INTERNATIONALE
ZUSAMMENARBEIT

Intermittent water supply (IWS) in Jordan

Current challenges and possibilities for mitigating the impact on network operation and water metering

Report of the IWS Study group

with contributions by

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ABBREVIATIONS

AWC	Aqaba Water Company
DZ	Distribution Zone
EFM	Electromagnetic Flow Meter
IWA	International Water Association
IWS	Intermittent Water Supply
IWSS	Intermittent Water Supply System
JAS	Jordan Accreditation System
JNMI	Jordan National Metrology Institute
JSMO	Jordan Standard and Metrology Organisation
LCD	Liter per Capita per Day
NRW	Non-Revenue-Water
MAP	Maximum Admissible Pressure
MWC	Miyahuna Water Company
MWI	Ministry of Water and Irrigation
PRV	Pressure Reducing Valve
PTB	Physikalisch-Technische Bundesanstalt
QI	Quality Infrastructure
RSS-JNMI	Royal Scientific Society/Jordan National Metrology Institute
SCADA	Supervisory Control and Data Acquisition
UFM	Ultrasonic Flow Meter
WAJ	Water Authority of Jordan
WFG	Water Focal Group
WU	Water Utility
YWC	Yarmouk Water Company

1 EXECUTIVE SUMMARY

Intermittent water supply (IWS) means that water is supplied to consumers only for specific periods or at certain times, rather than continuously. In IWS systems, water may not be available 24/7, and residents or users may experience periods of supply interruption or limited access. Intermittent supply often requires consumers to store water when it is available, and can present challenges related to water quality, pressure and accessibility. Intermittent water supply systems are prevalent in most developing countries and some developed ones. In Jordan the water supply is intermittent throughout the country, except for Aqaba city and some districts of Amman.

IWS can have adverse impacts on the water supply network. The rates of pipes deterioration could increase due to water hammers, a phenomenon that occurs in pressurized pipe systems when the flow of water is suddenly stopped or changed, leading to shock waves with hammering noise in the pipes. The impact of the shock wave can be strong enough to damage pipes, fittings and valves, posing economic challenges for the system operating water utilities.

IWS and water hammers can also have an impact on the accuracy of water metering. On the one hand, the performance of meters may be affected during the low flow phase of the supply period and lead to under reading. On the other hand, consumers doubting the accuracy of their household mechanical meters under IWS conditions complain about “metering of air instead of water flow”. The first effect contributes to commercial water losses of the water utilities. These refer to the portion of water supplied that is not fully billed or accounted for, typically due to issues such as unauthorized consumption, billing inefficiencies, or **inaccurate meter readings**.

Therefore, correct water metering under IWS conditions can contribute to improve water management and efficiency by increasing consumer satisfaction and reducing **Non-Revenue-Water** (NRW).

The objective of this study is to outline and to understand the concrete impacts of IWS on network operation and water metering in Jordan and to propose potential mitigation measures. These include internationally experienced specific recommendations on the selection of appropriate water meters, their proper installation as well as the installation of valves and tanks on the network.

For an overview of the geographical location of the different water utilities, see figure 1.1 below.

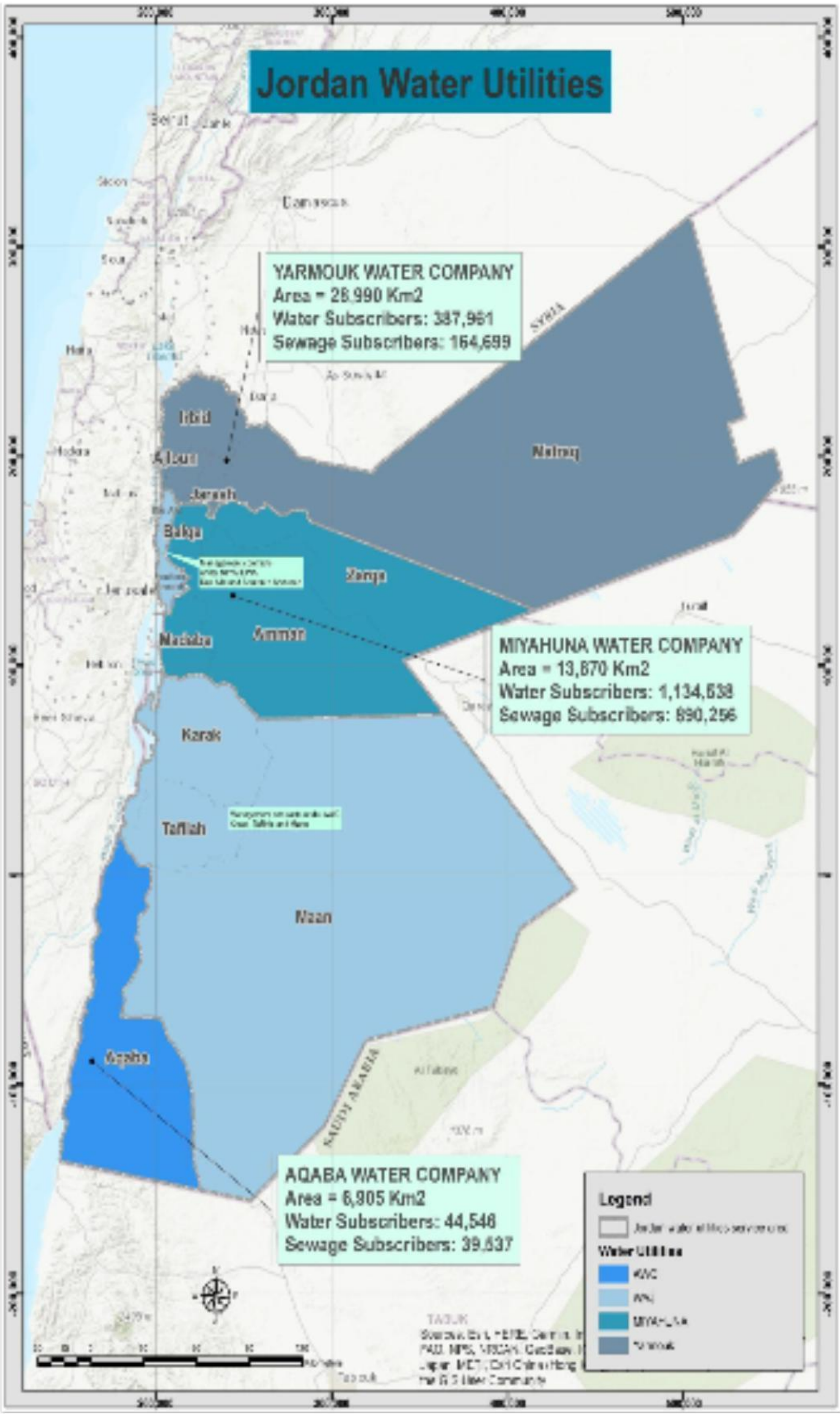

Figure 1.1 Overview of the Water utilities service areas in Jordan, image taken from MWI (UPMU Report 2023).

