Developing a methodology for transitioning from Intermittent to Continuous Water Supply

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Abstract

In many Middle and Low Income (LAMI) countries piped water supply to users is often intermittent. Under Intermittent Water Supply (IWS) regimes, water utilities cannot exercise effective operational management and planning of the water supply and distribution networks. Lack of efficient management and planning results in the water supply system being “out of control”. IWS has a detrimental effect on water networks, including ineffective supply and demand management, inefficient operations, increased difficulties in detecting and fixing leaks, greater number of illegal connections, as well as malfunctioning and registration inaccuracies of water meters. Therefore, it is imperative that water utilities “take back control” of their systems in order to avoid the detrimental effects caused by IWS. This paper will expand on the process of achieving the transition from IWS to continuous supply in a structured and sustainable manner, highlighting issues and challenges that need to be taken into consideration during the transitioning. The process entails “taking back control” of the water supply system starting with the transmission system followed by a phased approach for the distribution network. It is based on the principle of establishing the required infrastructure, policies, standards, etc. and sustaining these through monitoring, field inspections, maintenance procedures, benchmarking, and auditing. The process has the potential to become a standard approach for transitioning from IWS to 24x7 continuous supply.

Introduction

In many countries, especially in Low and Middle Income (LAMI) countries, IWS has been a reality for so long that governments, utilities, and citizens do not see the urgent need for change. Most of the LAMI countries suffer from water scarcity; millions of people have no piped water on their premises, especially in rural regions, where residents obtain their water supply from public taps which often operate intermittently and irregularly (Kaminsky & Kumpel, 2018). Even for those with piped water on premises, water is supplied for limited hours per day or days per week (Beard & Mitlin, 2021). It is estimated that only 52% of the world’s population has piped water on premises, i.e. about 3,8 billion out of a total world population of 7,3 billion, while approximately 1,3 billion are affected by IWS (Chrysi Laspidou & Spyropoulou, 2017).

The operation of water supply networks under IWS leads to various problems that are experienced by both water utilities and consumers (Klingel, 2012; Simukonda et al., 2018; Totsuka et al., 2004). Although IWS may seem to be a water saving measure it has been recognized that it leads to greater quantities of water being lost. In comparison to continuous supply the water supply under IWS conditions leads to excessive consumption as stored water tends to be discarded by consumers when the new supply comes in, storage systems overflow and taps that are left open lead to uncontrolled water loss (C. Laspidou et al., 2017).

The operation of water supply networks under IWS can create substantial health hazards due to the ingress of contaminants through broken pipes or joints or backflow through cross-connections (Calero Preciado et al., 2021; Kumpel & Nelson, 2014). The bacteriological water quality under an intermittent supply regime is substantially lower than that of a continuous service since there are no constant hydraulic conditions with the repeated emptying and filling of the network thus rendering ineffective proper chlorination levels and appropriate sterilisation of the network (C. Laspidou et al., 2017).

The operation of the supply network under IWS causes quicker asset deterioration and increased pipe bursts leading to higher leakage rates (Agathokleous et al., 2017; Agathokleous & Christodoulou, 2016; Mohammadi et al., 2020). As most network systems have been designed to operate under 24x7, the sudden variation in flows and pressures under IWS, as well as the repeated dry and wet conditions accelerate the deterioration of the pipe network and water meters. Detecting and repairing leaks becomes increasingly difficult as varying pressure levels and flow conditions in the network render leak detection and control near impossible.

Inconvenient supply times means that consumers will search for other sources of water (Beard & Mitlin, 2021; Burt & Ray, 2014). In most cases consumers pay high coping costs for additional facilities, such as storage tanks, pumps, alternative water supplies and household treatment facilities. IWS leads to inequitable distribution of water in the network, with consumers furthest away from supply points always receiving less water than those nearer to the source. Furthermore, those who are poor and underprivileged and cannot afford to pay coping costs will have to travel sometimes long distances and in the night to reach public taps, in order to secure a small quantity of water (C. Laspidou et al., 2017).

The operation of IWS leads to ineffective supply and demand management with inaccuracies in meter readings due to the frequent emptying and filling of the network and the subsequent vacuum and excessive air conditions in the pipe (Criminisi et al., 2009). Moreover, IWS results in inefficient operations with direct financial costs to the utility. This includes a decrease in revenue due to decrease in water sales, as well as additional expense for staff overtime for opening and closing valves and repairing the increased number of pipe bursts (Jayaramu & Kumar, 2014).

