LOW-COST INNOVATIVE TECHNOLOGY FOR WATER QUALITY MONITORING AND WATER RESOURCES MANAGEMENT FOR URBAN AND RURAL WATER SYSTEMS IN INDIA

Deliverable D3.2

Field Guide on operating under Intermittent Water Supply regime and transitioning to 24×7 operation

Lead: KANA Hydrocontrol Ltd

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Abstract

The delivery of sustainable water supply services in growing towns and cities in India continues to be inadequate. This Field Guide presents a practical methodology for water utilities to transition from Intermittent Water Supply to continuous 24x7 and improve their operations. The Guide initially provides facts and figures on the state of water demand and governance in India and the need to manage water distribution networks efficiently. Furthermore, it introduces the concept of Intermittent Water Supply along with its causes and implications. Next it elaborates on the steps needed for transitioning, breaking these down into the pre-transition, transition and post-transition stage. Moreover, it assists water utilities in drawing up a plan for transitioning explaining how to evaluate current water supply and distribution situation, compute a Water Balance and calculate Performance Indicators. Lastly, it presents the Use Case of DMA1 in Guwahati for which, due to the COVID19 situation in India at the time of compiling this Guide, it was not possible to gather and collate field and other data required to assess the current network situation and to prepare an improvement plan.

Keywords

Water distribution networks; Intermittent Water Supply; Continuous Water Supply; Transitioning to 24x7, Water Losses, Network Improvement, India

Disclaimer

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The LOTUS Project

LOTUS is a project funded by DG Environment under the European Union Horizon 2020 Research and Innovation Programme and by the Indian Government. It brings together EU and Indian prominent organisations with the aim to co-create, co-design and co-develop innovative robust affordable low-cost sensing solutions for enhancing India's water and sanitation challenges in both rural and urban area.

The LOTUS solution is based on an innovative sensor and includes tailor-made decision support to exploit the capabilities of the sensor as well as a specific approach to co-creation. LOTUS aims to be co-designed and co-produced in India, and have a wide, diverse and lasting impact for the water sector in India due to intense collaborations with commercial and academic partners in India.

Based on the low-cost sensor platform, solutions for the early detection of water quality problems, decision support for countermeasures and optimal management of drinking and irrigation water systems, tailored on the functionalities of the new sensor, will be developed and integrated with the existing monitoring and control systems.

This sensor will be deployed in five different use cases: in a water-network, on ground-water, in irrigation, in an algae-based waste water treatment plant and in water tankers. The packaging of the sensor, as well as the online and offline software tools will be tailored for each of the use cases. These last will enable to test the sensors and improve them iteratively.

The project is based on co-creation, co-design and co-production between the different partners. Therefore, an important stakeholder engagement process will be implemented during the project lifetime and involve relevant stakeholders, including local authorities, water users and social communities, and will consider possible gender differences in the use and need of water. Broad outreach activities will take place both in India and in Europe, therefore contributing to LOTUS impact maximisation.

The further development and standardisation (beyond the project) of the novel sensor platform will be done in cooperation with the Indian partners. This will create a level playing field for European and Indian industries and SMEs working in the water quality area.

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Acronyms and Definitions

Acronyms	Defined as
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
BCM	Billion Cubic Meters
DMA	District Metered Areas
ILI	Infrastructure Leakage Index
IWA	International Water Association
IWS	Intermittent Water Supply
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
KPI	Key Performance Indicator
KUWASIP	Karnataka Urban Water Sector Improvement Project
MLD	Million Litres/ day
MNF	Minimum Night Flow
NRW	Non-Revenue Water
PI	Performance Indicator
PL	Physical Losses
SCADA	Supervisory Control and Data Acquisition
SC	Service Connections
UN	United Nations
w.s.p.	When the system is pressurised under continuous supply

1 Executive Summary

India is the second most populous country in the world with a population of over 1.3 billion people, of which 99 million lack access to safe water. The delivery of sustainable water supply services in India is inadequate, with intermittent water supply (IWS) plaguing towns and cities in the country. Chapter 2 provides information on water demand, supply and governance for the context of India.

IWS is a deeply political problem that creates serious socio-economic inequalities and is often unrelated to the simple explanations offered by most. Chapter 3 examines the various factors that contribute to the existence of IWS, as well as the implications of operating water supply networks under IWS. The Chapter explains the concept of the downward spiral of IWS and considerations when transitioning from IWS to continuous supply.

Transition of IWS to 24x7 continuous supply could be achieved through a number of inter-linked activities, all of which can be customised for each unique situation to develop the most effective strategy. 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 the equitable provision of water use requirements. Chapter 4 presents a holistic methodology for transition from IWS to 24x7 in a staged approach. In the pre-transition stage certain preparatory actions need to be implemented for a water distribution network that has been identified as a target area suitable for conversion from IWS to 24x7, to ensure that the network can be sufficiently controlled to achieve a successful transition. The transition stage incorporates a two-stage approach whereby district water saturation is achieved followed by district water recovery. Lastly the post-transition stage outlines good management practices to apply after successfully transitioning from IWS to 24x7 to maintain results.

Chapter 5 presents the components and data required for analysis of the initial conditions for carrying out a water audit. The International Water Association (IWA) Water Balance methodology and water loss Performance Indicators are outlined along with their components. Through this analysis the magnitude of the water loss problem is identified, and priorities are set for rectifying the situation. Measures to reduce and control water losses are also presented.

Chapter 6 provides a simplified approach to evaluating current conditions of IWS in the case of limited availability of data. Evaluation of the problem of IWS, in the case of limited data is followed by a Rapid Non-Revenue Water Assessment as an initial water audit. Furthermore, the calculation of Physical Losses Indicators is outlined.

Chapter 7 presents the Use Case in the city of Guwahati, which has been chosen through the LOTUS Project to apply the context of this Guide to and improve current supply conditions. The Chapter describes the water supply in DMA1 and the data requested to carry out the Water Balance.

2 Background

India is the second most populous country in the world with a population of over 1.3 billion people, of which 99 million lack access to safe water[1]. India has and will continue to experience large and rapid population increase in urban areas, causing problems for urban planners and service providers on how to deliver access to safe water supplies. Longstanding efforts by the various levels of government and communities have seen a number of water development projects facilitating the provision of safe water. However, the delivery of sustainable water supply services in growing towns and cities in India continues to be inadequate. Increased access to safe drinking water in urban India has been mainly because of increased access to tap water[2]. While in 2001, 68.7% of the households had access to piped drinking water, in 2011, this increased to 70.6%. Out of these 70.6% of households having access to piped drinking water, 71% had drinking water available within premises, 20.7% near premises, and 8.1% away from premises as can be seen in Figure 1.

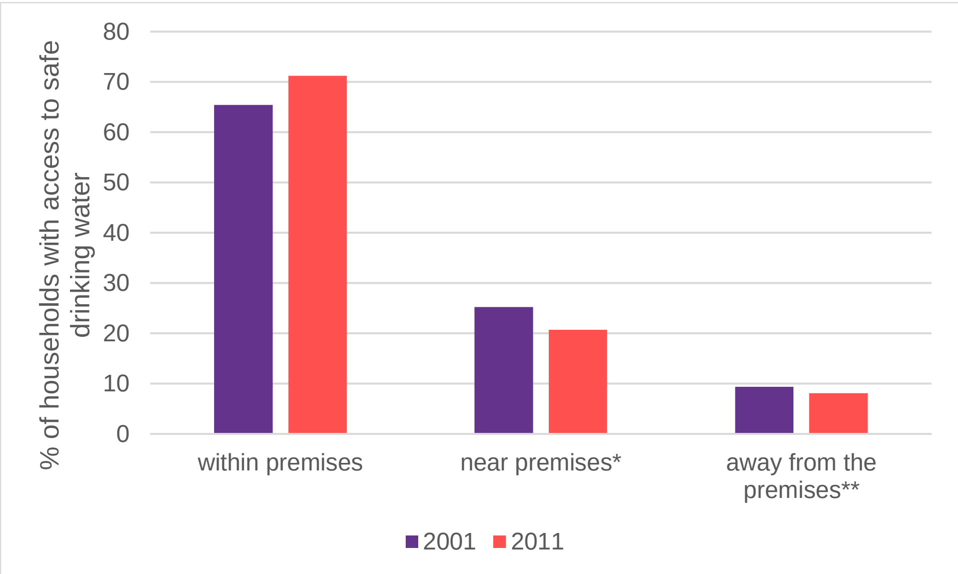

Figure 1-Percentage of households with piped drinking water[2]

Water supply in India is enabled through constitutional provisions as a State subject with limited policy and monitoring oversight by the central government. The States perform a crucial role in planning and managing water resources and partial financing water supply[2]. The states may give the responsibility of managing water supply to municipalities in urban areas, called Urban Local Bodies. At present, states generally plan, design and execute water supply schemes (and often operate them) through their State Departments (Public Health Engineering Department) or state-owned Corporations, or State Water Boards. The Ministry of Housing and Urban Affairs is primarily responsible for financing urban water supply along with their state counterpart departments for urban development. In regards to urban water supply there are close connections with other ministries, such as the Ministry of Drinking Water and Sanitation, Ministry of Water Resources, Ministry of Health and Family Welfare, and Ministry of Environment, Forest and Climate Change[2]. In the past two decades, with the rapid urbanisation and recognising the cities as engines of economic growth, Government of India has significantly increased policy and financial support for provision of drinking water both in urban and rural areas. In more recent times considering the need for integrated approach, the Government of Indian amalgamated some of the concerned ministries into a new Ministry of Jal Shakti. Government of India has launched Jal Jeevan Mission both in rural and urban areas with the objective of providing functional taps in every household in the country by the year 2024.

The current institutional framework for urban water supply is dogged by multiplicity of institutions responsible for different functions within delivery of urban water supply services with often weak accountability and blurred reporting lines[2]. The overall policy framework is defined by the National Water Policy, formulated by the Ministry of Water Resources, to govern the planning and development of water resources and their optimum utilization is operated at multiple levels from centre to state and from state to cities and towns. The key regulatory authorities in India for urban water supply are the Central Ground Water Authority, the Central Water Commission, the Central Pollution Control Board and the Ministry of Housing and Urban Affairs with their counterpart state departments and institutions[2].

Census 2011 states that 89 per cent of the urban population had access to safe drinking water (piped and other water sources)[3]. However, according to many other publications and assessments, the urban water services are highly unreliable, unaffordable for urban poor and water quality is much below the stipulated standards. Most of the Indian cities have intermittent water supplies. Pipe water supply is erratic and is available for only a few hours per day (Figure 2), regardless of the quality. Raw sewage and industrial effluents often overflow into open drains. In most cities, the Non-Revenue Water (NRW) is estimated to be between 40-70% of the water distributed.

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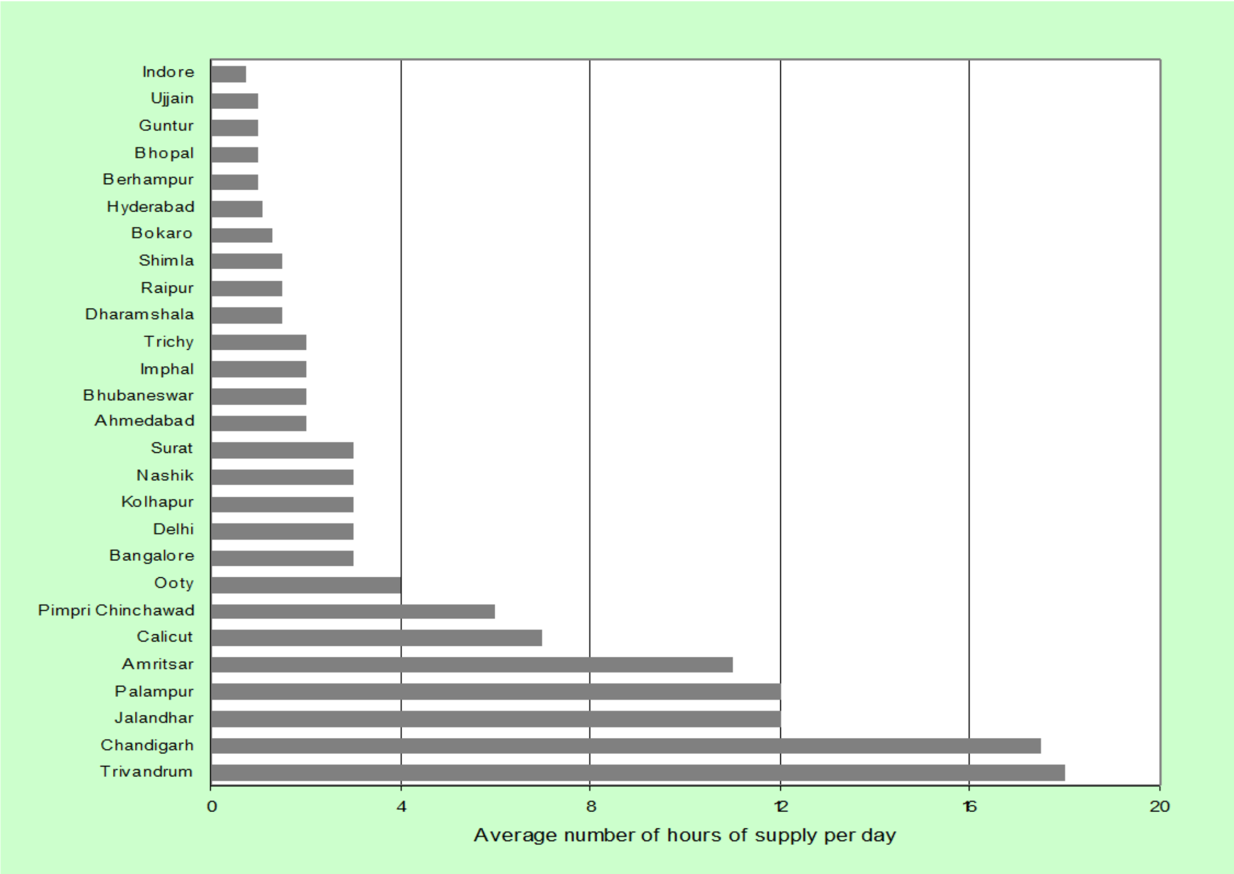

Figure 2-Supply hours in different cities in India[4]

Scarce and poor quality municipal water is one of the most pressing problems in India, where only 70% of the urban households have access to piped water supply[3]. Though the per capita availability as reported ranges from 90 to 120 litres per day, no city yet offers continuous water supply[5]. It has been reported that more than 40% of water produced in many Indian cities does not earn any revenue, be it water lost before reaching the consumer or high volumes of water not being billed for or both[2]. Operations and maintenance cost recovery through user charges is hardly 30-40%. Most urban operations survive on large operating subsidies and capital grants[6].