2 INTERMITTENT WATER SUPPLY

2.1 Definition, challenges and opportunities

An **Intermittent Water Supply System** (IWSS) is a water distribution system where water is supplied to consumers only for specific periods or at certain times, rather than continuously. In such systems, water may not be available 24/7, and residents or users may experience periods of supply interruption or limited access. This type of system is common in areas with insufficient infrastructure, limited water resources, or inadequate storage capacity to meet continuous demand. The interruptions could be scheduled (e.g. specific hours each day) or unscheduled due to system limitations, maintenance, or other factors. Intermittent supply often requires consumers to store water when it is available, and can present challenges related to water quality, pressure and accessibility.

The intensive usage of IWSSs in developing regions is mainly derived from water scarcity and economic and technical deficits. It is extensively reported that almost all water supply systems in developing countries are intermittent. Users of IWSSs are forced to employ ground/ roof private storage tanks as a means of collecting water during the unavailable periods of the water supply service and rely on the presence of sufficient pressure in the system to use water when the service is disconnected. The intermittent supply practices contribute, in conditions of water scarcity, to reducing background water losses without consuming a high financial potential. The prolonged use of this technique may have adverse impacts, as the rates of pipes deterioration could increase due to water hammers[1] (see chapter 2.5) being stimulated by the cycle of emptying and filling of the network. Moreover, the mechanical stability of the pipes will also be affected by the transient phenomena due to pressure surges and pressure fluctuations. This will increase the rate of bursts and leakages. Another relevant and important aspect is the quality of water. The low pressure or even negative pressure due to intermittent feeding and pressure deficits causes stagnation of water in the pipes. This allows contaminated water and soil particles to enter the pipes through leaks from the surrounding soil. Serious threat, with fatal consequences, arises where defective sewers run in parallel to water pipes (Shaher Zyoud, 2022).

One approach to address these challenges of IWS can be to strengthen the financial and commercial capacities of the managing water utilities to enable them to improve their water supply to customers. This includes the reduction of commercial water losses and as such the reduction of Non-Revenue-Water (NRW). Water meter inaccuracies, which could be increased by intermittent water supply conditions, contribute to the so-called “apparent losses”, comprising all water successfully delivered to the customer but not metered or recorded accurately and thus causing errors in the amount of customer consumption (definition by the International Water Association, IWA). In the case of IWS this can lead to under readings and is aggravated by customers dissatisfaction, not willing “to pay for metered air flow instead of water”.

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[1] **Water hammer** is a phenomenon that occurs in pressurized pipe systems when the flow of water is suddenly stopped or changed, typically due to the closing of a valve or a pump failure. This sudden change causes a shockwave or pressure surge that can create a loud banging or hammering noise in the pipes. The impact of the shockwave can be strong enough to damage pipes, fittings, and valves.

By a proven accurate water metering under IWS conditions, water utilities can meter correctly and improve the satisfaction of costumers, having a positive impact on their commercial and managerial situation for a more efficient water management. This is where the international cooperation project “Quality infrastructure for efficient water management in Jordan II” starts with its objective “Jordanian quality infrastructure institutions offer the Jordanian Water Authority and water supply companies demand-orientated quality infrastructure services for efficient and climate-resilient water management”.

2.2 Situation in Jordan

In urban areas, water supply is usually more consistent, with residents receiving water daily. However, even in these areas, water supply can be affected by breakdowns in the infrastructure, leading to periods of reduced water pressure or water cuts.

In rural and peri-urban areas, water supply can be more irregular, with residents falling back on private tankers or other alternative sources of water. In these areas, water cuts can last for several days, leading to significant hardships for residents who rely on water for household use, agriculture, and other purposes. In conclusion, the situation of intermittent water supply in Jordan is a critical issue that requires urgent attention and action. Addressing this issue is crucial for the health, well-being, and economic development of the country and for the sustainable and user-oriented management of its limited water resources.

All areas in Jordan are affected by IWS except Aqaba city and some districts of Amman. Table 2.1 below shows the service areas and the percentage of subscribers according to the service areas and the supply mechanism in each utility.

<table>
<tr><th>Water Utility (WU)</th><th>Area</th><th>Subscribers</th><th>Percentage of Subscribers %</th><th>Average Supply</th></tr>
<tr><td rowspan="4">Miyahuna</td><td>Amman</td><td>798,029</td><td rowspan="4">68 %</td><td rowspan="4">38 h/week</td></tr>
<tr><td>Madaba</td><td>39,068</td></tr>
<tr><td>Zarqa</td><td>196,295</td></tr>
<tr><td>Balqa</td><td>73,313</td></tr>
<tr><td rowspan="4">Aqaba</td><td>Inside Aqaba</td><td>44,300</td><td rowspan="4">9 %</td><td>continuous</td></tr>
<tr><td>Outside Aqaba</td><td>5,000</td><td rowspan="3">40 h/week</td></tr>
<tr><td>Ma’an</td><td>28,000</td></tr>
<tr><td>Karak</td><td>55,000</td></tr>
</table>

Water Utility (WU)	Area	Subscribers	Percentage of Subscribers %	Average Supply
	Tafila	19,000		
Yarmouk	Irbid	377,143	23 %	9 h/week
	Jerash			
	Ajloun			
	Mafraq			

Table 2.1: Overview of the water supply regime in Jordan: Jordan Water Utilities Monitoring Report from the Ministry of Water and Irrigation (2022) with additional data added by M. Abualshaikh.

Table 2.2 below shows the percentage of subscribers receiving continuous supply and water resources per capita per day, in addition to the water consumption per capita per day for the residential subscribers, taken into consideration that the data for Miyahuna cover Amman, Madaba, Zarqa while Aqaba water company represents the data of Aqaba city only before the management contracts of southern governorates. Due to the intermittent supply full pipe conditions at the meter inlet may not be always guaranteed. The data has been shown in an internal presentation on 18th of May 2023. As of 2022, there are 1.6 million subscribers for fresh water in Jordan, compare "Jordan Water Sector: Facts and Figures" p. 20.

	Unit	Water Utility	2019	2020	2021	2022	2023
Subscribers receiving continuous supply	%	Miyahuna	1	3	1	2	1.2
		Aqaba	97	93	96	95	100
		Yarmouk	0	0	0	0	0
Water resources (litres per capita per day)	lcd	Miyahuna	143	125	124	122	129.4
		Aqaba	404	369	364	324	348
		Yarmouk	113	97	101	98	95.2
Water consumption litres per capita per day (residential subscribers)	lcd	Miyahuna	64.8	54.1	53.6	52.9	58.3
		Aqaba	79.5	76.4	87.9	75.3	92.1
		Yarmouk	56.7	45.6	46.4	44.1	44.1

Table 2.2: Overview of the water consumption and the supply regime in Jordan: Jordan Water Utilities Monitoring Report from the Ministry of Water (2023).

2.3 Water metering and Non-Revenue-Water

An overview on the number and kind of water metres (mechanical, ultrasonic, smart, etc.) installed at household level with their approximate quality/ age as well as the extent of NRW (commercial and physical) is given in table 2.3 below.

