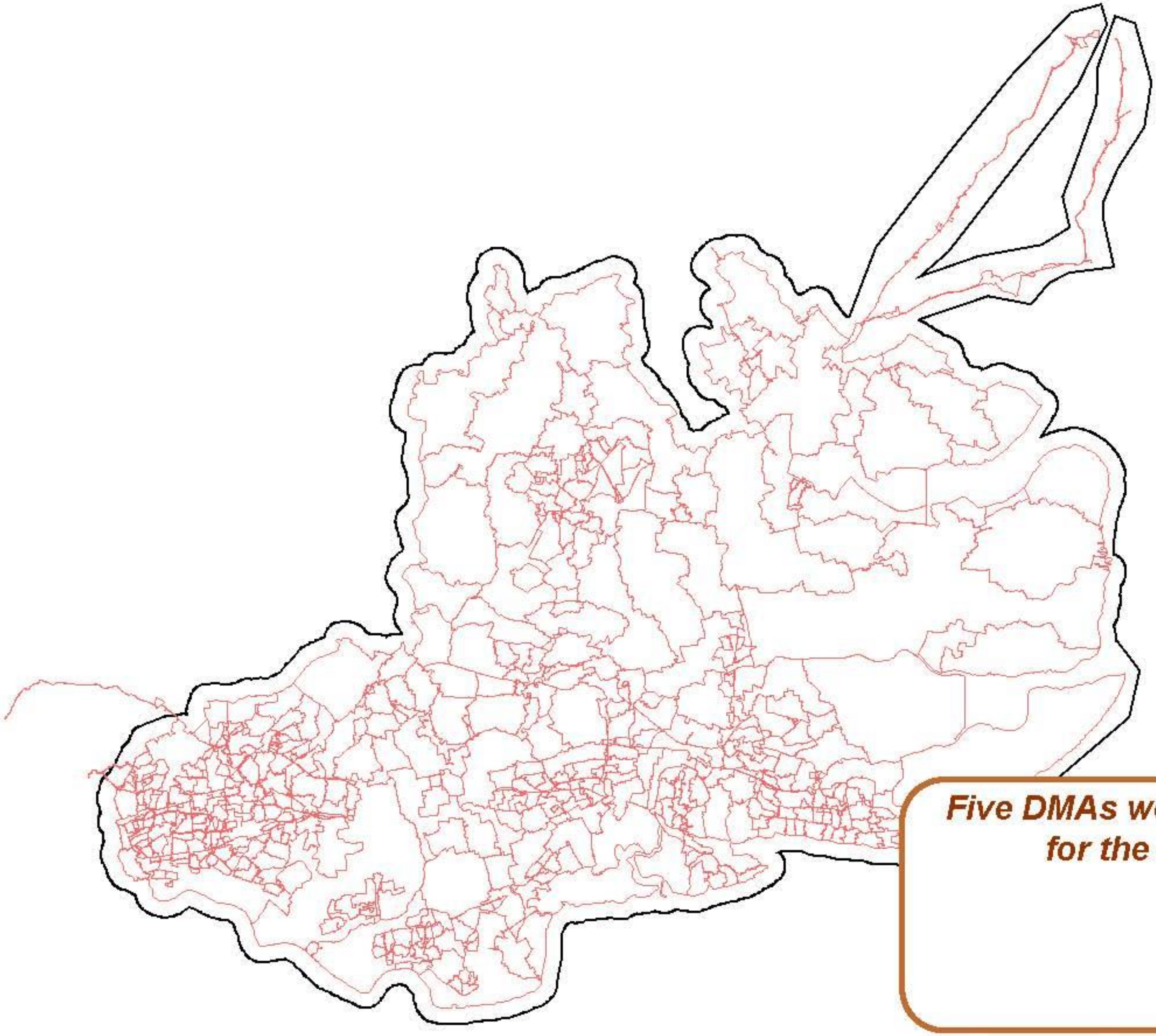

Abstraction meter
Water treatment works
Ball valve replacement
Service Reservoir
Reservoir overflow
Raw water drain
Production meter
Meter calibration point
Reservoir leakage
River
Supply zone bulk meter
Data logger + communication
Data logger + communication
DMA meter
Closed valve
Pressure control
Closed valve
District meter area (DMA)
Inter-supply zone meter
Leaks in mains
Leaks on service pipe
Data logger + communication

Typical DMA Layout

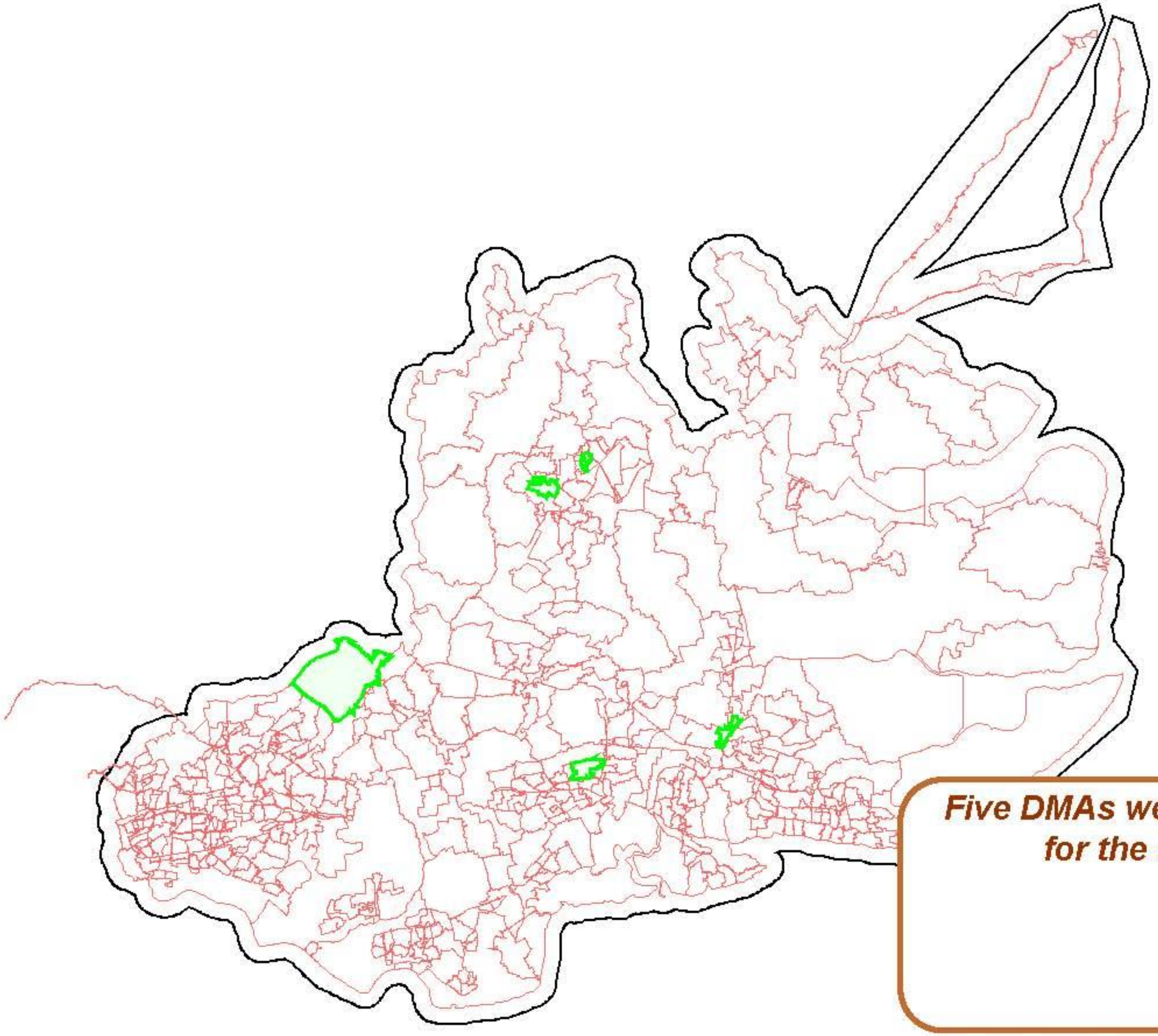




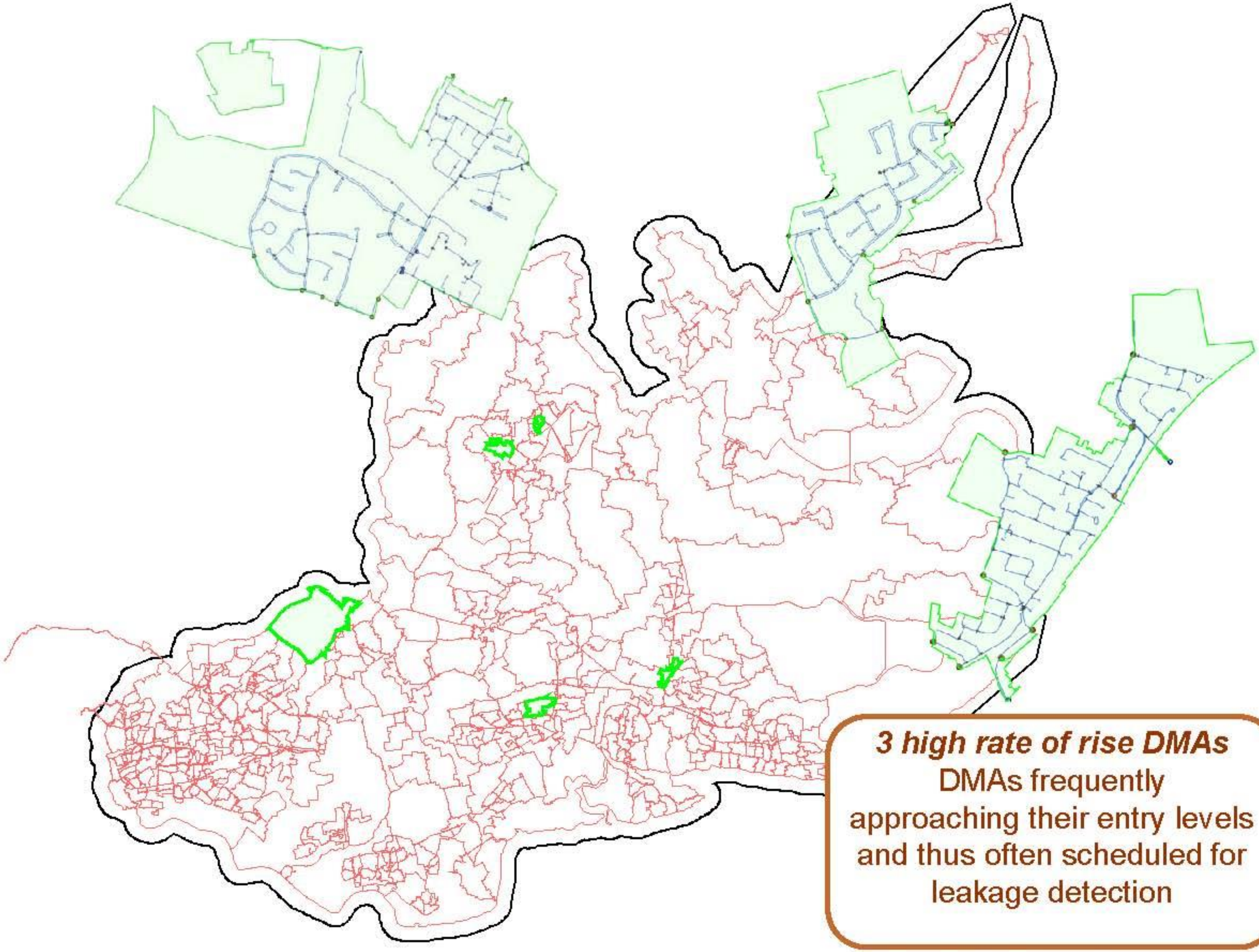
Typical 24-hour DMA flow profile
Flow rate vol/hr
Varying customer use
Customer night use
Burst leakage
Minimum flow
Leakage
Background leakage
0
2
4
6
8
10
12
14
16
18
20
22
24
Hours



