

A NEW INDEX SYSTEM FOR INTERMITTENT WATER SUPPLY

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ABSTRACT

Intermittent water supply is a worldwide phenomenon, that adversely impacts water availability, water quality, human health, reticulation network operation, maintenance, service life as well as water demand. A need was identified to develop an index designed to categorise, classify and better understand intermittent water supply in all its forms. Research to date has addressed the prevalence, causes, impacts, water quality, health problems, water demand and operational problems associated with intermittent water supply. Despite the available body of research, an index has not been developed to quantify the extent of intermittent supply in any given supply system, or part thereof. A study was conducted on the experience of intermittent water supply and lessons learnt throughout the world, with the specific aim of developing an index comprising all relevant parameters. The study included an extensive literature review and detail analyses of causes, impacts and magnitudes associated with intermittent water supply. As part of this research, all the relevant parameters were identified and incorporated to conceptually develop a generic index for intermittent water supply. It was found that intermittent water supply is often complicated by other factors leading to ephemeral periods of non-supply, especially in developing countries. Parameters that were available in quasi real-time, such as reservoir levels, flow rates and water pressure, were considered useful in view of future application to control and manage distribution systems so as to prevent areas of intermittent supply. With the index fully developed it will become possible to compare intermittent water supply in a global context, get an understanding of the causes, classify severity and potential impacts of intermittent water supply, better plan remedial action, and increase reticulation network resilience.

Keywords: intermittent water supply

1 BACKGROUND

1.1 A broad view of acceptable potable water supply

Access to safe drinking water and sanitation is considered indispensable to sustain human life and health. It is generally accepted that at least 50 to 100 L/c/d is required to serve the most basic needs and reduce health risks. Water is provided to homes through water reticulation networks for the purposes of domestic consumption, personal hygiene and some outdoor water uses. Most water supply systems are conceptually designed for continuous water supply (CWS). This implies that the piping system is designed to be filled with water under pressure continuously. An acceptable level of service could be viewed as a system where consumers have a continuous and sufficient volume of water (quantity) on demand, at an acceptable standard (quality) within a specified pressure range - not too high and not too low [1].

1.2 Prevalence of intermittent water supply

Although CWS is the design condition and the ideal, it cannot always be maintained. Millions of people worldwide live in environments where intermittent water supply (IWS) is experienced. IWS occurs when water is supplied through pipes for limited durations only, often by way of supply cycles [2]. It was found that IWS typically occurs more often in developing countries [2, 1]. Statistics show an estimated one third of the population with piped water supply in Africa, more than half in Asia and two thirds in Latin America experience IWS [1].

1.2 Methodology and Objective

The research team set out to develop a comprehensive understanding of intermittent water supply, to classify different causes, impacts and severity of IWS and to develop a new indexing system by means of a desktop study. The indexing system has to be useful to quantify IWS experienced within the supply boundaries of a water supply authority and to compare the IWS experienced within that authority to others.

2 CAUSES OF INTERMITTENT WATER SUPPLY

IWS is caused by various factors, many of which have been well researched in recent years. For the purpose of this indexing system, the causes have been combined under the following three main categories:

- Water resource limitations
- Increasing water demand
- Technical deficiencies.

These three main categories, together with their underlying sub-categories, are briefly discussed below.

2.1 Water resource limitations

Raw water supply, and by implication the available water resources, often limits the maximum water demand that can be met by a water supply authority. The maximum water supply potential of a water supply authority is limited by various factors, such as resources reaching the maximum yield potential and climate change.

Viable water resources at maximum limit. Surface water resources are the most susceptible to this cause of IWS. Rainfall, which leads to surface water run-off is limited by the climate of an area. In addition, natural streams and rivers present a limited number of opportunities for the construction of large dams. At some point during the development of an area, all available surface run-off water will have been collected in the available and viable water storage schemes. Through

similar reasoning, ground water schemes generally have a limited potential maximum yield. The only potential water source schemes left beyond this point, are often those that are non-viable. This problem is especially relevant to inland regions, where seawater is not available within reasonable distances for desalination. Should development be allowed to continue beyond the point where all the viable water resources have reached its maximum limit, IWS could result.

Climate change. Climate change refers to the persistent change of the climatic system of the globe over time [3]. Studies suggest that anthropogenic contributions, such as rapid population growth, industrialisation and land use changes, are the main reasons for climatic changes [3]. Human development is leading to an increase in greenhouse gas emissions. These gases are able to absorb and emit infrared radiation from the Earth, which in turn warms the Earth [4]. Studies conclude that global warming impacts the hydrological cycle and contributes to an increase in severe drought and flood events, as well as redistributed rainfall patterns [3, 5]. Climate change could therefore reduce water sources' historic yields and lead to supply problems and IWS, especially where water supply authorities rely on surface water run-off as their primary water source.

