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AN OPTIMIZATION AND DECISION SUPPORT TOOL FOR LONG-TERM STRATEGIES IN THE TRANSFORMATION OF URBAN WATER INFRASTRUCTURE

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The predicted demographic, climatic, and socio-economic changes will require adaptations of existing water supply and disposal systems, most urgently in rural areas. This paper presents a joint interdisciplinary research project with the objective to develop an innovative software-based optimization and decision support system for long-term transformations of existing infrastructures of water supply, wastewater, and energy. Criteria such as transformation time and sequence, cost effectiveness, financial feasibility, energy efficiency, nutrient recycling, and public acceptance are implied. One major challenge of the work is to tailor the model according to the diverse requirements and demands of different future model users. A systematic stakeholder analysis has been carried out to reflect these diverse demands. Besides, the paper deals with the creation and scope of scenarios for the development of population, settlement structure, and water demand as well as the generation of infrastructural concepts.

INTRODUCTION

Background

Predicted climatic, demographic, and socio-economic developments require major adaptations of urban water infrastructures. Central urban drainage and water supply systems in large parts of Europe do not meet the increased requirements of resource efficiency and sustainability anymore. Especially in rural areas, predicted demographic changes and the particularly differentiated settlement structure will affect the functionality of existing supply and disposal systems. These new challenges demand extensive and flexible adaptations or even long-term transformations with dynamic system changes for urban water and wastewater systems.

Previous scientific approaches of adaptation of existing infrastructures aim at the evaluation of infrastructure systems and the comparison of alternative solutions (cf. [1]). Approaches for sequencing of transformation processes are rarely investigated [2, 3] and do not consider the cross-sectoral connection of water, wastewater, and energy infrastructure. Resource efficiency and recovering of nutrients as well as energy from wastewater will become more important issues in the future, especially against the background of the aspired increase of renewable energies, e.g., defined in the European Renewable Energy Directive [4]. The large number and the complexity of decisions to be made as well as the interrelation of their outcomes require the application of a sophisticated optimization and decision support system.

Aim of the study

The main objective of the project presented here is the development of an innovative software-based optimization and decision support system for long-term transformations of existing infrastructures of water supply, wastewater, and energy. The model analyzes and evaluates possible future scenarios and intelligent system structures and deduces optimal strategies for planning, technical, and political processes aiming at sustainable urban water infrastructures. One major objective is the usability of the model by different users that will be either involved in the adaptation and transformation processes as planers and decision makers or affected by their planning and decisions.

The paper presents the approach and first results of a comprehensive stakeholder analysis carried out. Moreover, major aspects of the development of a mathematical optimization tool to determine an optimized transformation strategy of urban water supply and disposal systems taking into account multiple objective functions are considered.

IDENTIFYING STAKEHOLDERS

In order to be able to determine and balance all needs regarding the software based optimization system that will be developed within this research project, an analysis of the stakeholders possibly involved has been carried out. All persons or groups that have an interest in the optimization and decision support system to be developed are considered as stakeholders. Therefore, all involved project partners were asked to name the stakeholders from their point of view along with the individual requirements of each stakeholder. The results were collected, filtered and analyzed to consolidate the raw data. This provides a common understanding and vocabulary among the different project partners as a basis for further discussions.

The stakeholders identified have been grouped in two clusters: one cluster unifies the stakeholders that are directly related to the software system (group “IT-system”). They will be working with it, involved in the development process, or rely on the results of the optimization process. Examples of such stakeholders include the software developers building the software or consulting offices using the system afterwards. The second cluster combines the stakeholders that have an indirect interest or influence regarding the suggestions of the optimization system like politicians and consumers (group “supply and disposal system”). They are not directly working with or using the optimization tool but their needs must be fulfilled and taken into consideration in the development process of the optimization and decision support system. Table 1 shows the identified stakeholders.

