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Pseudo-genetic model optimization for rehabilitation of urban storm-water drainage networks

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Abstract

One of the main concerns in many cities is the need to rehabilitate or expand their drainage systems. Increasing rainfall intensities related with climate change, uncontrolled growth and excessive waterproofing of cities causes that original drainage networks design have became insufficient. Inadequate drainage networks make necessary to develop rehabilitation models of existing networks. This models should be compatible with them. This paper presents an optimization methodology to generate different solutions for the existing network improvement.

This methodology uses as starting point a model of the actual storm water network. In this paper the SWMM model is used to perform the hydraulic analysis of the network. Also a Pseudo-Genetic Algorithm (PGA) is used as optimization engine. This PGA model has been previously developed for other hydraulic optimization problems. The developed optimization model includes as decision variables: the rehabilitation or replacement of existing pipes, the potential location of stormwater retention tanks at certain points and their size, the initial state of the existing pumping units, and the start and stop levels of each pump.

To evaluate each solution during the optimization process it has been necessary to develop a series of costs functions: a) a cost function or damage function relating the flood level and associated damage costs; b) a cost function of stormwater retention tanks which relates the investment cost in the construction of the tank with its volume; c) a pipeline rehabilitation cost function that relates the cost of rehabilitation or replacement of a pipe with its nominal diameter; d) a cost function for each pump unit giving the cost of the electrical energy consumed during the operation. Finally, the methodology developed has been applied to solve the flooding problems of a small section of the drainage network of the city of Bogota (Colombia).

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1. Introduction

Urban drainage networks fulfill a hygienist mission, in so far as they conduct the runoff during rainy periods and protect up to a certain level against urban flood events. This level of network protection is given by its return period. Indisputably, the higher the design return period of network, the less tangible (economic) and intangible damages (social aspect, mainly) will happen, but also greater structural investment will result. The insufficiency of rainwater drainage networks in many countries has a clear origin: climate change. Although the effects of climate change in many areas lead to lower global rainfall, simultaneously it occurs that rainfall intensities are significantly higher. This fact, linked to growing waterproofing of our cities causes that flooding problems continue growing.

In a climate change context , there are different technologies which can be used to solve or alleviate consequences of excess runoff in our cities. The classic approach were addressed by total or partial renewal of the network and increasing its capacity. In this paper another solution is addressed, in which the renewal of pipes is used in combination with the techniques of sustainable urban drainage systems (SUDs). Of all these techniques, this work will be focused on those structural measures that control flows once they have entered into the network (retention tank construction and rehabilitation of pipelines network). Specifically, the work is focused on developing a comprehensive methodology for the rehabilitation of storm drainage network based on the partial renewal of the network and the installation of retention tanks. Other SUDS techniques, such as the construction of porous pavements, green roofs on buildings or small gardens on rooftops and terraces have not been considered. While they may partially reduce runoff, massive installation of them is necessary in order mitigate runoff significantly.

One of the first studies which relates the use of storm tanks and rainfall storm variations caused by climate change is presented by Andrés et al. [1]. Its probabilistic model allows to evaluate the efficiency in reducing floods depending on different parameters such as the size of tanks, climatic parameters and characteristics of the basin. The problem that arises in this case is slightly different by including the combined use of tanks and renewal of pipelines. In this sense, mathematical models of urban drainage play a key role. In this line, Butler and Schütze [2] develop a model which includes the efficiency of tanks based on a certain hydraulic modeling of the behavior of the network as a whole. However, its approach is more oriented to the quality of waste water than to flooding control. Later this work has been extended by Fu at al. [3] considering the optimization of urban wastewater as a multi-objective problem. For that, they use the multi-objective genetic model NSGA-II [4] to obtain the Pareto frontier of different optimal solutions.

In this context, technical and economic optimization plays a critical task to achieve the reduction of the final budget of the project of the civil work to be done. Thus, the work is focused on presenting a rehabilitation methodology which combines hydraulic analysis with an optimization model.

2. Methodology

The main objective of this work is to develop a methodology, through the combined use of mathematical optimization and hydraulic analysis of rainwater drainage networks, to find the most appropriate solutions for its rehabilitation.

Generally, for the development of the planned methodology, the some starting points or assumptions are admitted. On the one hand, different rain scenarios which correspond to different predictions made and based on studies of climate change studies will be used. Thus, the scenarios to consider are those considered as potentially hazardous within a confidence level. Also, a preliminary study of rainfall-runoff transformation must be available, so that the hydraulic model considers that the flows are provided directly to the input nodes of the model. In other