2.2 Increasing water demand

Population growth: One of the reasons for inadequate water supply is rapid population growth, which directly increases water demand. According to the United Nations [6] the global population is growing at 1.1% per year, leading to an additional 83 million people annually. Some regions, such as Africa, are predicted to have higher-than-average growth, leading to a more pronounced impact of population growth on the total water demand in the region.

Urbanisation: The concentration of population in urban areas is set to increase in future with rapid urbanisation [3]. The increased concentration of people leads directly to increased water demand. An increase in water demand in urban areas introduces expensive measures to convey water from remote locations to provide for the additional, concentrated, demand. If demand outstrips supply, IWS may result.

Temporal variation: In addition to the total demand of consumers being important, the temporal distribution of demand impacts service delivery. The demand of consumers may be relatively stable and given resources may be sufficient to meet the demand on, say, an annual basis. However, variation of demand may induce problems where demand exceeds the available supply, both seasonally [7] and also diurnally [8].

2.3 Technical deficiencies

In a water supply system, a deficiency can occur when the water supply authority is unable to provide the necessary services due to technical deficiencies [1]. Technical deficiencies can lead to IWS, even though the water resource, in principle, can meet the demand [1]. Technical deficiencies can have a number of causes, as discussed below.

Scarcity of qualified technical staff in water supply authorities: A census of the 231 local municipalities in South Africa showed that 79 municipalities do not have civil engineers, technicians or technologists, and that only 45 municipalities have civil engineers [9]. Technical staff are required for their expertise and knowledge to design and operate water reticulation networks efficiently in order to avoid technical deficiencies.

Data collection: Data collection and interpretation are deemed vital for the design and operation of a water reticulation network. Unfortunately, many water supply authorities, especially in developing countries, have no system in place to collect data on a continuous basis and no records that monitor the supply system. Those that are being kept are often outdated and unreliable. In a study by Klingel in the Algerian town Béni Abbès, data was compared to the actual supply system and showed irregularities in 86% of the supply system [1].

Reticulation network planning: Various studies confirm that developing countries often lack a fully developed water reticulation network concept. The present water demand is often designed for without considering factors such as population growth and urbanisation. Without proper planning systems tend to be inefficient and more prone to technical deficiencies. Furthermore, many water supply systems are designed with the assumption of continuous unlimited supply, rendering them unsuitable for IWS when water stress conditions occur [3].

Infrastructure management: Through the lack of qualified technical staff at water supply authorities, the lack of data collection and the lack of proper reticulation network and demand planning, water reticulation networks will deteriorate and will eventually fail to provide water to all consumers. Under these condition leakages increase that could result in significant water losses. Without proper infrastructure management it becomes difficult to manage and reduce leakage rates, and by contrast supply the demand, leading to an increase in IWS.

3. IMPACTS OF INTERMITTENT WATER SUPPLY

Intermittent water supply can lead to a number of adverse impacts. These impacts are often interactive and typically follow one other. In the section below the various impacts of IWS are discussed.

3.1 Consumer delivery failure

The most fundamental impact of IWS is the failure to deliver potable water to consumers. Factors such as short supply periods, unequal distribution of water and unreliable delivery timings compel consumers to make provision for the periods without water supply. Common provisional entities include in-house storage tanks, private pumps for extraction and secondary sources of water, such as private water sources, supply from a tank car and purchased bottled water [1].

3.2 Poor water quality

As stated earlier, one of the main water supply requirements is water quality. Complex biological, chemical and physical mechanisms in water supply can lead to water quality degradation. When referring to water quality degradation, it is closely related to microbial contamination of water. Microbial contamination is known as the most common type of contamination causing illnesses in developing countries [2]. Pathogens (disease-causing microbes) in the water lead to waterborne diseases, which cause 3.4 million deaths each year [10]. The three main mechanisms of water quality degradation introduced and/or aggravated by IWS are (1) intrusion and backflow and (2) stagnation of water and (3) flushing [2].

Intrusion and backflow: Intrusion takes place when contaminants from the environment enter the water supply system through infrastructure deficiencies such as pipe breaks and joints. Backflow occurs between cross-connections where there is a plumbed connection between potable water and a non-potable source [2, 11].

Stagnation of water: Between supply cycles before water drains, the water in the IWS system experience variable durations of residence time or stagnation. During this time pathogenic colonisation is encouraged by the decay of disinfectant residuals. Disinfectant residuals kill or inactivate waterborne pathogens and a low concentration is an indication of decreased water quality, as often seen in studies of IWS. Between supply cycles biofilms and loose deposits have time to accumulate on pipe walls and provide protection to pathogens against disinfectants. They have enough strength to withstand normal hydraulic conditions of CWS, but are sensitive to a change in shear stress, a distinct feature of IWS. In water reticulation networks subjected to IWS, biofilms can easily detach from the pipe walls and contaminate the water supplied to consumers [2, 11].