The operating principle of domestic water meters installed in most water supply distribution networks in Jordan is based on mechanical transmission via a moving mechanism located in the water stream to a volume accumulator (see Figure 2.1 below). These types of meters, known as **mechanical meters**, measure the flow velocity through a meter with a known internal volume. This flow velocity can then be converted into flow volume to determine usage. Customer meters used in Jordan could be meters with non-movable parts, so called “static meters” (as ultrasonic or electromagnetic) or meters with movable parts (as mechanical meters). 85 % of the meters installed in Jordan are mechanical meters, as shown in the table 2.3 below. For both variants so called smart versions with additional functionality exist.

Static meters have several advantages compared to traditional mechanical meters. However, domestic meters of this type represent a very small percentage of installations in water distribution networks in Jordan compared to mechanical meters, representing 15 % of the total household meters. They are only used in modern, advanced networks, in relatively small numbers, or in pilot projects. Smart static meters offer a range of data recording capabilities, such as monitoring air in the system, cracks or leaks in pipes, minimum and maximum flow, and more.

Such meters are the only meters, which could reliably work under intermittent water supply conditions registering only the water passing through the meter and not the air. However, this new technology although suitable for IWS is relatively expensive with an average price for a 15 mm diameter domestic meter of the order of 2 to 3 times compared to a corresponding positive displacement meter and to about 3 to 4 times for a corresponding velocity meter depending of course on the quality, characteristics, manufacturer, etc.

Despite this accuracy, it does not measure the amount of water mixed with air bubbles, which increases the percentage of water lost, especially at the beginning of the weekly water supply cycle.

Figure 2.1 Typical mechanical meter with opened lid, produced by Baylan meters, refurbished by WAJ, image by J. Steinbock, Amman (2022).

Figure 2.2 Ultrasonic meter with opened lid, produced by Neptune, image by J. Steinbock, Aqaba (2022).

Water Utility	Service Area	Customers			
			/static smart	mechanic	/Ratio static smart to mech-anic meters
Miyahuna	Amman	798,029	189,666	608,363	%31
	Madaba	39,068	0	39,068	%0
	Zarqa	196,295	10,023	186,272	%5
	Balqa	73,313	4,032	69,281	%0
Aqaba	Inside Aqaba	44,300	44,300	0	%100
	Outside Aqaba	5,000	0	5,000	%0
	Ma'an	28,000	0	28,000	%0
	Karak	55,000	0	55,000	%0
	Tafila	19,000	0	19,000	%0
Yarmouk	Irbid	377,143	0	377,143	%0
	Jerash				
	Ajloun				
	Mafraq				
	Total	1,635,148	24,8021		
	Whereof smart meters		%15		

Table 2.3: Overview of meters installed by the three water utilities in Jordan in 2022, provided by Miyahuna (M. Abualshaikh).

2.4 Usage Patterns under IWS conditions

Many customers are supplied with water once a week, therefore they need storage capacities for the period without supply. As the network is empty at the beginning of the supply period there will be high demand from starting off supply to fill up their tanks. A normalized graph for this flow regime is depicted in Figure 2.3 below.

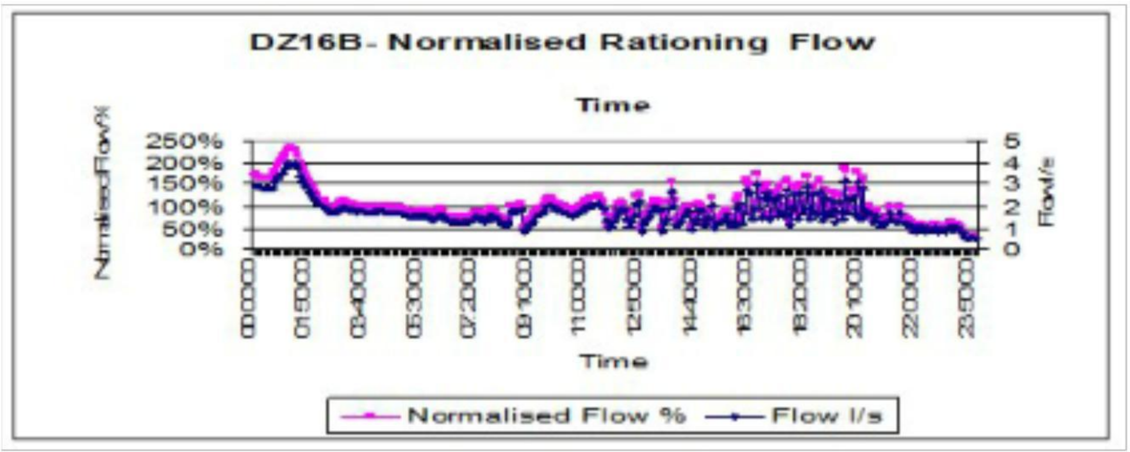

Figure 2.3 Normalized flow rate in the District Metering Area (DMA) 16B (Amman / Safut Upper) provided by Miyahuna, M. Abualshaikh , dated 2022.

At the beginning of the water supply a very high flow of up to 250 % of the average flow is observed. After about 3 hours the flow rate drops to the nominal value.