Five DMAs were selected for the study

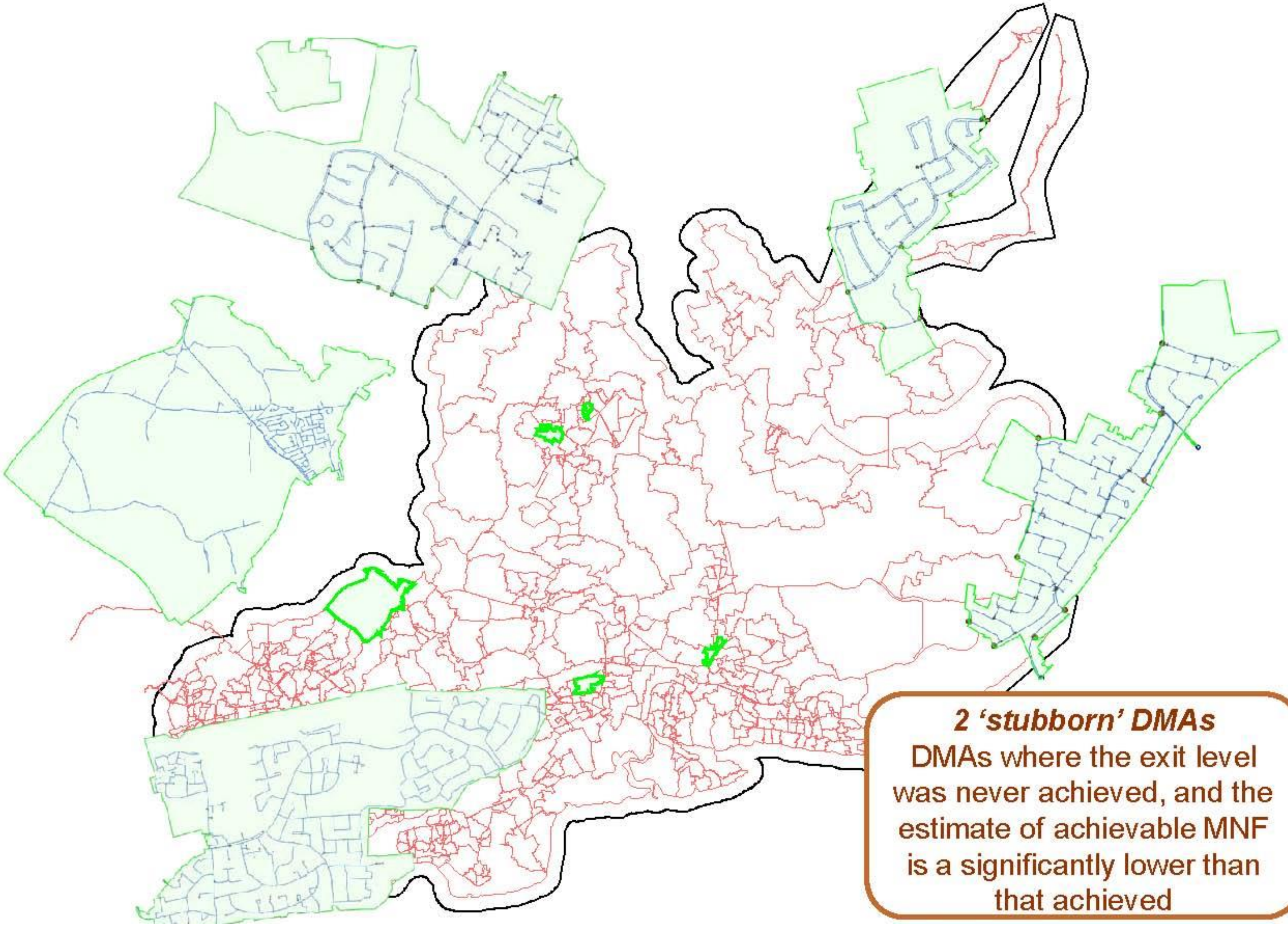


Five DMAs were selected for the study



3 high rate of rise DMAs

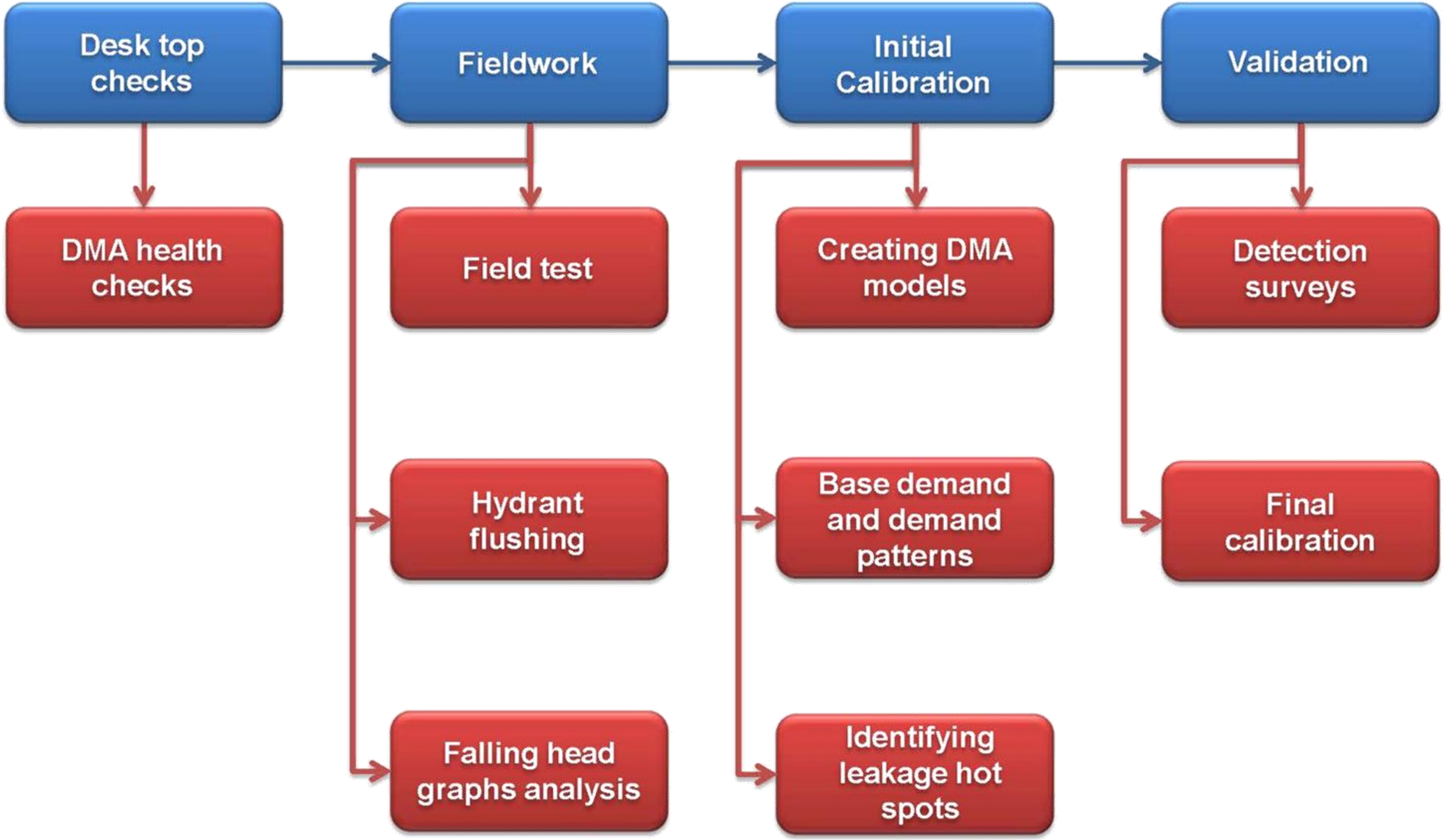
DMAs frequently approaching their entry levels and thus often scheduled for leakage detection



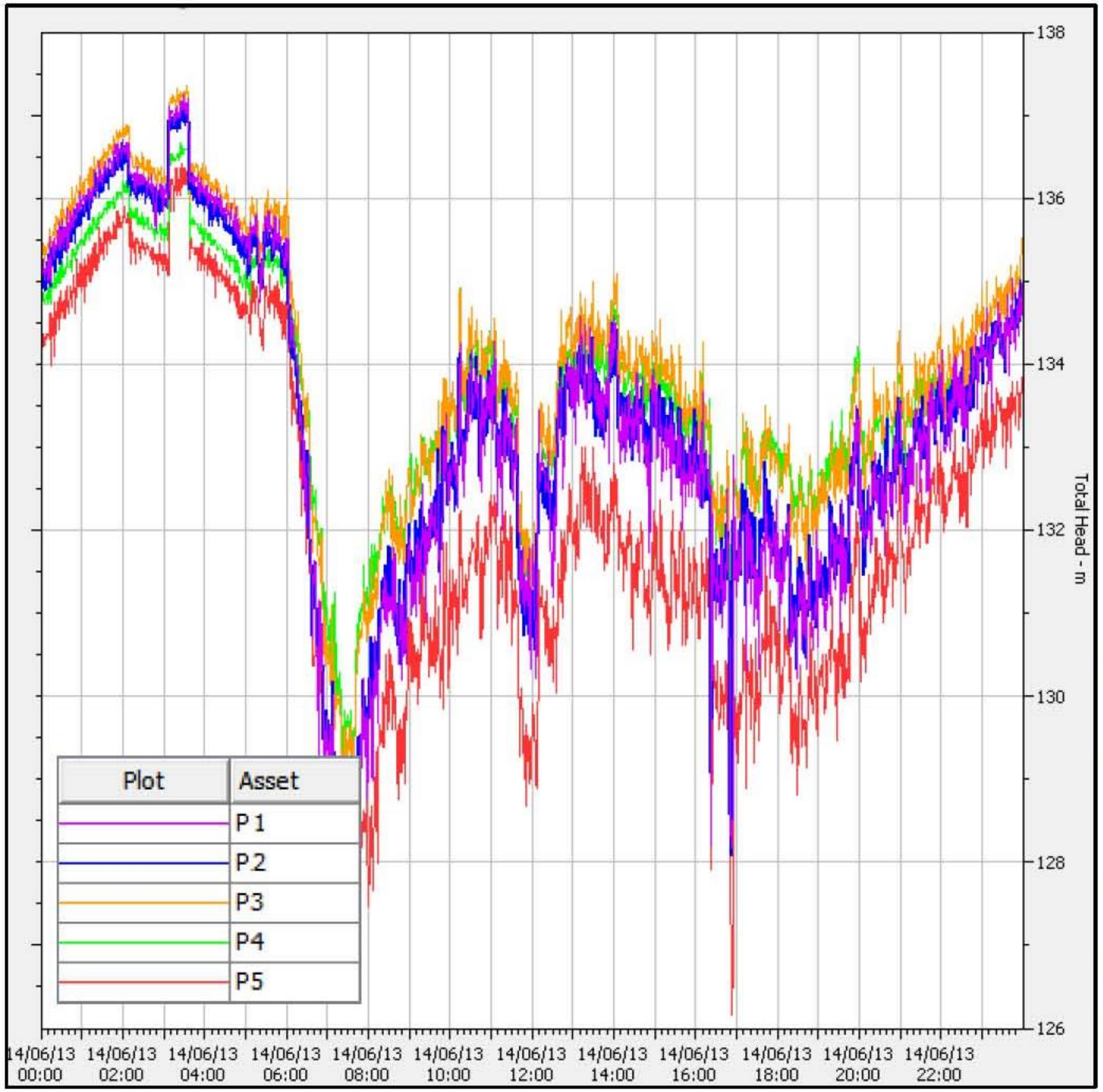
2 *'stubborn'* DMAs

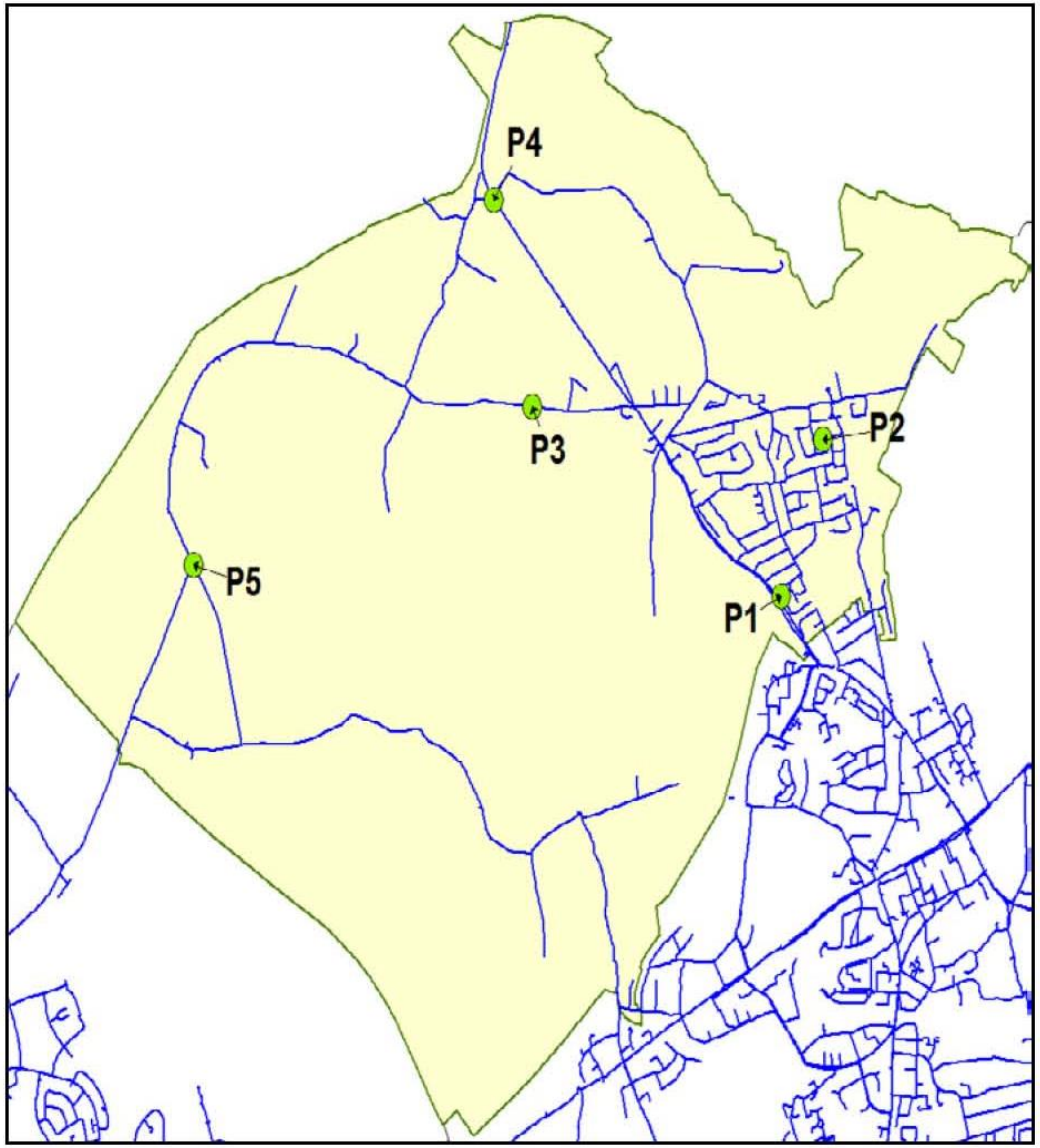
DMAs where the exit level was never achieved, and the estimate of achievable MNF is a significantly lower than that achieved

