Sustainable Planning and Management of complex urban water systems based on Macro-modelling, Simulation and Stakeholder participation-the case of the megacity of Lima

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Abstract Planning and management of urban water systems represent due to the complexity of the systems a challenging task. The paper presents on the one hand a methodology developed within the "LiWa – Lima Water" project and on the other hand the application of a Decision Support Tool (LiWatool) to model at large scale one part of the complex urban water system of the megacity of Lima. In order to achieve a sustainable planning and management of urban water systems, the tool allows and support to make management decisions (in a participative approach) taking into account environmental, economical, social, political an technical aspects.

Keywords: Decision Support Tool; Megacity; Modelling; Participation; Urban water system

INTRODUCTION

Sustainable planning and management of water resource systems are becoming more challenges with the growing recognition of the comprehensive interactions between environmental, economical, social, political and technical aspects to be considered (Matthies *et al.*, 2007). In addition, the effects from external drivers (e.g. climate change) and boundary conditions (e.g. hydrological) increase the challenges for achieving sustainable water and waste water system (urban water system) planning and management. This result in the need for new or improved integrated approaches in which the knowledge of diverse disciplines (e.g. political, environmental, etc.) is combined in a single methodological and operational framework (Giupponi *et al.*, 2008). The integration of scenarios (e.g. socio-political context, environmental scenarios) into the modelling of water systems and the involvement of the relevant stakeholders provide a platform for participative decision making.

There are a large number of tools which support the management of urban water systems. In most cases and due to the complexity of the systems, these tools consider only individual subsystems (e.g. river basin, water networks, etc.) (Rauch *et al.*, 2002, Robleto *et al*., 2010). These approaches can contribute to evaluate potential solutions for the water subsystem under analysis but are not necessarily appropriate for the entire water system.

In order to contribute to overcoming some of the presented challenges, a new decision support tool based on the principles of material flow analysis (Montangero, 2006) has been developed. It allows an analysis and representation of the entire system in an integrated form and in a single model. Furthermore, due to the flexibility of the software, users can modify or integrate new modules, parameters and variables by themselves. In addition, the program enables the analysis of scenarios of different disciplines (e.g. social, environmental, etc.).

METHODS:

Macro-modelling approach

The term “macro-modelling” is used here in order to distinguish modelling in a macroscopic level, which allows (in an integrated form) the consideration and analysis of the entire urban water system from detailed modelling “Micro-modelling”, which analyses each part of the urban water system in a detailed form (e.g. groundwater modelling, detailed hydraulic modelling of sewer networks (Rauch *et al.*, 2002). In order to consider the entire urban water system in one single model, the concept of macro-modelling is more appropriate. This does not mean that the approach of macro-modelling in a sector level (e.g. in a part of the entire system) could not be applied.

Main objectives of the water system simulator “LiWatool”

The main objectives of the macro-modelling water system simulator are to provide a platform for: participative discussion and decision making, involving the relevant stakeholders and decision makers of the different disciplines. Furthermore, the evaluation of identified planning and management alternatives and strategies and their possible impact not only on the part of the urban system under analysis (local level), but also on the entire urban water system (global level) is required.

Some components of the urban water system included in the current version of LiWatool

LiWatool allows representing the system by building blocks for each of its main elements (e.g. groundwater wells, water supply network, city districts, sewer network, wastewater treatment plants, etc.) (See Figure 1). City districts are characterised by, among others, population size, water consumption patterns (according to social economic level) and percentage of population connected to the drinking water supply and sewer networks. Besides water quantity, water quality (water supply and wastewater) fluxes are also considered.