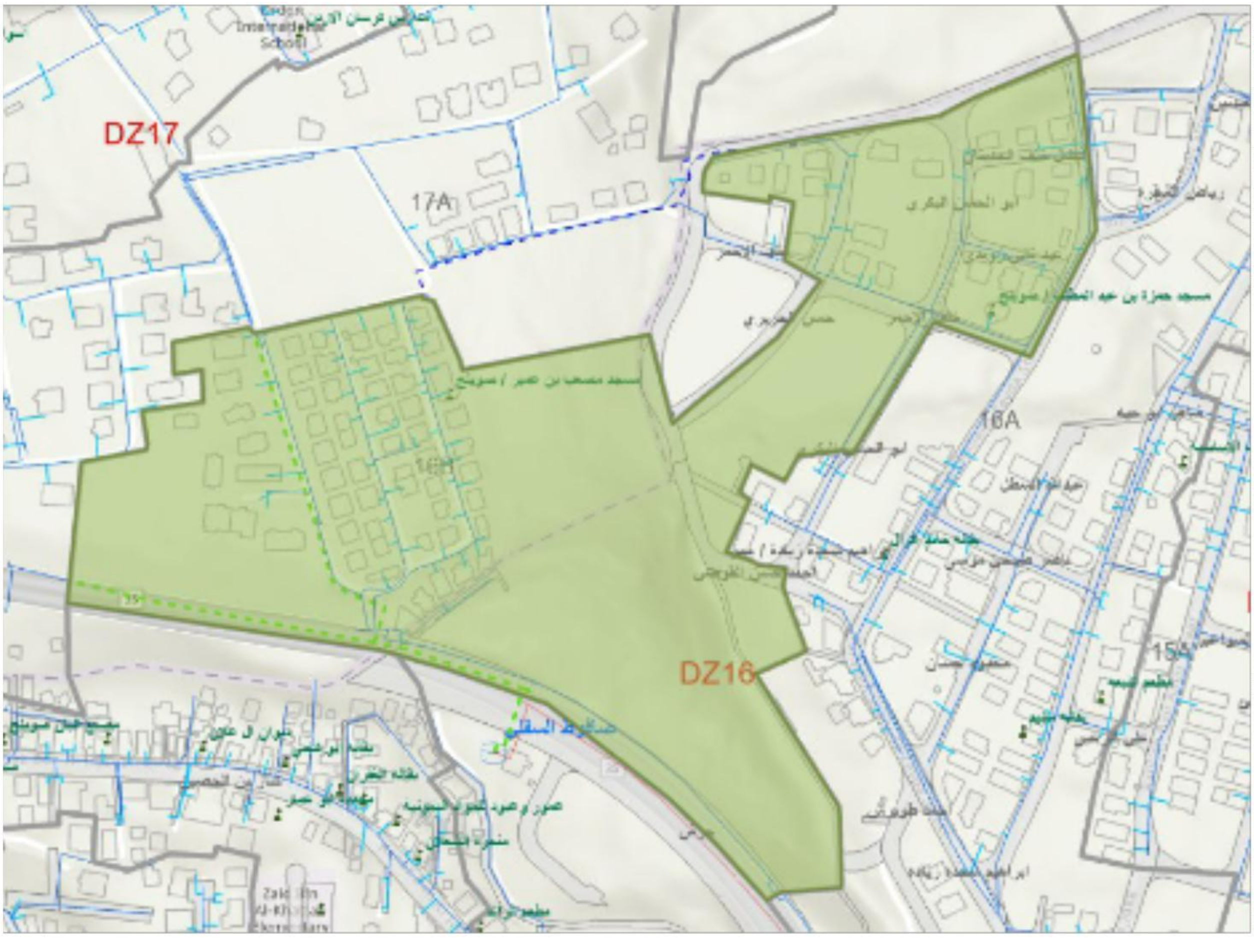

Figure 2.4 Geographical location of DMA 16B (Amman / Safut Upper), map provided by Miyahuna (M. Abualshaikh), 2025.

(AL-Washali et al. 2020) observe the influence of float valves [installed in the tanks] on the consumption pattern. During the supply circle in general a short period of high flow is followed by a prolonged low flow situation.

(Marchis et al. 2010) presents a methodology to model the filling of networks including storage tanks. The higher demand at the beginning of the supply period is also acknowledged.

During the low flow phase of the supply period the performance of the meter may be affected by under reading, due to the low flow, compare figure 2.5 below.

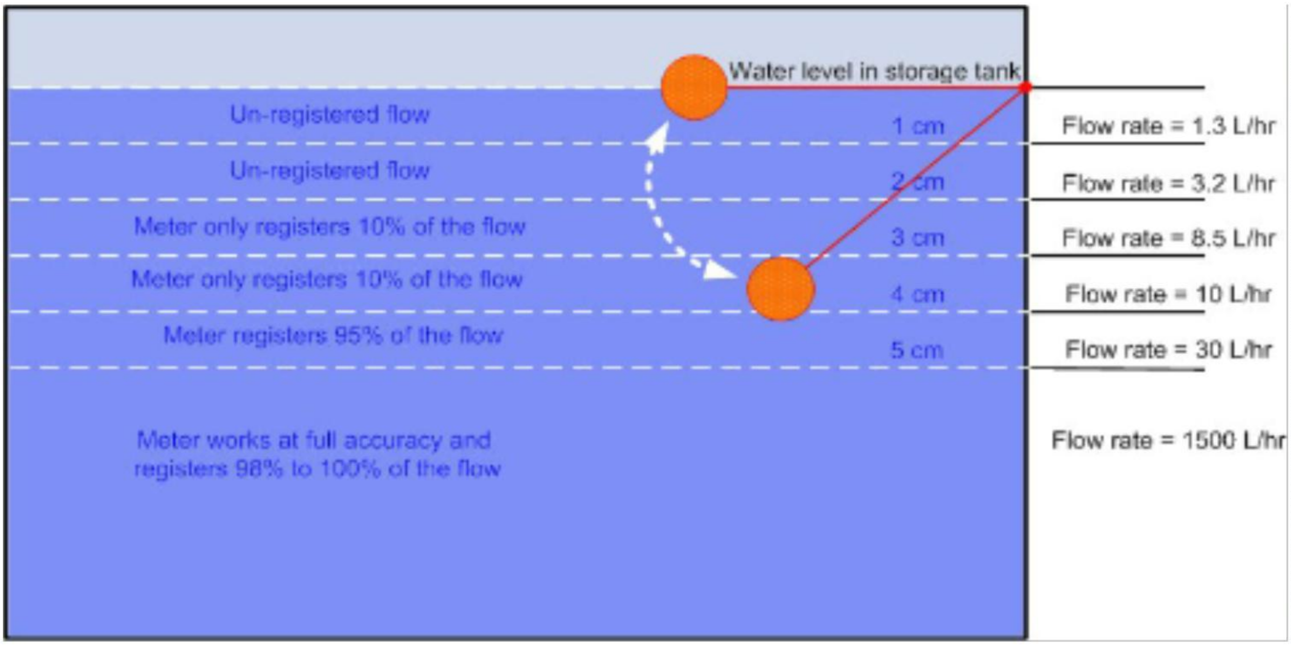

Figure 2.5 Performance of a mechanical water meter in relation to the position of the float valve in a storage tank. Sketch provided by JSMO (A. Gheniemat), based on (AL-Washali et.al. 2020).

As the available quantities do not meet the demand usually in summer seasons, a higher number of complaints are submitted by the customers at the critical points which is the highest points of the District Metered Areas (DMA).

2.5 Impacts of IWS on network operation

Intermittent water supply can have significant impacts on the operation of a water distribution network. A water distribution network is a complex system that requires a consistent and reliable supply of water to function properly. When water supply is inconsistent, it can result in a range of operational problems.

In a DMA without supply the pipes are emptied (by the customers). However, once the supply is reapplied, the pipe is filled with water, and the prevailing air must be released from the network. For this purpose, air release valves are distributed within the water network. However, for huge amounts of air the air release valves cannot remove all, and some air is distributed to the customer (meters).

An empty pipe may also affect the water quality due to the higher exposure of the water to oxygen or entrained air.

Another effect that is closely linked to the intermittent supply is the so-called **water hammer**. The water hammer occurs due to the energy conservation:
Whenever the fluid column is abruptly stopped or accelerated, the energy (of motion from the fluid) is transferred to pressure. This effect can be described by the Joukowsky equation (2.1), compare (KSB 2013):

$$\text{훯퐩} = \text{휌} \cdot \text{퐚} \cdot (\text{훯퐯}) \qquad 2.1$$

Where:

- 훯퐩 denotes the pressure difference in 퐏퐚,
- 휌 the density of the fluid in 퐤퐠/퐦^3,
- 퐚 the wave velocity in 퐦/퐬, and
- 훯퐯 the change in velocity in 퐦/퐬.