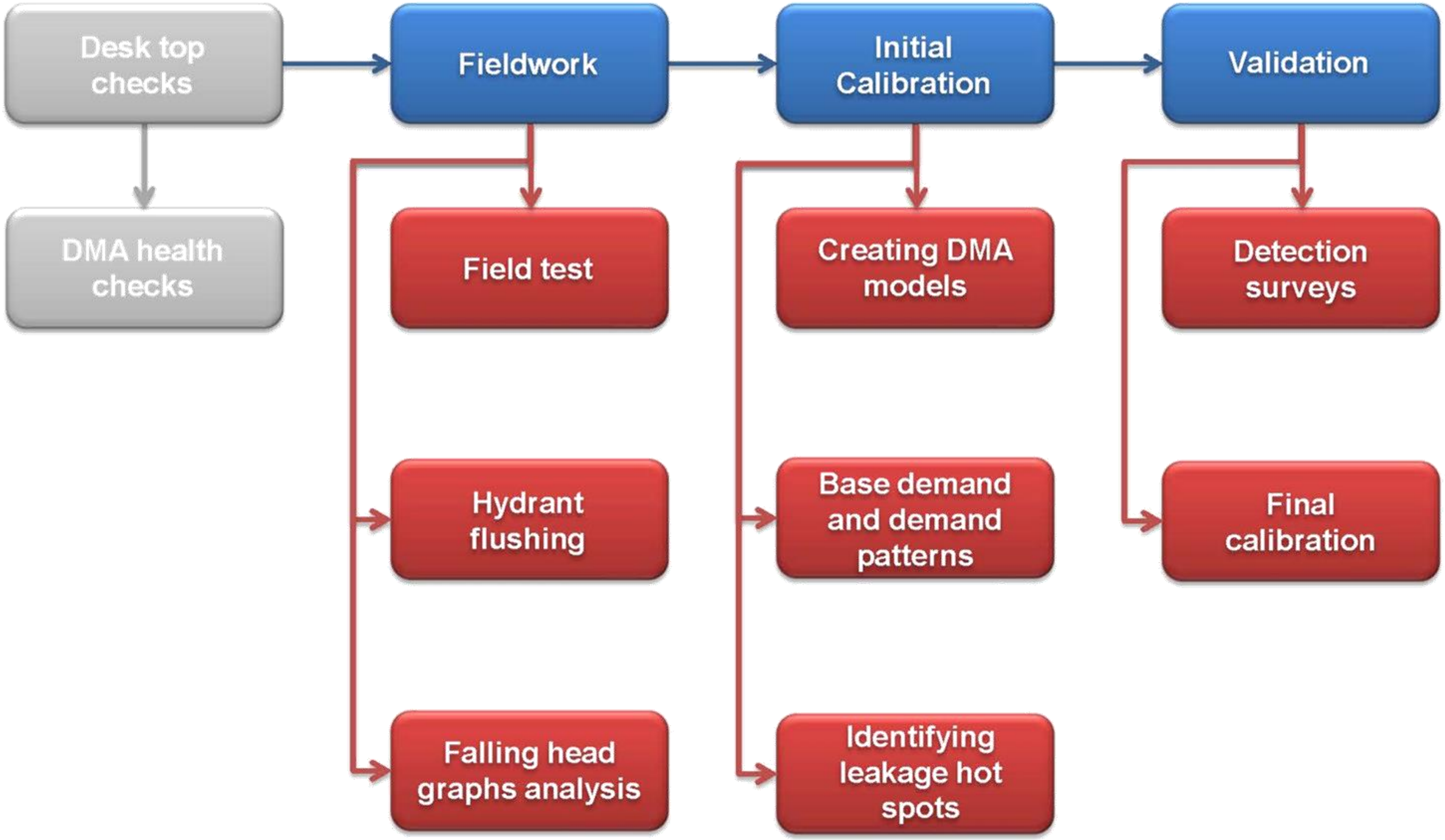
Modelling & Calibration



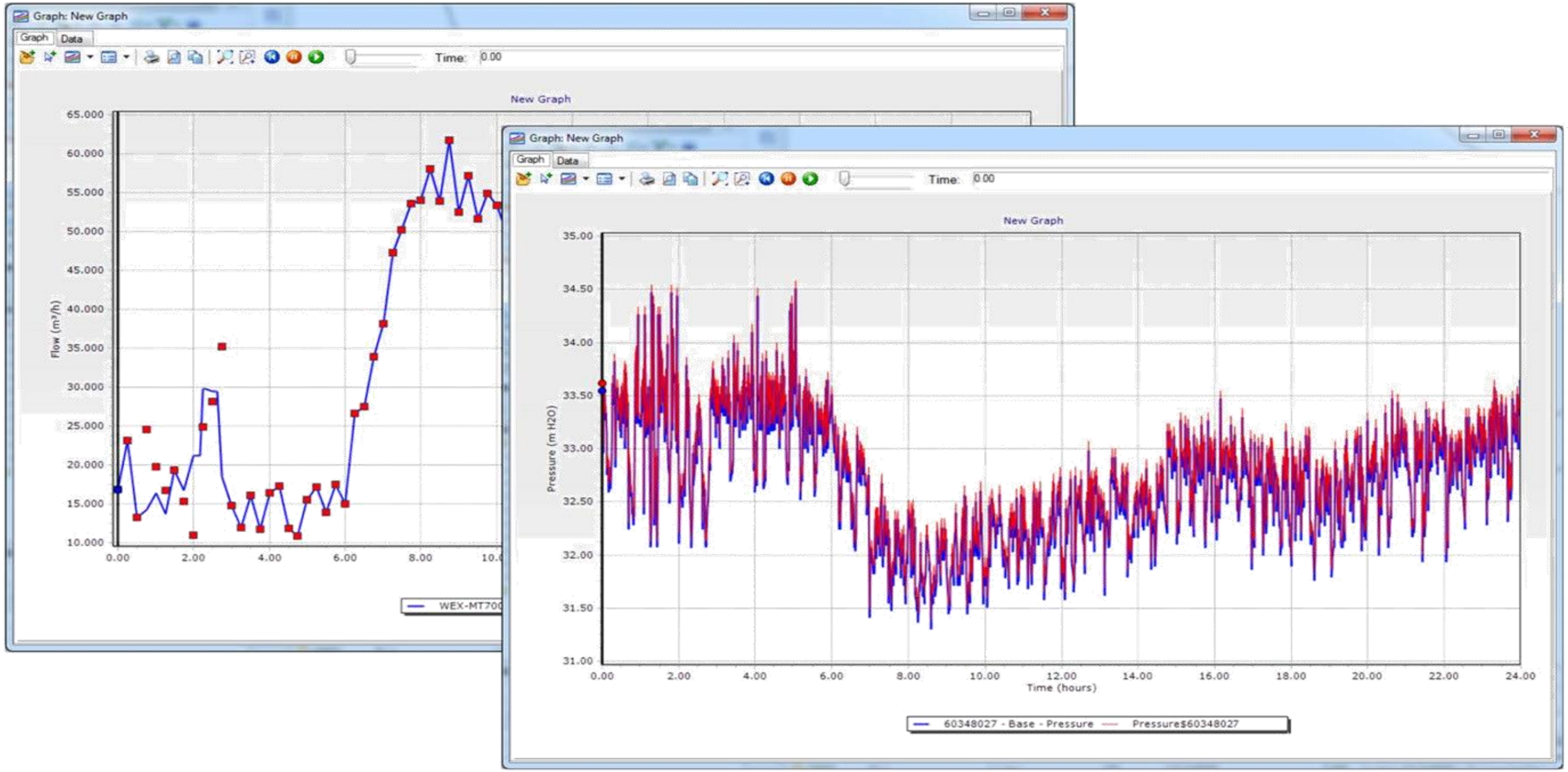
Desk top checks
Fieldwork
Initial Calibration
Validation
DMA health checks
Field test
Hydrant flushing
Falling head graphs analysis
Creating DMA models
Base demand and demand patterns
Identifying leakage hot spots
Detection surveys
Final calibration


138
136
134
132
130
128
126
Total Head - m
14/06/13 00:00
14/06/13 02:00
14/06/13 04:00
14/06/13 06:00
14/06/13 08:00
14/06/13 10:00
14/06/13 12:00
14/06/13 14:00
14/06/13 16:00
14/06/13 18:00
14/06/13 20:00
14/06/13 22:00
Plot
Asset
P 1
P 2
P 3
P 4
P 5

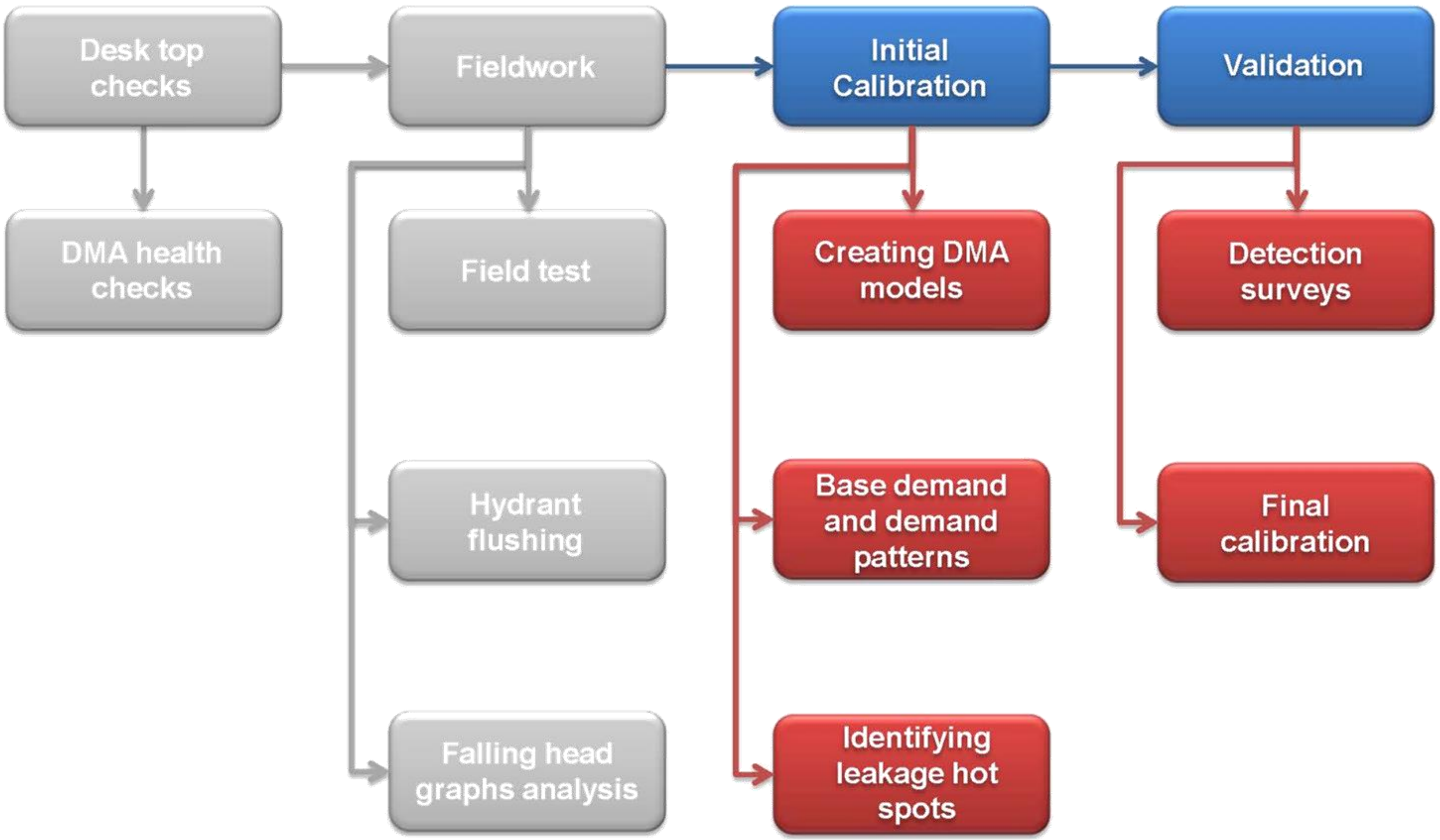

P4
P3
P2
P5
P1



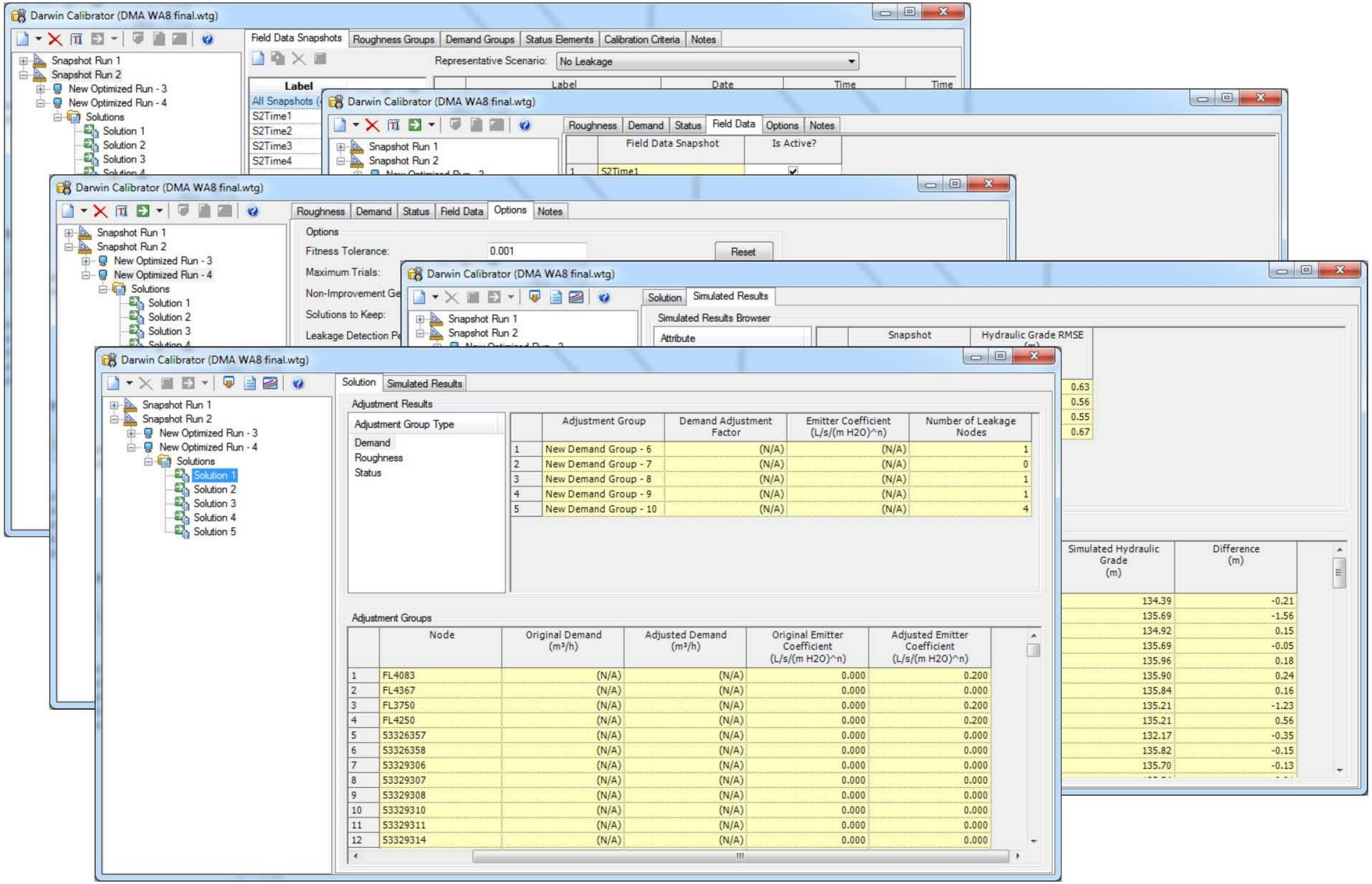
Desk top checks
Fieldwork
Initial Calibration
Validation
DMA health checks
Field test
Creating DMA models
Detection surveys
Hydrant flushing
Base demand and demand patterns
Final calibration
Falling head graphs analysis
Identifying leakage hot spots