In a further step, a goal analysis has determined the requirements of the different stakeholders and their specific needs (like providing cost and energy efficient solutions and the possibility to use the results for publicity). The project partners have then been asked to assign weights to different requirements with respect to their own assessment. For example, it is more fundamental to be able to provide alternatives regarding urban development then to have citizens involved in the decision process. The prioritization will be beneficial in order to focus on the more important requirements within the development of the prototype (cf. also Figure 2).

Table 1. Identified Stakeholders

stakeholder groups \ stakeholders		municipalities	municipal council	households	commerce and industries	agriculture	retail / industrial customers	supply and disposal providers	engineering / planning offices	(economic) consultants	regulatory authority	association	regional policy and government authority	federal policy	professional association	producer of innovative technologies	scientists / engineers
IT-System	system developer							X	X	X							X
	direct system user								X	X							X
	indirect system user	X	X	(X)	(X)	(X)	(X)	X			X	X					
supply and disposal system	supply and disposal provider							X									
	political decision maker	X	X					X			X		X	X			
	planner / consultant	(X)						(X)	X	X							(X)
	user			X	X	X	X										
	high-level influencer			X	X	X	X				X	X	X	X	X	X	X

OPTIMIZATION AND DECISION SUPPORT TOOL

Fundamental considerations

The overall structure of the software based optimization system will consist of and integrate several components. These components are mainly a knowledge and evaluation database, the implementation of the decision support and optimization model as well as a visualization tool. The visualization tool will be used by persons directly planning and working with the decision support and optimization model as well indirectly by decision makers relying on the produced results and their visual representation.

Software engineering methods like requirements engineering, usability engineering, and software architecture will be applied within this research project. This increases the chance that the developed system offers appropriate usability, flexibility, and interoperability.

Overall model structure

Within the presented research project, a decision support and optimization tool as shown in Figure 1 is designed. So far, a mathematical optimization model for the urban wastewater system including the wastewater treatment plant is developed. It sequences the spatial and chronological transformation on different decision and modelling levels for different infrastructural concepts. Thereafter, a model simulating the water supply system for portable water will be developed with an interface to the urban wastewater model.

In order to determine an optimized transformation strategy of urban drainage systems, a mathematical model based on integer linear programming (ILP) is used. For each possible adaptation measure and time step (year), a binary decision variable is introduced to decide whether the measure should be taken at this time step. Moreover, a network flow model with flow variables and appropriate side constraints is used to model the flows through the wastewater and water supply networks and ensure feasibility of the systems at each time step. The objective function of the ILP model consists of a weighted sum of the different objectives that are to be minimized. The weights to be assigned to the objectives can be determined by the user of the model. Hence, each user can specify her own preferences with respect to the importance of economic costs, environmental impacts, and flexibility.