For an in compressible fluid with instant valve closure. The wave velocity can be estimated by Equation (2.2)

$$\text{퐚} = \sqrt{\frac{1}{\frac{\text{휌}}{\text{퐊}_{\text{퐅}}} + \frac{\text{휌} \cdot \text{퐝}_{\text{퐢}} \cdot (1 - \text{휈}^2)}{\text{퐄}_{\text{퐑}} \cdot \text{퐬}}}} \ \text{퐦}/\text{퐬} \qquad (2.2)$$

Where:

- 휌 denotes the density of the fluid in 퐤퐠/퐦^3,
- $\text{퐊}_{\text{퐅}}$ the compression module of the fluid in 퐍/퐦²,
- $\text{퐄}_{\text{퐑}}$ the elasticity module of the pipe wall in 퐍/퐦²,
- $\text{퐝}_{\text{퐢}}$ the inside diameter of the pipe in 퐦퐦,
- 퐬 the pipe wall thickness in 퐦퐦, and
- 휈 the transverse contraction number.

The height of the introduced pressure peak can – for an existing flow network – be adjusted by the time difference for opening and closing the valves.

Another effect of intermittent water supply on the network operation is increased wear and tear of the fittings, mainly due to changes in pressure.

An experimental setup to simulate water hammer on domestic installation is described by (Ferrante, Rogers, Casinini, et al. 2022).

Miyahuna LLC WC have launched a new project to install remote controlled actuated shut-off valves (check-valve) on all house connections within one DMA. The shutoff valves are opened and closed by the WU. (Ferrante, Rogers, Mugabi, et al. 2022) suggest the use of check-valves but state that they might be subject to reliability issues.

2.6 Impacts of IWS on the accuracy of water metering

Intermittent water supply can have significant effects on water metering: When water supply is inconsistent, flow meters may not register the correct flow rate of water, as they rely on a continuous flow of water to function accurately (rated working condition). Interruptions in water supply can cause the flow meters to record false readings or to miss readings altogether, leading to inaccuracies in the measurement of water consumption.

Another effect of intermittent water supply on flow metering is increased wear and tear. Flow meters rely on a constant flow of water to prevent damage to their internal components. When water supply is inconsistent, the flow meters may experience fluctuations in water pressure, which can result in increased wear and tear, leading to the need for frequent maintenance and repair.

In addition, intermittent water supply can also result in the failure of flow meters. When water supply is interrupted for long periods of time, the flow meters may experience reduced water pressure, which can cause them to fail or become damaged. In extreme cases, this can result in the complete loss of the flow meter, leading to the need for replacement, which can be costly and time-consuming.

Mechanical water meters may be degraded if a high **air flow** is led through the measuring section. The reason for this is the friction bearings which require the liquid for cooling and drag reduction. Without water these bearing run dry and the axis can be damaged, compare (Ferrante, Rogers, Mugabi, et al. 2022).

The error introduced by passing air through **domestic mechanical** water meters has been experimentally studied by (Walter, Mastaller, and Klingel 2017). The introduced error depends on the meter type e.g. single jet or multijet, the pressure, the volume of air and whether the meter is wetted or dry. Formulars for estimating the error are given. (Ferrante, Rogers, Mugabi, et al. 2022) states an overreading of 30 to 50 % of the empty pipe volume. No influence of reverse air flow has been observed.

The main effects can be summarised as follows:

- The asserted over-readings of mechanical water meters are a function of the amount of entrained air (per cycle) and the pressure. As a reliable estimation of the volume of entrained air is very difficult to obtain, the generic recommendation is to reduce the overall amount of entrained air by introducing release valves in the network.
- The driving factor for customer satisfaction seems to be the supply situation (or outage) (compare Jordan Water Utilities Report 2020, page 26 and Ogatha et al. page 10) with up to 30 % of supply-complaints. However, as billing-complaints make up only 2 - 2.5 % of the customers, the investigation of the influence should be considered as a due diligence.
- During the low flow phase of the supply regime (mechanical) meters may be affected by under-reading, because the meters operate below their rated condition (almost closed valve). The stated under-readings for mechanical meter by (Al-Washali et al. 2020) are in the one-digit range. This effect is especially to be expected when switching from IWS to continuous operation (most people will keep their storage tank).

To mitigate the long-term impact of intermittent water supply on the water meters, Miyahuna LLC water company aims to replace mechanical meters every 5 years or after metering of 2000 cubic meter, which ever happens earlier. The cost for a typical mechanical meter is in the order of 30 JOD while a static meter is about 90 JOD (as of 2025). The meters are read out on a monthly basis.

3 METHODS FOR MITIGATION OF IMPACTS OF IWS ON FLOW METERING

Potential mitigation measures for reducing the impacts of IWS on flow metering could comprise the following on different levels, as customers, households, network and transmission pipelines:

1. Selection of more resilient water meters e.g. static (ultrasonic or electromagnetic) flow meters
2. Adapted installation of water meters and domestic piping
3. Installation of air release valves on the network
4. Installation of SCADA controllable DMA valves
5. Installation of surge tanks on the transmission pipelines
6. Leak detection considering IWS impacts

Where possible, mitigation measures should be established on the network at DMA level. After these efforts have been exhausted to a commercially viable level, the next level is to mitigate the remaining effects in the house installation or the water meter itself.

3.1 Selection of water meters resilient to intermittent supply

Where the effects of the (current) intermittent supply cannot be suppressed by mitigation on the network level, water meters should be selected as such that they can withstand the expected conditions for the proposed operation time.

This includes, but is not limited to:

- non failure on high air flows
- withstand pressure surges
- non measurement of air / empty pipe detection
- back flow prevention

Mechanical meters may be more prone to damage due to intermittent supply or water hammers. Therefore, the introduction of static meters should be envisaged were economically acceptable.

A static meter is a water meter with no moving parts, and therefore less prone to wear. Ultrasonic flow meter (UFM) and electromagnetic flow meters (EFM) are the most common types of static meters. Domestic static meters are commonly equipped with a lifetime-battery. The stated operation time of these battery-powered meters is in the order of 10-15 years. This exceeds the legal operation time (without testing), which is five years in Jordan. For comparison it is six years for a new and five years for a refurbished meter in Germany. The rated operation condition of these static meters surpasses those of the classical mechanical meters. Turn down ratios R (the ratio of the highest to lowest accepted flow rate) of 200 and more are asserted in comparison to turndown ratio of 20 to 80 for mechanical meters. Often these types of meters offer advanced functionality like empty pipe detection, fraud detection, communication interfaces for remote reading and status reports. The remote reading capability in connection with a 'proper gateway infrastructure' can turn these meters into 'so called' smart meters. A customer of a smart meter will have direct feedback on its consumption and usage patterns, which will help in reducing water consumption, compare (Cominola et al. 2021) and (Davies et al. 2014).

It should be observed that 'smart meters' according to the above-described criteria are 4 to 5-fold more expensive (in upfront costs) in comparison to traditional mechanical meters. However, the operational costs can be lower e.g. due to remote reading capability, faster leakage detection, less technicians needed in the field, compare (Unicef 2022), page 53, and tentatively (legal challenge) longer service periods.

3.2 IWS adapted installation of water meters and domestic piping

The following recommendations for the installation of water meters and auxiliary devices for minimising/ mitigating the impacts of IWS on the accuracy of water meters are given.