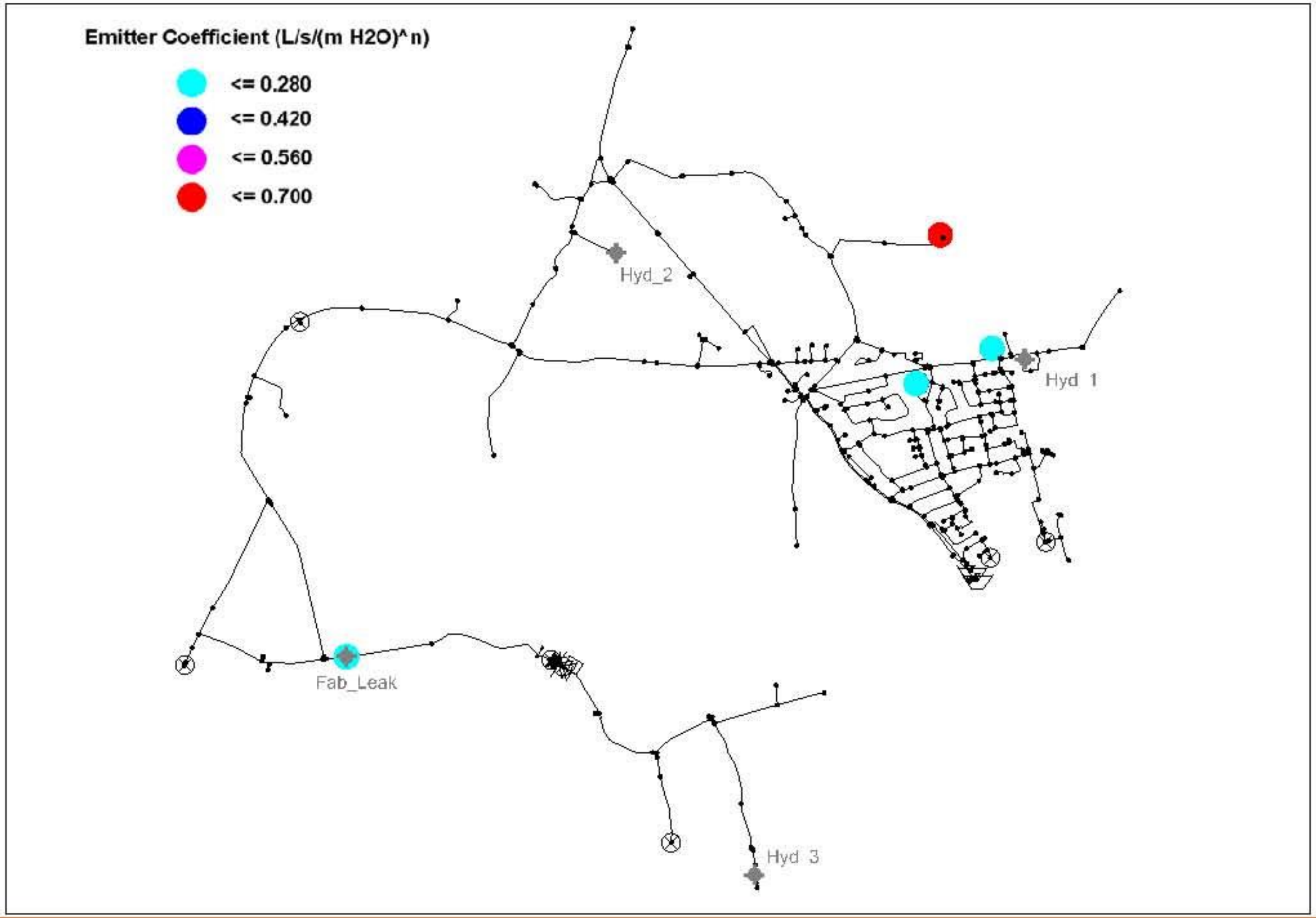
Comparison graphs, like the ones above were created for each analysed DMA.


Desk top checks
Fieldwork
Initial Calibration
Validation
DMA health checks
Field test
Creating DMA models
Detection surveys
Hydrant flushing
Base demand and demand patterns
Final calibration
Falling head graphs analysis
Identifying leakage hot spots

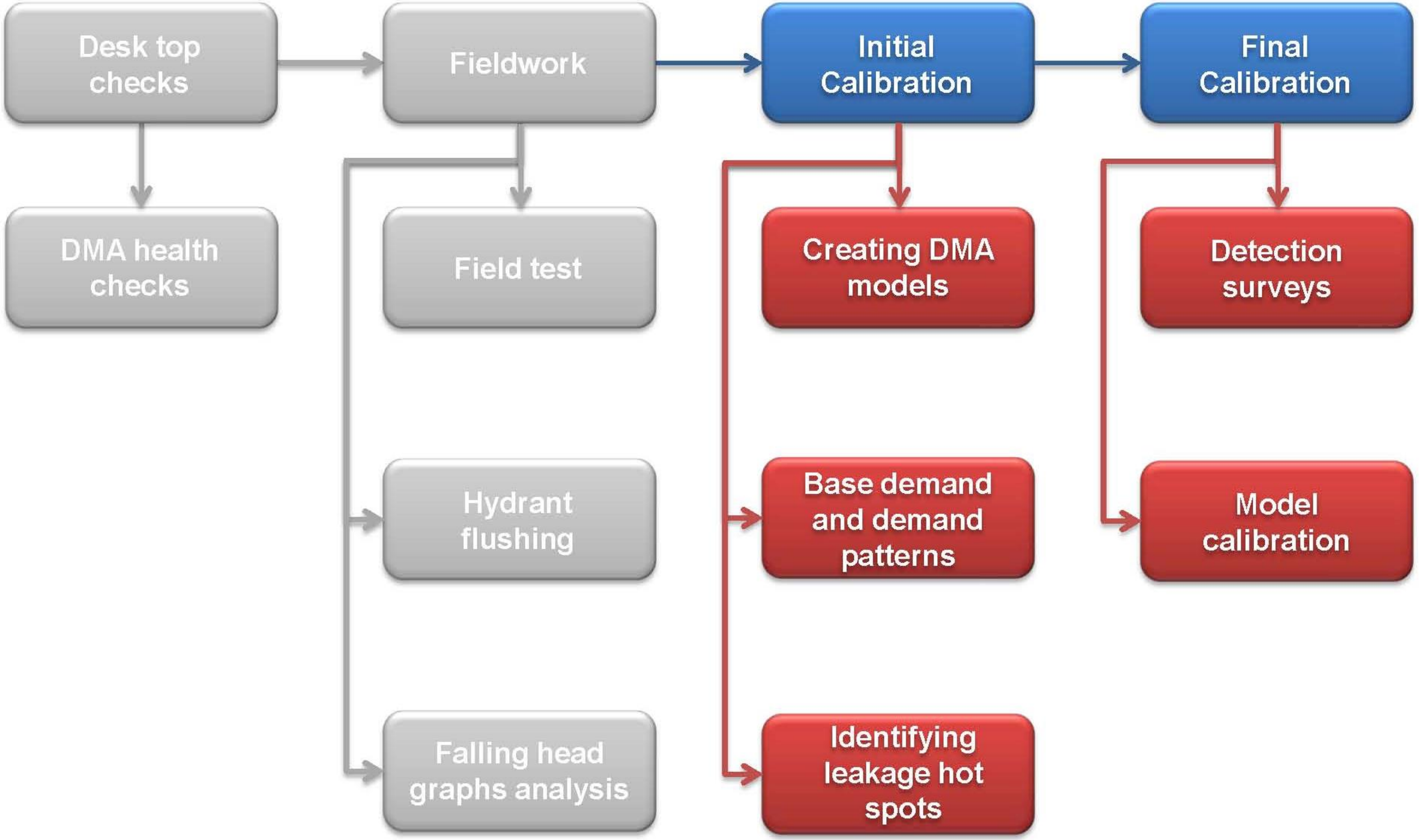
ENVIRONMENTAL ENGINEERING GROUP



EMG EnvironMental engineering Group · THE WORLD BANK · UNESCO-IHE · European Union European Regional Development Fund · IWA · NORTHUMBRIAN WATER living water · Crowder Consulting



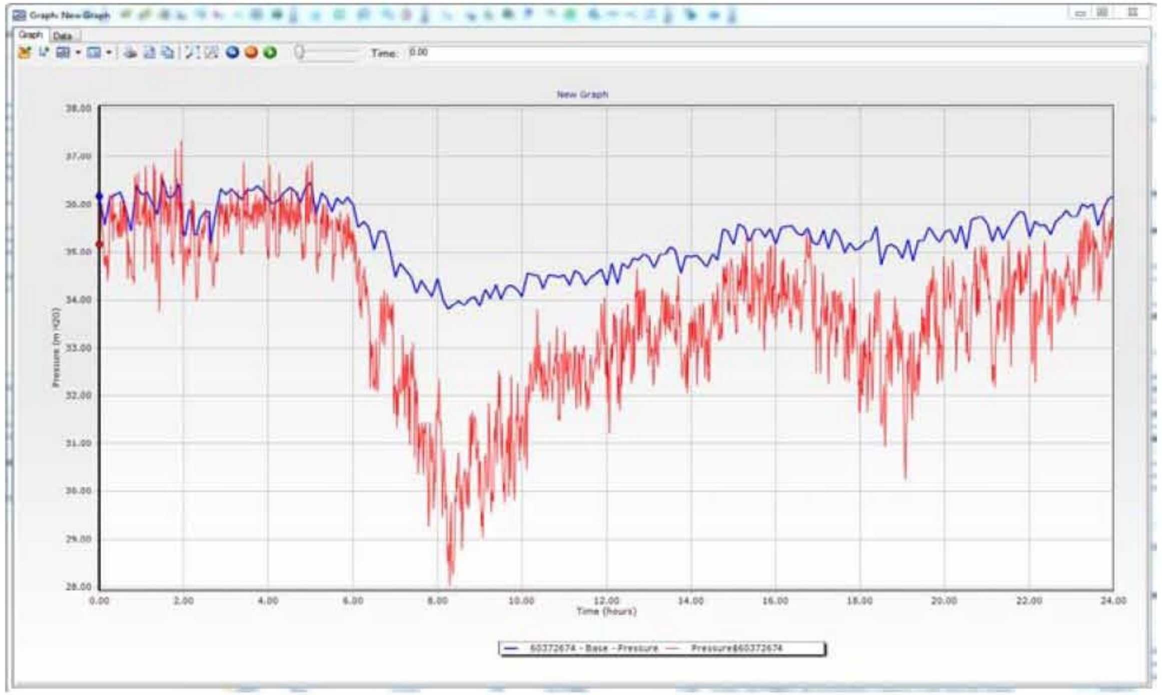
The plot shows the identified leakage emitters. All emitters are in the vicinity of the detected leaks.

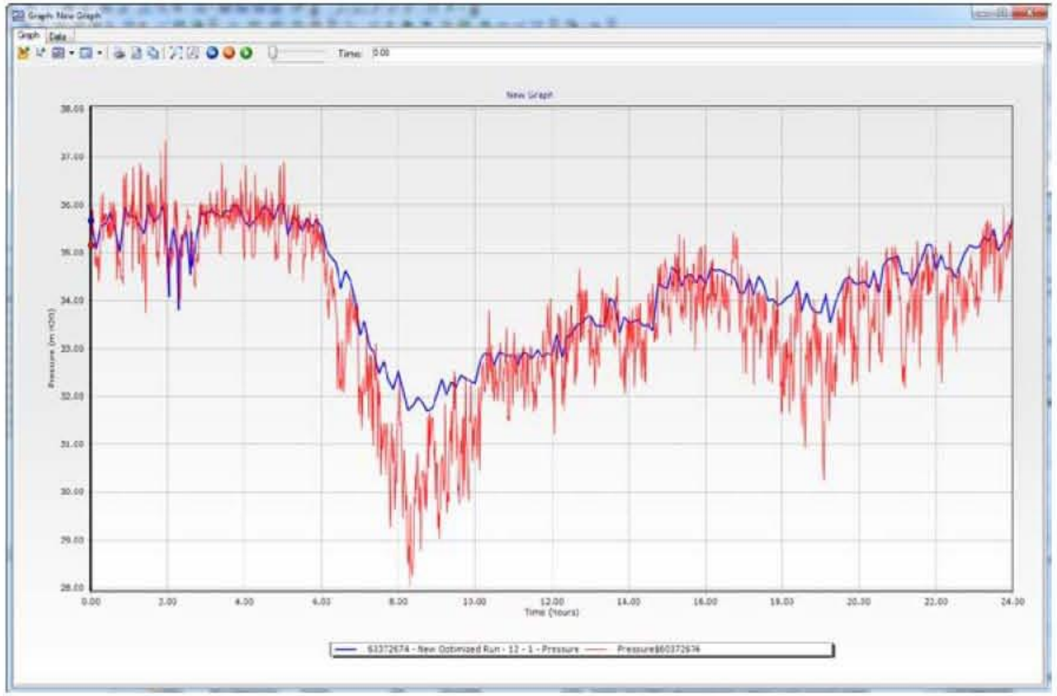

Desk top checks
Fieldwork
Initial Calibration
Final Calibration
DMA health checks
Field test
Creating DMA models
Detection surveys
Hydrant flushing
Base demand and demand patterns
Model calibration
Falling head graphs analysis
Identifying leakage hot spots

Outcomes

DMA	DMA Type	Number of leaks identified	Number of closed valves identified	Results of field investigations
DMA1	High Rate of Rise	3	12	No leaks or closed valves confirmed. Software bug found on closed valve analysis.
DMA2	High Rate of Rise	4	2	One leak confirmed; one not confirmed; two unable to investigate. Both closed valves confirmed.
DMA3	High Rate of Rise	4	2	Three leaks confirmed; one not confirmed. No valves found closed.
DMA4	High Rate of Rise	3	1	All leaks confirmed (5 leaks found). Valve not found closed.
DMA5	Boundary valve found open. Analysis not possible.			