The increasing gap between water demand and supply is widening. This has put huge pressures on the government to manage available water resources effectively. The Ministry of Urban Development has developed Service Level Benchmarks for the urban water (and sanitation) sector as a minimum set of standard performance parameters, the achievement of which are funded by the Finance Commission[2,4]. Currently, all these performance indicators fall short of the service benchmark. Table 1 presents the Service Level Benchmark Targets for the Water supply sector. There have been studies carried out on utility performance and benchmarking with differing results. The main reason for this difference in results is the limited availability of data. Although progress is made in certain governorates over the years, overall government capacities are lacking as far as improving water management is concerned, with inefficient policies and incentives, as well as absent institutions[7].

Table 1-Service Level Benchmark Targets for India[8]

Proposed Indicator	Benchmark
Coverage of water supply connections	100%
Per capita supply of water	135lpcd
Extent of metering of water connections	100%
Extent of non-revenue water (NRW)	20%
Continuity of water supply	24 hours
Quality of water supplied	100%
Efficiency in redressal of customer complaints	80%
Cost recovery in water supply services	100%
Efficiency in collection of water supply-related charges	90%

Overall, basic service levels in urban areas remain well below desired levels. There are questions about the equity and quality of services, and many water utilities in India suffer from chronic mismanagement and poor governance. A key reason is that investment in infrastructure has not always resulted in commensurate outcomes[2]. With this in mind, it is important to not only focus on technologies and infrastructure creation but also on delivery of service outcomes which will be based on operational efficiencies.

As per 2011 Census, 70.6% of the urban population in India is covered by individual connections, duration of water supply ranges from 1 hour to 6 hours and per capita supply of water ranges from 37lpcd to 298lpcd for a limited duration[3]. Most Indian cities do not have metering for residential water connections. The Government of India establishes norms for per capita supply of water based on the classes of cities, however the majority of states have their own classifications and norms[2] (Figure 3).

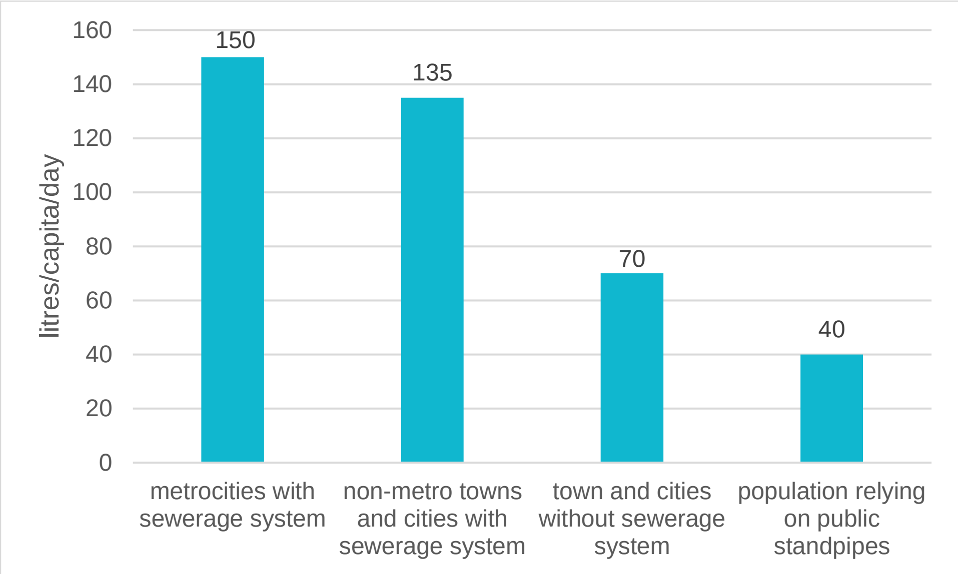

Figure 3-Average water supply norms based on classification of cities proposed by the Government of India[2]

Conflicts over water in India, reach every level and divide every segment of the society- political parties, states, regions and sub-regions within states, industries, farmers and households, especially in the more water-scarce areas[2]. While the water sector in India is still awaiting a comprehensive policy framework at the central level, there are several water policy documents that have emerged in the past two decades, at both central and state level. Urban water reforms remain an element of the state water policies in more than 10 states at least. Interestingly, Karnataka and Goa have separate urban water supply and sanitation policy documents. A look at these policy documents reveals that the reforms in urban water have been approached in various ways using different route maps across states.

Priority sector recommendations call for improvements in urban water service delivery for towns and cities in India, including reduction of NRW and improvement in cost recovery by service providers and efforts to serve more people with the limited water resources available. Additional priority for the water sector is to address the current situation of poor operation and maintenance of water supply schemes, higher leakage and quality concerns. For this, it has been stated that moving towards 24x7 water supply is anticipated starting with smart cities and subsequently scaling up in all cities and towns in a phased and systematic manner[2].

India has made some steps in the past to transition from IWS to continuous supply, with efforts carried out mainly through private-public partnership[5]. An example of transition from IWS to 24x7 supply is the Karnataka Urban Water Sector Improvement Project (KUWASIP) in the state of Karnataka[9]. In 2003, with the involvement of the Urban Infrastructure Development and Finance Corporation and Karnataka Water Supply and Sewerage Board and assistance from the World Bank and Indian think tanks, the three cities of Hubli-Dharwad, Belgaum, and Gulbarga in northern Karnataka (with a total population of around 2 million people) were chosen to carry out demonstration projects.

The KUWASIP project proved a success and led to a 10% reduction in overall water consumed, whilst increasing the revenue billed by a factor of five, and increasing the revenue collected by a factor of almost seven[9]. The average 10 hours of supply per week (two hours every 15 days in one zone) has become continuous water 24x7. From a level of authorized connections estimated to be serving less than 50 percent of the population there is now 100 percent household connection coverage. Based on the savings in operational expenditure, increase in revenues, and improved health benefits, the payback period on the capital maintenance investments is just two and-a-half years.

Another example is the follow-on demonstration zone experiment in Nagpur, Maharashtra, with 8,000 households now receiving continuous water supply with the significant comment that "standposts are out, house connections for all, and the poor have been the first to pay", with only 30 percent mains replacement necessary.[9] The challenge is to scale up demonstration projects, not only to the remaining parts of the demonstration cities but to other urban centres in India.

3 Introduction

IWS is a deeply political problem that creates serious socio-economic inequalities and is often unrelated to the simple explanations offered by most. IWS creates a gender issue, typically affecting young girls and women as they are the ones normally in charge of getting water for households. IWS is also a social issue, affecting mostly the poor and disadvantaged in society. As a result, IWS extends corruption and conflict within communities and deepens the gap between rich and poor. IWS affects productivity, since it is not uncommon to have one person in the family fully assigned to the task of securing the water supply.

It is important to recognize the problems of IWS and to make an effort to find realistic solutions. The vast majority of IWS systems could run 24x7 if physical losses were reduced to low levels (because then it would not make much difference whether you operate 12 or 24 hours a day). Of course, there are places where absolute water scarcity is so bad that there is simply no other way than extreme IWS.

The majority of Indian water utilities practice two types of IWS operations, (i) 'fixed rationing' where customers receive water for few hours in a day; and (ii) 'rotating rationing' where the service area is split into several micro zones and each zone is serviced based on a supply schedule for few hours mostly on alternate days or higher frequency.

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3.1Causes and Implications of IWS

3.1.1 Causes of IWS

International experience has shown that in most cases leakage is the primary cause of IWS, which forces operators to manage the networks intermittently. In fact, intermittency may start by reducing supply by only a few hours a day. However, as leakage situations tend to escalate, there is normally further reduction of the hours of supply to avoid the loss of vast quantities of water lost through the leaks. Various other factors are considered to contribute to the existence of IWS which are examined below, taking into consideration their relevance in India.

3.1.1.1 Water scarcity

Water scarcity is considered to be one of the most important root causes for IWS and can be classified into the following categories[10]:

- scarcity due to poor management practices from the utility's side, leading to high leakage and wastage, poor operation and management practices, governance issues and corruption, etc.
- economic scarcity which is caused by financial constraints to expand infrastructure so to meet increasing demand as well as poor planning and demand forecasting.
- absolute scarcity, which means insufficient quantity at the source and tends to be exacerbated by climate change.

The importance of water security for all is reflected in the United Nations (UN) Sustainable Development Goal no. 6, which aims to ensure availability and sustainable management of water and sanitation for all by 2030[11]. The world's population continues to grow and indications are that from an estimated 7.7 billion people worldwide in 2019 the global population could grow to around 8.5 billion in 2030[12]. According to the UN, there has been progress on the proportion of the global population using an improved drinking water source, with an increase from 76-90% between 1990 and 2015[13].

However, water scarcity still affects more than 40% of the global population and is projected to rise[13]. This rise in water scarcity will increase the cost of producing and delivering fresh water just to keep pace with current levels of service. The increased cost for production and delivery of additional water supplies will drain financial resources that would otherwise be available for investment in the development of other sectors of the economy[14].

Currently in India, 600 million people face high to extreme water stress and about 200,000 people die every year due to inadequate access to safe water[15]. By 2030, the country's water demand is projected to be twice the available supply.

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3.1.1.2 Fast population growth

The most significant reason behind inadequacy of domestic water supply is the explosive growth of demand. The fast population growth resulting from rapid urbanisation is especially evident in low and middle income countries, such as India. The increase in water demand is due not only to population growth but also due to the increase of per-capita water use as a result of economic growth and improvement of living conditions. India with a population of 1.37 billion comprised 18% of the total global population in 2019[12]. Population of the country is expected to increase by nearly 273 million people between 2019 and 2050[12].

It has long been predicted by international water resources experts that the lack of adequate renewable fresh water supplies due to demographic pressure will become the main constraint on their economic development[16]. For India, water requirements by 2050 in the high use scenario are expected to be 1,180 billion cubic meters (BCM), whereas the present-day availability is 695 BCM, while the total availability of water possible in the country is lower than this projected demand, at 1,137 BCM[17].

3.1.1.3 Rapidly increasing demand due to urbanization

Migration of the rural population to urban centres has resulted in towns and cities expanding rapidly. The increasing concentration of populations in urban areas and the growth of mega cities place a strain on existing public services and, together with prevailing economic realities, result in chaotic conditions in many towns and cities, especially in low and middle income countries. According to the UN report on World Urbanization Prospects, globally, 55% of the world's population were residing in urban areas in 2018[18]. Figure 4 presents the past, present and projected number of people living in urban areas worldwide.