- Installation of the (domestic) water meters with **no-return valve** and siphon to prevent partially wetted pipes. A no-return valve at the domestic meter can effectively prevent air from entering the DMA network. Due to the inherent pressure loss and thus reduced flow rate this is not a very popular option from a customer perspective.
- A better approach which would avoid additional pressure drop at the customer site could be the installation remote-controlled cut-off valve(s), as they introduce no additional pressure loss while not in operation.
- A siphon will ensure that the meter is always wetted, a prerequisite found in most manufacturers' description of the rated operation conditions. This will make the installation slightly more expensive, both in respect to the required space and piping.
- Most meters will work sufficiently if they are installed following the manufacturers' recommendations. This is especially important for mechanical meters with respect to orientation/ tilt and inlet length. Where it is not feasible to meet the manufacturers' requirement it may be better to switch to a meter which **by design** is more independent of the flow condition or orientation. It could be advisable to select a range of (cheaper) mechanical meters for easy/ standard installation sites and (more expensive) static meters for challenging sites (space or other constraints). It is also viable to install one smart meter at a substation and then use consecutive mechanical meters for sub metering.
- In the case of storage tanks, prefer the installation of vertical tanks since they inherently reduce the time where the flow rate is smaller than the stated operational flow rate of the water meter. Furthermore, they offer a smaller footprint (area) which could be beneficial.

3.3 Installation of air release valves on the network

In case where the entrainment of air cannot be prevented by the means of back-flow preventers or cut-off valves, air release valve may be a viable mean to reduce the amount of air passing through to the customer. In figure 3.1 the working principle of a gravimetric air relief valve is explained.

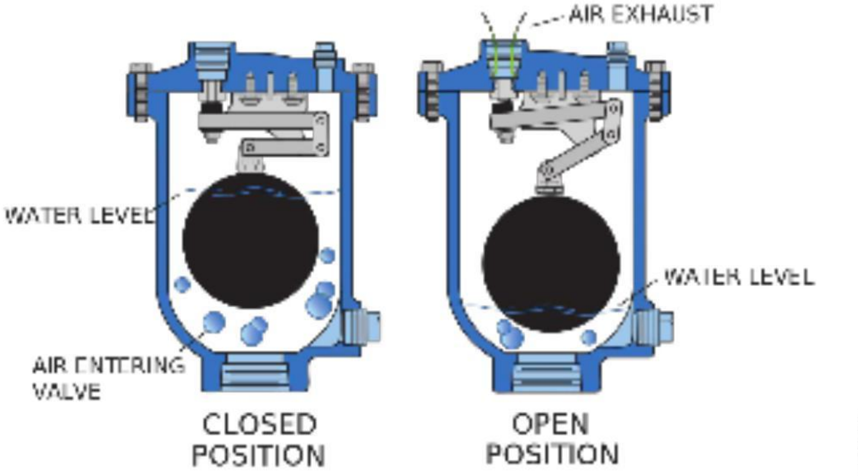

Figure 3.1 Schematic of an Air Release Valve by (Val-Matic Valve & Manufacturing Corporation 2021). Left: The water level is high enough to support the floating lever which closes the valve. Right: The water level is low; the floating lever drops and opens the valve to release the excess air.

Figure 3.2 Installation of a domestic air release valve. Image provided by Miyahuna (M. Abu-alshaikh), 2024.

The installation of air release valves is recommended on every high point of the network and additionally every 2500 ft (~833m) of horizontal network, according to (Valmatic 2021). More information on air release valves can be found in the AWWA C512-15 standard.

The use of air relief valves is consistent with the operation of networks and ensures the reduction of water hammer to avoid damages to pipes, fittings, and valves. However, there have been observations of introduced pressure surges due to air release valves.

3.4 Installation of SCADA controllable DMA valves

The pressure peak of a planned shutdown can be minimized by prolonging the opening and closing time of the DMA entry valves. Therefore, the installation of SCADA (Supervisory Control and Data Acquisition)[2] controlled valves at the [entrance of] DMA Zones is recommended. The opening and closing of the valves shall be as slow as possible to reduce the pressure peaks.

The procedures and recommendations for opening and closing valves optimally should be adhered, and where not available implemented according to up-to-date recommendations by the network operator.

3.5 Installation of surge tanks on the transmission pipelines

The installation of surge tanks on DMA lines is a good practice to reduce the effect of water hammers. A possible generic installation sketch is depicted in Figure 3.4. The surge tanks should be located in close proximity to the pressure pumps to effectively protect the entire network.

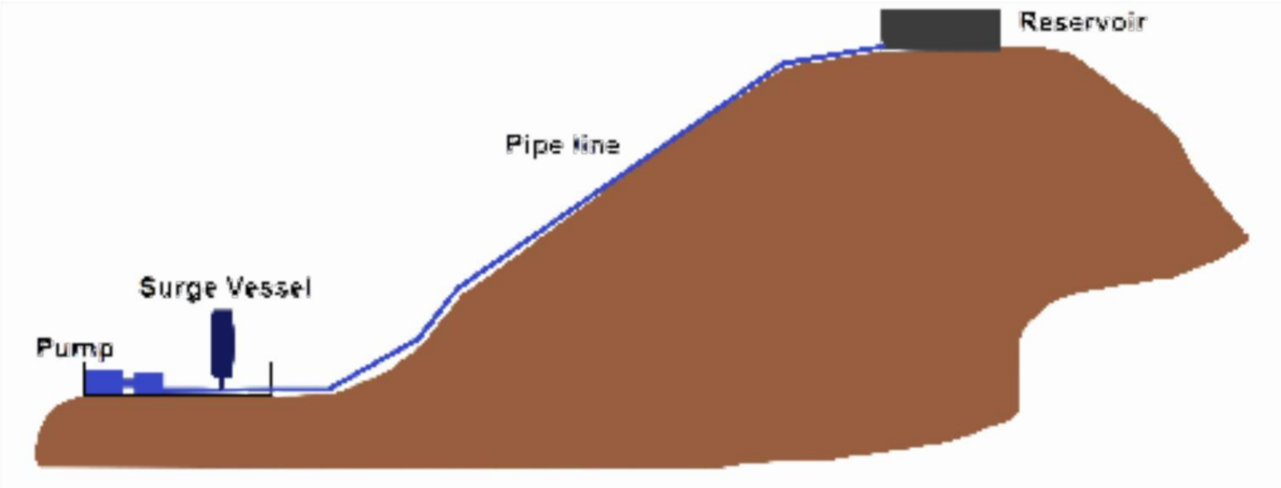

Figure 3.4 Generic installation scheme for surge tanks as integral part of a water hammer protection system on transmission lines and network. Sketch by MWI (N. Saleh), 2023.

[2] SCADA in water supply systems are critical for efficiently managing and monitoring the entire water distribution process, ensuring reliable delivery, quality control, and operational optimization. SCADA systems in this context allow water utilities to oversee the flow of water from source points to treatment plants, and then to consumers, while also managing wastewater treatment processes.

Figure 3.5 Horizontal surge tank in Amman, image provided by Miyahuna (M. Abualshaikh), 2025.

Figure 3.6 Vertical surge tanks. Images provided by Miyahuna (M. Abualshaikh), Amman, 2025.