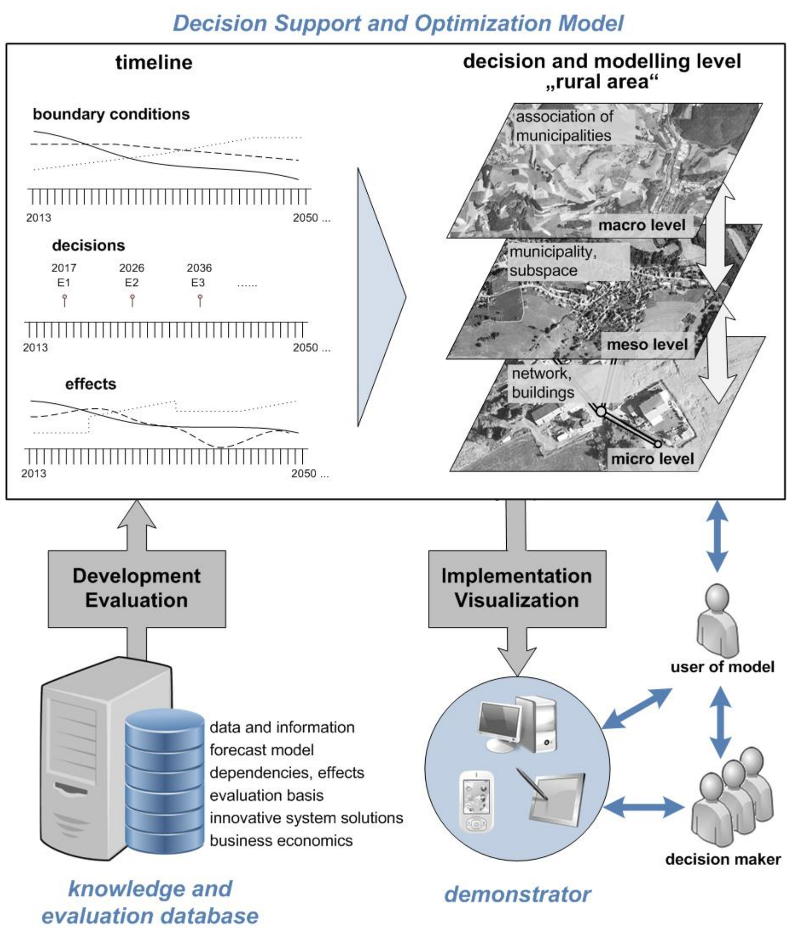

Figure 1. Concept of the decision support and optimization model

CONNECTION OF STAKEHOLDERS AND MODEL DEVELOPMENT

The stakeholder groups, which are identified in Table 1, have a considerable influence on the development of the model. Figure 2 shows the connection between the different stakeholder groups or their goals respectively and the components of the optimization and decision support tool. The required input data as well as the definition of objective functions depend on the stakeholders. Moreover, they influence the planning of infrastructural concepts, which are developed as a basis for the modelling process.

Input data and objectives of the model

All input data for the investigated settlement and possible innovative structures or adaptation measures are stored in a knowledge and evaluation data base. As database management system, the open-source software PostgreSQL (Version 9.3) is applied. The mathematical model requires, besides water supply and disposal infrastructure data, the variable input parameters inhabitants, drainage area (types, runoff coefficient, and categories of pollution), water demand as well as dry weather flow (e.g., grey water, black water) and their valuable contaminants (e.g., nutrients, energy content). These data are provided by the local supply and disposal providers and the planners and consultants. Besides the input data, multiple requirements of water supply and disposal systems have to be considered in the modelling process.

Several selectable objective functions, which were adjusted with the stakeholders, are implemented in the model. These are economic costs and environmental impact, nutrient and water recycling, energy efficiency as well as flexibility of the urban drainage system. The model includes mass balances for water, electric and thermal energy, and the nutrients Chemical Oxygen Demand (COD), nitrogen, and phosphor.