Flushing: A flushing effect at IWS charge-up is a result of increased shear stress due to empty supply pipes pressurising and expelling air from the system. Studies confirm that IWS has higher micro-organism and turbidity concentrations during flushing than during the remaining supply period. During flushing sediment deposits, chemical and metal scale and biofilms are removed from pipe walls. In CWS flushing is an infrequent activity which is used to cleanse pipes and increase the water quality. In IWS flushing can have the same positive effect on water quality if the supply duration is long enough. However, if the supply period is too short, a large part of the consumer supply will consist of flush water with higher concentrations of contaminants. Another critical distinction between IWS and CWS is that consumers of IWS will most likely still collect and store the flush water as provision for periods of zero supply [2, 11].

3.3 Health risks

Poor water quality leads to increased health risks; however, lengthy discussions about the health risks, bar that contained in **Section 3.2**, was considered to be outside the scope of this study, which focusses on developing an indexing system for IWS from an engineering perspective.

3.4 Water losses

Infrastructure components of supply systems are exposed to pressure surges (water hammer), regular depressurisation and pressurisation of IWS systems and system design defects, which reduce the service life thereof [1]. The related consequences are that water reticulation networks function inefficiently and that more pipe breaks occur followed by increased water losses. When a supply system does not sustain continuous flow under pressure, i.e. IWS, important measuring methods for water losses and detection of leakages cannot be applied [1]. This makes it difficult to manage and reduce water losses. Furthermore, the practice of charge-up and charge-down in IWS can damage water meters [2]. Additionally, float valves in in-house tanks and air pockets in IWS systems may cause incorrect water flow readings [2].

3.5 Wastage of water

Wastage of water exacerbate the critical problem of water losses. The concept of charge-up and charge-down of IWS leads to the supply of large volumes of water in a short period of time. Consequences are the overflow of in-house tanks and tanks that are emptied prior to supply periods in order to make space for new fresh water [1]. In conclusion studies show that poor management of private tanks has a noticeable impact on water wastage [1].

3.6 Financial impacts

IWS can have direct and indirect impacts on the consumer's financial circumstances, as consumers feel the need to make additional provision for water supply. The purchase of private pumps and in-house tanks are common in IWS areas, which lead to expensive energy-related costs. Additionally, consumers also rely on the use of secondary water sources such as bottled water and private wells for water supply [1]. When a household cannot afford float valves or large enough in-house tanks, a household member is obliged to watch during supply periods and fill the water tanks [1]. Indirect costs are generated when that member is unable to provide an income for the household. Another example of indirect costs is related to the treatment of water-borne diseases and the loss of income as consequence thereof [1]. IWS can therefore become a critical problem in poor communities.

4. QUANTIFYING LEVELS OF IWS

When attempting to quantify the levels of IWS, a number of factors should be considered. These factors are generally considered within the supply boundaries of a single water supply authority:

- Population number experiencing IWS
- Percentage of population experiencing IWS
- Demand volume affected by IWS
- The demand supplied as IWS, expressed as a percentage of the total water demand
- Average duration of supply periods associated with the IWS
- The ratio between IWS and CWS within a water supply authority, on the basis of supply volume, as well as supply duration.

The reason why all these factors should be considered during attempts to quantify levels of IWS within a water supply authority, is because both quantum and relative quantum is required to determine the relative extent of IWS. Large water supply authorities may supply 100 ML/d via IWS, which may constitute only 10% of the total water demand. Smaller water supply authorities may supply 3 ML/d via IWS, which may constitute 50% of the total water demand. While the quantum of the former is significantly higher, the relative extent of IWS in the latter is far greater. Yet, developing new water resources to supplement the CWS shortfall of 3 ML/d for the latter, could be far more achievable than developing new water resources to supplement the CWS shortfall of 100 ML/d for the former (assuming that the raw water is available in both instances).

5. INDEXING SYSTEM FOR IWS

A conceptual indexing system was developed as part of this project. The research team is currently still developing and finalising the indexing system, and plans to apply and test the index to a number of case studies where IWS is experienced. The IWS index (IX) is a function of the following factors:

- Causes (C)
- Impacts (I)
- Quantum (Q)

The relationship can be expressed mathematically as follows:

$$IX = f(C, I, Q)$$

This implies that cause, impact and quantum are the key parameters in the index, albeit comprising, where relevant, the underlying fundamental principles.

6. CONCLUSION

While IWS is already a widespread phenomenon, many developing countries are further reducing supply durations [2]. This trend can be largely attributed to limited natural water resources and the considerable global population growth and urbanisation. Many water supply authorities will therefore be faced with the challenge of IWS in the foreseeable future; therefore an improved understanding of IWS is vital in order to improve service delivery. The causes, impacts and quantum of IWS have been discussed extensively in this paper. It is envisaged that the ultimate index will make it possible to classify intermittent water supply in a global context, improve understanding of the causes, classify severity and potential impacts of intermittent water supply, better plan remedial action, and increase reticulation network resilience.

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