Figure 3.7 Example of flexible piping attached to a pump. This installation reduces the stress on the pipes. Image provided by Miyahuna (M. Abualshaikh), Amman, 2025.

Figure 3.8 Example of horizontal surge tanks in Amman. Provided by Miyahuna (M. Abualshaikh), 2025.

3.6 Pressure relief valves and water hammer arrestors

Common domestic appliances like washing machines, dish washers or toilets are prone to introduce water hammers / shock waves to the installation due to the rapid closing of internal valves. The effect has also been documented for modern one-handle mixing water taps which can be closed rapidly.

On domestic networks the installation of so-called water hammer arrestors can help to mitigate and dampen the effects of the pressure peaks to protect the water meters, valves and the domestic piping. A typical working principle for a pressurized gas loaded domestic arrestor is depicted in figure 3.9.

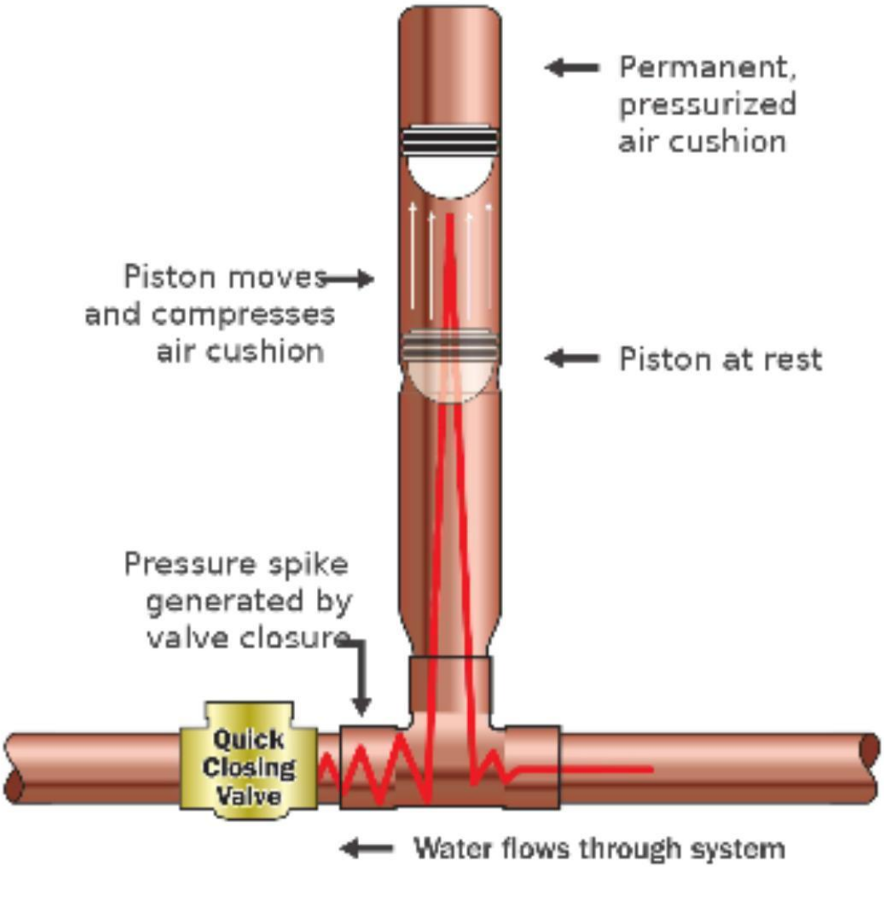

Figure 3.9 Principal sketch of a gas tension-ed water hammer arrestor. Sketch taken from (Sioux Chief 2024).

Other recommended applications include industrial facilities and process systems, as well as pumping systems with frequent start and stop operation.

The equivalent to the water hammer arrestor on a DMA network is the installation of a pressure relief valve, as depicted in figure 3.11. The prevailing working principle are spring loaded pressure relief valves. More information on pressure release valves can be found in the standard (EN ISO 4126-1).

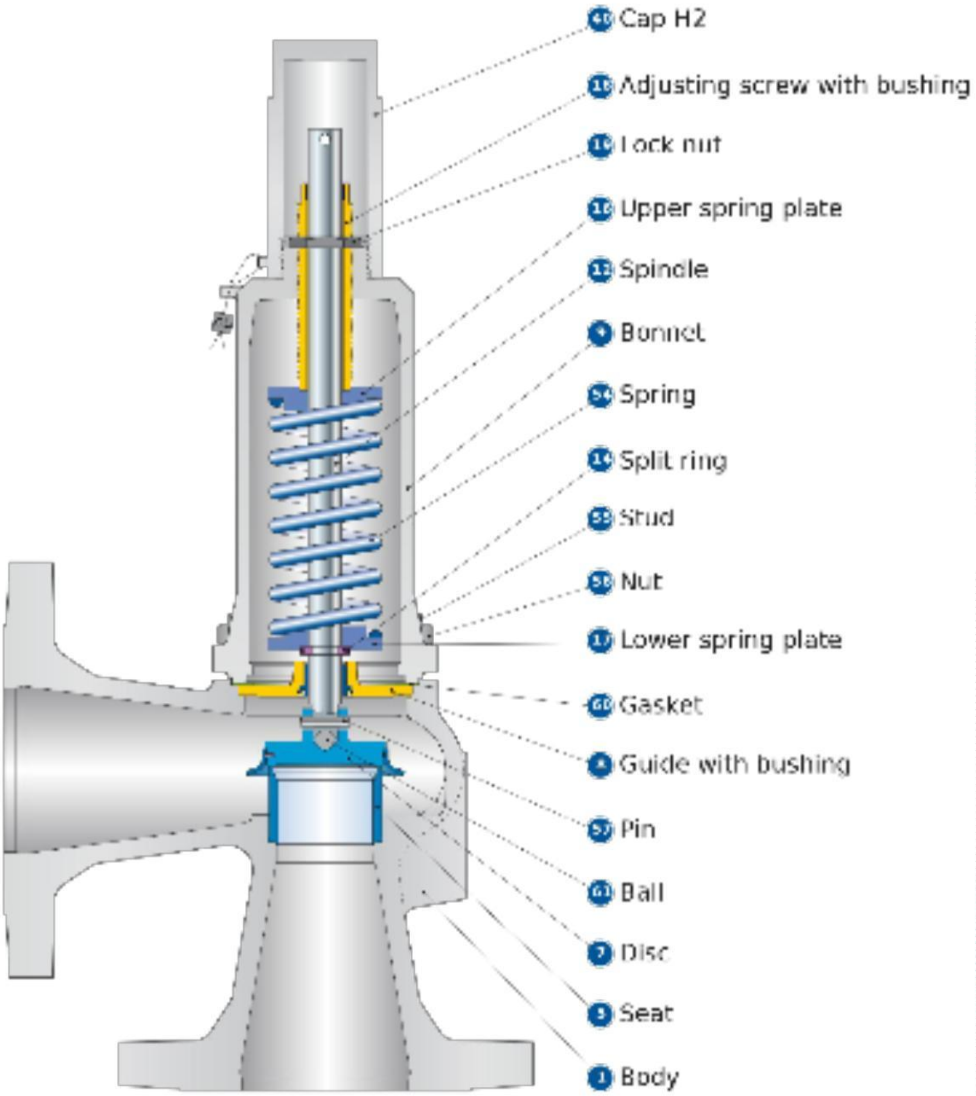

Figure 3.11: Spring loaded pressure relief valve Type 433, from (Leser 2020).

