Sustainable Planning and Management of the complex water and wastewater system of the megacity of Lima-based on Macro-modelling and Simulation

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Abstract: Sustainable Planning and Management of complex urban water systems in an integrated form in many cases requires the consideration and analysis of various subsystems of the water systems (e.g. the interactions between the water sources with the drinking water distribution systems and the wastewater collection systems) that interact, very often, not only with each other strongly, but also with external drivers (e.g. climatic conditions). This is particularly true in the context of urban agglomerations with a population more than ten million inhabitants (megacities) in terms of expected changes due to population growth, scarcity of water resources in time and space, increasing water demand in different sectors and the impact of climate change. In order to provide tools and methodologies that can contribute to overcome (or to tackle) these challenges, a new macro-modelling simulator based on the principles of the modelling of material flows (e.g. water, wastewater and load) and energy has been developed. Its application to the urban water system (all in a single model) of the desert megacity of Lima – a system with particularly adverse hydrologic boundary conditions – allows not only the determination of the state of the system under different conditions, but also the identification and analysis of potential alternatives and measures (e.g. construction of new infrastructure, etc.) for a better management of the system on a local and global level.

Keywords: Macro-modeling, Megacities, Simulation, Sustainability, Water management

1. INTRODUCTION

In many cases, sustainable planning and management of complex water systems requires not only the consideration the water subsystem under analysis, but also their interactions with other parts of the entire water system and the effects from external drivers (e.g. climate conditions) on this. Furthermore, water systems interact very often and simultaneously with other dimensions including these related to socio-cultural, politic, economic, technical and environmental aspects. All these aspects contribute not only to the complexity of management of water systems in an integrated form, but also to find and analyse optimal solution in a global level, taking into account the entire system. These aspects occur particularly in a megacity context, where the urban water systems change (in some form) every day, water demands increase, and, in many cases, the water sources for the water supply of the city are going to disappear or the water availability has a poor quality.

Simulation methods within interactive software packages can provide a basis for planners and managers to identify and evaluate the impact of design plans or management strategies (before they are implemented in the reality) (Loucks and Beek, 2005).

There are a large number of tools which support the planning and management of water and wastewater systems. In most cases, these tools consider only individual subsystems (e.g. drinking water network, sewer system, river basin, the groundwater bodies, wastewater treatment plant, etc.).

In order to contribute to overcoming (or to tackling) some of the presented challenges, the development of innovative tools, research and provision of new concepts and methods of different areas are required. In this context, a new macro-modeling simulator based on the principles of material flow analysis (Montangero, 2006) has been developed. Through the interconnection of various modules (which represent individual parts of water and wastewater systems) allows an analysis and representation of the entire system in an integrated form and in a single model.

2. CHALLENGES IN THE WATERMANAGEMENT IN THE DESERT MEGACITY OF LIMA

The emerging megacity Lima is located on the Pacific coast of Peru. Climate conditions (e.g. Humboldt Stream) have a very pronounce influence on the precipitation and temperature patterns in the city. With an average annual rainfall of nine millimetres, Lima is the world's second-driest city after Cairo.

The irregular distribution of water in space and in time, the actual population of more than eight million inhabitants at present and the population growth (annual rate of more than two percent), thus lead for water supply of the city, to a high dependency on water sources located in the Pacific and Atlantic catchments. Furthermore, water supply is mainly from four rivers: the Rimac, the Chillón, the Lurín and the Mantaro. These rivers are fed by rainfall and snowmelt in the Andean mountains. In addition, to ensure not only water supply for the city, but also to generate hydropower, a number of reservoirs are constructed and are in operation. These multi-objective reservoirs, located in the Atlantic and pacific watershed, lead to conflicts between the water and electricity companies, particularly, when the precipitations within the watersheds are low and the stored water in the system is insufficient to cover (at the same time) both types of demand. Groundwater supplies are of lesser significance for water supply of Lima – but nevertheless over-exploited.