IWS leads to a downward spiral whereby increased urbanization leads to higher water demand to which water utilities respond with network expansion, often carried out after poor planning thus leading to network extension beyond capacity (C. Laspidou et al., 2017). This in turn lowers the quality of service for consumers and leads to an inadequate supply. Those consumers who are more privileged may proceed with private investments to improve their service, however for most it will mean a poor level of service. These circumstances inevitably lead to corruption and conflict among different citizen groups, low willingness to pay for the service and thus less income for water utilities. Concurrently, due to intermittent operations of the network, the utility is faced with more leaks and a need for more staff to repair them. In the end, implementing intermittent supply results in a deteriorating network, increased leakage and higher non-revenue water.

Water utilities are increasingly resorting to delivering intermittent supplies, e.g. South Africa (Loubser et al., 2021), due to the abovementioned downward spiral, poor management and high leakage. The challenge of managing a water supply system that is intermittent and with high levels of water losses poses water utility managers with a conundrum regarding how to address these and how to move to continuous supply. Although there is a generic approach for quantification and management of water losses based on IWA best practices, their application to IWS systems presents great challenges to practitioners (Charalambous & Liemberger, 2017).

This paper expands on the process of achieving the transition from IWS to continuous supply in a structured and sustainable manner. The subsequent sections expand on the suggested methodology for transitioning to 24x7 and conclude with general recommendations for successful transition.

Transitioning from IWS to 24x7

The implementation of a successful transition from IWS to 24x7 depends on the effective operation of multiple system elements that in combination will enable the water utility in essence "take back control" of the system. Therefore, each component of the proposed transition method is assumed to equally address both technical and human resources aspects.

The three major components that require attention in order to successfully achieve and sustain continuous water supply are:

1. Water supply availability and stability at the network inlet,
2. Distribution network efficiency, whereby leakage is minimised, and
3. Water use efficiency, whereby equitable water use is established, and excess use is minimised.

These three important components are illustrated in Figure 1. Once a network system is selected for transitioning each of these components needs to be evaluated to determine whether transition of the network system to continuous supply is achievable. Then, the control requirements for each one of the above components must be established before proceeding to implement the transition process. Following completion of the transition, the requirements for "control" must be sustained.

To carry out a successful transition to continuous supply, a transition plan must be put in place. The goal of a transition plan is to ensure reliable supply at the water production and transmission level, minimise leakage at the water distribution level, and minimise demand at the water user level, therefore ensuring continuous water supply and equitable provision of water use requirements.

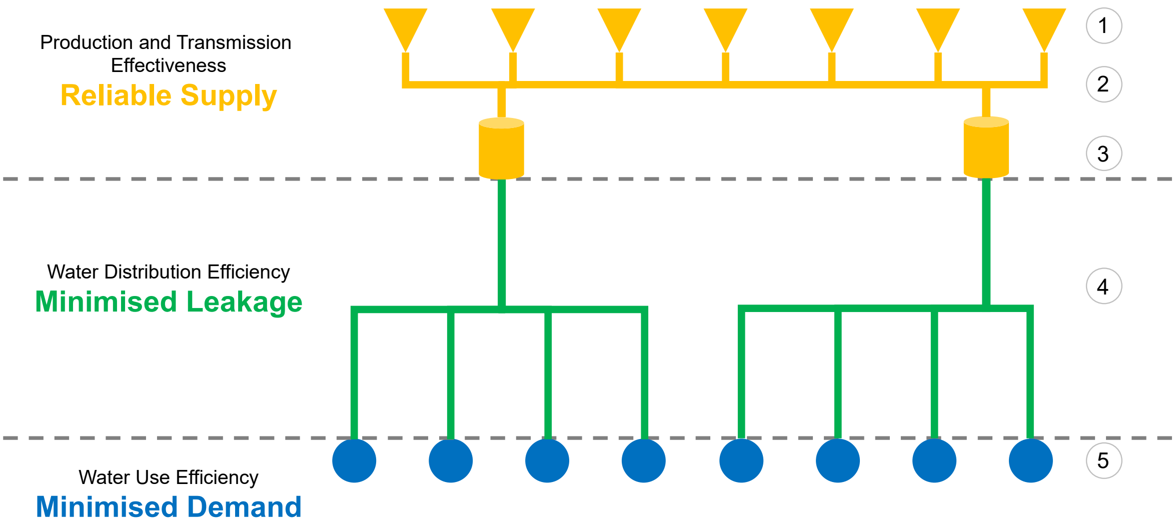

Figure 1: Major components to be addressed in IWS transitioning.