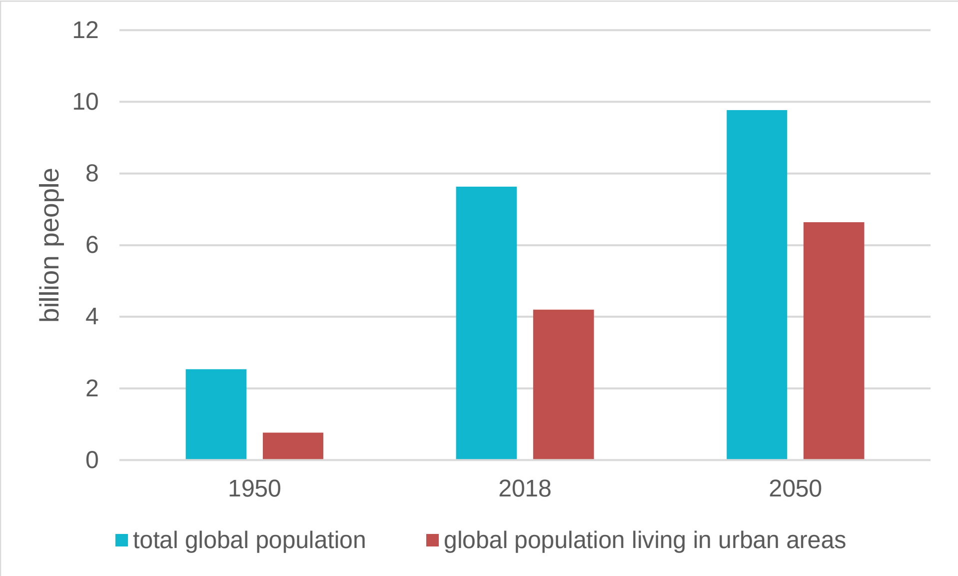

Figure 4-Past and projected global population living in urban areas[19]

From the above figure, it can be deduced that in 1950, 30% of the world's population was urban, and by 2050, 68% of the world's population is projected to be urban. However, there is significant diversity in urbanization levels for different geographic regions. In India, the population more than tripled since 1950 to 1.35 billion and the level of urbanization nearly doubled, reaching 34 in 2018[19]. It is expected that India will have an additional 416 million urban dwellers by 2050, nearly doubling the size of its urban population between 2018 and 2050.

Increasing population densities concentrated in urban centres demand extensive measures in conveying water from remote locations and distributing this[20]. At the turn of the century in 2000, there were 371 cities in the world with 1 million inhabitants or more. By 2018, the number of cities with at least 1 million inhabitants had grown to 548 and in 2030, a projected 706 cities will have at least 1 million residents[18]. Water supply to cities is crucial not only for the survival of its inhabitants but also to maintain a healthy level of economic development.

Awareness of what happens when there is a lack of water is all too apparent in many developing cities, where poor living conditions and limited access to adequate water and sanitation significantly increase the health burden on the urban poor, who often constitute the very labour source that generates the cities' wealth[21]. For example, 85% of India's urban population has access to drinking water but only 20% of that water meets the minimum health and safety standards. It has been estimated that by 2050, a half of India's population will be living in urban areas and will face acute water problems[22]. Naturally, this rapidly increasing water demand due to urbanization only makes matters such as network rehabilitation, reduction of physical losses and conversion to 24×7 a total necessity.

3.1.1.4 Alternatives are perceived as impossible

For many countries, IWS has been a reality for so long, people do not see the urgent need for change. In South Asia, the use of IWS is so high that most people regard it as normal and are therefore not greatly motivated to do anything about it[23]. IWS is usually adopted through necessity in water stressed regions and is very common in low and middle income countries, especially in South Asia[20]. Duration of water supply in Indian cities is reported to range between one to six hours, with per capita supply of water ranging from 37 to 298 litres/capita/day[2].

Changes in water supply can be effected by Asia's growing middle class and its small but very powerful wealthy group, if they decide to use their influence. However, motivation for such decision is usually low, since they secure their water supply as individuals through the use of tanks, pumps, and in many cases private wells[23]. As long as the interests of the wealthy are served, the motivation for change will be weak.

Faced with the pressure of scarcity, water authorities will increasingly resort to delivering intermittent supplies, if they are not convinced that alternatives do exist. Usually during drought periods, water utilities impose water restrictions to both domestic and agricultural supplies. However, in most cases, water authorities seem to overlook the obvious, which is to manage the water networks in the most efficient and effective way in order to minimize physical losses through leakage, as well as address demand management. In most cases there is also a lack of experienced and trained human resources.

3.1.1.5 Lack of planning

In many cases it is difficult to assess whether water is truly scarce in the physical sense (a supply problem) or whether it is available but should be used better[24]. There are cases where IWS is adopted due to water scarcity, but there are many cases where lack of planning (and management) leads to water supply networks being operated under intermittent mode.

It is important to identify and recognize the realities when designing and operating water supply networks and to examine the necessary supply scheme[25]. The lack of organizing the use of IWS drives to inefficient and ineffective results. A major reason for the poor performance of intermittent supply systems is the fact that they are often adopted in a reactive way as opposed to proactive planning. It is important to recognize intermittent supplies as a reality that is eventually hard to escape and an attempt must be made to be proactive in the design of IWS management plans at least as fall-back plans to ensure adequate service standards[14].

Additionally, the demand for different uses (agriculture, industry, households, recreational and environmental uses) is rapidly increasing due to the continuously increasing population, especially in low and middle income countries, and due to the growing awareness of environmental, health and recreational issues. Developing a plan that prioritises water uses and expands water availability through new infrastructure becomes more difficult as the cost of developing new sources or expanding existing ones is continuously increasing as the most accessible water resources have already been tapped[21]. In many cases, lack of planning drives to wasteful use of existing water supplies[26].

In many water supply systems insufficient responsive maintenance and total absence of preventive maintenance of network infrastructure led to IWS. Instead of undertaking timely repairs of leaks and bursts, the utilities resort to shutting off the pipelines to minimise physical losses. Very low and often negative pressures during supply periods do not permit conventional preventive maintenance tasks like regular leak detection. This trend continues to increase the backlog of leaks and bursts necessitating at some stage high capital injection in pipeline renewals.

3.1.1.6 Lack of awareness

People are generally not actively opposed to the use of IWS, mostly because they are unaware of the consequences, such as health risks and incurring high costs. Lack of awareness, education and understanding of the subject drives the public to consider IWS as the norm, without knowing that continuous supply is the norm in most countries in the world. Consumers are often unaware of government policies and there is low government accountability; as a result, poorly informed consumers do not demand better services and do not exert pressure on the relevant authorities.

3.1.2 Implications of IWS

The implications of operating water supply networks under IWS are many and affect, aside from water supply networks and their operation, the consumers and the water utilities. The following are deduced from Charalambous et al.[27] to summarize the various effects of operating supply networks under IWS. IWS leads to water contamination and wastage, potential health hazards and network deterioration. On the whole, IWS has a detrimental effect on the network, results in ineffective supply and demand management, inefficient operations, increased difficulties in detecting and fixing leaks as well as greater number of illegal connections.

3.1.2.1 Water contamination and health hazards

Intermittency entails a high risk of contamination, which creates substantial health hazards. Interruption of continuous supply to a network can create low pressures or even a vacuum condition in pipelines that last for a significant period of time. This can cause potentially contaminated water (e.g. rainwater, sewage spills, latrine drainage, etc.) to enter the network through fractures or broken pipes or joints when supply is off. It is therefore difficult to keep proper chlorination levels in the network, since there are no constant hydraulic conditions with the repeated emptying and charging of the network. Therefore, chlorination levels which are adequate for a network under continuous supply may not be sufficient to deal with the cases of contamination ingress. This can lead to potential severe health hazards as the bacteriological quality of a water supply network under intermittent mode is substantially lower than of a continuous service. This situation is especially serious in cities with no or poor sanitation facilities, where sewage flows in open ditches close to distribution pipes. In order to reduce health risks, such as bacterial contamination, utilities tend to significantly increase chlorination, which of course entails other dangers such as the potential creation of trihalomethanes, a by-product of chlorine and organic matter, which have been associated with adverse health effects.

An additional contamination risk occurs at household tanks. Storage is rarely constructed under supervision of the water company or according to certain standards with prescribed prevention of contamination. Moreover, as water is stored for long periods of time additional water quality issues arise.

3.1.2.2 Water wastage, inconvenience and high coping costs for consumers

Water wastage is another, albeit perhaps unexpected consequence of IWS. Due to the fear of not having sufficient water, consumers experiencing IWS try to store as much water as possible. Consumers exposed to IWS are likely to keep their taps open or install suction pumps (-Installation by consumers of suction pumps after the metersFigure 5) to obtain the maximum volume of water possible whenever the service resumes. In addition, consumers usually remove the control valves that are installed in the ground and/or roof tanks, so to remove any flow restriction in the hopes of attaining larger volumes of water in a shorter period of time. Furthermore, consumers tend to empty their tanks to replace their stored water with the fresh water of the next supply. Under these circumstances, water will likely be wasted by consumers serviced with IWS than those who receive a 24×7 supply.

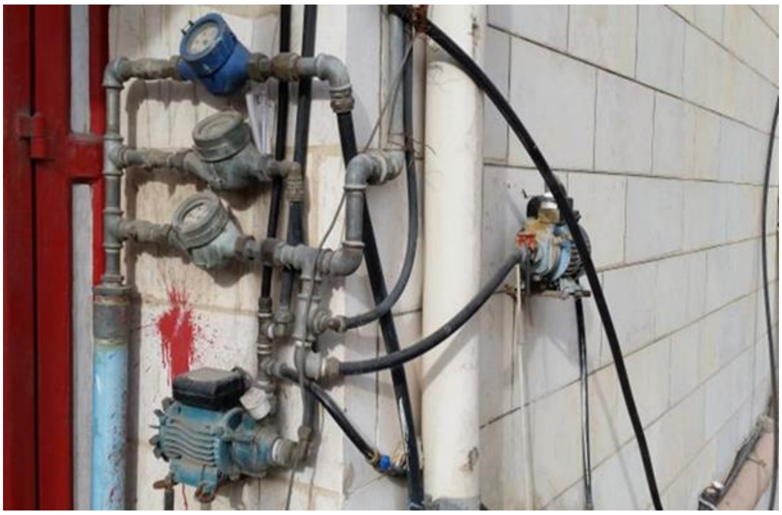

Figure 5-Installation by consumers of suction pumps after the meters[27]

As a consequence of IWS, consumers have to pay the so called *coping costs*, for additional facilities, such as storage tanks, pumps, alternative water supplies and household treatment facilities. The poor who cannot afford such facilities spend their time to fetch water from public taps or vendors at comparatively high total costs considering their time and energy spent. Figure 6 presents a breakdown of the coping costs for high, medium and low -income households.

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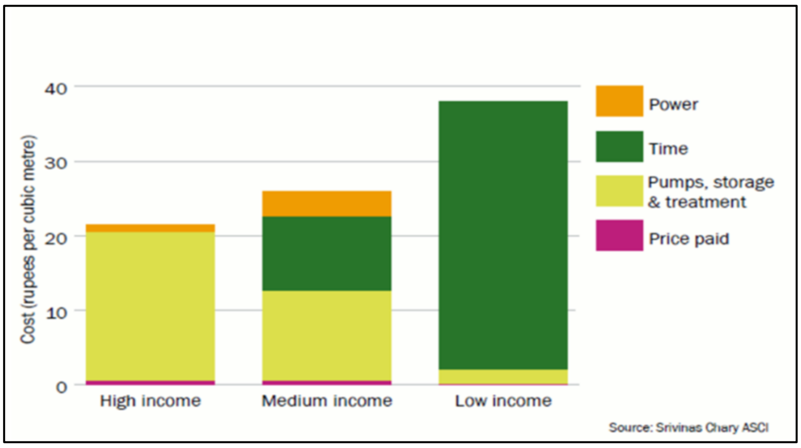

Figure 6-Coping costs for high, medium and low income households in India[28]

3.1.2.3 Network deterioration, inefficient operations and high costs for water utilities

Systems which are designed to operate under continuous supply, are forced to operate under different flow conditions with IWS mode. The emptying of the network in IWS operations when supply is cut-off causes vacuum conditions, which can cause meter registers to reverse. Additionally, air expelled from the pipes during filling, when supply is resumed, might drive meters at excessive speed during the charging stage resulting in the accelerated wear and tear of the registration mechanism. The repeated dry and wet conditions of IWS would also accelerate deterioration of water meters. There is also frequent wear and tear on valves. The repeated filling and emptying of the network result in a substantial increase in the number of pipe breaks, thus increased leakage (Figure 7).

20 DMAs: 373Km: 45%total 2008 – 2009 Intermittent Water Supply (IWS)			
Description	Number of reported breaks		
	2007 Before IWS	2010 After IWS	% increase
Mains	14 / 100km	42 / 100km	**200**
Service connections	15 / 1000 connections	30 / 1000 connections	**100**

Figure 7-Example of the increase in the number of pipe bursts due to IWS[27]

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Another issue that is raised with the use of IWS is the inequitable distribution within a network. As the amount of water flowing out of taps depends on the pressure head once the supply to the network has been restored, peak flows that are larger than expected will occur in the pipelines, increasing the pressure losses in the network. Consequently, those consumers furthest away from supply points will always collect less water than those nearer to the source.

For water utilities, IWS has direct financial costs and additional difficulties of operation. First of all, they incur loss of revenue due to the decrease in water sales and less willingness of people to pay. In addition to this they must pay their staff for overtime for opening and closing valves (to implement water rationing) and to repair breaks (caused to the pipes due to the frequent emptying and filling of the pipes).

