MULTI-OBJECTIVE OPTIMIZATION FOR URBAN DRAINAGE REHABILITATION

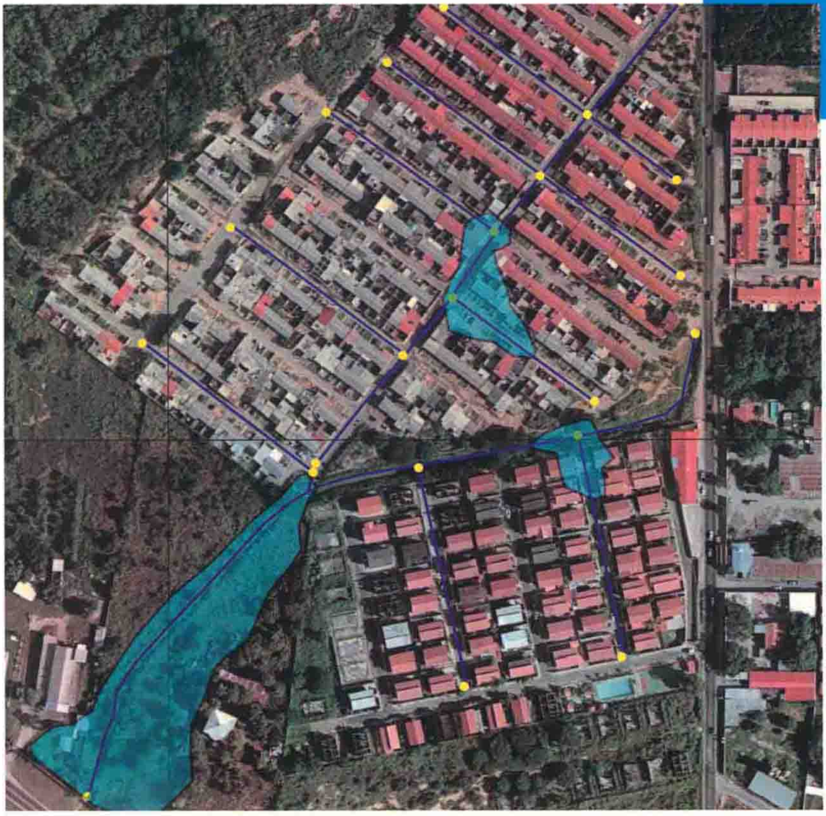

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Table of Contents

List of Figures

List of Tables

Multi-Objective Optimization for Urban Drainage Rehabilitation

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to my lovely mother and
to my daughter Ana Lía

Summary

Flooding in urbanized areas has become a very important issue around the world. The level of service (or performance) of urban drainage systems (UDS) degrades in time for a number of reasons: structural deterioration, siltation, new developments, climate change etc. In order to maintain an acceptable performance of UDS, early rehabilitation plans must be developed and implemented.

Cities are growing fast, and budgets for the rehabilitation of urban drainage grow at a far slower rate than budgets for urban development. In developing countries the situation is serious, little investment is done and there are smaller funds each year for rehabilitation. The allocation of such rehabilitation funds must be "optimal" in providing value for money. However this task is not easy to achieve due to the multicriteria nature of the rehabilitation process, taking into account technical, environmental and social interests. Most of the time these are conflicting, which make it a highly demanding task.

Multiobjective optimization approaches adopt appropriate tools and facilities to simplify the optimal rehabilitation of a UDS. Heuristic and Genetic Algorithms have been applied and have proven to be efficient for multiobjective problems. However, the large number of possible solutions (or scenarios) in UDS and the number of function evaluations needed by, say, evolutionary algorithms (EA) makes their application difficult for practitioners.

The present research is aimed at defining a framework to deal with multicriteria decision making for the rehabilitation of urban drainage systems, and focuses on several aspects such as the improvement of the performance of the multicriteria optimization through the inclusion of new features in the algorithms and the proper selection of performance criteria. The new framework, called a "*Multi-tier Approach*", must be suitable for use in developing countries, be scalable and be able to provide several solutions in an elapsed time that is suitable for practitioners.

