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Gradual transition from intermittent to continuous water supply based on multi-criteria optimization for network sector selection

Amilkar E. Ilaya-Ayza [a,*], Carlos Martins [b], Enrique Campbell [c], Joaquín Izquierdo [b]

[a] Facultad Nacional de Ingeniería, Universidad Técnica de Oruro, Ciudad universitaria s/n, Oruro, Bolivia

[b] FluIng-IMM, Universitat Politècnica de València., Camino de Vera s/n, Edif. 5C, 46022 Valencia, Spain

[c] Berliner Wasserbetriebe. Cisero Straße 40, 10107 Berlin, Germany

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ABSTRACT

Piped intermittent water supply bears numerous population health problems and may damage the network infrastructure. Thus, a transition to continuous supply is an option that must be studied. Nevertheless, many water companies have not enough resources to produce the big investments necessary for a direct transition. Consequently, we propose a gradual transition process based on optimal sector selection at the various network upgrading stages of the process, while considering the possibility of simultaneously having continuous and intermittent supplied sectors. We ultimately seek every sector to have continuous supply at the end of the process. Sector selection takes into account qualitative and quantitative criteria, which guarantees equity for still intermittent sectors, benefiting the highest number of users, and facilitating water company operation tasks. Thereby, it is possible to achieve a planned transition that meets water company economical limitations. The problem of optimal sector selection is a computational complex task, since it deals with a non-linear problem with mixed decision variables and is affected by uncertainty and qualitative criteria.

1. Introduction

Piped water supply for few hours a day, or intermittent water supply, is a common form of access to water in developing countries [1], where water facilities increasingly operate based on crisis management criteria and commonly use water rationing measures, instead of implementing better planning on their systems [2]. Intermittent water supply exists due to various reasons; Totsuka et al. [3] indicate three types of problems that can cause or perpetuate intermittent supply: poor technical management, which increases leakage and reduces water availability [4,5]; economic scarcity, when there are not enough economic resources to enlarge the supply infrastructure; and absolute scarcity of water resources. These conditions, together with extreme events caused by climate change and population growth, may lead to a more frequent use of intermittent water supply [6].

* Corresponding author.
E-mail addresses: amilkar.eia@gmail.com (A.E. Ilaya-Ayza), carlos.martins.a@gmail.com (C. Martins), Enrique.Campbellgonzales@bwb.de (E. Campbell), jizquier@upv.es (J. Izquierdo).

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Usually, intermittent supply systems use sectors to organize supply hourly [7]. Nevertheless, water in small systems is commonly delivered to the entire network by hours. In this paper, we analyze the transition process for a sectorized network [8]. However; if the network is not sectorized, sectorization must be a first step before the transition process [9].

Many studies have shown that network deficiencies, caused by intermittent water supply, may not guarantee safe and reliable provision of water [10], due to intrusion of contaminated water when pressure is low or negative, and contamination during storage, bacterial growth in stagnant water, etc. [11], while sanitation and safe and reliable provision of water are fundamental components of basic municipal services. The drawbacks associated to intermittent water supply undermine possible improvements in public health in developing countries [12].

One of the best ways to assure water quality in the network, and to reduce health risks for users, is by maintaining a positive and continuous pressure level throughout the network [11,13], since using continuous supply ensures security of water. Transformation from intermittent to continuous water supply is thus one of the main challenges in developing countries concerning water and health [14].

One of the main problems for this transition is economic scarcity. Water companies are not able to make large investments to achieve twenty-four-hour supply, so that efficient, long-term planned strategies are required. For instance, a gradual transition based on improvement stages is deemed to be a good option.

Moreover, gradually improving the network enables us to learn from each stage over time to perfect the next improvement. The first transitioned sectors to continuous supply serve as guidance for next sectors. Furthermore, huge one-time investment projects may be vulnerable to initial strategic mistakes even before they have started.

Additionally, high leakage rates might often make impossible a transition to continuous supply on an entire network at once. However, it may be possible to continuously supply some sectors and reduce leakage in them, since leakage management is easier performed under continuous supply conditions [15,16] before conversion of next sectors.

Although no specific references for gradual transition processes may be found in the literature, there are recommendations suggesting the expansion of operation zones that work with continuous supply [17]. Usually, transition processes are performed with large and single investment projects [18,19], something that is, most of the times, unaffordable. In this paper, we describe a methodology that enables gradual transition. It is mainly useful for water systems' operators that work constrained to an economic scarcity context.

This methodology is based on a balanced temporal coexistence of intermittent and continuous water supply. However, one must consider equity of water supply in intermittently working sectors, so that the limited amount of water is distributed as fairly and equitably as possible [20].

Guaranteeing water supply equity is one of the biggest problems of intermittent supply [21]. The main factors involved in equity supply are: node pressures, delivered flows, line velocities, node elevation differences, size of supplied areas [22], duration of water supply, supply schedules, connection types and locations [2], network configuration, and location of supply sources [21]. If a system with intermittent water supply is designed considering supply equity, the problematic consequences of water scarcity can be reduced [23]. Hence, a water supply equity index is proposed in this paper that controls equity. It is used to evaluate each sector to prioritize its conversion from intermittent to continuous supply.

Equity in the network can be improved through planning staged hourly supply [21]. As a prerequisite, a network division into sectors is essential to achieve water delivery per hours [7]; we assume the existence of such a division of the network into sectors to achieve gradual transition.

Our paper is based on a process of gradually increasing the network capacity by stages [24]. It helps improve the hydraulic behavior of the network at every stage, and it thus leads to new scenarios with increased capacity that allows higher pressure level in all sectors. Following these stages, we claim that it is possible to perform a gradual transition, where sectors selected to start with continuous supply are those better meeting certain criteria. The transition process is complete when all sectors in the network have continuous water supply.

Thus, in each stage some sectors change to continuous supply while others still continue with intermittent water supply. Selection of sectors that would work with continuous supply must: benefit as many consumers as possible, ensure water supply equity in sectors that still work with intermittent supply, and assure suitability of operation and maintenance tasks for the water company.

The problem of optimal sector selection is addressed by using multi-criteria analysis and genetic algorithms. Using binary variables that define the intermittent/continuous state of the sectors, mixed quantitative and qualitative criteria, and the non-linear relationships between flow and head loss in the mathematical model of the network, makes the optimization process a complex task [25].

In intermittent supply systems with economic scarcity or poor technical management, monitoring and collecting system data resources are limited. Thus, this improvement proposal must be adapted to basic available information, avoiding excessive model simplification though. Moreover, it is necessary to look for alternatives to complete missing information. Therefore, collecting available quantitative information and qualitative information is important to compensate this deficiency.

The quantitative criteria account for the physical and hydraulic variables of the system through the classical theory-driven hydraulic models, and for some management variables used by the water company. Qualitative aspects are introduced in the optimization process through the water company experts' perception of operating conditions of sectors, using surveys based on the Analytic Hierarchy Process (AHP) methodology [26,27]. Finally, the network topology is included in this process through the reorganization of the network as a directed graph.