Further inefficiencies in the operation of utilities are caused by the malfunctioning of meters, which results in difficulties to monitor the water use and collect accurate tariffs. Moreover, there are many difficulties in conducting leakage detection activities in networks under IWS with numerous parameters that need to be considered (e.g. duration that the system is pressurised, pressure, pipe material, customer tanks, etc.). Aside from the previous, utility staff must also deal with numerous complaints made from consumers regarding lack of pressure and problems with water quality.

3.1.3 IWS Downward Spiral

IWS can be considered to be a downward spiral (schematically presented in Figure 8). As increased urbanization leads to higher water demand, water companies tend to respond with network expansion, which often takes place after poor planning and extends the network beyond capacity. This in turn decreases the quality of service for consumers and leads to an inadequate water supply for towns and cities. In many cases people (and mostly the privileged) make private investments that will improve their supply of water. However, for most the result is poor service, inevitably leading to corruption and conflict among different citizen groups. Such instabilities lead to the public being less willing to pay for water, thus less income for water utilities. Water utilities meanwhile have to deal with more bursts in the network, need more staff to respond to such failures and are faced with lack of funds due to reduced income.

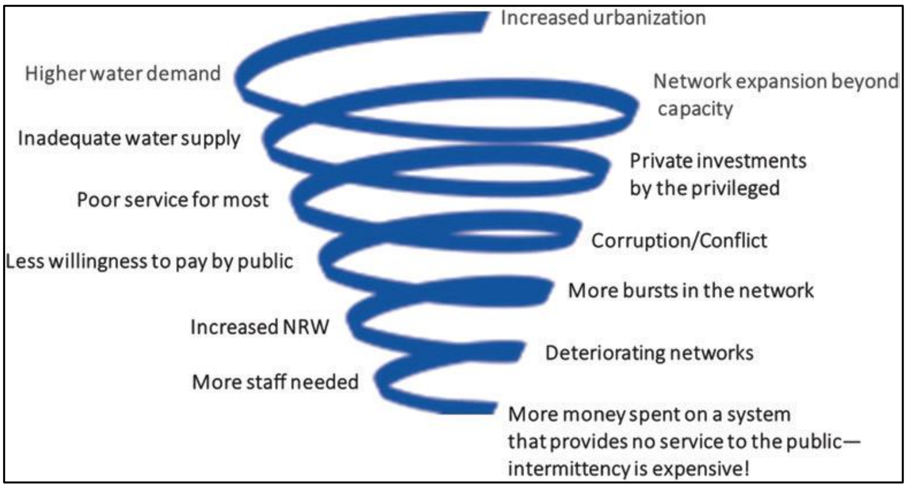

Figure 8-The downward spiral of IWS[27]

The result of IWS is a deteriorating network with increased leakage and higher NRW. In the end, more money ends up being spent on a system that provides lower quality service to the public. This proves that while intermittency may be considered the cheapest option when funds are limited, it ends up being an expensive regime to follow!

3.2Transitioning from IWS to continuous supply

The transition from IWS to 24×7 can vary depending on the type of IWS experienced. In systems that were designed for IWS (like some in South Asia) pressurizing the system 24×7 on a zone by zone or district meter area (DMA) by DMA basis, starting from a zone or DMA closer to the water source, would be the way forward for a successful transitioning scheme. On the other hand, in systems where IWS was not planned but became a reality due to poor network management, water loss reduction in the part of the network with best supply and highest water losses would first be implemented and the water saved could then be supplied to the poorly supplied areas.

The IWA Water Balance and water loss Performance Indicators (PIs) have become international standard for assessment of water utility performance. The challenge of managing a water supply system that is intermittent and with high levels of NRW poses water utility managers with a conundrum regarding how to address these. Although there is a generic approach for quantification and management of NRW based on IWA best practices, their application to IWS systems poses great challenges to practitioners.

For instance, water loss PIs, e.g. physical losses (litres/connection/day) needs to be readjusted to continuous supply (i.e. when the "system is pressurized"). With this indicator and the average operating pressure, the level of water loss can be understood and the transformation from IWS to 24×7 planned.

In the case of IWS the IWA Water Balance methodology and water loss PIs can be used if the supply time is properly taken into account. Once the water loss situation is properly understood, forecasts can be made on how much water will be required to supply the network in its present condition on a 24×7 basis and how much will be needed after network rehabilitation.

Transitioning from IWS to 24x7 requires a structured holistic approach built on a long-term strategic plan. This plan would comprise major interventions geared toward significant NRW reductions with major investments in leakage reduction as appropriate, followed by fine tuning of the operational performance of the network towards reaching an economic NRW level. Ultimately performance needs to be sustained at an economic level of NRW with minor, but annual recurrent investments with full cost recovery through appropriate tariff structures.

Transitioning from IWS to 24 × 7 supply is not an easy task. It requires commitment and dedication from all concerned, governments, water service providers and consumers. The following areas need to be addressed simultaneously and in parallel in order to have a successful and sustainable impact:

• Technical – gradual increase in the hours of supply aiming for continuous service, introduction of customer metering policies, improved network operation using DMA/sectorisation practices and targeted rehabilitation/replacement of mains.

• Financial – implementation of tariff structures linked to performance incentives for saving water, cost recovery, adoption of commercial thinking and reform of water service providers to make them accountable.

• Institutional – water service providers that have fallen into operating under IWS conditions have major governance and incentive flaws and need in-depth reform; moving to continuous supply requires often very difficult political and institutional choices that many governments prove reluctant to make. A paradigm shift is imperative!

• Social – the water service providers need to gain the trust of the consumers, have the willingness to change, involve the public in this effort in order to provide the required level of service at all times in a reliable and sustainable manner.

• Communication with the customers – it is of the utmost importance to communicate all the above in an effective and convincing manner to all involved in order to have the maximum possible impact. Transitioning from IWS to 24 × 7 supply is possible, applying the appropriate approach, techniques, methodologies and practices. However, it requires commitment and dedication from all concerned, governments, regulators, water service providers and consumers.

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4 Transition Plan

Transition of IWS to 24x7 continuous supply could be achieved through a number of 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. This 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, and applying appropriate customer metering policies and management. 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 and 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.

Implementing a successful transition from IWS to 24x7 depends on the effective operation of multiple water supply system elements in such a way that the water utility “takes back control” of the system. Therefore, each element of the method proposed for transitioning from IWS to 24x7 is assumed to equally address both technical and system specific aspects.

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

- Water supply availability and stability at the bulk supply system,
- Distribution network efficiency, whereby leakage is minimised, and
- Water use efficiency, whereby equitable water use is ensured, and excess use is minimised.

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These three important components are illustrated in Figure 9. To implement a successful transition from IWS to 24x7, each component needs to be evaluated to determine whether transition of the network system to continuous supply is achievable. Once a network system is selected for transitioning the control requirements are established for each one of the above components before proceeding to the implementation of the transition process. After the transition has been completed, the requirements for control are sustained.

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 the equitable provision of water use requirements.

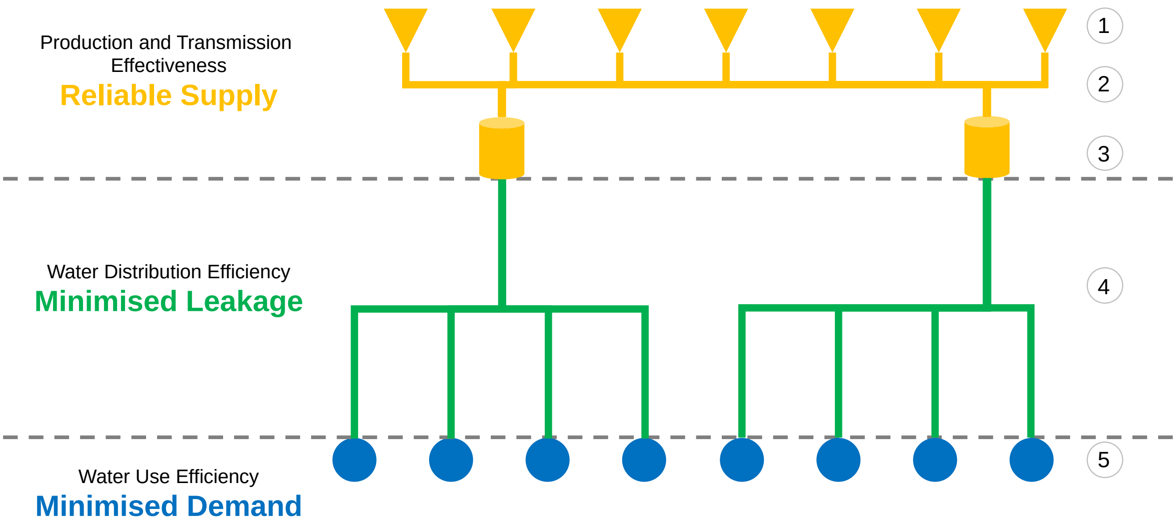

Figure 9-Major components to be addressed in IWS transitioning.
(Legend: 1. Water production and treatment, 2. Bulk water transmission, 3. Water storage reservoirs, 4. Water distribution network, 5. Water users.)

4.1Evaluation of potential for transitioning to 24x7

To verify whether a particular water system or network is capable of being transitioned to continuous supply, or to prioritise among several networks where the transitioning process is to be implemented, an evaluation of each major system component needs to be carried out. 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.

To evaluate water supply reliability, assessment of the bulk supply system, including the production and transmission 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 bulk supply system are examined. This evaluation should result in a clear demonstration of whether the water supply at the inlet of each target area may currently, or with additional control measures can, be reliably sustained, and at which capacity, as well as any anticipated daily or seasonal supply fluctuations.

To evaluate distribution network efficiency, a water audit must be carried out to assess the level of leakage, ideally through the IWA Water Balance methodology[29] with declared uncertainty of each quantity at 95% confidence limits, and with field verification of each input parameter to reduce the uncertainty to the minimum feasible levels. In addition to the estimated leakage calculated through the 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 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 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 also the extra volume of water that will be lost due to leakage[27]. Following this, calculation of a target leakage level for the rehabilitated network can be determined under a 24x7 basis.

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 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.

Based on the evaluation results of each component it is possible to determine the suitability of each target area to transition by ensuring that the water supply shall meet 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 10 and is described in detail in the following sections.

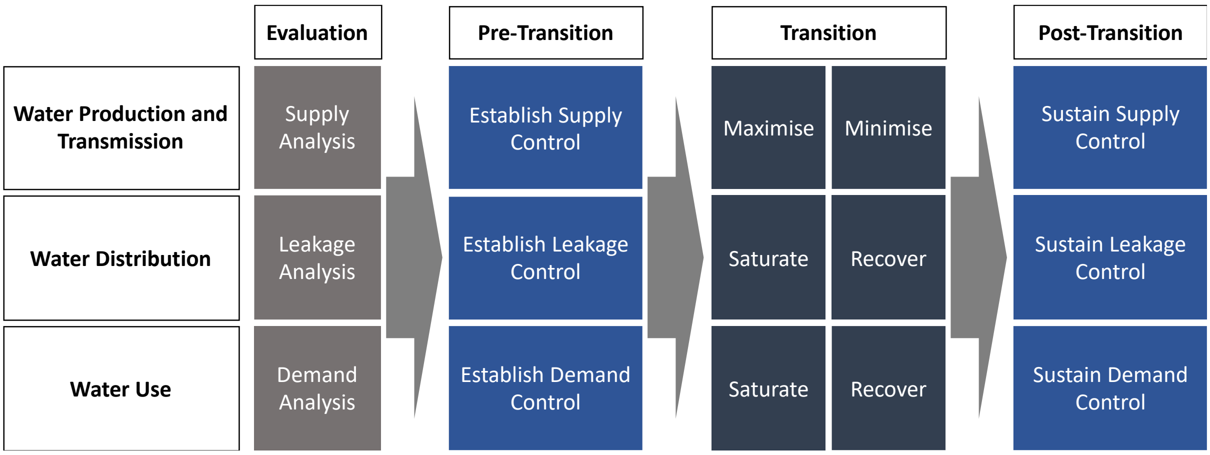

Figure 10-Methodology for transitioning from IWS to 24x7 continuous supply across the three defined areas of supply, leakage, and demand.

4.2The Pre-Transition Stage

Certain preparatory actions need to be implemented for a water distribution network that has been identified as a target area suitable for conversion from IWS to 24x7, to ensure that the network can be sufficiently controlled and thus achieve a successful transition. These actions address the three main components of water supply systems.

4.2.1 Production and transmission

Ensuring the availability of adequate supply quantities with sufficient reliability is key to safeguarding a successful transition to 24x7 supply. The continuity of supply source can be often found problematic where production resources are overstressed, transmission systems are cross connected usually by trial and error to solve short-term supply complications given the prevailing 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. Therefore, there are some challenges that could be faced which may contribute to or result in IWS that include:

- Power fluctuations at the source preventing continuous water production.
- Fluctuations in produced water quantities or quality.
- Fluctuations in imported bulk 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 which have problems in accumulating adequate water storage.