Legend: 1. Water production and treatment, 2. Bulk water transmission, 3. Water storage reservoirs, 4. Water distribution network, 5. Water users.

Evaluation of the potential for transitioning to 24x7

To verify whether a particular water system or network has the capacity to transition to continuous supply an evaluation of each major system component needs to be carried out. This evaluation must also be carried out if there is a need to prioritise among several networks where the transitioning process is to be implemented. This evaluation relies on the collection and analysis of data pertaining to water quantities and flow patterns of each component across the wider water system and not merely the particular target area under consideration.

Evaluation of the water supply reliability of the primary system, including the production and transmission system, is key. Factors such as power supply availability, water resource quantity and quality fluctuations, storage capacity, transmission trunk main integrity and capacity, and the flexibility of water allocation throughout the primary system must be examined. This evaluation should result in a clear demonstration of whether the water supply at the inlet of each target area in its current condition or with additional control measures, be reliably sustained, and at which capacity. Anticipated daily or seasonal supply fluctuations must also be considered.

Evaluation of the distribution network efficiency requires the completion of a water audit to assess the level of leakage. Ideally the IWA Water Balance methodology (Lambert & Hirner, 2000) should be used, with declared uncertainty of each quantity at 95% confidence limits, and with field verification of each input parameter so to reduce the uncertainty to the minimum feasible levels. In addition to the estimated leakage calculated using the IWA Water Balance, other key information should be collected including current average supply time; average network pressure; pressure extremes throughout the supply duration and at different locations, lengths and types of mains, historical repair records, and number of service connections. If sufficient information about the network is available, a hydraulic analysis of individual networks should be carried out. This will reveal the potential opportunities and limitations for pressure optimization under IWS and continuous supply, and therefore the potential opportunities and limitations for leakage optimisation. The evaluation of the distribution network efficiency should result in the calculation of the physical loss performance indicators expressed in litres/ service connection/ day/ meter head adjusted for the daily supply time. The additional water that is required to supply a specific area under consideration for 24x7 continuous supply needs to be calculated, including the extra volume of water that will be lost due to leakage (Charalambous et al., 2017). Following this, a target leakage level for the rehabilitated network under a 24x7 basis can be determined.

On the water user side, the assessment must evaluate water use and storage practices and the extent of dependence on alternative water supply means, such as tankers. Additionally, the evaluation should cover consumption needs of expected user behaviour under 24x7, the extent of volumetric metering and billing and an estimation of unauthorised water use. Where customer metering is the norm, an assessment of the water meter conditions and meter management practices can be carried out. These will help plan investments and capacity improvements needed to maintain demand management through measured and accountable consumption, which is key for sustaining continuous supply conditions. The evaluation should result in an estimation of basic water use requirements for the target areas examined, as well as the current levels of excessive water use and shortages for each differentiated group of users.

Results from the evaluation of each component will help in determining the suitability of each target area to transition. It must be ensured that water supply (in the selected area for transitioning) meets the sum of expected leakage and water demand at all times. The methodology for transitioning from IWS to 24x7 continuous supply is shown diagrammatically in Figure 2 and is described in detail in the following sections.