2 closed valves identified in DMA 2



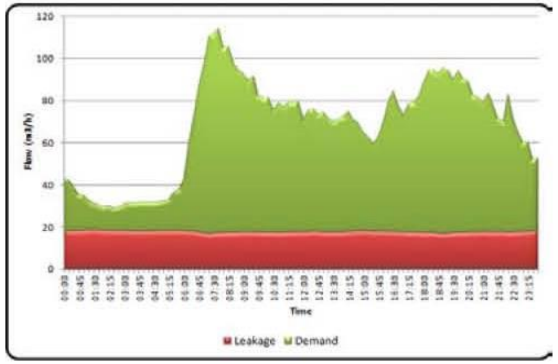


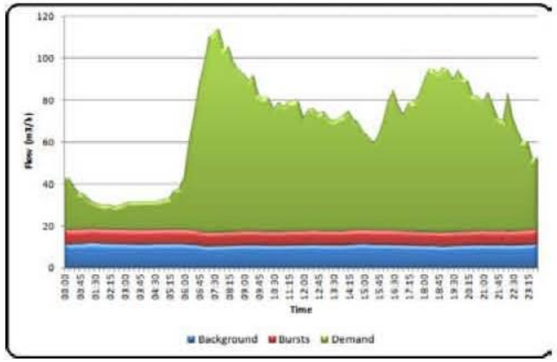
Detailed Analysis

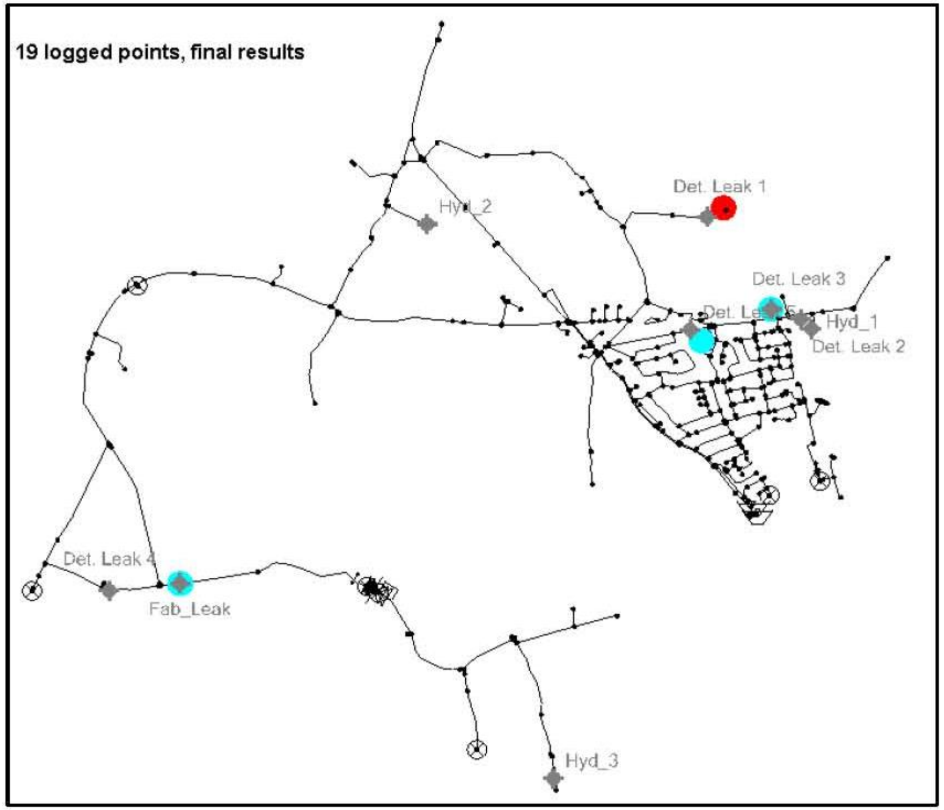
Splitting Leakage into Bursts and Background

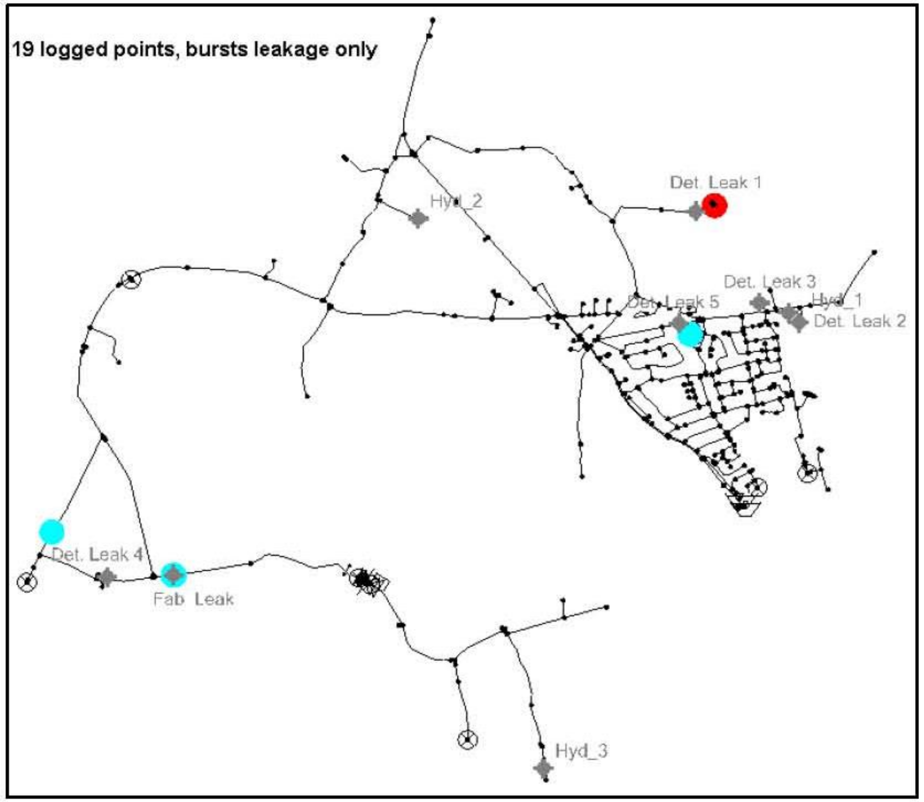
Emitter Coefficient (L/s/(m H2O)^n)

- <= 0.280
- <= 0.420
- <= 0.560
- <= 0.700

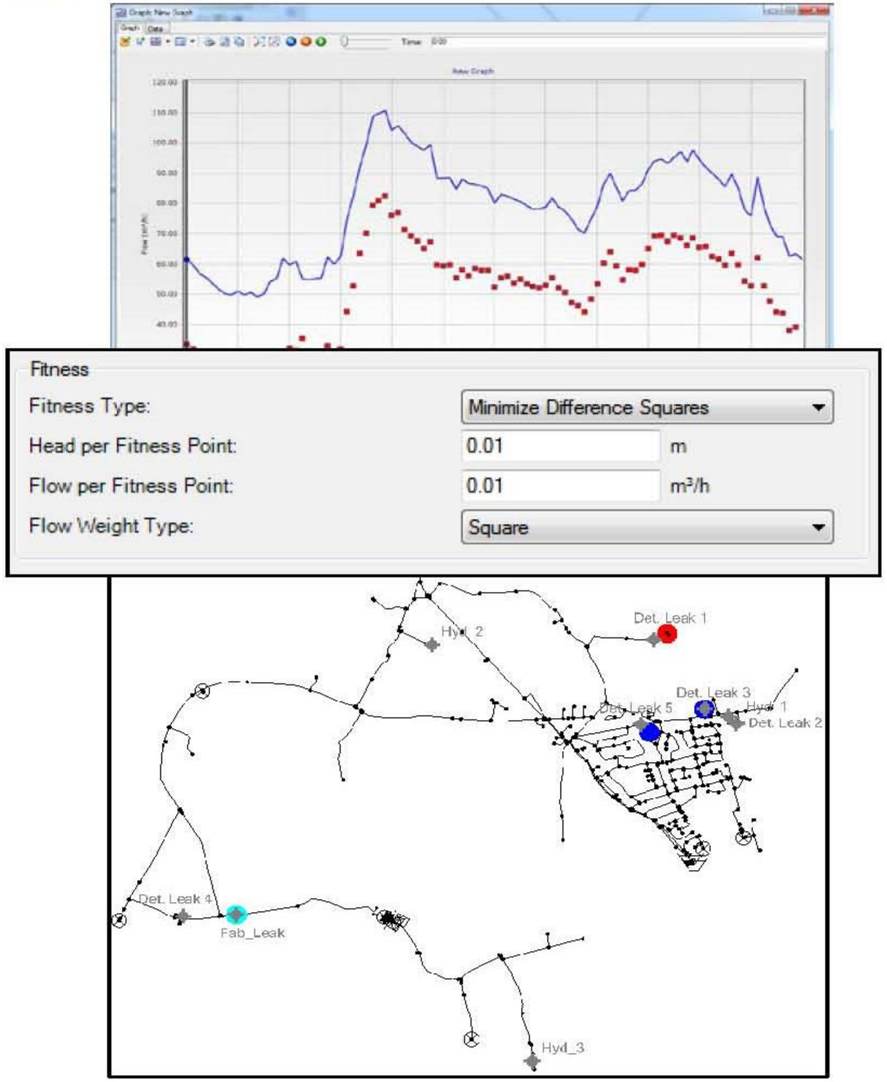


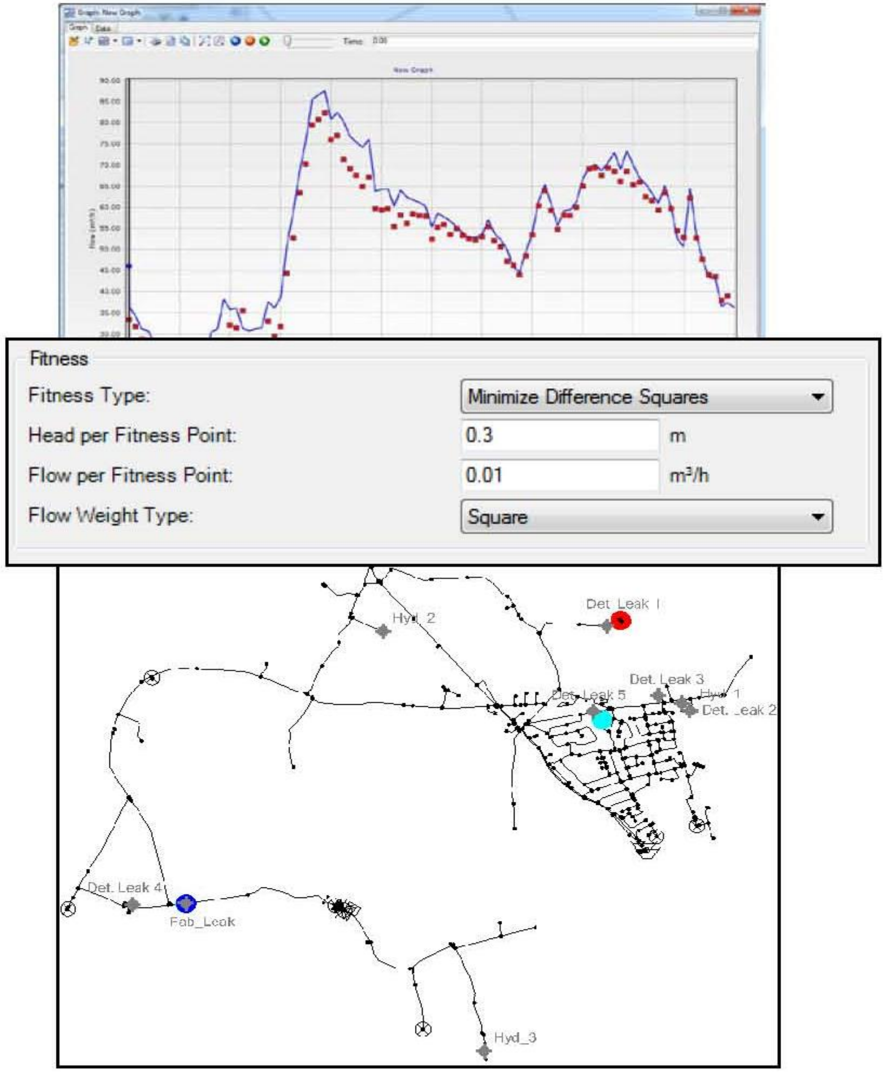




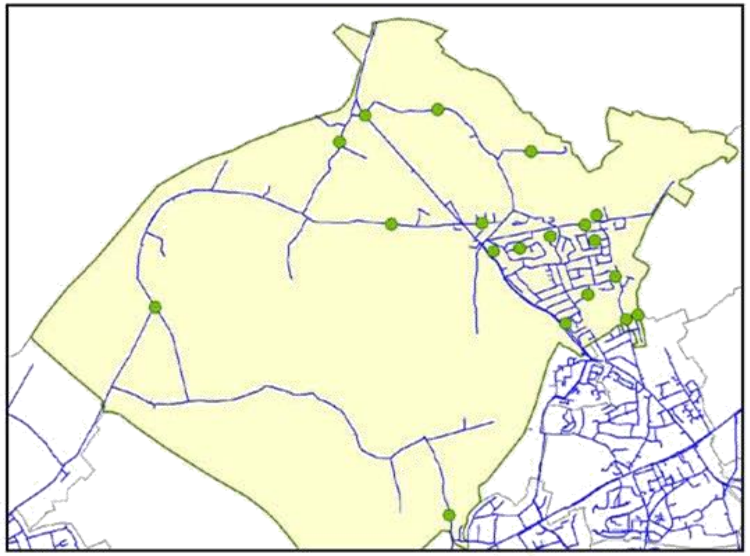


Investigating difference between modelled and observed flow rates





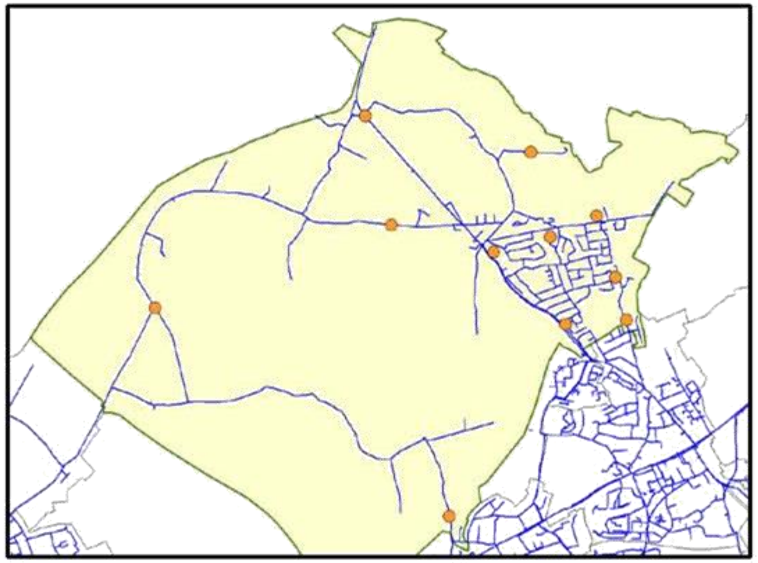
Optimising the Numbers of Pressure Loggers