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Several good practices which enhance control of the bulk water supply system (production and transmission) 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 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 for ensuring a well-designed and operated bulk water supply system. However, given the associated cost and time considerations of the above, the application of the following two major activities are crucial for any areas selected for transition.

1. Mitigating of supply failures risks to the selected areas based on a hydraulic assessment of the bulk flow system calibrated using flow and pressure field data.
2. Installation of critical system monitoring and control devices such as telemetry / SCADA systems as required, to ensure sufficient control over the system.

The pre-transition preparations should focus on the following:

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

4.2.2 Distribution networks

Reducing excessive leakage is a main pillar of successful transitioning from IWS to 24x7 continuous supply. While 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. In summary, the following factors that often accompany IWS need to be addressed:

- Hydraulic conditions that cause excessive leakage from existing leaks, in addition to the escalation of the number of newly created leaks.
- Large water volumes, which are supplied during shorter periods that often translate to hydraulically breaching the original water network design.
- Interrupted supplies that prevent the identification of day-night flow patterns which allow for the monitoring of leakage levels.

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- High noise levels in the network caused by the continuous filling of customer storage tanks which prevent the effective location of leaks.
- A reactive work style, due to the difficult working conditions of managing a water distribution network under IWS.

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.
- Verification of correct installation and pressure testing of new networks.
- Use of high-quality parts in maintenance.

Ideally, most of the above listed practices should be required to ensure the success of the transition to 24x7 supply, but in many cases only a subset can be established effectively, and within the control of the water utility, 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.

1. 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. 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.
2. Establishing network monitoring is a requirement to observe and verify operational control parameters, flow and pressure, during the transition period and beyond, through measurement devices that allow the operator to rapidly assess, monitor, and respond to network events. Relevant software applications allow for the daily monitoring and assessment of network conditions.

It is worthwhile noting that networks in India are already divided into micro zones by temporary or permanent valve closures thus forming the so called “rationing” zones which could be used as DMAs monitoring flows and pressures. Of course, it would be prudent to check such zones for hydraulic efficiency and adjust these accordingly to achieve improved hydraulic conditions. It is often the case that networks expand as the city grows and hence it would be prudent to optimise the existing networks utilising existing micro zones.

Often many utilities consider that transitioning to IWS would entail replacing the entire network in order to set up DMAs. Currently in India a number of utilities are considering this approach, to install new networks based on DMA zoning principles. However, this approach is extremely expensive and most probable may not deliver the desired 24x7 supply. Therefore, careful consideration must be given to all the prerequisites and conditions for transitioning from IWS to 24x7 before taking such decisions.

Using the existing zones with proper measurement and monitoring instrumentation would in most cases serve the purpose of the DMA concept always bearing in mind the dynamic nature of a growing and expanding city thus adjusting the hydraulic boundaries of such zones as deemed necessary to achieve better hydraulic conditions. Furthermore, optimising operational management and preventive maintenance of the existing networks compared to their original design criteria would be extremely beneficial. Due to minimum pipe size requirements by Indian Standards and Specification, networks are grossly oversized for 24x7 supply, since most networks were design with IWS in mind, thus their replacement would be very capital intensive.

4.2.3 Water users

The need for achieving 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.
- 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, can 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 above 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.

1. Public engagement campaigns are required. Water use efficiency promotional campaigns and events can play a positive role in water demand management. However, due to the limited control over the effectiveness of traditional campaigns, direct and transparent communication with the users within the targeted areas should be aimed for so to create a level of engagement whereby the public are treated as partners in achieving successful transition to 24x7 supply. Replacing generic water awareness materials, the pre-transition campaigns should focus on public announcement of the goal of transitioning from IWS to 24x7 supply in the target area, the results anticipated, and the planned time schedule. Establishment of public communication channels using information tools, such as web and mobile applications or tools available that can achieve similar results. Leveraging the achieving of 24x7 supply as a combined goal of both utility and users is of the utmost importance.
2. 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. Identification of customer meter availability, status, and installation conditions through a field survey, preferably using GPS and image capture enabled mobile applications is essential.

4.3The Transition Stage

4.3.1 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 may tend to maximise consumption in the district given habitual water hoarding behaviour that often develops due to IWS. The success of this step is dependent on the ability of allocating sufficient water supply at the district inlet, which is supported by actions implemented during the pre-transition stage that provide the controls needed for improved supply reliability. The impact of this step is also alleviated through the successful implementation of preparatory actions that assist in the control of leakage and demand.

4.3.2 Step 2: District water recovery

The second step focuses on the recovery of excess leakage and demand towards achieving optimum minimization of water supply required for each district. Throughout this step, intensive field activities are carried out that include:

- 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 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) that is under transition, the process is repeated in the next available for transition DMA(s), as shown diagrammatically in Figure 11. This progressive upscaling of transitioning using the DMA concept allows for the optimum use of the available water by making additional water available. The additional available water which is saved from the transitioned DMA(s) is used to supply the next selected DMA(s) that is to be transitioned. Therefore, additional water required at any time is minimal.

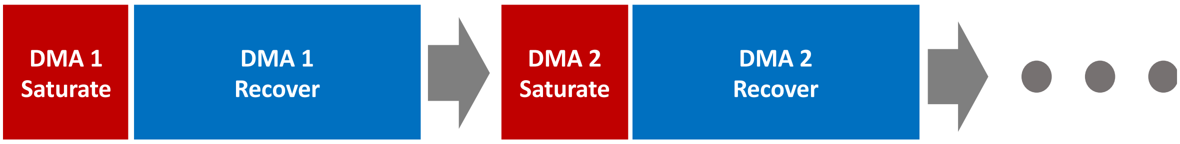

Figure 11-Progressive transitioning of district metered areas (DMAs) ensures the availability of water and human resources during the transition stage.

4.4Post-transition

After successfully transitioning from IWS to 24x7 continuous supply, maintaining control over each water system components is necessary for sustaining the benefits gained through the transitioning efforts and preventing the fall back into previous operational habits. Each established activity will therefore require the support of day to day activities that exert good management practices. These good management practices include:

- Defining clear job descriptions and responsibilities through the utilization of staff in existing department or the introduction of new units at the water utility organization.
- Providing sufficient skilled staff, either directly employed 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 to 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.

5 Water Audit and Water Loss Control

5.1Water Audit - IWA Water Balance

Significant contribution to reaching the point of water accountability was the establishment of the IWA Water Balance (Figure 12) that is a useful tool in analysing the various components of water production, storage and distribution. Through this analysis the magnitude of the water loss problem is identified, and priorities are set for rectifying the situation based on the component analysis of the Revenue and NRW elements. The IWA Water Balance and relevant PIs have become international standard and are promoted by many regional and national professional associations around the world.

The IWA water balance methodology and relevant PIs can also be used in IWS systems provided the supply time is properly taken into account. Once the water loss situation is properly understood, forecasts can be made to establish the volume of water required to supply the network in its present condition on a 24x7 basis and the volume of water required after network rehabilitation. Appendix 1 provides a list of data required to compute the Water Balance.

<table>
<tr><td rowspan="5">Water from own Sources (corrected for known errors)</td><td rowspan="11">System Input Volume</td><td>Water Exported</td><td rowspan="5">Authorised Consumption</td><td rowspan="3">Billed Authorized Consumption</td><td>Billed Water Exported</td><td rowspan="3">Revenue Water</td></tr>
<tr><td rowspan="10">Water Supplied</td><td>Billed Metered Consumption</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="8">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="6">Water Imported</td><td rowspan="6">Water Losses</td><td rowspan="3">Apparent Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Customer Meter Inaccuracies</td></tr>
<tr><td>Systematic Data Handling Errors</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage on Transmission and Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility’s Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to Point of Customer Metering</td></tr>
</table>

Figure 12-The International Water Association's Water Balance[27]

The following are definitions of the Water Balance’s principal components:

- ***System Input Volume***: the annual input to a defined part of the water supply system.
- ***Authorized Consumption***: the annual volume of metered and/or non-metered water taken by registered customers, the water supplier and others implicitly or explicitly authorized to do so. It includes water exported, and leaks and overflows after the point of customer metering.
- ***Non-Revenue Water (NRW)***: the difference between System Input Volume and Billed Authorized Consumption.
- ***Water Losses***: the difference between System Input Volume and Authorized Consumption, consisting of Apparent (Commercial) Losses and Real (Physical) Losses.
- ***Apparent (Commercial) Losses***: consist of Unauthorized Consumption and Customer Metering Inaccuracies.
- ***Real Losses (Physical)***: the annual volumes lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering.

5.2Performance Indicators

The performance indicators recommended by the IWA for NRW and which are derived from the Water Balance calculations are shown in Table 2 and are described in detail below.

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Table 2-IWA Performance Indicators

Component	Type	Performance Indicator
Apparent Losses	Operational	% of Authorised Consumption
Real Losses	Operational	Real losses as litres/service connection/day when system pressurized
Real Losses	Operational	Infrastructure Leakage Index (ILI)
Non-Revenue Water	Financial	Volume of NRW as % of System Input Volume
Non-Revenue Water	Financial	Value of NRW as % of annual cost of running system
Non-Revenue Water	Operational	litres/service connection/day when the system is pressurized

- **Apparent Losses expressed in % of Authorized Consumption:**

This represents the volume of water used, for which no revenue was received by the water utility. To minimise this percentage, accurate customer meters must be employed together with appropriate data handling. Thorough inspections are required to be carried out in order to immediately replace all stopped meters, install new meters on any unmetered connections and minimise the illegal connections. Accuracy tests on existing water meters need to be conducted in order to ascertain the current meter under-registration and take relevant measures to minimise or eliminate this. Meter readings must be checked for errors by the billing department.

- **Real Losses as Litres per Service Connection per Day [when the system is pressurized (w.s.p.)** - this means the value is already corrected in the case of intermittent supply] OR Litres per Connection per Day per meter Pressure (w.s.p.) OR m^3/km mains per hour (w.s.p.):

This performance indicator is recommended for assessing effectiveness of operational management of Real Losses in distribution systems. The choice for this performance indicator - either 'litres/service connection/day' or 'm^3/km of mains/day' depends on the density of service connections. If this exceeds 20 service connections per km of mains, component analysis for well-managed systems has shown that more than half the volume of Real Losses is generated from leaks associated with service connections, 'per service connection' is therefore the preferred Indicator. If the density of service connections is less than 20 per km of mains, it is preferable to express Real Losses 'per km of mains'.

- **Infrastructure Leakage Index [ILI]**:

This is the most appropriate performance indicator for comparing performance in operational management of Real Losses. It is a non-dimensional index (Current Annual Real Losses / Unavoidable Annual Real Losses) which assesses the overall efficiency of management of Real Losses in the system infrastructure (up to the customer meters) at the current operating pressure.

- **NRW by Volume (%):**

Although this PI is widely quoted, it is not necessarily particularly meaningful, as it is strongly influenced by consumption. It is expressed as a percentage of the System Input Volume that does not yield any revenue for the utility. Percentages must not be used to address water losses or NRW.

- **NRW by Value:**

Because of the problems of interpreting NRW as % by Volume, it is recommended that the NRW should also be expressed as a % by value, of the cost of running the system. Because the different components of NRW (Unbilled Authorised Consumption, Apparent Losses and Real Losses) can have widely different values per unit volume, the NRW % by value may differ significantly from the NRW% by volume. It is usual to value Apparent Losses based on the sale price of water to customers. The lowest valuation for Real Losses can be based on the variable production and distribution cost (or bulk purchase price plus distribution costs), plus other costs as appropriate (deferred capital costs, environmental costs); and Unbilled Authorised Consumption can be valued somewhere between the valuations for Apparent and Real Losses.

- **NRW in litres/service connection/day when the system is pressurized**:

This PI is recommended for assessing the NRW in terms of litres / service connection/ day in order to ascertain in which NRW performance category the utility is and to decide on appropriate action as defined in Table 3.

Table 3-The international Non-Revenue Water assessment matrix[30]

NRW Management Performance Category		**Non-Revenue Water in liters/connection/day** when the system is pressurized at an average pressure of:				
		10 m	**20 m**	**30 m**	**40 m**	**50 m**
High Income Countries	**A1**		< 50	< 65	< 75	< 85
	A2		50-100	65-125	75-150	85-175
	B		100-200	125-250	150-300	175-350
	C		200-350	250-450	300-550	350-650
	D		> 350	> 450	> 550	> 650
Low and Middle Income Countries	**A1**	<55	<80	<105	<130	< 155
	A2	55-110	80-160	105-210	130-260	155-310
	B	110-220	160-320	210-420	260-520	310-620
	C	220-400	320-600	420-800	520-1000	620-1200
	D	> 400	> 600	> 800	> 1000	> 1200

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Depending on the category the utility falls under, the following general actions are recommended:

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

5.3Reduction and Control of Water Losses

NRW comprises of Unbilled Authorized Consumption, Apparent (Commercial) Losses and Real (Physical) Losses. These components are briefly described below:

Unbilled Authorized Consumption is water used legally and to the full knowledge of the water utility but is not billed and therefore does not produce any revenue. Indicative examples are:

- water that is used for firefighting.
- street cleaning.
- drain flushing.
- municipal buildings and public gardens.