3.7 Leak detection under intermittent supply conditions

Most leak detectors operate on the audible leak principle. This means that the higher the pressure in the network, the larger the leak, and therefore the louder the sound. In the event of a power outage, restoring pressure can take hours.
This makes locating a leak a significant challenge due to the low network pressure, especially since Jordan's water supply relies on gravity flow rather than pumps. Furthermore, much of Jordan is mountainous, making it difficult to build network pressure in high-altitude areas.

A viable approach to perform leakage estimation (and possible detection) in a DMA affected by IWS is described by (Al-Washali et. Al 2018): The DMA is saturated with continuous supply for a few days until the the demand reaches a stable minimum night flow condition (all customers tanks are full). In this regime the pressure could be elevated to the more favourable levels for detection where the topology of the network is permitting this. Due to the strict rules in respect to the water distribution plans enhanced coordination between network operation and leakage detection is recommended and long time scheduling is envisaged.

Figures 3.3: Typical leakages left with low pressure and right at high pressure condition, photos provided by Miyahuna (M. Abualshaikh), 2023.

3.8 Conclusions

While the overall objective should be the provisioning of continuous supply for all customers, intermittent water supply (IWS) offers a modus operandi to address water shortages by reducing peak usage. The prevailing IWS however, introduces significant challenges that can degrade the overall efficiency and integrity of the water distribution system. The challenges include but are not limited to pressure surges, air entrainment, degradation and wear of piping, valves and meters, metering, leakage, water quality and losses.

To mitigate these issues, several engineering measures are recommended:

- Network Design: Implement strategies to minimize pipe velocities and control pressure fluctuations.
- Pressure Management: Install water hammer arrestors, vessels, and relief valves at susceptible locations.
- Valve Control Systems: Utilize automatic control systems (SCADA) for gradual valve operations.
- Air pockets Mitigation: Introduce air release valves and cut-off valves to reduce the impact and the size of air pockets in pipes.
- Maintenance Practice: Adopt regular maintenance schedules to prevent air accumulation and pressure surges.
- Advanced Metering: Replace traditional mechanical meters with static, electromagnetic or ultrasonic meters for enhanced resilience against water hammer effects.

By integrating these solutions, we can effectively address the operational challenges posed by IWS while enhancing the robustness of the water supply networks.

3.9 Summary of recommendations

Actions to reduce IWS impacts on water metering can be undertaken on three levels:

- Selection of water meters intended to be operated in intermittent supply conditions
- Adapted installation of domestic water meters exposed to intermittent supply conditions
- Adapted installation and operation on the water supply (DMA) level

The specific order and weighting of recommendations must be established on a case-by-case basis, generically speaking whenever addressing a problem is economically feasible, it makes sense to begin by tackling the underlying issue rather than focusing on mitigating its effects.

4 AUTHOR CONTRIBUTION STATEMENTS

- M. Abualshaik (lead contribution for the water sector) contributed to investigation, resources, data curation and writing of the initial draft.
- N. Saleh contributed to resources and visualization.
- A. Gheniemat (lead contribution for the quality infrastructure sector) contributed to resources, conceptualization and writing of the original draft.
- A. Banikhalid contributed to investigation and resources.
- K. Bark contributed to supervision and review and editing.
- J. Steinbock contributed to conceptualization, investigation, supervision, writing of the original draft, review and editing.
- A. Weissenbrunner contributed to investigation, supervision and writing of original draft.

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5 ANNEXES

5.1 Proposal for the selection of water meters intended to be operated in intermittent supply conditions

Water meters which need to be deployed in intermittent supply conditions should fulfil the following characteristics to enable a fault-free operation and long-term reliability:

- Ideally no mechanical or moving parts exposed to the water flow (static meters).
- Mechanical resilient to surges or water hammers due to the repeated switching of the water supply or domestic devices. This can be verified by future water hammer test facility of JSMO.
- Enhanced pressure rating. This can be verified by the future static pressure test rig of JSMO.
- Resistant to the presence of air bubbles or entrained air in both directions (filling and emptying of the network).
- Withstand reverse flow.
- Empty pipe detection. Does not measure air flow.
- Enhanced corrosion resistance.
- Wide turn-down ratio to effectively measure low-flow (full storage tank) and high-flow conditions (empty storage tank, begin of supply period).
- Resistant to suspended particles.
- Low fluid pressure operation feasible.

These characteristics should be considered on top of the common advice for the selection of water meters which include -but are not limited- to the following key points:

- Sizing according to expected permanent consumption and usage pattern.
- Available upstream (inlet) and downstream (outlet) installation and the associated flow conditions on site (e.g. swirl or asymmetry).
- Acceptable pressure loss.
- Maximum Admissible pressure (MAP) according to conditions at installation site.
- CE certificate and conformity assessment.
- Envisaged orientation.

5.2 Proposal for the adapted installation of domestic water meters exposed to intermittent supply conditions.

Water meters exposed to intermittent supply conditions face increased wear and tear due to the repeated emptying and filling of the pipe. This includes entrainment of air or air-bubbles, pressure peaks due to the network operation, domestic installation (float valves) and usage patterns. The following mitigation measures should be considered for a domestic installation to keep the meter filled with water at all times:

- Mandatory installation of back flow preventers, preferable in low pressure loss implementation.
- Installation of the meter in a siphon.

The following recommendations aim to reduce the impact of a surge / water hammer on the meters:

- Installation of a water hammer arrestors.
- Slow closing (float-) valves on top of storage tanks or in domestic appliances. Ideally a valve with hysteresis is installed.
- Installation of meter in brackets to reduce the mechanical stress imposed by the installation during a water hammer event.

Generic recommendations for the installation of water meters can be found in (ISO 4064-5, 2014) and the manufacturer's installation manuals.

For domestic storage tanks equipped with float valves, wherever possible a vertical orientation should be preferred, since it inherently reduces the operational time at partially closed valve.

5.3 Proposal for adapted installation and operation on the water supply (DMA) level in intermittent supply regime

The following recommendations aim at reducing the amount of entrained air in the network:

- Installation of remote-controlled cut-off valves at the (domestic) metering station. This effectively prevents the in-flow of air.
- Installation of air release valves at every high-point of the supply network and in long horizontal supply-lines to drain the remaining air out of the network.
- Installation of pressure relief valves in the pumping stations.

Generic guidance on pressure relief valves is found in the standard (EN ISO 4126-1, 2013).

The effect and the onset of pressure surge is effectively countered by the following measures:

- Slow closing of valves, preferable with SCADA control.
- Installation of surge tanks and flexible joints at pumping stations.
- Operate in the adaptive pressure regime.

The following recommendations should be considered for effective leakage monitoring:

- Coordinate between leakage detection and network supply planning.
- Enable regular leakage detection / estimation time slots e.g. by the “saturated DMA” approach.