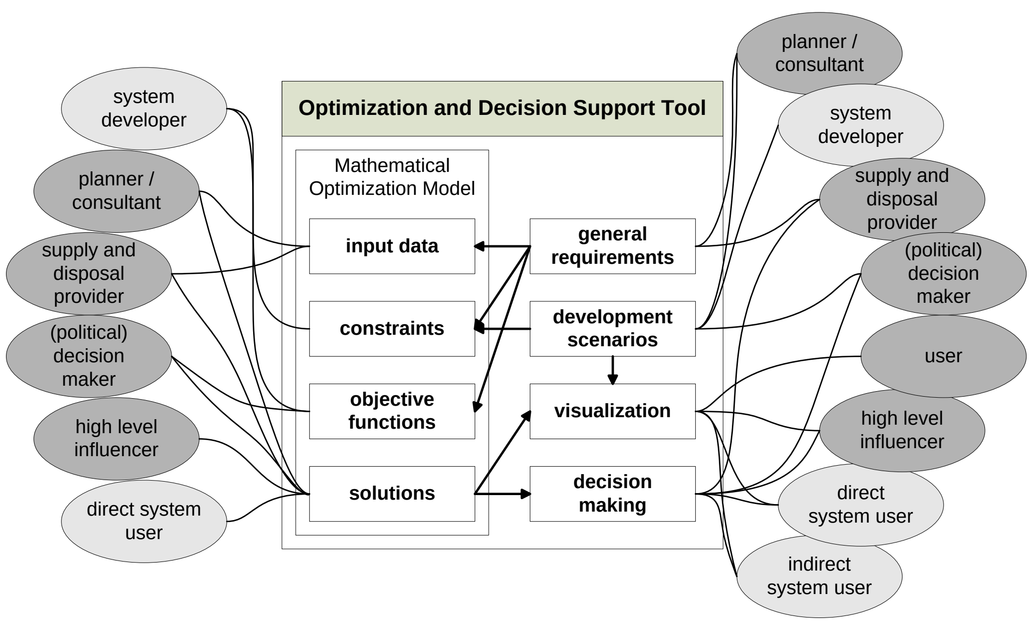

Figure 2. Connection of stakeholders and model development

Based on a literature review and practical knowledge from project partners (engineers, communities, water operators, and consulting firms), adaptation measures and strategies for supply and disposal systems have been composed. This collection includes measures in the field of water supply, urban drainage, storm water management, and wastewater treatment. The compatibility of measures is mapped in a matrix (cf. [5]), which is necessary to ensure that only compatible measures are selected by the model.

Infrastructural Concepts

Previous to the modelling process, a scenario management approach of generating scenarios and concepts for the settlement and the urban water system is undertaken (see Figure 3). These concepts are developed on two different levels, one for the macro (municipality) and one for the meso level (particular village). They include the future development of population and settlement structure, but also the development of water and energy consumption as well as of the legal framework. The development of concepts can provide a rough trend and the possible adaptation measures are restricted. This is essential for an effective application of the optimization model.

Spatial development scenarios are generated from population forecasts and linked with settlement developments. Therefore demographic developments for the time frames 2030 and 2060 have to be analyzed due to the long life span of water infrastructures.

Based on the spatial development scenarios on the macro level, the water demand per capita is predicted. It takes into account effects of technical improvements, user behavior, demographic and climate change, income as well as water price [6]. The future energy demand is predicted as well and the development of the legal framework is considered. Then, the functional capability of the supply and disposal systems is examined and need for action presented. In parallel, general urban water management objectives are defined together with the stakeholders. As a result, different supply and disposal concepts on the macro level are generated.

Based on the spatial development scenarios on the macro level, spatial planning concepts for the meso level are developed. Thereon, the development of the water consumption is determined, which can differ from the future water consumption of the municipality due to the different consideration levels. The development of the energy consumption and the legal framework on the macro level are valid for the meso level as well. With a site-specific analysis, the functionality of the water supply and disposal system is examined and concretized urban water management objectives are taken into consideration. By selection of adaptation measures and strategies, infrastructural concepts are generated. They have to suit the supply and disposal concepts on the macro level.

In the concepts, the intended development of the municipality and, thus, the influence of the stakeholders are integrated. The concepts are created after consulting with project partners from engineering science, operational practice, and municipal water and wastewater works.