This component must be examined carefully by the water utility and minimized to the maximum possible degree.

Apparent (Commercial) Losses have been clearly defined as influenced by the following four components, and that these components can act and interact interchangeably (Figure 13):

- *Meter under-registration* is the inability of a revenue meter to accurately measure water, especially at low flows. This tends to increase with time and as the meter degenerates.
- *Water theft* is easy to conceptualize and consists usually of bypasses to the water meter, illegal connections, or wilful damage to the water meter.
- *Meter reading errors* consist of genuine mistakes or intentionally incorrect meter reading.

- *Water accounting errors* consist of billing anomalies, such as computer-based estimations that do not reflect actual consumption values.

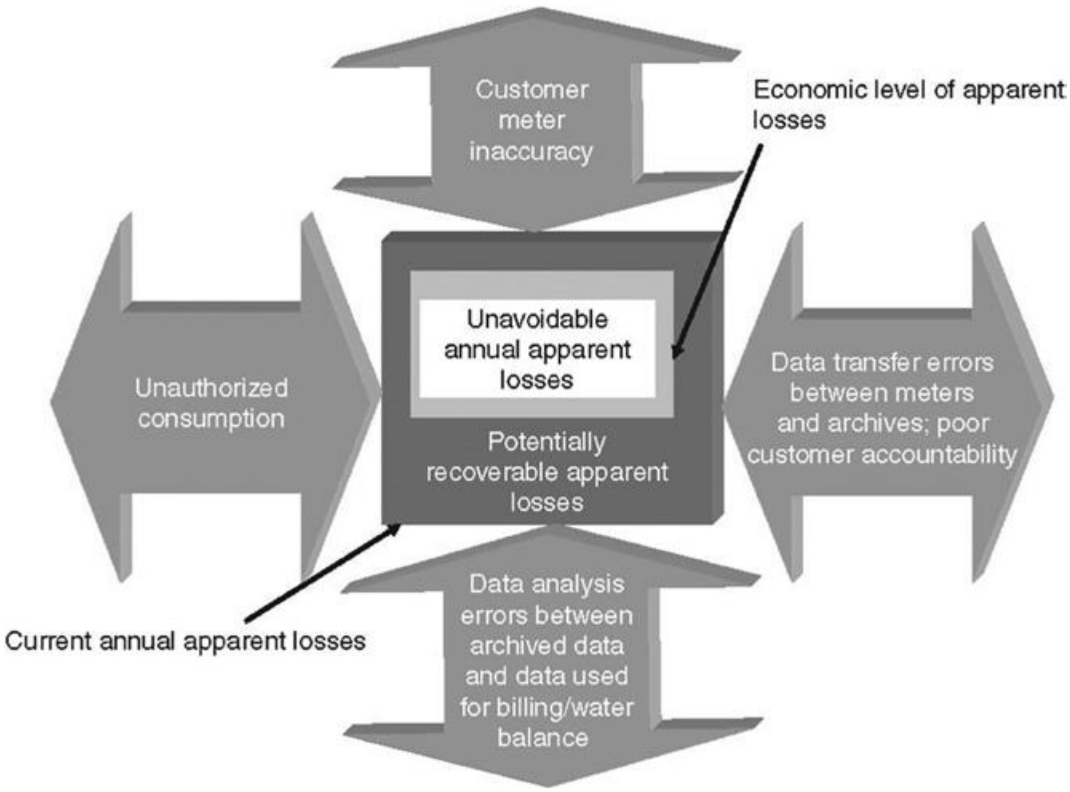

Figure 13-The main factors influencing Apparent (Commercial) Losses[27]

Real (Physical) Losses are caused by physical losses from the network, such as leakage and breaks. It should be noted that Physical Losses cannot be eliminated totally. However, they can be reduced by the following four leakage control strategies:

- *Active leakage control*: is the process of undertaking leakage detection surveys on a targeted or regular basis in order to manage leakage within a water distribution network.
- *Pressure management*: probably the most cost-efficient method of controlling leakage. Pressure management includes all the processes involved in monitoring and controlling pressures within the supply and distribution networks.
- *Speed and quality of repairs*: reducing the time it takes to repair a leak will reduce the volume of water being lost thus reducing leakage. It is equally important to carry out a high quality repair both in terms of workmanship and materials used thus avoiding leak recurrence.
- *Targeted renewal of infrastructure:* blanket replacement of mains is best avoided as it leads to replacing pipes which do not experience serious integrity problems. If target replacement is

followed based on failure analysis it is inevitable that infrastructure renewal will be focused and cost effective.

These four strategies need to be balanced in order to achieve the most cost effective leakage program that reduces leakage to an economically, environmentally and socially acceptable level (Figure 14).

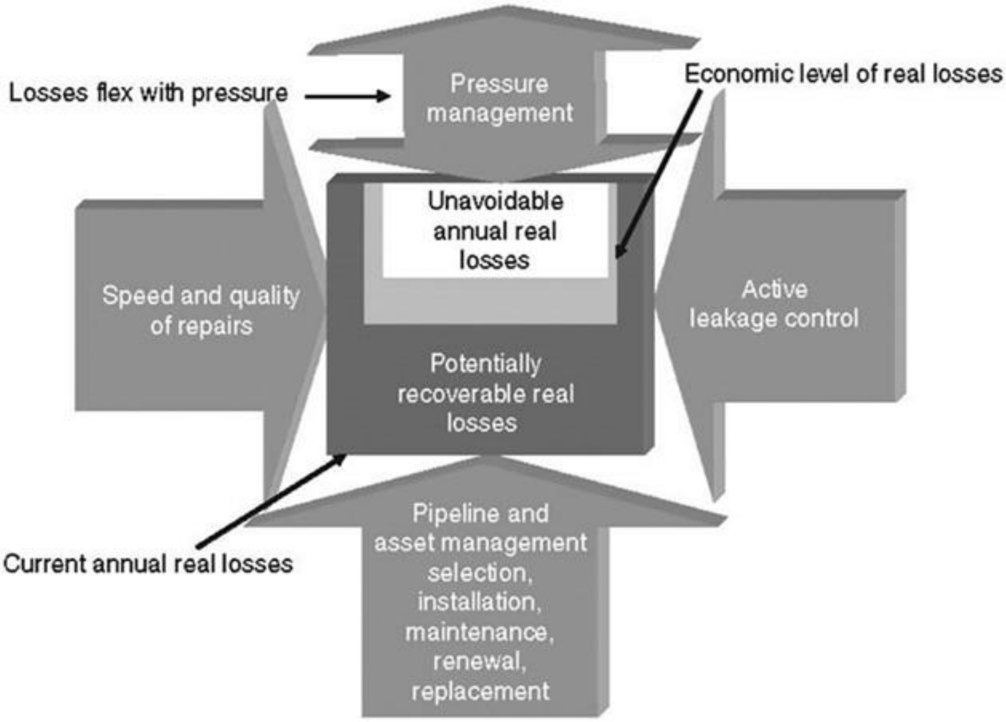

Figure 14-Leakage control strategies[27]

Practice has proven that a passive control policy is insufficient to moderate water losses. Crisis management can result in damage to roads and housing, loss of supplies, difficulty in manpower planning, premium costs for repair and the loss of large volumes of water. It is true to say that within any distribution system there is a “natural rate of rise” in water losses. This is primarily caused by on-going deterioration of the water meters and of the network, new leaks and bursts, and in carrying out “business as usual”. Therefore, a passive approach will result in a continuous rise of NRW, with detrimental effect on the level of service to the consumers. Gradually, this deterioration may result in IWS and ultimately to a complete failure by the water utility to continue to provide the required service.

6 Assessment of current conditions in the cases of limited data

6.1IWS problem analysis

The first step to transition as mentioned above is to analyse why there is IWS and to what extent.

- *Was the system designed for IWS?*

i.e. Was the system always planned to deliver water only once or twice per day to consumers? In these cases, oversized pumping stations and trunk mains are normally present since the same volume of water needs to be supplied during a short period and therefore the flow rates during this period are high. In such systems most, except the urban poor, customers have ground and roof tanks. When water supply is provided all consumer ground tanks are filled and therefore pressure in the pipes is very low.

- *Has IWS been introduced in a system that was previously supplied on a continuous basis?*

This would be typical of systems where supply is not meeting demand, due to system expansion and/or high leakage, where the utility's management is afraid that they may run out of water and hope that with IWS water demand and leakage can be substantially reduced. Customer storage tanks are normally introduced in such cases to store water during supply hours. Pressure variations when opening and closing to schedule supply to different areas (or the entire system) will cause extreme pressure fluctuations and transients, which will have a massive impact on the burst frequency and network rapid deterioration.

Transitioning to 24×7 will need different strategies for the different situations. Hydraulic analysis of the distribution network would be useful, to identify possible hydraulic bottlenecks and areas with highest levels of physical losses.

6.2Initial water audit

Ideally a full water audit should be carried out resulting in an IWA Water Balance with 95% confidence limits. However, if a full water audit is not feasible, at least an initial audit, or "Rapid NRW Assessment" is required. The Rapid NRW Assessment is a simple, fast and usually inexpensive methodology to get a first understanding of the NRW situation in a water system. It is a precondition for understanding the magnitude of the IWS problems and the prospects of transitioning to 24×7.

Collection of all necessary data and information to determine the following:

- Daily volume of NRW

Review available records and identify possible irregularities and determine the most likely average daily volume. Review billed consumption data, both billed metered and billed unmetered consumption and determine the annual daily average volume of billed consumption.

- Average supply time

Calculate the average daily supply time. Identify areas with different supply times, determine the approximate number of service connections of each area and calculate a weighted average supply time using the number of connections as weighting factor.

- Average pressure

The average pressure in a certain point is the 24-hour average. Pressures will be recorded with electronic pressure loggers for at least a 24h period at each point. If no pressure loggers are available, pressures during low-pressure periods (normally during peak demand time) and during high pressure periods (usually night-time pressures) shall be measured with pressure gauges. Identify areas with different pressure characteristics, measure pressures and calculate average pressure for each area, determine the approximate number of service connections of each area and calculate a weighted average pressure using the number of connections as weighting factor. Please note that only pressure during supply hours must be used in the calculation.

- Number of service connections

Determine the number of service connections, which is in many cases not equal to the number of customers. Only in cases where each customer (account) is supplied by an individual service connection the number of connections equals the number of customers. If, for example, every single condominium in a building is considered one customer (=one account) then the number of service connections will be significantly less than the number of customers (one condominium building may consist of, for example, 100 customers but is supplied by only one service connection.

6.3Physical Loss Indicators

Based on the rapid assessment as explained in Chapter 6.2 the next essential step is to determine the physical loss condition of the network under IWS. The following elements of the physical water loss components should be calculated:

- Physical losses

Physical losses will be expressed in litres per service connection per day per meter (head) average pressure and adjusted for the average daily supply time:

l/conn./d/m when the system in pressurised 24x7 (w.s.p.)

Below is a step by step instruction on how to calculate the physical losses:

1. Determine daily volume of Physical losses. These are the different scenarios:

   a. Water audit available – simply take average daily volume of physical losses from the Water Balance.
   b. Metered consumption data available but no water balance: assume the volume of physical losses, e.g. 90% of the volume of NRW.
   c. Consumption data not available and consumption measurements have been carried out: Physical losses (PL)= [system input volume] – [calculated volume of water consumed]
2. Divide average daily (PL) by the number of service connections (SC) and express result in litres/connection/day (PL in l/conn./d)
3. Adjust to supply time: [PL (l/conn./d)]/[average supply time (hours/day)] × [24hours] = [PL l/conn./d (w.s.p.)]
4. Divide by average pressure: [PL l/conn./d (w.s.p.)]/[average pressure (meter head)] = [PL l/conn./d/m (w.s.p.)]

The above PI is crucial in the volumetric assessment of the additional water (system input) that would be required to supply the area under consideration 24×7 with the network still in its present, leaky, condition before leak finding and rehabilitation works will start thus slowly reducing the input volume required.

- Volumetric assessment

This is one of the most important, and often overlooked step in planning the transitioning from IWS to 24×7. First, the additional water (system input) required to supply the selected area 24×7 with the network still in its present, leaky, condition must be calculated. Second, a target leakage level for the rehabilitated network must be determined. Third the volume of physical losses and then the total water demand for 24×7 and a rehabilitated network can be calculated. In detail:

1. Additional volume of water required:

(a) Volume of physical losses for present network condition and 24×7 supply:

[Number of SC] × [PL l/conn./d/m (w.s.p.)] × [expected average pressure (meter head)]

Note: it needs to be expected that pressure will increase when supplied 24×7; make a reasonable assumption based on the local situation

(b) [Volume of PL for 24×7] – [Volume of PL for IWS] = [Volume of additional water required]

2. The target leakage level will depend on the present leakage level. As a first suggestion, the following formula can be used to get an idea about a realistically achievable physical loss target level:

[target PL l/conn./d/m (w.s.p.)] = [present PL l/conn./d/m (w.s.p.)] × 0.05 + 8

Once this (still high) level of physical losses has been achieved further physical loss reduction programs can be designed and implemented to reduce physical losses further until the most economic level is reached.