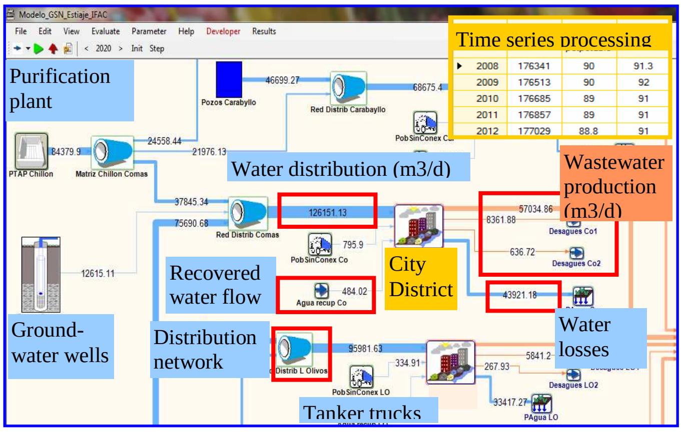

Figure 1. Some parts of the urban water system included in the current version of LiWatool (Example)

Background of the water system simulator “LiWatool”

One aim of the water system simulator is to provide not only a platform for participative decision making but also to allow an easy description of the structure of the complex urban water system. For this purpose it is necessary to define the transported water, material and energy flows and to describe the transformation of these flows in the different process units of the water and wastewater system. The description of these transformations are organised in LiWatool in module libraries, which can be defined and extended by users like process engineers. To allow a module definition without the need to have programming language skills, a simple model editor was developed to describe the transformations using symbolic equations. The recent version of the software allows only stationary models for these transformations (algebraic transformations). Different solvers for the system of nonlinear algebraic equations are implemented (Newton-Raphson, Levenberg-

Marquardt and a specialised nonlinear iterative solver). From first experiences of the application of the program in real urban water system, a strong need for the option to include dynamical description methods (Difference equations, Differential equations) was identified. This need results partly from a number of important storage elements in the system (groundwater body, water reservoirs, storage tanks in drinking water networks), but more seriously from the need to combine unit modules with tight interactions which can be described better using differential equations (ODEs). The latest version under development will include this option and the related ODE solvers (for stiff systems).

Interactions of the Macro-modelling with other aspects to support participative decision making

Taking into account the interactions between the water systems with other aspects (e.g. social, environmental aspects, etc.), a set of scenarios (which are results of qualitative analysis) of potential future developments are developed (León 2010 b). These scenarios serve, on the one hand, as input data for the macro-modelling simulator and on the other hand as inputs for river basin catchment modeling, which determine a water balance of the four most important river catchments for the water supply of Lima. This analysis involves a regionalisation of global climate models to the Andean region (Chamorro and Bárdossy, 2010). The results feed into macro-modelling of the entire urban water system of Lima. It provides a base for informed discussions and participative decision making, involving the relevant stakeholders. Discussions will feedback into scenario definition (definition of additional or new scenarios) and/or model development and application. An analysis of water tariffs accompanies this process, directly feeding into modeling and evaluation of options (See Figure 2). Capacity building and potential measures are contributions which supplement the areas of research mentioned above.

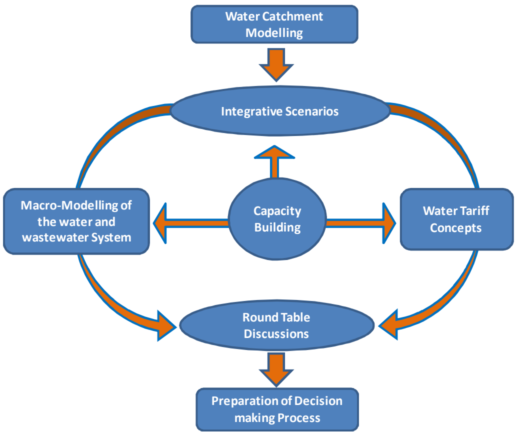

Figure 2. Macro-modelling as a crucial part for decision making processes (León, 2010a)

Modelling and simulation of a part of the urban water system of Lima

The climate conditions have a very pronounce influenced on the precipitation and temperature patterns in the water catchments around the megacity of Lima. With an average annual rainfall of nine millimetres, Lima is the world's second-driest city after Cairo. The water scarcity in the city and the actual population of more than eight million inhabitants at present, thus lead for water supply to a high dependency on water sources located in the Pacific and Atlantic river basins.