A review of the state-of-the-art in urban drainage rehabilitation has been done. During a rehabilitation process several aspects have to be addressed. Issues such as the determination of performance indicators for hydraulic, structural and environment assessment have to be considered. Data availability and the identification of critical pipes and channels are also of major importance in any rehabilitation plan. Hydrological and hydrodynamic modeling plays a key role during for the hydraulic, structural and environmental assessment. Dual modeling of the above and below-ground systems is preferred in order to evaluate the surcharge consequences for the different assessments. There now exist mature computational modeling packages for 1D and 2D modeling, however, the interaction between the models produces by these packages is still a matter of research for them to become available for practitioners. Sustainable approaches, oriented to the control of runoff volumes from the beginning of the rainfall are preferable than methodologies based on conveyance. These sustainable approaches are also oriented to keep environment, social and economical values in balance. Different hydrodynamic modeling packages were reviewed in order to select the most suitable for this research, based on their advantages and disadvantages.

An approach for urban drainage rehabilitation using a multi-tier framework is developed.

This approach is innovative in that it introduces hydrodynamic modeling inside a multi-objective optimization process, using parallel computing to make it attractive for practitioner. It is modular and flexible depending on the data availability, making it suitable for the use in developing countries. It allows for the inclusion of expert knowledge at different stages of the optimization process. The framework application is simple but does not omit important features for the rehabilitation of drainage systems. The use of external tools for modeling, optimization and visualization allow for scalability which implies that the tools can grow as much as needed. A prototype framework was built and successfully tested on real problems in developing countries.

A review of the state-of-the-art for optimization in engineering problems was completed. It shows that there is no unique method for optimizing all kinds of problems, instead an appropriate methodology has to be selected taking into account the problems being optimize. Few applications in the area of urban drainage were found, and no application to real cases using hydrodynamic models inside the optimization algorithm unless they have been applied to small networks only. A special type of problem was identified called a "*highly computationally demanding*" problem, also defined in some literature as an "*expensive problem*". Multi-criteria urban drainage rehabilitation is classified as such a kind of problem where large computing power is required. An approach to face such a kind of problem is developed and tested for multi-objective algorithms using four benchmark functions. The method is based on the assumption that practitioners need only a few solutions and not a large set that are similar to each other. The new approach outperforms NSGA-II on three of the benchmarks, while NSGA-II was slightly better on the fourth benchmark function.

The proposed multi-tier framework for the rehabilitation of an urban drainage system was implemented and tested, performing a "*proof of concept*" on a small study case. Firstly, a structure for estimating the investment cost was implemented; features like pipe replacement, storage tanks and ponds, and diversion structures were included. A method for damage cost estimation was also incorporated. The cost structures are based on equations in common use and follow a unitary price analysis, including the preset worth in the cost estimation.

A prototype tool was developed and tested. A small study case was used as a "*proof of concept*". Two multi-criteria algorithms based on genetic algorithms were tested; they were NSGA-II and ε-MOEA. NSGA-II was incorporated onto a library and into an optimization tool called NSGAX. In order to compare the performance of the algorithms, four metric indicators of the multi-criteria performance were used: cardinality, time, number of functions evaluations, hyper-volume and ε-Indicator. Using these indicators it was concluded that NSGA-II outperforms ε-MOEA in general, but the differences were not substantial. Hyper-volume and ε-Indicator show convergence, and they were used as stopping criteria during the optimization process. The application of the framework to a larger network with 63 pipes showed the need for more efficient algorithms or computers to reduce computational time. In both case studies of 12 and 63 pipes, it was possible to find rational solutions that may be expected by practitioners; for instance the storage tanks were properly selected depending on their location and were also satisfactorally dimensioned. It is concluded that the developed framework is suitable for use in the rehabilitation of urban drainage systems. It shows scalability and flexibility. The use of intangible costs was also