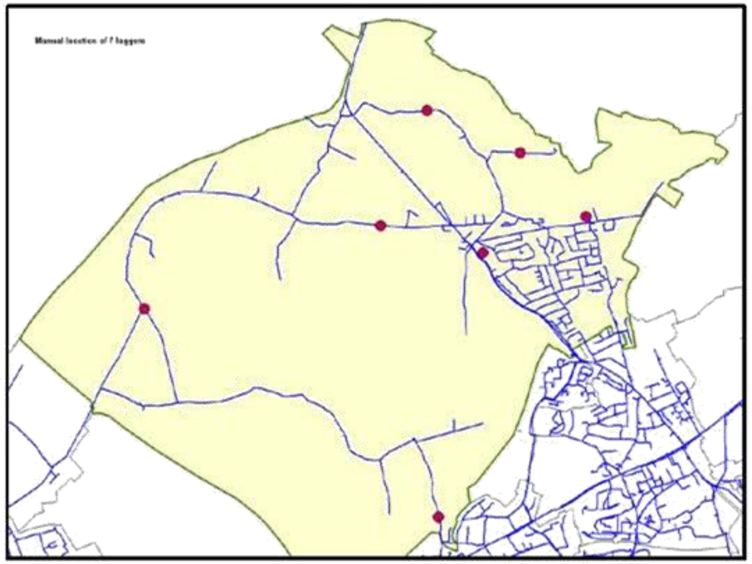


19 logged points

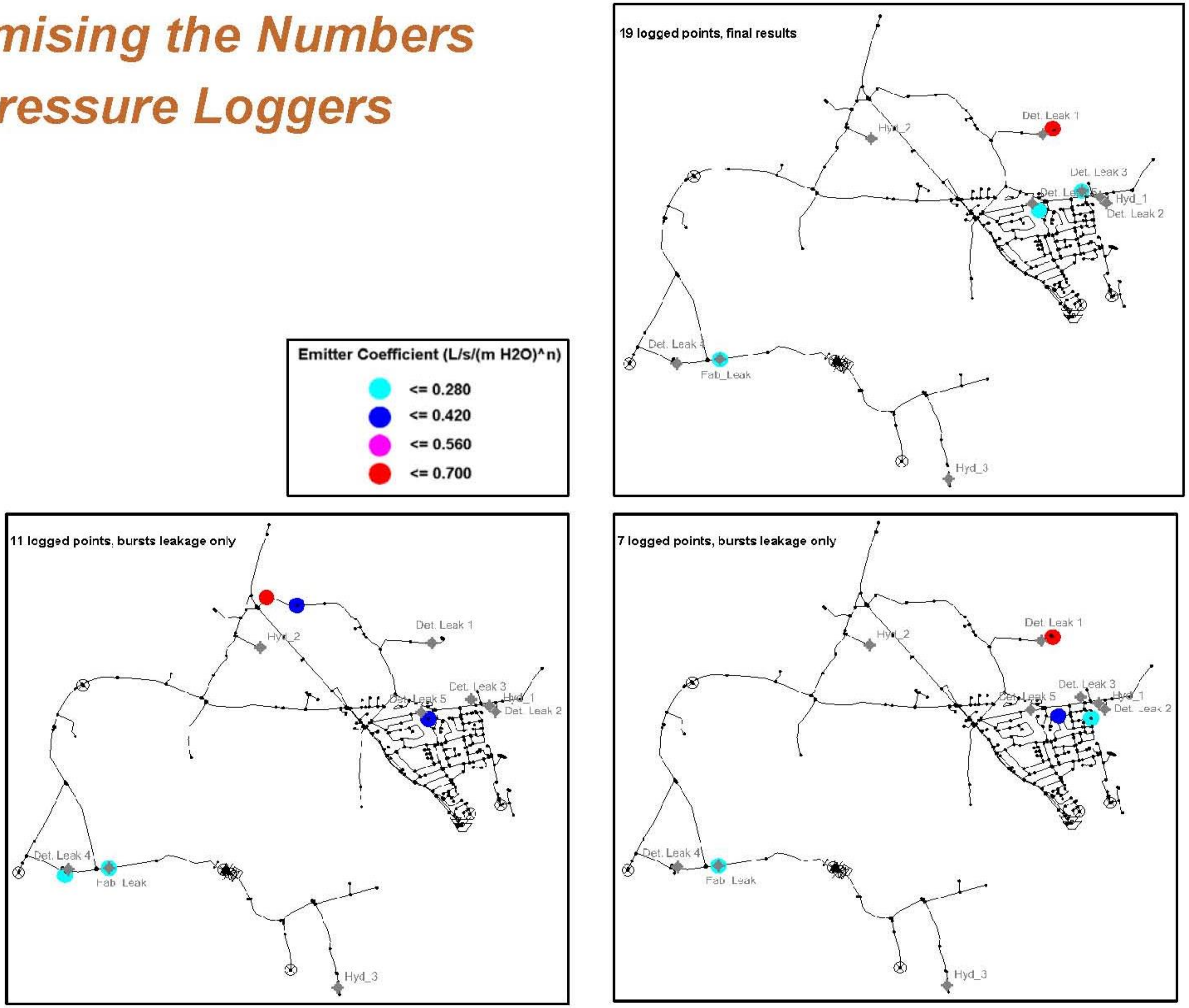
11 logged points

7 logged points

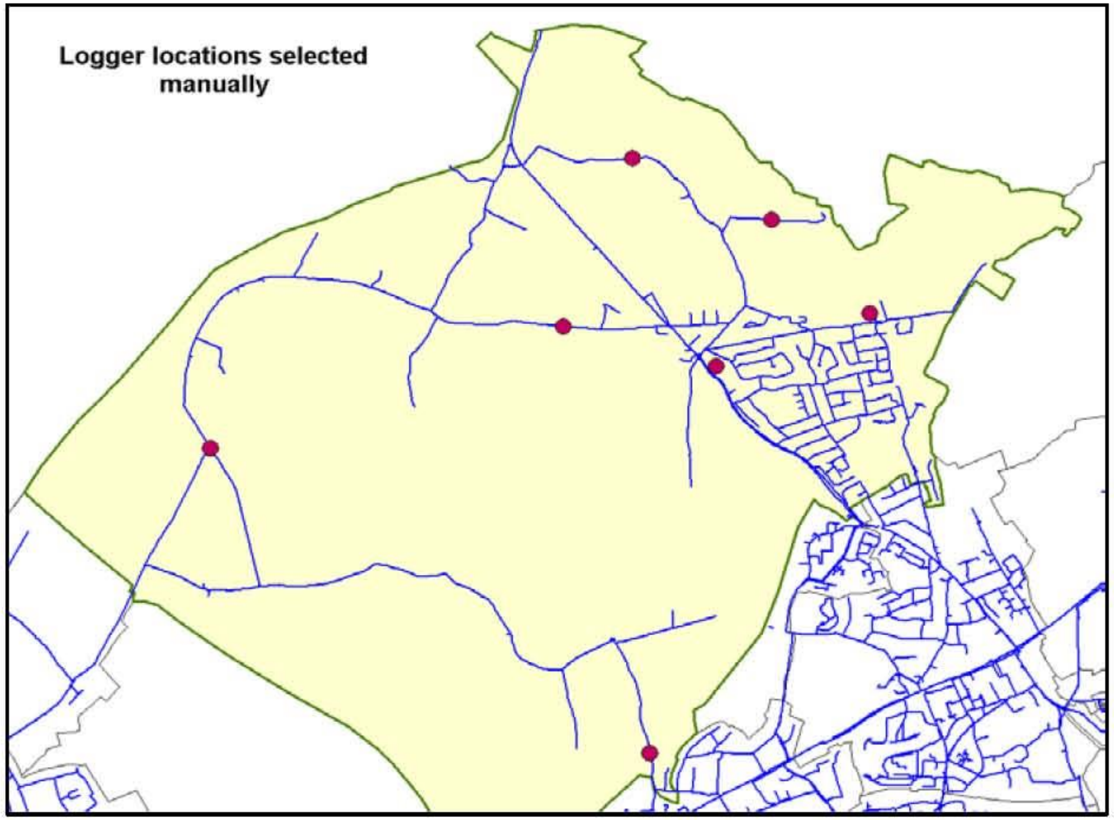


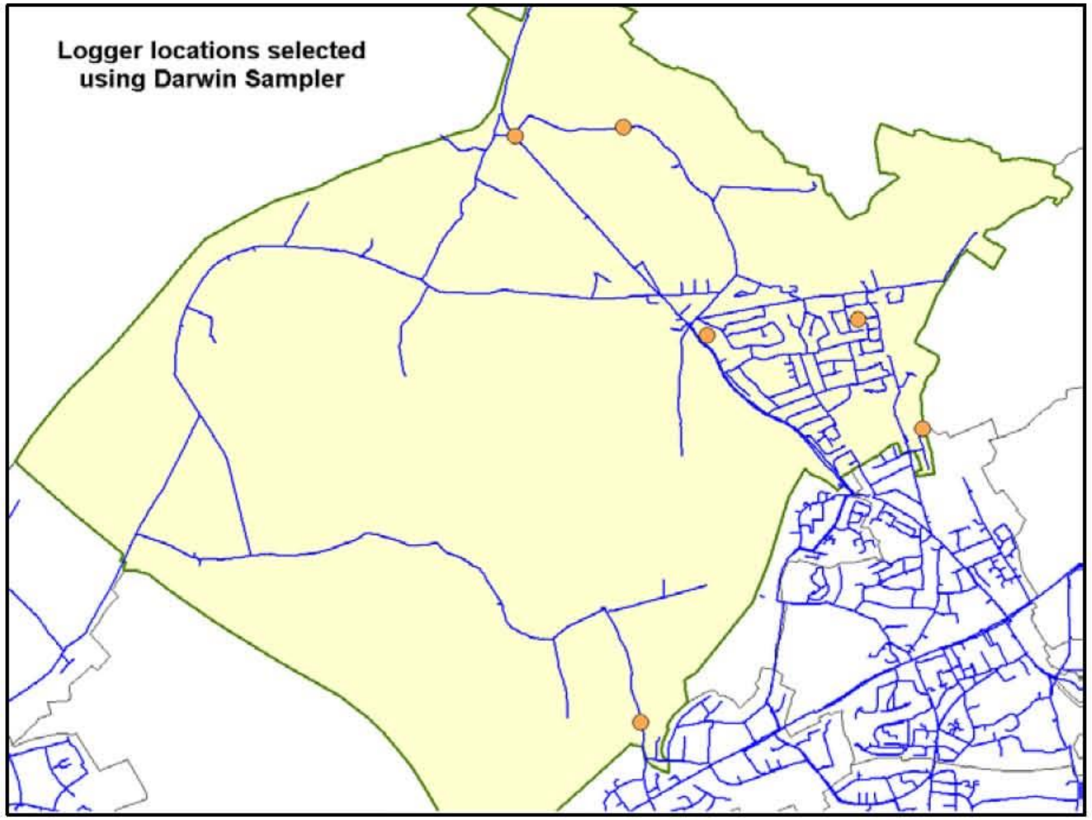


Optimising the Numbers of Pressure Loggers

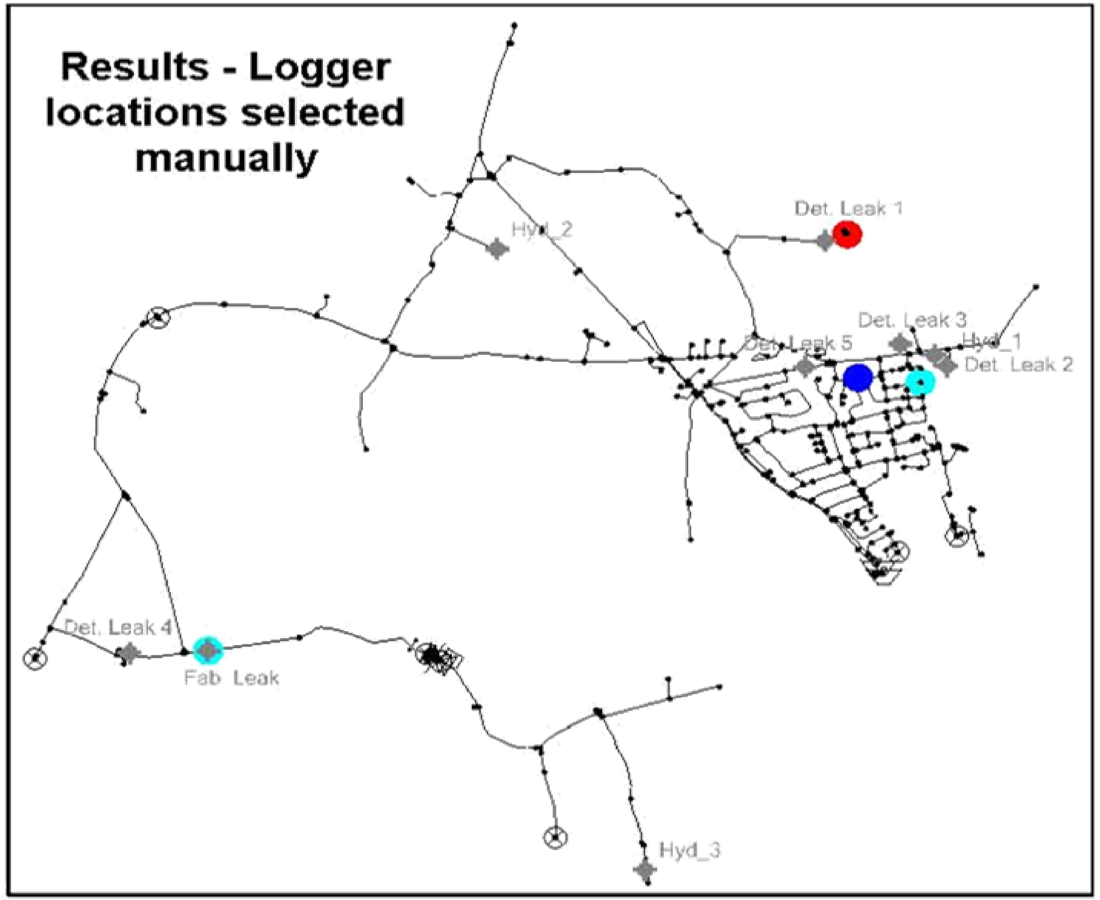


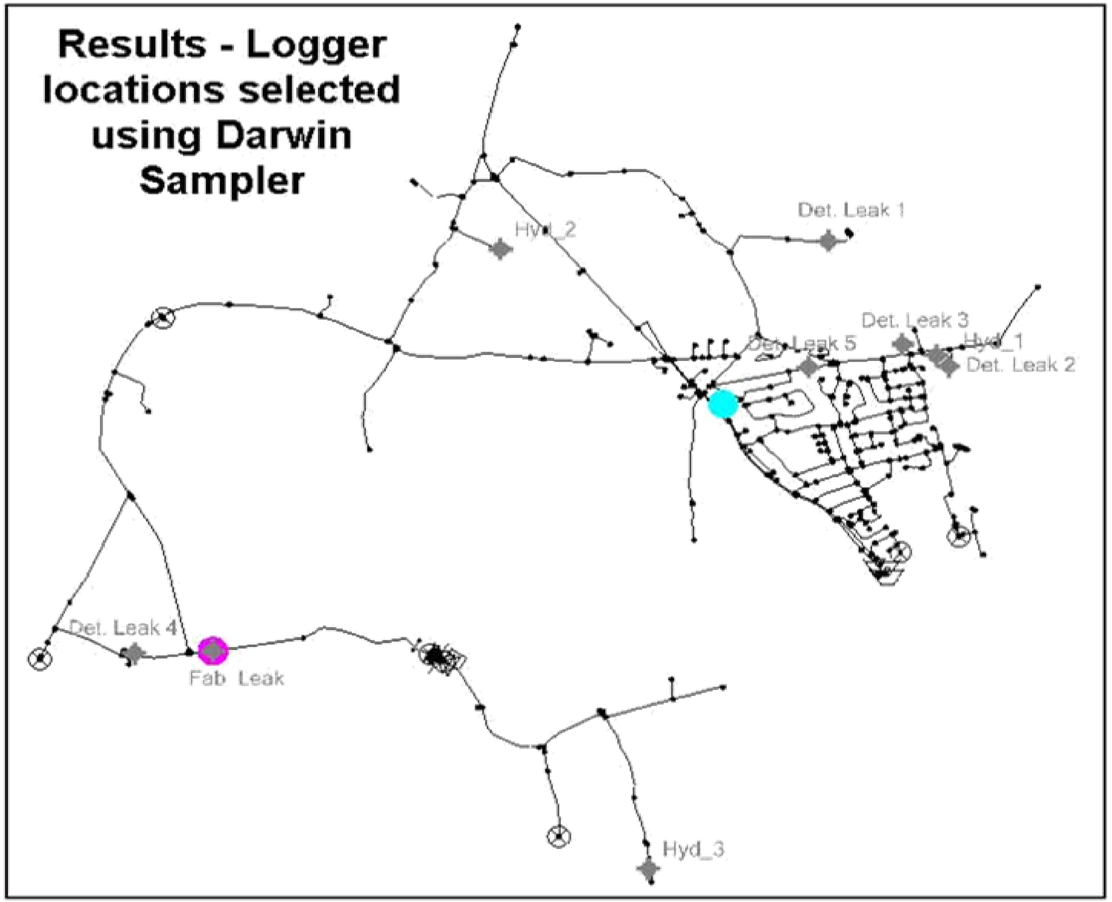
Optimising the Numbers of Pressure Loggers





Optimising the Numbers of Pressure Loggers





1000,000 Trials with roughness changing						1000,000 Trials no roughness changing					
Solutions	1	2	3	4	5	Solutions	1	2	3	4	5
Node	Adjusted	Adjusted	Adjusted	Adjusted	Adjusted		Adjusted	Adjusted	Adjusted	Adjusted	Adjusted
FL121											
FL137											
FL155											
FL129											
533903											
533903											
533903											
N936006											
N936448											
533906											
N937325											
N937497											
533987											
533988											
533988											
603478											
603480											
603480											

1,000,000 Trials with roughness changing							
		Solutions	1	2	3	4	5
Adjustment Group	Link	Original Darcy-Weisbach e (mm)	Adjusted Darcy-Weisbach e (mm)	Adjusted Darcy-Weisbach e (mm)	Adjusted Darcy-Weisbach e (mm)	Adjusted Darcy-Weisbach e (mm)	Adjusted Darcy-Weisbach e (mm)
New Roughness Group - 3	WEX-MT700848	0.99	0.495	0.495	0.495	0.495	0.495
New Roughness Group - 3	53407975	1.5	0.75	0.75	0.75	0.75	0.75
New Roughness Group - 3	53407978	0.01	0.005	0.005	0.005	0.005	0.005
New Roughness Group - 3	53407979	0.01	0.005	0.005	0.005	0.005	0.005
New Roughness Group - 3	53402177	0.01	0.005	0.005	0.005	0.005	0.005
New Roughness Group - 3	P-2	0.2591	0.1295	0.1295	0.1295	0.1295	0.1295
New Roughness Group - 4	53407535	1.5	22.5	22.5	22.5	22.5	22.5
New Roughness Group - 4	53407536	1.5	22.5	22.5	22.5	22.5	22.5
New Roughness Group - 4	53407537	1.5	22.5	22.5	22.5	22.5	22.5
New Roughness Group - 4	53407538	1.5	22.5	22.5	22.5	22.5	22.5
New Roughne							
New Roughne							
New Roughne							
New Roughne							
New Roughne							
New Roughne							
New Roughne							
New Roughne							

1,000,000 Trials with roughness changing						
Solutions		1	2	3	4	5
Link	Original Status	Adjusted Status	Adjusted Status	Adjusted Status	Adjusted Status	Adjusted Status
53407681	Open	Open	Open	Open	Open	Open
53407729	Open	Closed	Closed	Closed	Closed	Closed
53407682	Open	Open	Open	Open	Open	Open
53407585	Open	Closed	Closed	Closed	Closed	Closed

1,000,000 Trials no roughness changing					
Solutions	1	2	3	4	5
				djusted Status	Adjusted Status
				pen	Open
				osed	Closed
				pen	Open
				pen	Open

	with roughness	no roughness
No of trials	1,000,000	1,000,000
Solution	**Fitness**	**Fitness**
Solution 1	370.53	370.11
Solution 2	370.54	370.12
Solution 3	370.57	370.16
Solution 4	370.58	370.17
Solution 5	370.60	370.19

Darwin Calibrator

WWW.BENTLEY.COM

HAESTAD METHODS
WATER SOLUTIONS

25 years
130,000 users
170 countries

WATER

- **WaterGEMS.** Water distribution modeling with geospatial integration
- **WaterCAD.** Water distribution modeling and design
  - **Darwin Designer.** Model calibration optimization
  - **Darwin Calibrator.** Network design automation
  - **WaterSAFE.** Advanced water quality and security
  - **Skelebrator.** Network reduction or simplification
- **HAMMER.** Transient flow analysis and modeling
- **SCADAConnect.** Supervisory and control data integration

SEWER

- **SewerGEMS**. Urban sewer modeling with GIS integration
- **SewerCAD**. Sanitary sewer design and modeling

STORM

- **CivilStorm.** Stormwater management and dynamic modeling
- **StormCAD**. Storm sewer design and modeling
- **PondPack**. Detention pond design and analysis
- **HEC-Pack.** Floodplain modeling
- **CulvertMaster.** Culvert design and analysis
- **FlowMaster.** Hydraulics calculator