3. Calculation of the future system input volume at 24×7 supply, target level of physical losses and target pressure:

(a) Volume of physical losses for future network condition and 24×7 supply:

[Number of SC] × [target PL l/conn./d/m (w.s.p.)] × [target average pressure (meter head)]

Note: the target pressure will depend on the hydraulic situation and the level of service policy

of the water utility

(b) [Future Volume of PL] + [Consumption] = [Future System Input Volume]

7 Guwahati Use Case

7.1Introduction to Guwahati

The climate and subsequently rainfall distribution in India vary across the country. Guwahati located in north-east state of Assam has a predominantly humid sub-tropical climate, thus exhibiting a highly wet weather. The city of Guwahati receives its highest rainfall from April until September every year. The Brahmaputra River, which is part of the Ganga river basin, flows through the heart of Guwahati city debouching at the Ganga Delta in Bangladesh (Figure 15). The water table in the area is constantly at a high level and gets fully recharged during the rainy season. There is no shortage of water per se, but a shortage of purified water.

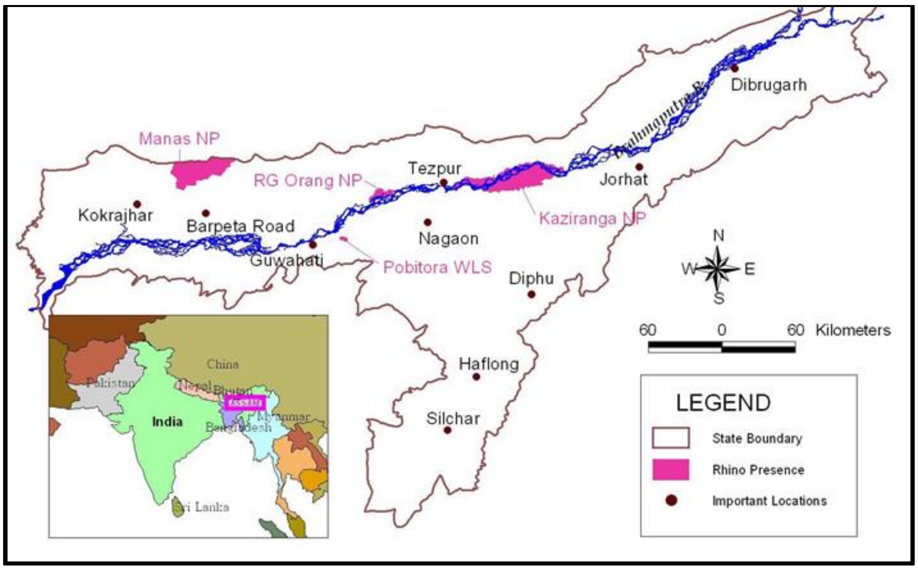

Figure 15-Map indicating the location of the city of Guwahati

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Guwahati (Figure 16) faces a problem of irregularity in water supply, with sharp seasonal variation. In general, the water has high turbidity levels, especially during the monsoon season as the water carries a large amount of silt. Therefore, the settlement process takes longer than usual. During the floods, polluted water enters into the water distribution pipes through the cracks and holes, further reducing the quality of water.

Figure 16-Guwahati Panorama

The present water supply in Guwahati caters for less than 30% of the population, for about 1-2 hours a day. As most of the water treatment plants and pipelines have outlived their design life, the output from the plants is about 70% of their capacity and the water losses in the transmission pipelines is about 40%. The water distributed through the network is not suitable for drinking. Due IWS, individual homes are constructed with local storage tanks to achieve 24x7 supply, where water may be stored for months.

In order to provide affordable, reliable, safe, pressurized and continuous supply of water to this fast developing area, the Government of Assam has taken up major water supply projects. On completion of these projects, Guwahati will have brand new water supply infrastructure for the entire metropolitan area, with a facility to monitor from a central location and control at the local level through SCADA systems. These projects aim for 100% coverage either through house connections or community connection.

For efficient monitoring of operation and maintenance of the projects, it is essential for the Guwahati Jal Board to have a centralized remote monitoring system using sensors along with control over the delivery of water from water treatment plants through the transmission and storage systems and down to local DMAs. The Guwahati Water Board is planning a major upgrade of the network with the long-term goal to provide 24x7 water supply. The demonstration and optimal operation of such a network may provide a point of reference for urban water systems in India.

The proposed advanced design, monitoring and operation solution for the distribution network is expected to:

- improve water supply to Guwahati residents from 2 hours per day to 12 hours per day
- provide water quality parameters in real-time so that tap water can be used without further local treatment, reducing wastage of water by 30 % (through the improvement of utilities' safety plan)
- reduce operational costs by 10 % and NRW by 10 %
- optimise chemical dosage by 10% with the help of optimal control algorithms and real-time sensing of residual chlorination levels
- reduce the energy consumption of the water distribution network by minimising boost pumping at end point
- detect accidental contamination in the network early and propose rectification procedures to minimize the delivery of impure water.

An area in the existing water distribution network of Guwahati which is currently supplied intermittently was identified as a use case, described in the following section. This use case is to be used to demonstrate how to improve water supply conditions with the aim of moving towards continuous supply.

7.2Description of DMA 1

The DMA use case which will be focused on for transitioning from IWS to 24x7 is DMA1, one of 4 DMAs in the Kamakhya Water Supply Scheme of Guwahati Metropolitan Area. The location of Kamakhya Water Supply Scheme is presented in Figure 15Figure 17, while Figure 18 shows the location of DMA 1,2,3 and 4.

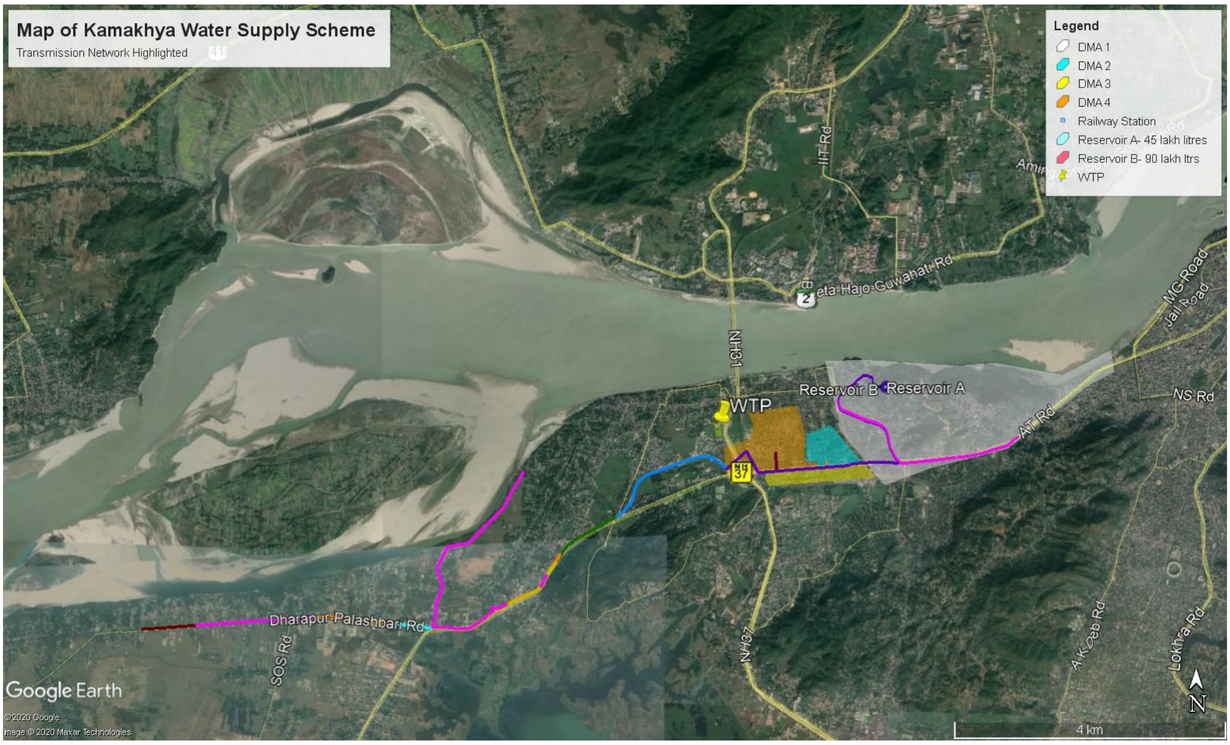

Figure 17-Map of Kamakhya Scheme

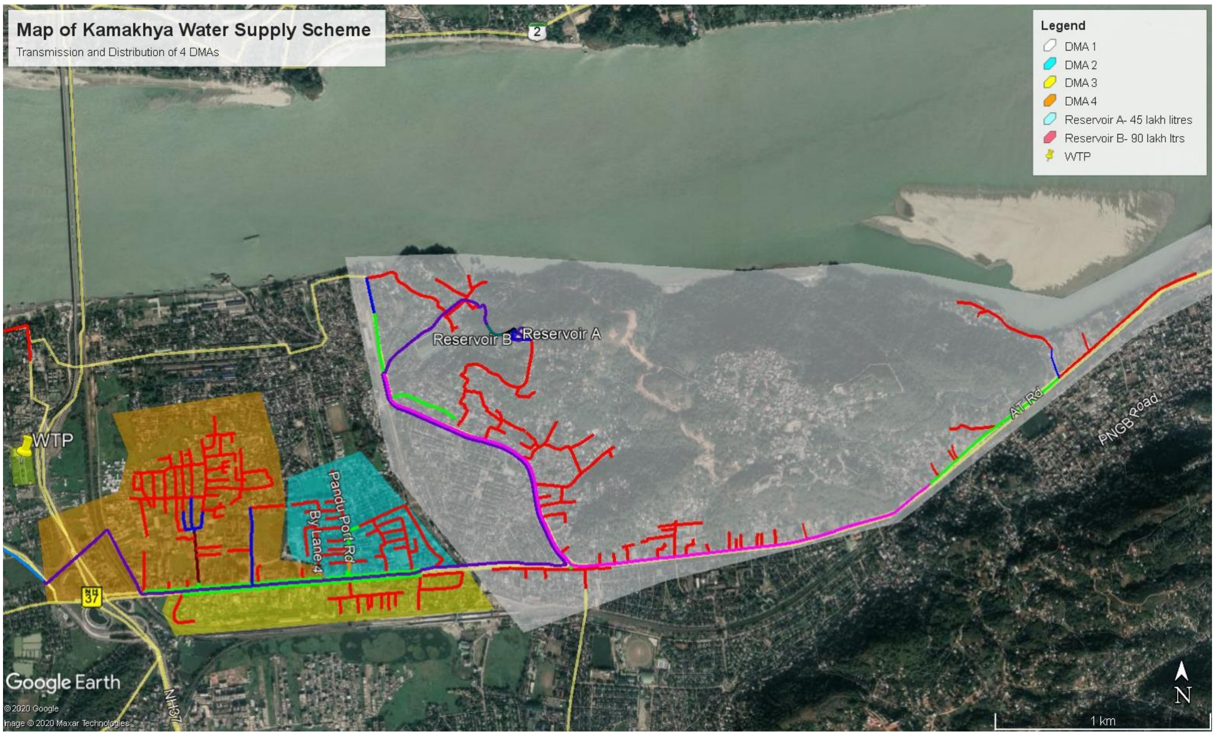

Figure 18-Map of DMA 1,2,3,4

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Figure 19 provides an illustration of the water supply operations in the Kamakhya Water Supply Scheme. As can be seen from the figure, there are three intake wells for extraction of raw water, with six vertical turbine pumps, of which three are on standby. The transmission network for raw water from the abstraction point to the water treatment plant is approximately 5.4 km of 1400 mm diameter mild steel pipe. A 53.5 million litres/ day (MLD) water treatment plant has been constructed as the first phase of a proposed 107 MLD water treatment plant. There are six centrifugal pumps (of which three are on standby) pumping water from a 3600-m^3 clean water reservoir at the water treatment plant via a treated water transmission network of approximately 5.7 km long and 1400 mm diameter mild steel pipes to two reservoirs of service storage capacity of 13.5 MLD located on the Kamakhya hill. A ductile iron gravity main of 700-mm diameter supplies stored water by gravity from the reservoir to DMAs 1-11. The distribution network length of about 33 km in DMAs 1,2,3 and 4 is completed and commissioned.

