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Planning regional wastewater systems across borders

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ABSTRACT

Regional wastewater systems are aimed at guaranteeing surface water quality by properly collecting and treating the wastewater generated in the population centers of a region. But the most suitable planning regions are often divided by political or social boundaries and may include upstream–downstream surface water quality conflicts. A cross-border planning approach allows for the coordination of pollution control and can embrace both economic and environmental considerations. In this paper, a methodology for wastewater system planning across borders is presented. An optimization model is used to identify reference solutions for negotiation between parties, regarding the layout of the infrastructure to be included in the system. The model takes into account costs and water quality in the receiving water body, and is therefore able to meet surface water quality standards in the shared waterway. A heuristic method is used to solve the model, based on a simulated annealing algorithm enhanced with a local improvement procedure. A region designed to replicate a real-world problem containing two countries is used as a case study. The transboundary wastewater system planning approach is compared with the consideration of separate systems for each country. The features of the transboundary solutions are discussed, with particular focus on the basis of the asymmetries in willingness to pay and different cost allocations.

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1. Introduction

Sanitation is generally considered to be the primary reason for the vast worldwide increase in life expectancy during the last century [1]. The need to preserve the good quality of water bodies to protect human health and the environment has led to the definition of several environmental guidelines and regulations to restrict pollutant discharges. The pollution problems faced by water bodies such as rivers are extremely relevant in regions with dense urban developments. Regional wastewater systems are aimed at guaranteeing surface water quality by properly collecting and treating the wastewater generated in the population centers of a region.

A regional wastewater system solution comprises the layout of the sewer network (including possible pumping stations) that will connect the population centers with the river, and the location, type and size of wastewater treatment plants (WWTPs) where the wastewater will be treated before being discharged into the river. Because of the large and upfront investment involved, and because of the very large number of possible configurations, the search for the best regional wastewater system should be pursued through optimization models. Melo and Camara [2] presented a survey of the first optimization models applied. When all the relevant features of these problems are taken into account, the subsequent models can be extremely difficult to solve. Modern heuristics are often inspired in natural processes to apply search strategies that can avoid local optima and have become very popular among scientists and engineers to handle such models [3]. In particular, the simulated annealing (SA) algorithm has been used with remarkable results in several hydraulic system planning models [4,5]. Recently, Cunha et al. [6] described a realistic discrete nonlinear optimization model for regional wastewater system planning solved through an SA algorithm. A model of this type enables solutions to be evaluated against the cost of installing, operating and maintaining the infrastructure, and against the water quality in the river that receives the treated wastewater generated in the region. Water quality can be assessed using various environmental parameters, and it varies in accordance with the characteristics of the river and the effluent discharged into it. An optimal solution would be the one that yields a minimum cost for collecting and treating the wastewater generated in the region while ensuring the water quality in the river.

In water resources the basin scale is usually considered to be the natural unit for the management approaches. Similar regional level approaches to wastewater system planning can take advantage of scale economies, while achieving a better environmental performance. But both river basins and other appropriate regions for the planning are often divided by political or social boundaries. The multiplicity of parties involved may include conflicting ancient rivalries or different development goals. Such unfavorable political framework conditions would benefit from a planning approach across borders to help in the integrated decision-making process, allowing the coordination of pollution control. The transboundary Rhine river protection program in Europe was one of the earliest well-documented success stories of international river cooperation as described by Mostert [7]. The agreement between riparian nations comprises issues such as water needs, water quality standards and wastewater treatment costs. The Polluter Pays Principle (PPP) is often presented as an equitable and fair way for appropriating the cost of pollution abatement. The PPP is assumed to provide economic efficiency and environmental sustainability but has been found difficult to implement, leading to the proposal of alternative cost allocation principles [8]. The willingness to pay problem particularly arises in asymmetrical situations, such as in the USA/Mexico environmental relations. Fischhendler [9] focused on the pollution abatement regime along the border cities of Tijuana and San Diego. One of the proposed alternative cost allocations addressing such situations of asymmetries is the Beneficiary Pays the Difference Principle (BPDP) that overcomes questions of justice by making each polluter pay only for bringing wastewater to a level compliant with its own standards [8]. To achieve the pollution abatement targets different economic incentive instruments can be used, such as emissions taxes and pollution abatement subsidies. These targets can be attained at minimum cost through economically efficient methods as the facilitation of bargaining, however subjected to some limitations [10].

Optimization based approaches have been applied in recent years to different transboundary water resources problems to find cost-efficient optimal solutions. Devi et al. [11] presented a linear