WWW.BENTLEY.COM

WaterCAD & WaterGEMS

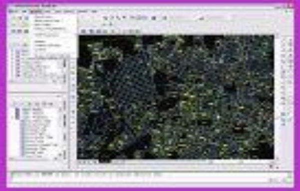
WaterGEMS V8
XM Edition

ArcGIS platform

WaterCAD V8
XM Edition

Windows Stand-alone

MicroStation platform



AutoCAD platform

LoadBuilder

Terrain Extraction (TRex)

ModelBuilder

Included

Available Add-ons

Darwin Calibrator

Darwin Designer

Skelebrator

HAMMER and SCADAConnect – Available Add-on

WaterCAD Modules

Available for WaterCAD
Included with WaterGEMS

Darwin Calibrator

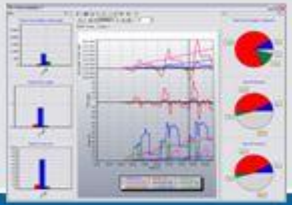
Automated model calibration

Darwin Designer

Optimized and automated network design.

Skelebrator

Hydraulic-smart network reduction



HAMMER

Water Surge and Transient An

WWW.BENTLEY.COM

HAESTAD METHODS
WATER SOLUTIONS

25 years
130,000 users
170 countries

WATER

WaterGEMS. Water distribution modeling with geospatial integration

WaterCAD. Water distribution modeling and design

- **Darwin Designer.** Model calibration optimization
- **Darwin Calibrator.** Network design automation
- **WaterSAFE.** Advanced water quality and security
- **Skelebrator.** Network reduction or simplification

HAMMER. Transient flow analysis and modeling

SCADAConnect. Supervisory and control data integration

SEWER

SewerGEMS. Urban sewer modeling with GIS integration

SewerCAD. Sanitary sewer design and modeling

STORM

CivilStorm. Stormwater management and dynamic modeling

StormCAD. Storm sewer design and modeling

PondPack. Detention pond design and analysis

HEC-Pack. Floodplain modeling

CulvertMaster. Culvert design and analysis

FlowMaster. Hydraulics calculator

Background

- Darwin Calibrator is an optimisation module that uses genetic algorithms to calibrate hydraulic models of water distribution networks
- One of the operations available in this module is 'Detect Leakage Node', which enables pinpointing of potential leak locations
- The main purpose of this project was to gain a better understanding of the practical processes involved in using hydraulic models in a dynamic way for the purposes of localising bursts for detection teams to target
- In addition, the project identified potentially closed valves and investigated the optimum number of pressure loggers required

Darwin Designer

Automated design

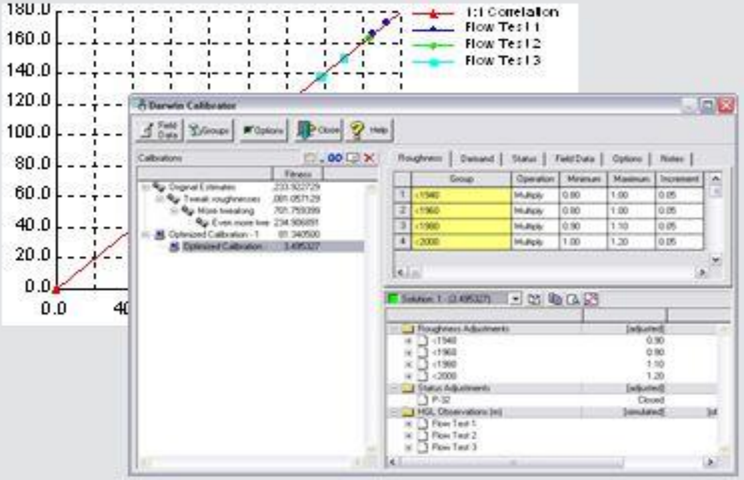
Evaluate thousands of design and rehabilitation alternatives that meet your hydraulic constraints, maximizing hydraulic performance and savings to your Capital Investment Program (CIP).

1. Enter design requirements (Max./Min. pressures & velocities)
2. Assign cost tables or functions
3. Determine optimization objective (Cost, benefit or trade-of)
4. Let Darwin find thousands of valid design solutions
5. Choose an optimum solution for implementation

Darwin Calibrator

Automated calibration

Streamline the time-consuming model calibration process and make sure your decisions are based on a model that truly reflects the real world.



1. Enter multiple **field measurements** for calibration
2. Let Darwin generate **millions of possible solutions**
3. Create a **calibrated model** using optimum values for pipe roughness, junction demands and element status

BENTLEY

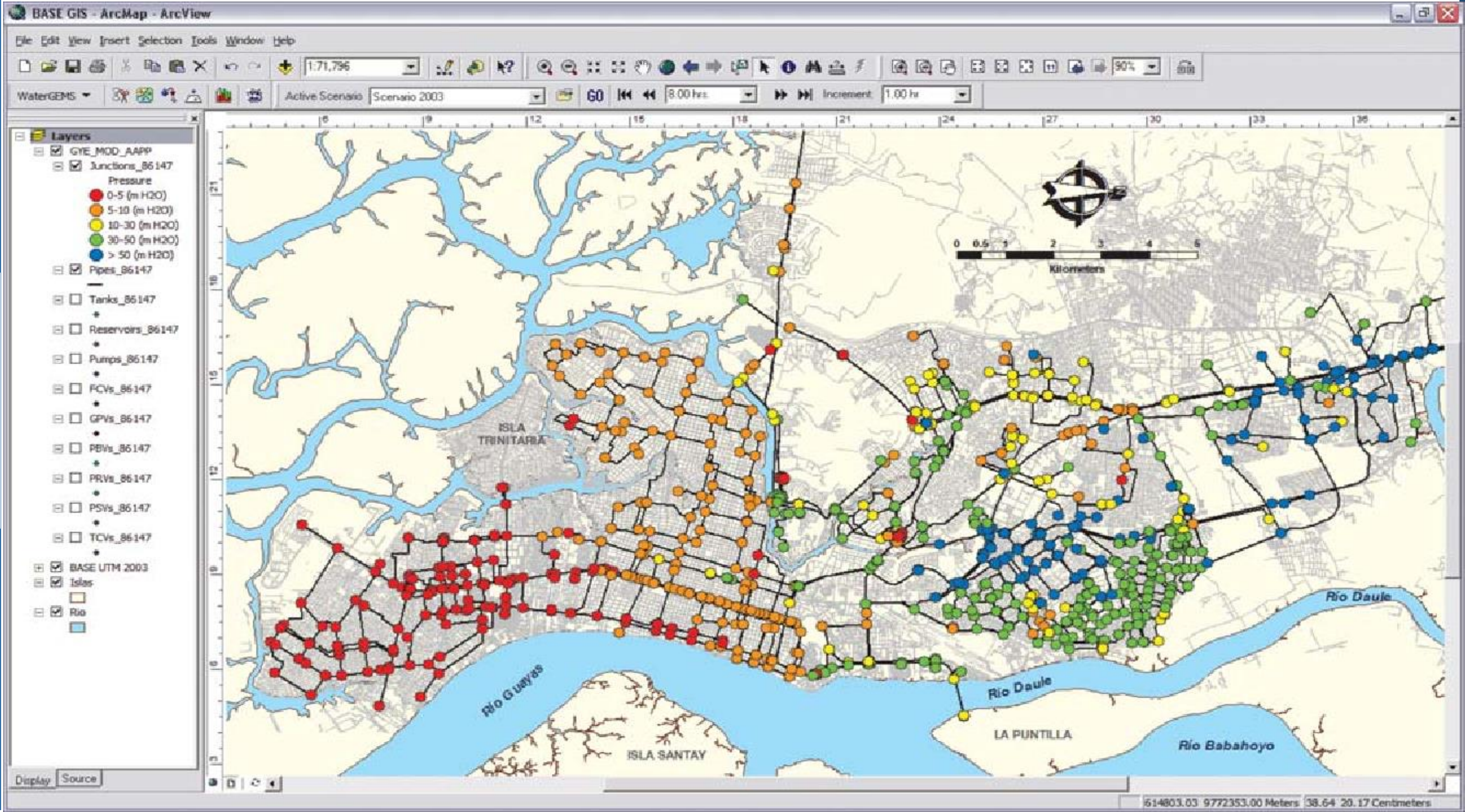

BASE GIS - ArcMap - ArcView
File Edit View Insert Selection Tools Window Help
1:71,796
WaterGEMS
Active Scenario
Scenario 2003
GO
8.00 hrs
Increment
1.00 hr
Layers
GYE_MOD_AAPP
Junctions_86147
Pressure
0-5 (m H2O)
5-10 (m H2O)
10-30 (m H2O)
30-50 (m H2O)
> 50 (m H2O)
Pipes_86147
Tanks_86147
Reservoirs_86147
Pumps_86147
FCVs_86147
GPVs_86147
PBVs_86147
PRVs_86147
PSVs_86147
TCVs_86147
BASE UTM 2003
Islas
Rio
Display
Source
0 0.5 1 2 3 4 5
Kilometers
ISLA TRINITARIA
Rio Guayas
Rio Daule
Rio Daule
LA PUNTILLA
ISLA SANTAY
Rio Babahoyo
614803.03 9772353.00 Meters
38.64 20.17 Centimeters