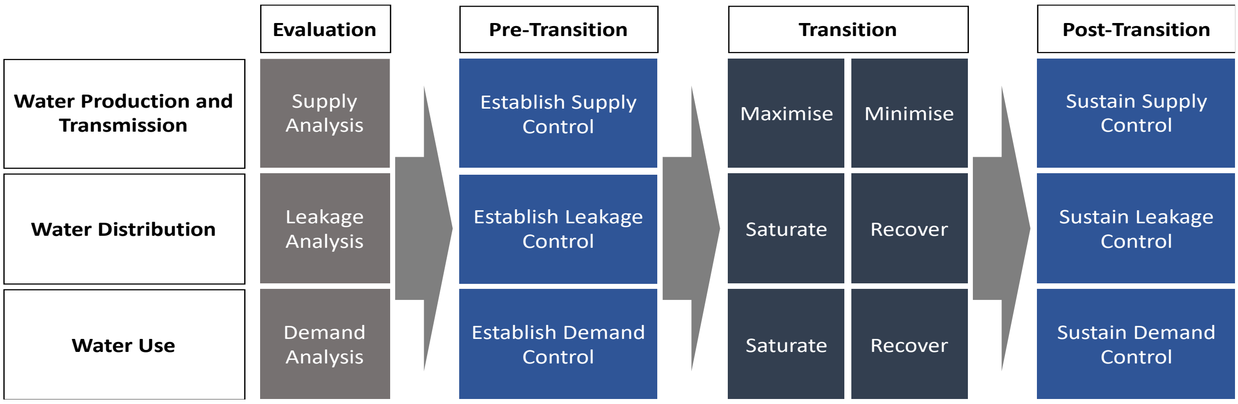

Figure 2: Methodology for transitioning from IWS to 24x7 continuous supply across the three defined areas of supply, leakage, and demand.

The Pre-Transition Stage – Establishing the requirements for optimum control

To ensure the successful transition of a selected water distribution network from IWS to 24x7, certain preparatory actions need to be implemented. These preparatory actions must address the three main components of the water supply system (production and transmission, distribution network and water use) so that the network can be sufficiently controlled. The issues and challenges as well as the necessary preparatory actions for each of the three water supply system components are presented below.

Production and transmission

It is of the utmost importance and key to ensure a successful transition to 24x7 that the availability of water supply is sufficiently reliable and in adequate quantities. The continuity of the supply source can often be found to be problematic. For example, production resources may be overstressed or transmission systems are cross-connected, usually by trial and error to solve short-term supply complications under IWS conditions. In some cases, however, water production and transmission facilities may not be the cause for the adoption of IWS but are adversely affected over time by such operational setup. Some of the challenges which may contribute to or result in IWS include:

- Power fluctuations at the source preventing continuous water production.
- Fluctuations in produced or imported water quantities or in water quality.
- Transmission mains operated outside their design parameters leading to risk of pressure surges and supply interruptions.
- Insufficient storage capacity or storage reservoirs resulting in water storage.

Several good practices which can enhance control of the bulk water supply system and would benefit both IWS and 24x7 operations include:

- Monitoring and control of critical system components using supervisory control and data acquisition (SCADA) systems.
- Adequate storage capacity, normally equal to 24 hours supply, that allows continuous supply to the distribution network, while allowing flexibility of bulk water allocation via different bulk transmission mains.
- Alternative supply sources that are connected to the transmission system allowing flexible supply allocation.

- Protection devices that guard against pressure surges located at critical locations.

Ideally, all aforementioned practices should be applied to guarantee well-designed and fully functional primary systems. However, given cost and time considerations, the proposed methodology focuses on two major activities that can target the areas selected for transition.

Firstly, the hydraulic reinforcement and protection of the primary system is required to ensure sound hydraulic operations by mitigating risks of supply failures. The pre-transition preparations should focus on the following:

- Update of the transmission system maps and parameters, including storage reservoir capacities, pump curves, and bulk water distribution schedules.
- Hydraulic assessment of the transmission system calibrated using flow and pressure field data.
- Simulation of system failure scenarios and calculation of pressure surge values when required.
- Design and implementation of targeted transmission network modifications and the required addition of control and protection elements.
- In certain cases, the design and implementation of supplemental storage reservoirs to aid isolation of fluctuations in production and transmission from affecting the targeted transition areas.

Secondly, the installation of critical system monitoring and control devices operated through a SCADA system will ensure sufficient control over the primary system. The pre-transition preparations should include:

- Targeted installation of accurate bulk meters, reservoir level indicators, and pressure sensors.
- Targeted installation of remotely controlled isolating and regulating valves and pump controls.

