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Optimisation of wastewater systems under uncertainty

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Abstract: An optimisation model for regional wastewater system planning under uncertainty is proposed. The model aims to determine the best layout for the sewer network and for the location, type, and size of the pump stations and treatment plants to include in the system. Solutions are evaluated in terms of cost and water quality in the river where the discharges are made. A hybrid simulated annealing–local improvement algorithm is used for solving the model. A case study is presented.

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Introduction

The importance of promoting the good quality of all water bodies is widely recognized. In the European Union, the introduction of the Water Framework Directive offered an integrated vision of water resources with the aim of achieving a 'good water status' of all water bodies. The pollution problems faced by water bodies are extremely relevant in areas surrounded by high urbanization. This is particularly threatening in developing countries where more than 60 per cent of the population is not provided with wastewater treatment systems. Because wastewater systems are costly, difficult to reverse, and essential to guarantee the quality of water bodies, they should involve complex planning processes. Such planning processes are often undertaken at local level for each city or part of a city. But a regional planning can provide better solutions with regard to costs, taking advantage of scale economies, while achieving a better environmental performance.

The regional wastewater system planning problem can be described as follows. Given a region comprising several population centres, the wastewater generated in these centres must be collected and treated before being discharged into a river or a set of rivers. The decisions to be made involve the setup and operation costs of the infrastructure, and the water quality standards to be met in the river that receives the wastewater. The infrastructure for treating wastewater includes wastewater treatment plants (WWTP), sewer networks and pump stations. The water quality varies along the river in accordance with the effluent discharges, and is assessed through different environmental parameters such as dissolved oxygen, nitrogen, and phosphorus.

The search for the best regional wastewater system should rely on optimisation-based approaches to allow full exploration of possible planning solutions. Several optimisation models have been developed for that purpose, as presented in the survey from Melo and Camara (1994) on the first optimisation models applied. Some recent literature has been devoted to more complex model formulations of regional wastewater system planning, also involving modern heuristics (Cunha et al. 2009). Planning problems of wastewater systems have typically been addressed through deterministic optimisation approaches, not considering the presence of uncertainty. However, they are affected by different uncertainties that, if not taken into account, may lead to substantially suboptimal solutions.

In this paper, we present an optimisation model for regional wastewater system planning under uncertainty. The model is based on a robust approach aimed at helping to determine the optimal configuration for the wastewater system of a region for a set of possible scenarios that might occur. Robust solutions are expected to be obtained, that is, solutions that will perform well under all possible scenarios but are not necessarily optimal in any of them. The application of the model is illustrated through a case study in the Una River Basin region, in Brazil, so that the results obtained for different levels of reliability can be compared.

Material and Methods

Regional wastewater system planning aims to determine an optimal solution for the layout of the sewer network, and for the location, type, and size of the pump stations and WWTP to include in the system. The optimisation model proposed in this paper fits into a line of research initiated with the cost-minimization model presented in Cunha et al. (2009). In Zeferino et al. (2010) this model is extended to a multi-objective version where environmental objectives are (also) taken into account. In Zeferino et al. (2009a) first steps were taken in the development of a robust optimisation model considering the uncertainty in the flow of the river. The objective function of these models is subjected to different constraints to ensure that the sewer network will be sized according to hydraulic laws and regulations. Constraints to ensure that the treated wastewater discharged from each WWTP will not create environmental damage have also been considered.

The robust approach proposed is this paper considers the presence of uncertainty in variables such as the flow of the river and the populations (wastewater demands) in the centres of the region. It consists in a stochastic formulation based on scenario planning to optimise the expected performance of a wastewater system according to the probability distribution function associated with the future scenarios. The performance is accessed in terms of the regret for the cost of the system to be established in a region. In order to include risk-aversion, making the model more realistic and less conservative, possible environmental and technical infeasibilities were considered by restricting scenario space through the alpha-reliable concept (Daskin et al., 1997). The model will lead to robust solutions, which are near-optimal and feasible with a certain level of reliability.