FIGURE 2 Darwin calibration illustration of comparison between the observed and simulated pressures over 24 hours

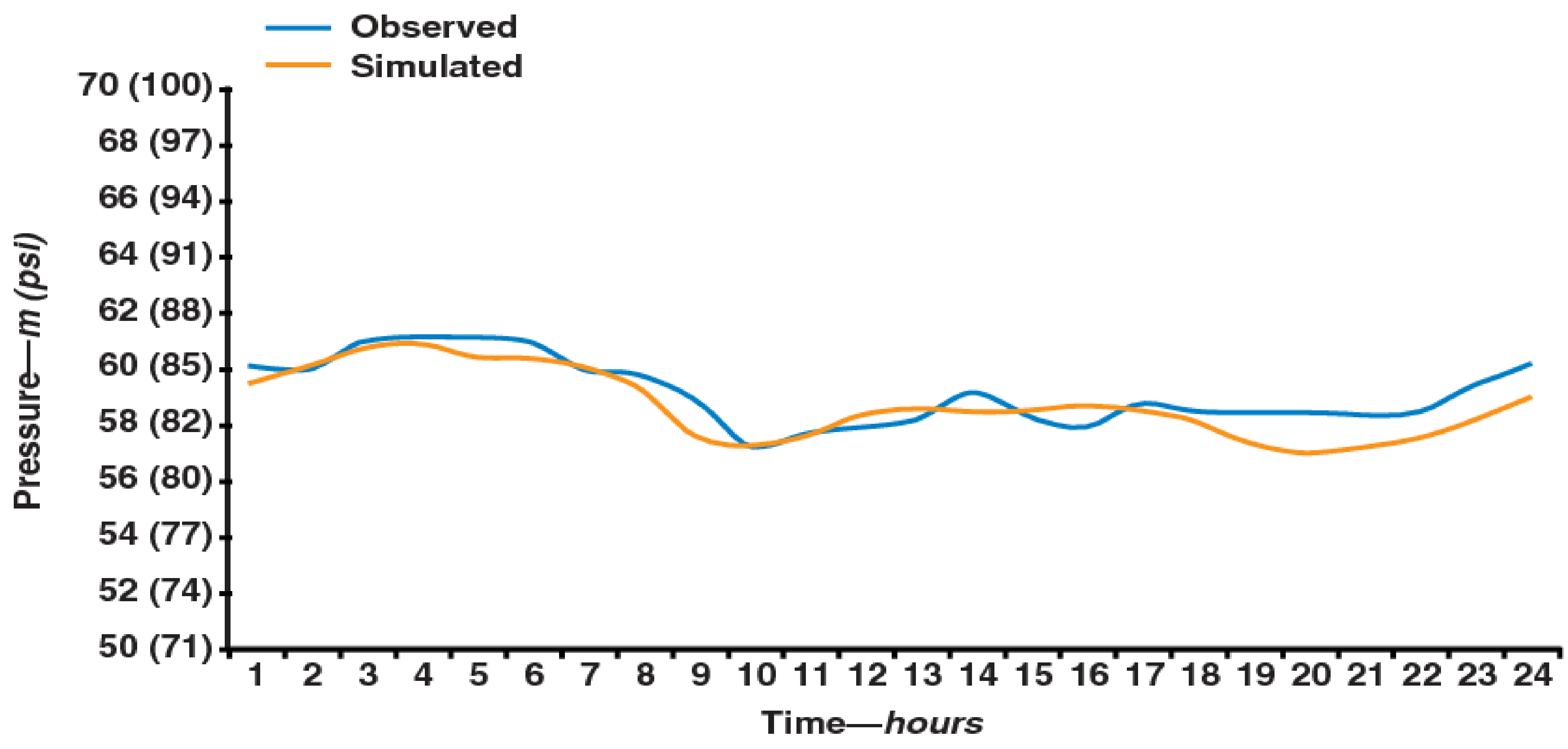
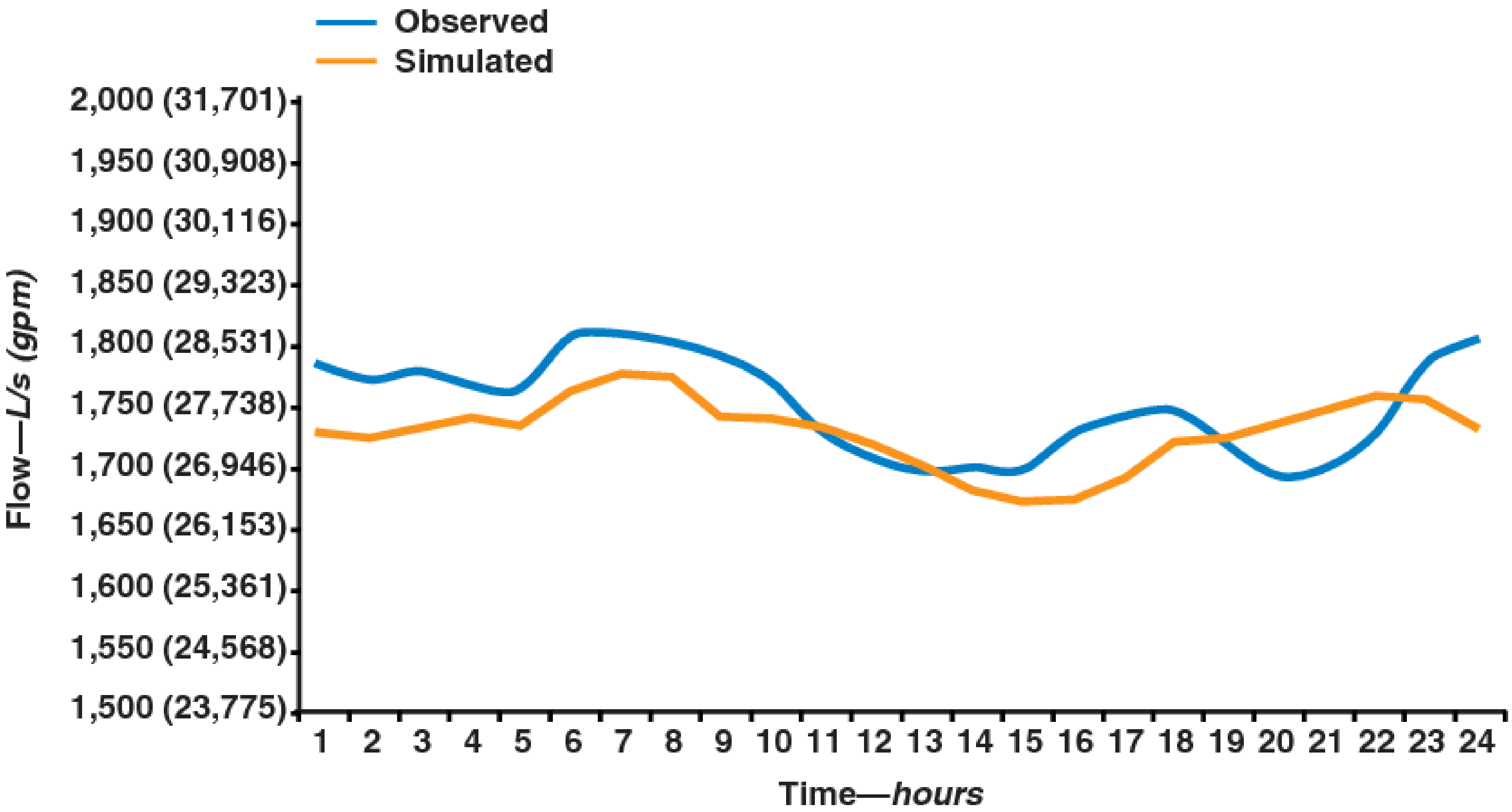
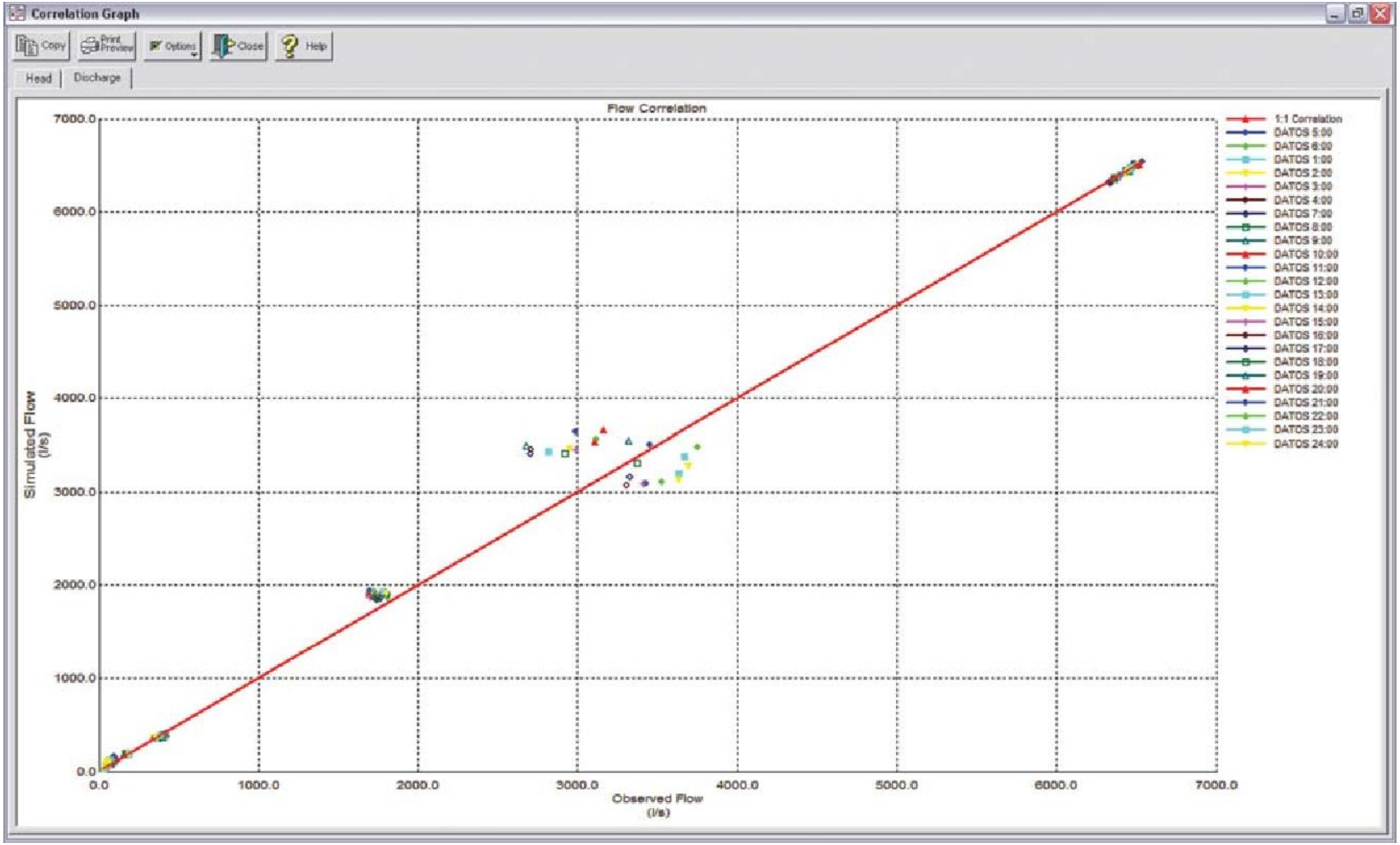


FIGURE 3 Example of comparison between observed and simulated flows over 24 hours for a large-diameter pipe





Correlation Graph
Copy
Print Preview
Options
Close
Help
Head
Discharge
Flow Correlation
Simulated Flow (l/s)
Observed Flow (l/s)
0.0
1000.0
2000.0
3000.0
4000.0
5000.0
6000.0
7000.0
1:1 Correlation
DATOS 5:00
DATOS 6:00
DATOS 1:00
DATOS 2:00
DATOS 3:00
DATOS 4:00
DATOS 7:00
DATOS 8:00
DATOS 9:00
DATOS 10:00
DATOS 11:00
DATOS 12:00
DATOS 13:00
DATOS 14:00
DATOS 15:00
DATOS 16:00
DATOS 17:00
DATOS 18:00
DATOS 19:00
DATOS 20:00
DATOS 21:00
DATOS 22:00
DATOS 23:00
DATOS 24:00

Conclusion and Lessons Learnt

- The robustness of the solutions obtained is highly dependent on the best possible definition of the network configuration (valve status) and its physical condition (i.e. pipe roughness)
- A refined approach to the night time demand allocation can also have a significant impact on the accuracy of the results
- Hydrant flushing should be arranged during the night time field tests to enhance hydraulic gradients through the network
- The location of the loggers should ensure an even coverage of the whole of the area
- High initial cost of work required and effort involved in bringing DMA models up to standard
- Risk and effort related to the flushing exercise that is essential
- Enhances the quality of final model calibration
- Found successful in locating ‘hard to find’ leaks on ‘stubborn’ DMAs
- Significant benefits to the location of unknown closed valves

EMG
EnvironMental engineering Group

ENVIRONMENTAL
ENGINEERING GRUOP

بيئة نظيفة واستخدام اقتصادي للماء، من مقاصد الإسلام