Distribution networks

Reducing excessive leakage is a main pillar of successful transitioning from IWS to 24x7 continuous supply. Although many utilities use IWS as a means for reducing leakage, operating distribution networks under IWS conditions leads to escalation of the number of leaks due to extreme pressure fluctuations. IWS conditions may also often lead to conditions where parts of the network are excessively pressurised, while other parts receive very low pressure. Additionally, utilities operating under IWS often lack the capacity and organization to perform adequate asset management leading to a backlog of issues that often necessitate costly network replacement projects. The following are a summary of issues that often accompany IWS and must be addressed:

- Hydraulic conditions that cause excessive leakage from existing leaks, in addition to the escalation of new leaks in parts of the network generally receiving excessive water pressure throughout supply times.
- Hydraulic conditions that cause the escalation of the number of newly created leaks in parts of the network experiencing high pressure variations within supply times, such as at critical points and surrounding areas.
- A reactive work style, due to the difficult working conditions of IWS networks and the high numbers of complaints received, which does not allow the flexibility for scheduled and systematic asset management and maintenance.
- Large volumes supplied during shorter periods, which often translate to operators hydraulically breaching the original water network design to alleviate temporary and/or long-standing problems, and often without keeping relevant records.

- Interrupted supplies that prevent the identification of day-night flow patterns and subsequently prevent the effective identification and repair of excessive leakage.
- High noise levels in the network caused by the filling of customer storage tanks which prevent the effective location of leaks through the use of acoustic leak detection devices.

Moreover, the lack of applied good practices needed for optimum control of leakage at the water distribution network level, whether under IWS or 24x7 supply, can exacerbate the leakage problem caused by IWS. Practices that encourage efficient and effective leakage control include:

- Network design based on pressure management and district metered area (DMA) zoning.
- Installation of pressure and flow monitoring devices for continuous measurements.
- Use of high-quality pipe and fitting materials and installation practices.
- Verification of correct installation and pressure testing of new networks.
- Use of high-quality parts and workmanship in maintenance.

Although most of the listed practices should be required to guarantee the success of transition to 24x7 supply, in many cases only a subset can be established effectively and within the control of the water utility, especially during a limited pre-transition period. The methodology presented herein focuses on two major activities while encouraging utility-wide collaboration to achieve a comprehensive leakage control strategy.

Firstly, network restructuring and reinforcement is a requirement given that control over leakage begins with control over network hydraulics. An added benefit is improving demand equity through the normalization of pressure and elimination of air trapped in the pipe network during IWS as well as 24x7 supply. The pre-transition preparations should focus on the following:

- Update of network maps and field verification of critical network elements.
- Hydraulic assessment of the water network under IWS and field collection of calibration data using flow and pressure measuring devices.
- Design of network modifications that allow control of network pressure to the lowest feasible limits by network zoning, limiting zone elevation differences, and selection of pressure reducing device sizes and locations.
- Design of network modifications that allow the stabilization of critical point pressures through adequate network reinforcement and sizing.
- Implementation of network alterations and update of GIS mapping.

Secondly, establishing network monitoring is a requirement to observe and verify operational control parameters during the transition period and beyond, through measurement devices which will allow the operator to rapidly assess, monitor, and respond to network events. The pre-transition preparations should focus on the following:

- Installation of chambers and permanent devices for continuous monitoring of flow, as well as pressures, at the critical, average, and maximum pressure points in each DMA/pressure zone.
- Installation of pressure control devices, and if needed or required, the installation of automatic control instruments based on pressure set point control at the critical point.

- Installation of software applications that allow for the daily monitoring and assessment of network conditions.

Water users

The need to achieve control over excessive water use in areas operated under IWS is especially highlighted when some or most users do not receive basic water quantity, whether due to hydraulic reasons or due to user behaviour. In summary, factors that may result in excess water use and/or water use inequity under IWS may be attributed to:

- Different hydraulic characteristics, where pressure variations during supply times allow some users to receive sufficient or even excess pressure while others receive insufficient water pressure.
- Varied household water storage facilities, where some users install ground tanks that can accumulate larger water quantities than those users with roof tanks.
- Inconsistent application of customer metering, whereby unmetered customers or those with dysfunctional meters may retain connections open and therefore take in the entire water volume they have access to.
- Illegal water tapping and water meter tampering which can, similarly, allow some users to take in excess water volumes.
- Use of suction pumps on the house service connections by some users which can put other users at a disadvantage.

Applying good practices that can generally encourage efficient water use will in turn facilitate the effective transition to 24x7. These practices include:

- Accurate and reliable customer metering.
- Volumetric water tariffs and effective water pricing.
- Mechanisms for incentives and penalties for water users.
- Policies and regulations that address unauthorized water use.
- Targeted user engagement programs.
- Efficient water facilities at residential, commercial, and industrial properties.

Ideally, all of the listed practices should be applied but, in the cases, where this is not possible the following two major activities should be focused on, while encouraging sector-wide collaboration to achieve a comprehensive water demand management strategy.