Another major challenge is the management of the water distribution system. Although the city has only few water sources, in some parts of the system there are more than 35 percent water losses (mainly due to water leakage). Moreover, official numbers state that about 9 percent of the population are not connected to the drinking water network (Sedapal, 2007). These mainly live in the hilly and dry periurban areas, getting drinking water (in most cases, with questionable water quality) from private water trucks at high prices. 86 percent of the population are connected to the sewer network discharging the wastewater to 18 wastewater treatment plants (most of then being small plants). Currently 85 percent of the wastewater is discharged into the Pacific Ocean without treatment. The construction of a new large wastewater treatment plant to cover 100 percent of the produced waste water is currently under preparation.

The challenges mentioned above clearly illustrate that the urban water system of Lima is a very complex system. It is characterized by the dependence on numerous interactions within and beyond the system and is expected to be subject to significant changes in the future. Additionally, in order to cope with the challenges, it is necessary to search and to develop new innovative solutions that provide a sustainable use of the water resources (both in the present and future) according to the increasing water demand of the city meeting decreasing resources.

3. MACRO-MODELING SIMULATOR "LIWATOOL"

3.1 Macro-modeling approach

The term "macro-modelling" is used here in order to distinguish modelling in a macroscopic level, which allows the consideration and analysis of the entire system from detailed modelling "Micro-modelling" (Schütze and Robleto, 2010), which analyses each subsystem in a detailed way (for example, groundwater modelling, detailed hydraulic modelling of water and sewer networks). In order to achieve the overall objective of representing the entire water and wastewater system (and also with the energy 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.

3.2 Main Objectives of LiWatool

Among the main objectives of the simulator are the support of planning and management of complex water and wastewater systems in an integrated form. This aspect includes, among others, the consideration of the interactions of the urban water system with other aspects. Taking into account these aspects, potential solutions could be defined and analysed with the support of the macro-modeling. This contribute not only to find optimal solutions, but also to achieve a successful participatory decision making.

3.3 Distinctive features of LiWatool

This section summarizes some of the distinctive features of the simulator "LiWatool".

- It allows the consideration and analysis of complex systems (e.g. water, wastewater and energy system) in an integrated way, and, in a single model. In most cases, available tools allow to consider and analyse only individual subsystems (e.g. drinking water network, sewer system, the groundwater bodies, wastewater treatment plant, etc.). This restricts not only the viewing and consideration of the system as a whole, but also to find global potential solutions.
- It allows to visualise the results in many different ways and modes of illustrative presentation (See Fig. 3 for an example of a bar graph and Fig. 5 for an example of Sankey diagram)
- Due to the high flexibility of the software, users can modify or integrate new blocks, optional parameters and variables by themselves. In addition, they can also define and analyse scenarios and alternatives (e.g. scenarios of population growth, comparison of different infrastructure projects (according to capital and operational costs (See Section 3.5 and Section 3.6 for details)). The flexibility also allows the adaptation of the software to other cities with straightforward manner.
- Furthermore, in order to promote the development of user-defined module libraries, the module editor and simulator support also the: encryption of module definition files (protection of internal know how) and digital signing of modules to ensure valid and original modules and to acknowledge authorship.

3.4 Resource flow calculation

One aim of the presented macro-modeling simulation software is to allow an easy description of the main water, wastewater, material and energy flows of large scale water and wastewater systems in urban areas. For this purpose, two approaches are applicable. One option is to use a GIS-based representation of the modelled entities and to present results also in geographical maps. The second option is to use a flow scheme oriented representation of the logical structure of the system. In this case, also the logical flow scheme can be utilised to present simulation results. It was decided to follow the second approach for the development of LiWatool (see Fig.). One reason for this decision is the need to describe the system in a significantly simplified way in order to allow an inexpensive model setup for the use cases. For simplified conceptual models, a flow scheme based representation seems to be more appropriate than a geographical representation which tends to require more detailed structural information. Nevertheless, the option to present simulation results in geographical maps is included in LiWatool as well.