To represent the problems to be solved as accurately as possible, the model must incorporate discrete variables and nonlinear functions. Because of the complexity involved in the resolution of mixed-integer non-linear optimisation models, it must be handled through heuristic algorithms (Michalewicz and Fogel, 2004). A hybrid algorithm composed of a combination of a simulated annealing algorithm (SA) and a local improvement procedure (LI) has been used as the solution method (Zeferino et al. 2009b).

An easy-to-use computer program, *OptWastewater*, incorporates the different models for regional wastewater system planning, and was designed to be a decision support tool aiming to make such approaches more likely to be used in practice.

Results and Discussion

The type of results that can be obtained by applying the optimisation model for regional wastewater system planning under uncertainty are illustrated for a case study based in Una River Basin region, in Brazil (Figure 1.1). The Una River region has an area of approximately 6736 km^2, and involves 38 municipalities, with a total population of about 800 thousand inhabitants. For the implementation of WWTP, 10 possible locations were defined. Taking into account the topography of the region and 15 additional intermediate nodes, a network of 319 possible connections between nodes was defined (Figure 1.2).

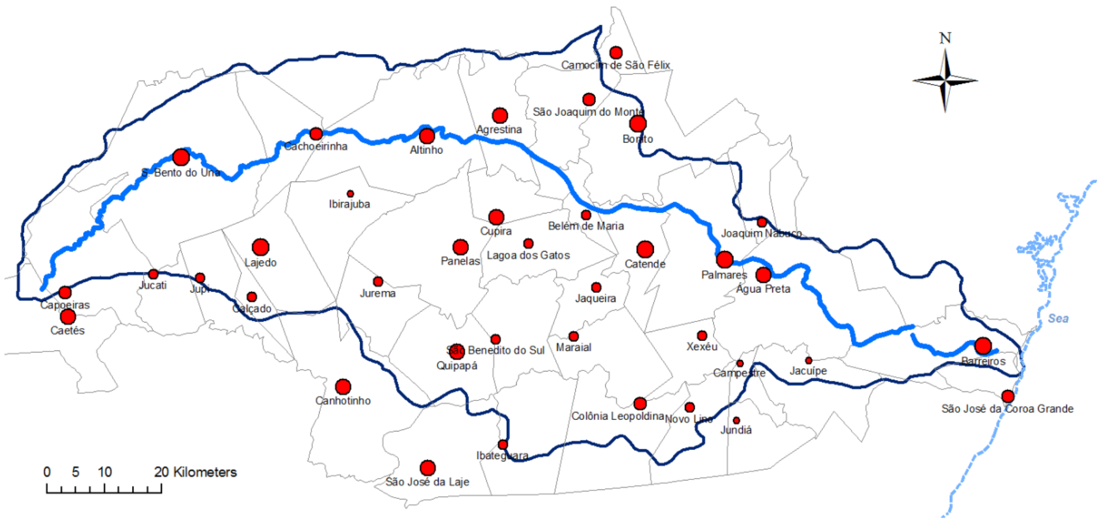

Figure 1.1 Una River Basin region and municipalities of the case study.