Firstly, public engagement campaigns are required. Water use efficiency promotional campaigns and events can play a positive role in water demand management. Even more effective is the direct and transparent communication with the users within the targeted areas which will create a level of engagement whereby the public are treated as partners in the transition to 24x7 supply. Replacing generic water awareness materials, the pre-transition campaigns should focus on the following:

- Identification of the water users in the target area, who may be composed of billed customers and unbilled authorized or unauthorised users.
- Identification of social influencers, community leaders, and public organisations operating in the target area.
- Public announcement of the goal of transitioning from IWS to 24x7 supply in the target area, the objective results anticipated, and the planned time schedule.
- Establishment of public communication channels using information tools such as web and mobile applications or the tools available that can achieve similar results.

- If possible, the utilization or the establishment of incentives and penalties, whether financial or non-financial.
- Leveraging the achieving of 24x7 supply as a combined goal of both utility and users.

Secondly, customer meter rehabilitation is required. Whether a volumetric tariff and an effective pricing scheme can be achieved or not, accurate customer metering is key in creating a sense of accountability over excessive water use, as well as demonstrating the cases where basic water demand requirements are not met. Additionally, accurate customer metering can greatly reduce the uncertainty when assessing and monitoring water leakage in the distribution network by allowing the calculation of a more precise water balance. The pre-transition activities should focus on the following:

- Identification of customer meter availability, status, and installation conditions through a field survey, preferably using GPS and image capture enabled mobile applications.
- Replacement of identified dysfunctional meters, and if needed and feasible, replacement of inferior meters that do not provide adequate accuracy.
- Rehabilitation of the location of incorrectly installed meters.
- Identification and disconnection of meter by-passes and illegal connections.
- Documentation of the final meter status on a meter management system and on GIS maps.
- Establishment of technical standards for the selection, installation, and testing of meters.
- Establishment of meter information update workflows and procedure templates throughout the utility business processes.
- Establishment of policies, guidelines and procedures for continuous meter inspection, replacement, and rehabilitation.

The Transition Stage

Once the primary system is under control and reliable and adequate supply is ensured for the target area then commencement of the transition can proceed. Data relating to the primary system such as flow quantities, pressures and reservoir levels are monitored in order to have absolute control over the distribution system to be transitioned.

The transition requires close monitoring and control and high field presence and is carried out one DMA at a time to minimise additional supply requirements. If additional supplies are feasible, more than one DMA could be addressed at a time (say two or maybe three). The transition stage can be divided into two steps as presented below:

Step 1: District water saturation

The first step of carrying out the transition is to saturate an isolated district in the network by maintaining continuous water supply at its inlet. Supply at this stage does not represent ideal operating conditions, given that leakage in the saturated district will be maximised due to prolonging the supply duration. Additionally, water users in the district may maximise their consumption, due to habitual water hoarding behaviour that often develops due to IWS. For this step to be successful sufficient water supply needs to be allocated at the district inlet. This step is dependent by actions implemented during the pre-transition stage that provide the controls needed for improved supply reliability. The successful implementation of preparatory actions that assist in the control of leakage and demand will also alleviate any impacts from this step.

Step 2: District water recovery

The second step focuses on the recovery of excess leakage and demand with the aim to achieve optimum minimization of water supply required for each district. Throughout this step, intensive field activities are carried out including:

- Intensive leak detection and repair campaigns through multiple equipped and trained field teams working 24x7.
- Intensive user engagement campaigns through multiple trained field teams.
- Continuous monitoring of DMA flows and pressures to monitor the results of reducing excess leakage and demand.

Due to the intensive and critical nature of this step, the assistance of trained and experienced contractors can be of key value to ensure that adequate field resources are available. Work is carried out over a period of days or weeks depending on the size of each DMA selected to ensure that satisfactory leakage results have been achieved. Flow and pressure patterns are used to continuously monitor the performance of the DMA against the set targets for leakage reduction.

When optimum conditions (for leakage and demand) are achieved in the DMA(s) under transition, the process is repeated in the next DMA(s) available for transition, as shown diagrammatically in Figure 3. This progressive upscaling of transitioning using the DMA concept allows for the optimum use of the available water by making additional water available by saving water quantities from the transitioned DMA(s). Thus, the additional water required at any time is minimal.