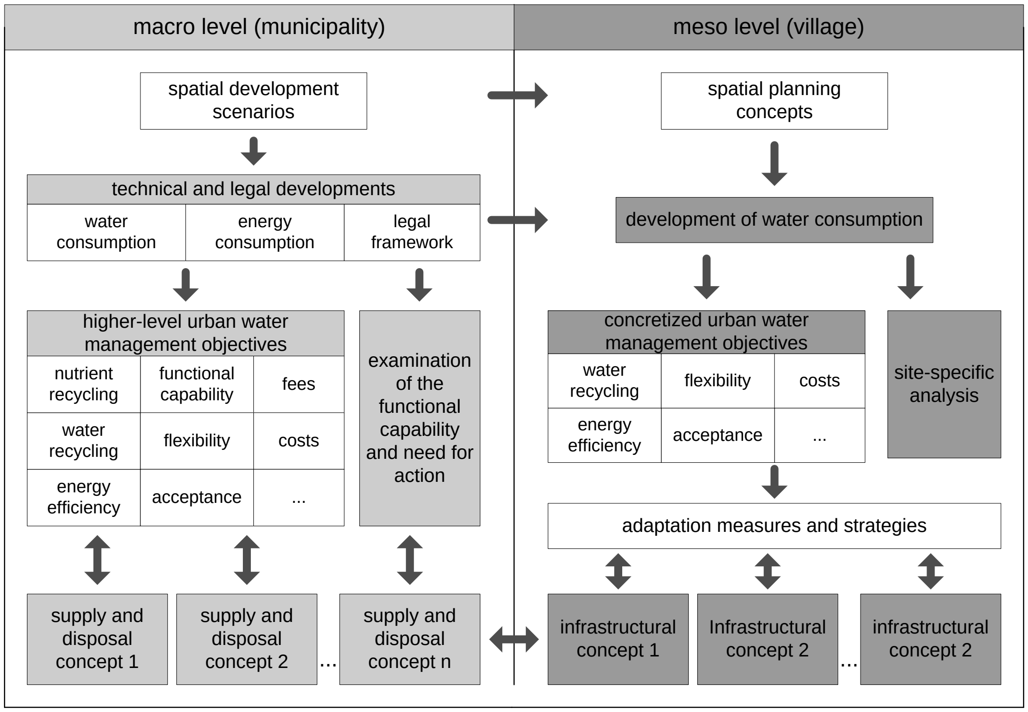

Figure 3. Generation of infrastructural concepts

Implementation of the model

The prototype of the decision support and optimization model will be tested and evaluated in a rural case study region in the Southwest of Germany. The two municipalities considered in the study have a wide range of settlement structures and face different challenges for the future design of urban water systems. They are representative for numerous municipalities in rural areas in other parts of Germany as well as in other countries.

The implementation of a strategy is considered on different decision and modeling levels. These include the macro level (association of municipalities), the meso level (village), and the micro level (building/street) (see Figure 1). Decisions of stakeholders (municipalities, water utilities, citizens) have also to be prepared and made at these different levels.

CONCLUSIONS AND OUTLOOK

This paper presents the design of an optimization and decision support tool for long-term strategies in the transformation of urban water infrastructure. The benefit from the model is the calculation of optimal adaption measures and strategies for urban drainage systems, taking into account weighted objective functions. The identified stakeholders influence the model development. Especially for the selection of objective functions and the generation of infrastructural concepts, the stakeholders should be involved.

The next step will be the testing of the model in the selected model region. Possible future scenarios in terms of demographic changes, decrease of water consumption, and alternative water infrastructure concepts will be developed and evaluated. The model will illustrate and visualize the following criteria: sequencing of the transformation process, cost effectiveness, financial feasibility, energy efficiency, nutrient recycling, as well as political requirements and legal modifications. Interactive visualization of results will allow comprehensive decision support for planners, municipalities, decision makers, and citizens.

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REFERENCES

[1] Meinzinger F., *"Resource efficiency of urban sanitation systems: A comparative assessment using material and energy flow analysis"*, Institute of Wastewater Management and Water Protection, Dissertation Series, no. 75, University of Hamburg, Germany, (2010).

[2] Kaufmann Alves I., "A Mathematical Approach to find long-term Strategies for the Implementation of Resource Orientated Sanitation", *Wat. Sci. Tech.*, 67 (7), 2013, pp 1442-1454.

[3] Schiller G., *"Evaluation of costs and adaption of central wastewater systems to demographic change"*, Leibniz Institute of Ecological Urban and Regional Development, Dissertation Series, no. 51, Rhombos Verlag Berlin, Germany (2010).

[4] EC, Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (Text with EEA relevance). European Parliament, Council publication date 23/04/2009.

[5] Maurer M., Bufardi A., Tilley E., Zurbrügg C., Truffer B., "A compatibility-based procedure designed to generate potential sanitation system alternatives", *Journal of Environmental Management*, 104, 2012, pp 51-61.

[6] Schleich J. and Hillenbrand T., "Determinants of residential water demand in Germany", *Ecological Economics*, 68, 2009, pp 1756-1769.