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# Cost minimizing water main quality index: A static cost minimization approach

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ABSTRACT

Our paper focuses on the issue of obsolete water mains which is the main cause of water loss in developed countries. We determine the cost-efficient water mains quality index according to different parameters such as the cost of water supply, the demand for water and the cost of good quality water mains. We use French and American data for parameter calibration and conduct simulations to test the consistency of our theoretical model. We show that the difference in water abundance, water mains material and demand for water are key drivers in determining the cost-efficient water mains quality index.



## 1. Introduction

Water loss is a major issue that concerns all nations around the world. In developed countries, water leakage from water mains is the main source of water loss. In the U.S. "for decades, these systems – some built around the time of the Civil War – have been ignored by politicians and residents accustomed to paying almost nothing for water delivery".[1] Such a scenario is not exclusive to the U.S.; the presence of leakage from water mains is a concern in Europe as well. The Water Framework Directive put forward by the European Union in 2000, is one example of a supranational level enforcement strategy which requires water utilities in Europe to be able to cover their total cost. In other words, it enforces utilities to set water tariffs that cover not only the cost of water supply but also the cost of leakage reduction [13]. However, water utilities are concerned that an increase in water tariffs may reduce the demand for water, which may lead to lower revenues. Lower revenues would inhibit utilities from further engaging in leakage reduction.

In France, about 800 million euros are spent annually on replacing leaky mains. However, the current estimate of the need for mains renewal amounts to 1.5 billion euros, which is twice the current expense [36]. Water utilities resort to pumping additional water and manipulating water main pressure since this is much cheaper and more practical than repairing or replacing mains. However, such temporary solutions cannot ensure water supply sustainability in the long run. Moreover, if only temporary solutions are implemented, water mains will keep aging, which will expose the utilities to a sudden surge in costs when the need for mains renewal becomes urgent [12]. For example, main breaks may occur frequently once the mains have exceeded their useful life, causing major disruptions in cities such as flooding, which would amount to high damage compensation costs [30]. Recently some projects have emerged to develop efficient methods for leakage reduction. For instance, the PALM project in Italy (2013) has developed a method that can help detect the origin of the leakage, facilitating maintenance and repair.

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[1] The New York Times March 14, 2010.

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Moreover, with their "efficiency calculator",[2] water utilities can estimate an optimal leakage ratio which is cost-efficient. In other words, utilities will decide whether to replace mains according to this threshold level of leakage. Our model is also based on cost-efficiency but we depart from their approach by proposing a model that takes into account the *cost-minimizing water main quality index*: an index that shows the proportion of "good" mains in the network.

The existence of water loss has various repercussions: economic and financial impacts along with health and hygiene. Economically speaking, volumes of water that are lost through poorly maintained mains are extractions of water resources that are directly wasted, thereby aggravating water scarcity. Although water is never physically lost, the resources put into the production of water lost in leaks are lost forever (such as chemicals for treatment and energy for pumping) [29]. In financial terms, water loss is the amount of water that is not sold to the consumer, hence a loss of potential revenue. Moreover, "leaky pipes are known for increasing pumping energy [...] and can increase the risk of compromised water quality by allowing intrusion of polluted groundwater" [9]. The rise in the total cost due to increasing water input is the "marginal cost associated with drilling, consisting mostly of energy and treatment cost" [19]. This wasted energy has further consequences on the environment via emissions of $CO_2$ and other greenhouse gases released by energy production and consumption.

To our knowledge, a theoretical model on the issue of the quality of water main infrastructure has not yet been developed in the economic literature. Moreover, our model emphasizes the necessity of leakage reduction, which not only alleviates the stress on water resources but also contributes to the cost-efficiency of the water utility. We introduce a static cost minimization model that illustrates the benefit to the utility of maintaining good quality water mains. A dynamic model with "capital accumulation" is not relevant here since water mains are not "capital" in the traditional economic sense. In our model, the length of water mains is fixed (the kilometers of mains already exist and are given) and this stock of water mains consists of old and young mains. The distinction between old and young is determined by the expected lifetime of the mains which is supported by a huge literature on underground water mains deterioration. Hence there are no capital accumulation dynamics here. The question we ask is: how much of the existing water main network should consist of young mains? The solution we obtain is a theoretical guideline for the minimum threshold of water main network quality that should be achieved by a water utility. This threshold would depend on the characteristics of the water utility.

We define a cost function that comprises the cost of water production (pumping and treatment costs), the cost of good quality water mains and the cost of bad quality mains. The decision to increase the proportion of good quality mains or water extraction not only depends on their relative costs but on other parameters such as the demand. We calibrate the parameters of our model with French and American data in order to illustrate the theoretical results and observe the impact of the different parameters of the model. The results show that the quantity of good quality water mains depends highly on water production costs, the material of the mains and the demand for water.

The paper is divided into five sections. The second section is devoted to a review of the literature and the third section describes the theoretical model. The data and results are presented in the fourth section and the fifth section concludes.

## 2. Literature review

There are many papers that deal with the issue of water main replacement in the world of hydraulic engineering (among them, [28,3,38] and [12]); yet this issue seldom appears in the economic literature as the prime focus of a study. We can find many papers today that estimate water utility cost functions and determine the efficiency frontier for evaluating performance levels, most commonly via the method of Data Envelopment Analysis (DEA), such as the paper by García-Sánchez [21]. Our aim is quite different from this traditional method of performance evaluation or the so-called benchmarking technique.

Within the economic literature, we find only a few papers that deal with water loss from water mains. Moreover, very few are based on a theoretical approach. For example, Pearson and Trow [31] estimate "economic levels of leakage" (ELL). They conclude that if producing water is less costly than investing in leakage reduction, water utilities should extract additional water to compensate for the amount of water lost through leaks. The marginal cost of water is estimated by the difference in the cost of producing one more unit of water in terms of power (energy), chemicals (for treatment) and labor. Indeed, in practice for many utilities the cost of water extraction is low, which leads to pumping more water. The difference between our model and the ELL approach is the nature of the model. We develop a static firm cost minimization model subject to an output constraint, whereas the ELL model is a technical unconstrained cost minimization model, where short run costs are separated from long run costs. Moreover, the objective of our model is to obtain a "quality index" of the water main network and to provide a sensitivity analysis when parameter values change, whereas the goal of ELL is to estimate the optimal frequency of intervention (active leak detection) of the network. It is very useful for water utilities as a practical tool in planning the optimal interval for leakage detection activities. Lastly, the ELL model is based on substantial data from utilities and requires that utilities are already engaged in "active leakage control", which is unlikely to be the case in most utilities outside the U.K. [15]. Our model requires very little data input but captures the overall impact of the leakage issue in a simple framework.

Another example is the theoretical paper applying

[2] The efficiency calculator is a DSS (Decision Support System) which calculates the optimal level of leakage (the point where the marginal cost of leakage reduction equals the marginal cost of water production).