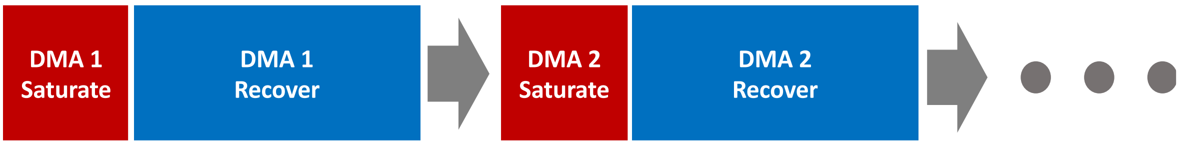

Figure 3: Progressive transitioning of district metered areas (DMAs) ensures the availability of water and human resources during the transition stage.

Post-transition – Sustaining the requirements for optimum control

After successfully transitioning from IWS to 24x7, sustaining control over each water system component is necessary for sustaining the benefits gained from transitioning efforts and preventing the fall-back into previous operational habits. Each established activity therefore requires the support of day-to-day activities that enable good management practices. These good management practices include:

- Defining clear job descriptions and responsibilities through the utilization of staff in existing departments or the introduction of new units at the water utility organization.
- Hiring sufficiently skilled staff, either by direct employment or through external services.
- Providing sufficient equipment and vehicles needed for continuous field activities.
- Maintaining processes and workflows for assessment, monitoring, inspection, repair, and data updating, supported by powerful information systems.
- Ensuring that sound operational procedures are followed.

Sustaining control also depends on applying standards and policies. Updated and ambitious technical standards successfully used in the transition should be adopted as basic design standards for all future works. This will prevent unnecessary expenditures needed for restructuring existing systems in the future. Operational policies that promote efficient investments and customer management should be re-examined and enforced.

Sustaining control over systems transitioned into 24x7 supply can be challenging within prevailing IWS conditions, as disciplined and scheduled activities can be easily overlooked to prioritise crisis handling and reactive “firefighting” behaviour. The use of modern information systems such as GPS-enabled mobile applications can assist in exerting management control and maintaining data quality.

Recommendations

Transition of IWS to 24x7 continuous supply could be achieved through several inter-linked activities, all of which can be customised for each unique situation to develop the most effective strategy. This transition should be achieved in a cost-effective manner combining improved operations with targeted capital works. The proposed approach advocates sound data, strong control measures, responsible technical and financial modelling, and the introduction of sustainable management practices.

Moreover, the transition should aim to see a well-functioning utility that has the capacity to operate the system at the end of the transition by building the utility through the introduction of modern management systems, procedures, protocols and equipment. The adopted strategy should incorporate improved operations and maintenance, gradual restructuring of the network to improve hydraulic performance, targeted asset replacement, introducing active leakage control to reduce losses in a cost-effective manner, applying appropriate customer metering policies and management an introducing appropriate technology. The strategy must also include specialised and dedicated on-going training of staff which should be an integral part of the whole staffing process including concepts, such as accountability of staff through proper structuring and target setting, responsibility through appropriate procedure and control protocols, etc.

Aside from cost-effective, the preferred strategy needs to be realistic. It should integrate all the elements of monitoring, management and investment, and not treat aspects such as operational distribution system leakage in isolation. The presented methodology highlights a holistic approach where the benefits established in the initial stages can extend to assist in reducing costs and improving the impact of subsequent transitioning attempts in a cumulative manner.

Developing a standard approach for transitioning from IWS to continuous supply is an ongoing process that tackles a critical challenge which remains largely unaddressed. Building on the presented methodology, the development of protocols, training programs, and policy advocacy should follow for developing knowledge and expertise.

Acknowledgements

This paper is dedicated to the loving memory of our dear friend Mohammed Shafei, who passed away unexpectedly in 2021. Mohammed Shafei was a Non-Revenue Water and Water Utilities Expert, as well as a Senior Hydraulic Designer and a key member of the international water loss community. Mohammed was a leader in expanding Water Loss knowledge, not only in the Middle East, where he was based, but globally, as he collaborated on several projects worldwide. Mohammed had a passion for advancing

knowledge and current thinking in water utility management. He had an exceptional work ethic, integrity, and dedication. He is sorely missed.

This paper is solely dedicated to his memory.