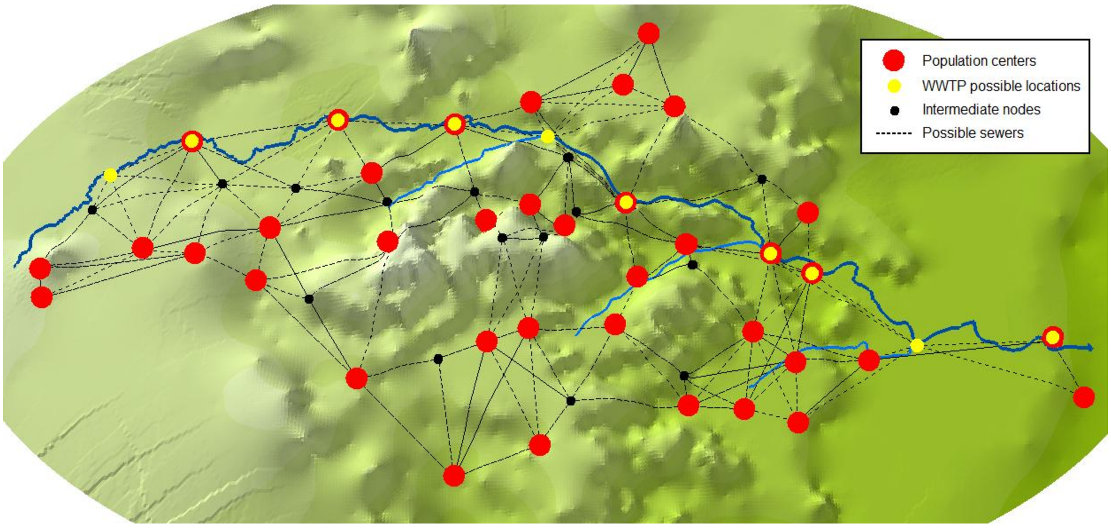

Figure 1.2 Topography of the region and distribution of nodes and possible connections.

The results obtained show that, with a reasonable cost increase, is possible to obtain a configuration that is designed to accomplish the set of possible scenarios, according to the desirable level of reliability. In addition, the system can be designed to guarantee minimum levels of dissolved oxygen in the river (Figures 1.3 and 1.4).

The work described in this paper explores an important direction of research owing to the technical challenges involved in the shift from a deterministic to a robust approach.

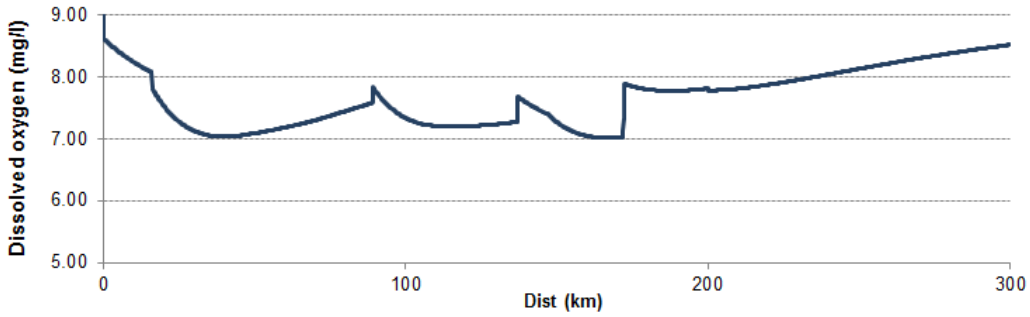

Figure 1.3 Dissolved oxygen concentration along the river.

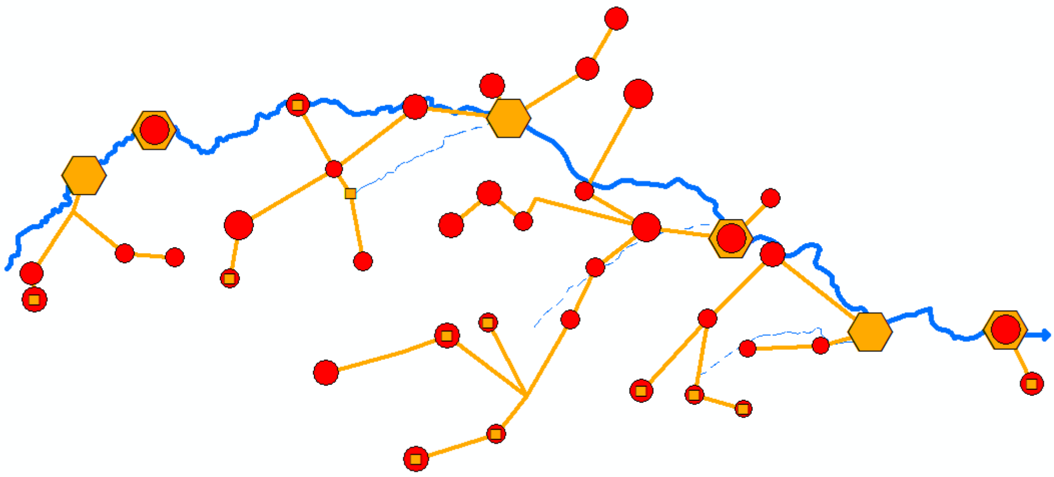

Figure 1.4 Optimal configuration for the wastewater system of the region.

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