The district of Lurin is located in the southern part of Lima. The district has an area of 180 km^2 and has a population of 62940 inhabitants (National Census data of 2007). Due to Lurin is mostly dedicated to agricultural activities, the percentage of population connected to the drinking water supply and sewer networks are quite low. Official numbers state that about 34% percent of the population of the Lurin district are connected to the water network and about 29 percent to the sewer network (SEDAPAL, no year). Water supply in large parts of this district is by groundwater wells, whilst a smaller portion of drinking water is taken from La Atarjea purification plant, where water from Rimac River is abstracted and treated. Scenarios considered so far for this application include, for example, population growth over 18 years as anticipated by Sedapal (SEDAPAL, 2010) and information on climate developments obtained from regionalised global climate models (in this case, from the model ECHAM 5 with Scenario A2 for the next 30 years) (Chamorro and Bárdossy, 2010). After specification of exemplary assessment criteria (including water availability for the population; energy consumption of groundwater pumps, distribution network and treatment plants; pollution discharges to the Ocean; revenues from water tariffs), the simulator allowed the effect of various acting options, here as operational strategies (e.g. leakage reduction and operational regimes of groundwater pumps, See Figure 3), to be simulated, visualised (this proved to be very important) and discussed.

RESULTS AND DISCUSSION

According to an evaluation of various operational strategies, it could be concluded that a more uniform use of groundwater sources and a reduction of the energy consumption of the wells can be largely achieved (see Figure 3). For this example, it results that prudent operation of the groundwater wells can maintain water supply for some time, however, the need to activate additional water sources will also arise in any case soon in the coming years, with only the exact date being dependent on the assumptions made.

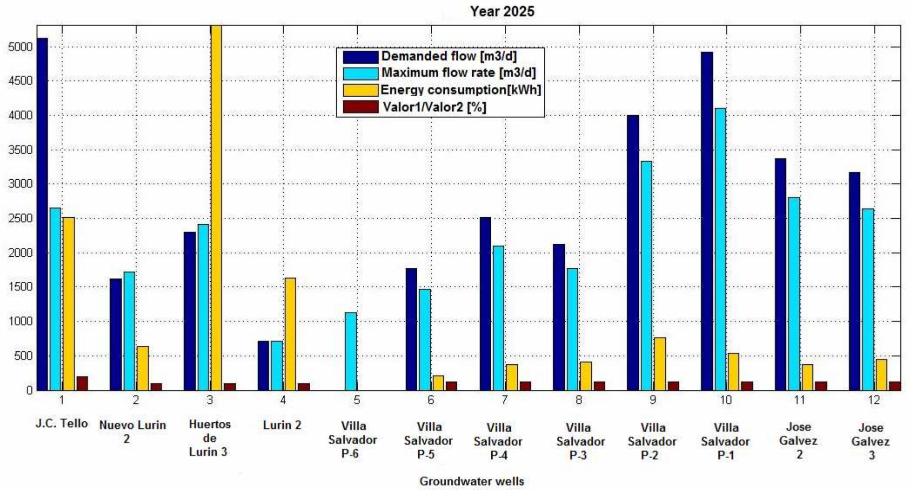

Figure 3: Results of Strategy 2 (Year 2025)

CONCLUSIONS

The more detailed application of macro-modelling with interactions between environmental, economical, social, political and technical aspects to be considered in the district of Lurin will represent a significant contribution, not only for the analysis and evaluation of project alternatives, but also for decision making of the water company for future investments (e.g. currently, the construction of a new water purification plant in the Lurin catchment is under consideration), particularly since Lurin is discussed to be one of the future areas of urban development in Lima.

ACKNOWLEDGEMENTS

The presented work in this paper forms part of the Peruvian-German cooperation project "LiWa – Lima Water". Funding of this project by the German Ministry of Education and Research (BMBF) is gratefully acknowledged.

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