References

Agathokleous, A., Christodoulou, C., & Christodoulou, S. E. (2017). Influence of intermittent water supply operations on the vulnerability of water distribution networks. *Journal of Hydroinformatics*, *19*(6), 838–852. https://doi.org/10.2166/hydro.2017.133

Agathokleous, A., & Christodoulou, S. (2016). Vulnerability of urban water distribution networks under Intermittent Water Supply operations. *Water Resources Management*, *30*(13), 4731–4750. https://doi.org/10.1007/s11269-016-1450-3

Beard, V. A., & Mitlin, D. (2021). Water access in global South cities : The challenges of intermittency and. *World Development*, *147*, 105625. https://doi.org/10.1016/j.worlddev.2021.105625

Burt, Z., & Ray, I. (2014). Storage and non-payment: Persistent informalities within the formal water supply of Hubli-Dharwad, India. *Water Alternatives*, *7*(1), 106–120.

Calero Preciado, C., Husband, S., Boxall, J., del Olmo, G., Soria-Carrasco, V., Maeng, S. K., & Douterelo, I. (2021). Intermittent Water Supply Impacts on Distribution System Biofilms and Water Quality. *Water Research*, *201*, 117372. https://doi.org/10.1016/j.watres.2021.117372

Charalambous, B., Jansen, J., & Liemberger, R. (2017). Transitioning from IWS to 24x7. In *Dealing with the complex interrelation of Intermittent Supply and Water Losses* (pp. 41–56).

Charalambous, B., & Liemberger, R. (2017). Understanding water losses in the context of IWS. In *Dealing with the complex interrelation of Intermittent Supply and Water Losses* (pp. 35–39). IWA Publishing.

Criminisi, A., Fontanazza, C. M., Freni, G., & La Loggia, G. (2009). Evaluation of the apparent losses caused by water meter under-registration in intermittent water supply. *Water Science and Technology*, *60*(9), 2373–2382. https://doi.org/10.2166/WST.2009.423

Jayaramu, K. P., & Kumar, B. M. (2014). A study on Non-Revenue Water in intermittent and continuous water service in Hubli City, India. *Civil and Environmental Research*, *6*(10), 14–22.

Kaminsky, J., & Kumpel, E. (2018). Dry Pipes: Associations between utility performance and intermittent piped water supply in low and middle income countries. *Water*, *10*(8),

1032. https://doi.org/10.3390/w10081032

Klingel, P. (2012). Technical causes and impacts of intermittent water distribution. *Water Science and Technology: Water Supply*, *12*(4), 504–512. https://doi.org/10.2166/WS.2012.023

Kumpel, E., & Nelson, K. L. (2014). Mechanisms affecting water quality in an intermittent piped water supply. *Environmental Science & Technology*, *48*(5), 2766–2775. https://doi.org/10.1021/ES405054U

Lambert, A., & Hirner, W. (2000). Losses from water supply systems: Standard terminology and recommended performance measures. *IWA Blue Pages*.

Laspidou, C., Spyropoulou, A., Charalambous, B., & Sridhar, S. (2017). Root causes and implications of IWS. In *Dealing with the complex interrelation of Intermittent Supply and Water Losses* (pp. 17–27). IWA Publishing. https://doi.org/10.2166/9781780407074

Laspidou, Chrysi, & Spyropoulou, A. (2017). Global dimensions of IWS-number of people affected worldwide. In *Dealing with the complex interrelation of Intermittent Supply and Water Losses.* (pp. 5–16). IWA Publishing. https://doi.org/10.2166/9781780407074

Loubser, C., Chimbanga, B. M., & Jacobs, H. E. (2021). *Intermittent water supply : a South African perspective*. *47*(1), 1–9.

Mohammadi, A., Jalili-Ghazizadeh, M., Moslehi, I., & Yousefi-Khoshqalb, E. (2020). Survival analysis of water distribution network under intermittent water supply conditions. *Water Supply*, *20*(8), 3531–3541. https://doi.org/10.2166/ws.2020.228

Simukonda, K., Farmani, R., & Butler, D. (2018). Intermittent water supply systems: causal factors, problems and solution options. *Urban Water Journal*, *15*(5), 488–500. https://doi.org/10.1080/1573062X.2018.1483522

Totsuka, N., Trifunovic, N., & Vairavamoorthy, K. (2004). Intermittent urban water supply under water starving situations. *People-Centred Approaches to Water and Environmental Sanitation, 30th WEDC International Conference*, 505–512.