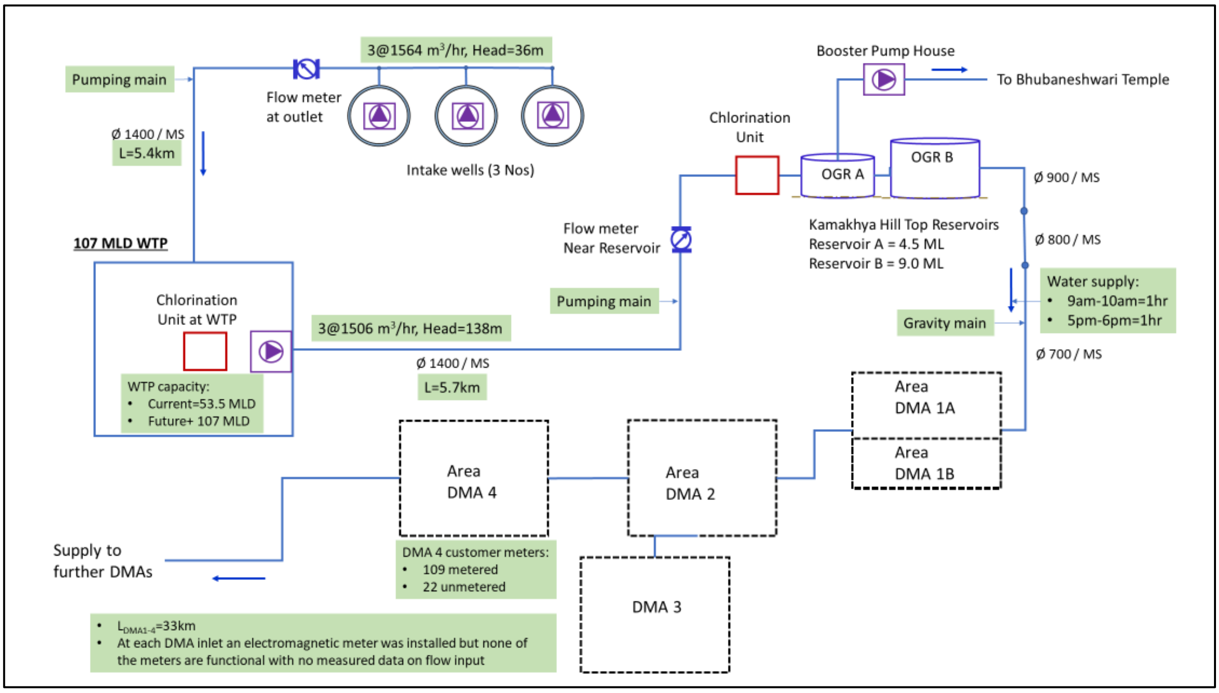

Figure 19-Schematic of the Kamakhya Water Supply Scheme

Currently, daily water supply provided to DMA1-4 is on average two hours, one hour at 9 – 10am and another hour at 5-6pm. Each DMA inlet is equipped with an electro-magnetic flow meter but none of the meters are functional, with no measured data on flow input.

From a potential 4000 service connections, some 2500 service connections were already installed. Customer meter installation was halted since March 2020 due to the COVID-19 lockdown in India.

While installing customer meters, the operational staff were also collecting the geo-reference data on the location, number of users per connection and initial meter reading. However, the collection was only partially completed and paused due to COVID-19 lockdown and hence no measured supply and consumption data is available.

7.3Data required

The following data and information were to be collected in order to form the basis for assessing the current situation of water supply in DMA1 area, as per procedure outlined in Chapter 5 of this Guide:

- Data and set-up showing potable water sources, main water storage reservoirs, pumping facilities, main supply network layout and mode of operation.
- Data on current distribution network sectorisation, including boundaries and operating hydraulic heads of network pressure areas.
- Data and information on the quality, material, lengths and age of network.
- Current water supply regime from water sources to the Zone, hours of supply giving corresponding supply volumes and average operating pressure.
- Current water supply regime to the distribution areas, hours of supply per area per no of days giving corresponding supply volumes and average operating pressure in each area.
- Flow and pressure data, accuracy of production supply meters, continuous monitoring showing Minimum Night Flow (MNF) data and pressure variation if available.
- Information on network monitoring equipment and specialised leak detection equipment available (pressure loggers, bulk flow meters, listening sticks, ground microphones, leak noise correlators, leak noise loggers, etc.).
- Records on leak repair statistics, differentiating them between leaks on service connections and main pipes, both for reported leaks and leaks detected by leak detection teams indicating average repair time for leaks on mains and service connections as well as quality of repairs and current repair practices.
- Pipeline replacement records as well as existing pipeline replacement plans.
- Information on current customer metering practices, including type, manufacturer and age of customer meters used as well as customer meter testing facilities and replacement practices.
- Customer database (type of customers, connection and disconnection policies, illegal connections) and their consumption profiles.
- Tariff structure (flat rates, unmetered, large customers).
- Billing policies (government and municipal buildings, temples, public gardens, etc.).
- Billing policies (public and municipal buildings, etc.) and collection process.

To carry out the Water Balance the following data and information have been requested:

- Available data and information, for the entire network for a 12-month period in accordance with the format of the IWA indicating the error ranges of the water balance components.
- Data and information on the total system input and output volume for the period.

- Billing records, billed consumption of the different customer groups, as well as estimates of the potential commercial losses due to inefficiencies of the billing system and/or the billing process.
- Unbilled authorized consumption including total volume of unbilled authorized consumption.
- Components of unauthorized consumption and volume of unauthorized consumption based on the utility's experience and records.
- Availability of water supply against forecast demand.

In the absence of detailed data and information as required in the above listings it was proposed to provide the absolute minimum data that is needed in order to assess the current IWS situation, carry out an initial water audit and performance assessment and develop an improvement plan for water supply to DMA1.

Data were requested on water volumes and network characteristics for DMA1 as described in detail in the template provided in Appendix 2 and summarised below for ease of reference:

- *System Input Volume* (DMA Inlet Meter): This would be the volume of water which was supplied into the network during the period under consideration and was recorded by the DMA1 inlet meter.
- *Consumption* (metered and unmetered): This would be the volume of water used by the registered metered consumers in DMA1 as measured during the period under consideration as well as the estimated volume of water used by any registered consumer in DMA1 that is unmetered.
- *Service connections*: The number of service connection pipes which connect the consumers to the network pipeline, and normally should be less than the number of registered consumers since in many cases more than 1 consumer is served by a single service connection.
- *Average pressure*: The average (taken over a 24-hour period) operating pressure at the mid-point of DMA1.
- *Supply time:* The actual time that the network is supplied with water per day.

The data was to be collected during March to July 2020, however due to the COVID-19 lockdown it was not possible to obtain the field and other data required.

The availability of data and information pertaining to the water volumes and network characteristics as described in Appendix 2 would have enabled the Rapid Assessment of the current situation in DMA1 on the basis of which a water supply improvement plan to DMA1 would have been developed. The improvement plan would have centred on an increase in the supply time to DMA1 through a reduction of leakage in the DMA1 thus making more water available for distribution to the consumers. Ultimately this process would result in a system that is supplied on a 24x7 basis having optimal leakage levels.

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9 Appendix 1-Data required to compute the Water Balance

Required Data	Unit	Description
System input volume	m^3	is the volume of treated water supplied to the network for which the water balance calculation is carried out
Billed authorized metered consumption	m^3	is all metered consumption that is billed and includes all groups of customers, such as domestic, commercial, industrial and institutional
Billed authorised unmetered consumption	m^3	is all billed consumption that is calculated based on estimates or norms but is not metered
Bulk water supply (water exported)	m^3	is the volume of water transferred across operational boundaries that is either metered or unmetered and billed
Unbilled authorized metered consumption	m^3	is metered consumption that is for any reason unbilled, e.g. metered consumption by the utility itself or water provided to institutions free of charge.
Unbilled authorized bulk water supply (export)	m^3	includes any water transferred across operational boundaries metered and unbilled. This type of consumption is rarely unmetered.
Unbilled authorized unmetered consumption	m^3	is any kind of authorized consumption that is neither billed nor metered and typically includes items such as firefighting, flushing of mains and sewers, street cleaning, etc.
Domestic Illegal connections	no.	is defined as a connection to domestic premises which is not formal and is not included in the utility's billing register
Average number of persons per household served by domestic illegal connection	no.	is normally the average number of people that are in the households served by the informal connections and if not known the average for the respective city/region
Per capita consumption in households served by domestic illegal connection	litres/pers on/day	is an assumed per capita consumption which usually is much higher than the national average

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Other Illegal connections	no.	is any connection to non-domestic premises which has been installed onto a main or another service pipe without the permission or authority of the utility
Average consumption of other illegal connections	litres/connection/day	is an estimated or assumed use based on local conditions and knowledge
Meter tampering, bypasses, etc. at registered customers	no.	is defined as the number of registered customers having meters who obtain water by fraudulently tampering with the meter or bypassing it
Average daily consumption from meter tampering, bypasses, etc. at registered customers	litres/customer/day	is an estimated or assumed use based on local knowledge and conditions
Customer meter inaccuracies and data handling		which are caused by errors in the meter reading and billing system. The data required include the following:
Under-registration of billed metered consumption by customer meters	%	is defined as the average percentage that the billed customer meters are under-registering the actual volume of water which passes through the meter
Under-registration of metered bulk supply to areas	%	is defined as the percentage that the bulk meters are under-registering the actual volume of water transferred across operational boundaries
Under-registration of unbilled metered consumption	%	is defined as the average percentage that the unbilled customer meters are under-registering the actual volume of water which passes
Corrupt meter reading practices	%	is defined as a percentage of the actual customer consumption representing possible malpractices by meter readers in entering the true consumption values in the billing system
Data handling errors	m^3	is the difference between the volume of true consumption and billed consumption due to billing or data handling errors
Total length transmission mains and distribution network	km	is the combined length of the transmission mains and distribution network but does not include the service connections

Possible under-estimation of the total length of transmission mains and distribution network	%	is defined as the possible underestimation of the total length in case the network is estimated without being accurately measured using GIS maps and drawings
Service connections of registered customer accounts	no.	is defined as the pipe from the main pipe in the street to the premises. One service connection may serve one customer account (meter) in the case of a single house, or several customer accounts, in the case of apartment blocks.
Active registered customer accounts	no.	registered customers who have active accounts and receive water from the utility
Inactive customer accounts with existing service connection	no.	customers that do not receive water and have deactivated their accounts but the service connection to their premises is still in place
Average length of service connection from property boundary to customer meter	m	is defined as the average length of pipe on private property from the property boundary to the customer meter or to the building in case of unmetered customers
Daily average pressure	m	is the 24-hour average operational pressure in the network
Supply time	hours/day days/week	is the time period which the system is pressurised adequately to water maintain supply to customers
Average water tariff	price per m^3	is the average sale price of water for a unit volume of water
Marginal cost of water	cost per m^3	is the cost of producing and distributing an additional unit volume of water

10 Appendix 2-Minimum data required to assess current water supply situation in DMA 1

DESCRIPTION	VALUE	UNIT	COMMENTS
Water Volumes			
Period under consideration	From(date)	To(date)	This would cover the period that the readings are available (from – to)
Water balance period		days	This would be the number of days for the period under consideration. It will depend on the availability of readings. An absolute minimum period of one month would be needed. The longer the period the better.
System Input Volume (DMA Inlet Meter)		m^3	This would be the volume of water which was supplied into the network during the period under consideration and was recorded by the DMA inlet meter.
Consumption (metered) - for the consumers connected to the network		m^3	This would be the volume of water used by the registered metered consumers during the period under consideration
Consumption (unmetered) - if any such consumers are connected to the network		m^3	This would be the volume of water used by the registered unmetered consumers, if any, during the period under consideration
Illegal connections		m^3	If the utility is aware of any such use and an estimate can be made. If not, an assumption will be made depending on whether this is a minor or significant problem in this DMA
Customer meters' accuracy		YES/NO	Are the customer meters new, in good condition and properly installed (respond as appropriate in yellow cell)

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DESCRIPTION	VALUE	UNIT	COMMENTS
Network Data			
Length of pipelines		km	This is the length of network in DMA 1 after the inlet meter and does not include the length of service connection pipes
Service connections		number	A service connection is the pipe which connects the consumer to the network pipeline, it is normally of small diameter ranging from 15mm to 50mm depending on the number of consumers connected to each service connection. This should include the connections that are installed and active awaiting connection to a consumer
Length of service connection on private land		m	This is the average length of service connection from the property boundary to the consumer’s meter. If the consumer meters are located at the property boundary then this length is zero
Daily average pressure		m	This is the average (taken over a 24-hour period) operating pressure at the mid-point of the DMA. The mid-point is normally taken as the average elevation in the DMA provided the network layout is equally spread over the DMA
Supply time		hours/day	This is the actual time that the network is supplied with water per day
Metered consumers		number	This is the number of consumers that are physically connected to and are taking water from the network, through a meter installed at the property
Unmetered consumers		number	This is the number of consumers that are physically connected to and are taking water from the network, without a meter installed at the property

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