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The impact of intermittent water supply policies on urban water distribution networks

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Abstract

The research work presented herein presents a mathematical model that simulates the behaviour of urban water distribution networks (UWDNs) during a period of intermittent water supply (IWS). It investigates the effects of this policy on the condition and failure rate of the pipeline system by studying the change in the rate of occurrence of failures, using survival analysis. The analysis, based on an eight-year dataset (2003-2010) from a local Water Board, takes into account information related with the breakage incidents as well as external factors and vulnerability assessment. The results show that during the time period of implementation of the IWS and right after that, there is a significant increase in the number of water-leak incidents and a deterioration of the network condition, which indicates that the impact of IWS affects negatively the vulnerability of UWDNs.

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Keywords: Water distribution networks; Intermittent Water Supply; Survival analysis; Data Analysis; Risk Assessment

1. Introduction

Countries of arid climate conditions facing extended periods of drought and short supply of water, have turned to IWS policies as a means to reduce water consumption and to prolong their national water reserves. Unfortunately,

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adoption of this type of service fails to consider the impact of IWS on the condition of the UWDNs and the resulting water losses, inefficiencies and overall maintenance cost.

In appraising the effectiveness of IWS policies, one should examine comprehensively the results of implementing such policies and specifically on how the balance of revenue water compared to that of non-revenue water is affected, as well as the impact of IWS on the condition of the pipeline system. Reliable conclusions can only be drawn by thoroughly studying the performance of the WDN before, during and after implementing the IWS measures, and by drawing conclusions on the change of a WDN's vulnerability as a result of IWS policies.

The work presents a spatio-temporal analysis on the performance of a case-study WDN subjected to IWS operations for a two-year period, and it is an extension of research efforts by Agathokleous [1]. Survival analysis models have been developed to evaluate the performance of UWDNs under IWS operation. The results indicate that the condition of UWDNs is negatively affected during the IWS period.

2. State of knowledge

Even though a great volume of work on WDNs has already been performed, very little work has been reported in literature with regards to IWS operations and their effects on the vulnerability of WDNs that have been designed for continuous water supply. During the last decades, researchers have developed mathematical models which examine and simulate the operating mode and condition of WDNs. The models varied from mathematical models expressing the failure pattern or system reliability, to multi-objective failure models, and to multi-factored simulation systems. Recent research activities focused on abnormal operating conditions due to exogenous factors that affect the condition of the network.

Shamir and Howard [2] developed mathematical relationships which express the time from pipe installation until the first failure incident, and the failure frequencies after the first failure occurred. Andreou et al. [3] used proportional hazards models to estimate failure at an early pipe age, and a Poisson-type model for the later stages. Also Goulter and Kazemi [4] presented a non-homogeneous Poisson distribution model which predicts the probability of successive breaks. Kleiner and Rajani [5] proposed a framework to assess future rehabilitation needs using limited and incomplete data on pipe conditions. Christodoulou et al. [6] and Christodoulou [7] developed a framework for integrated GIS-based management, risk assessment and prioritization of water leakage actions. Kanakoudis [8] presented a methodology for the hierarchical analysis of the preventive maintenance policy of WDN that uses performance indices estimated by an economic analysis of the cost of actions taken for the network rehabilitation.

As aforementioned, research on the performance of WDNs operating under abnormal conditions and particularly under IWS has to date been limited, although there is an extensive literature reference for the operation, behaviour and simulation of WDN under normal operating conditions. Among the few studies on IWS, a number of them focuses on the design of pipeline systems that operate properly and functionally under IWS conditions. Such are the works of Batish [9], Sashikumar et al. [10], Vairavamoorthy et al. [11] and De Marchis et al. [12]. Work on the effect of IWS on the vulnerability of WDN is reported by Criminisi et al. [13] who studied issues related to water-meter under-registration, and by Andey and Kelkar [14] who compared continuous water supply (CWS) with IWS in four Indian cities. Their most important finding is that water consumption does not change appreciably under IWS compared with that of CWS, presuming that water demand is satisfied under IWS. In both cases, though, the reference on the vulnerability of the WDN due to the application of the IWS policy is superficial. Christodoulou and Agathokleous [15] reported on the performance of WDNs under IWS, citing that of the 12,000 water-loss incidents in a two-year period the majority were related to house connections and small-diameter pipes, with an increase in incidents during the intermittent supply period of about 28% compared to the normal operating conditions period (uninterrupted supply).

3. Case study and dataset

The data utilized in this research work originates from the Water Board of Nicosia (NWB) and relates to the WDN of the said city. The WDN in study is divided into 21 DMAs and, according to year 2007 data, it requires for its operation about 19,400,000 m3 of water per year in continuous flow, while the maximum daily demand in the summer is around 59,200 m3. The minimum consumption per day is 47,200 m3, while the daily average water consumption