ENERGY AND RESERVOIR MANAGEMENT FOR OPTIMIZED USE OF WATER RESOURCES. A CASE STUDY WITHIN THE WATER-FOOD-ENERGY CONTEXT OF NEXUS IN THE NILE RIVER BASIN.

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ABSTRACT

The Nile, the longest river in the world, is a source of fresh water for millions of people. Eleven African countries share its basin and compete for its resources. However, the continuously growing water demand in combination with the population growth have led to enormous water scarcity in the Nile River basin. The potential impacts of climate change has increased the concern about the water crisis in the basin.

Sufficient and integrated water resource management is required to provide water security in the Nile basin. The NIMA-NEX project (NIle MAnagement Nexus EXpert tool) aims at optimizing the use of water resources along the Nile River in terms of a nexus approach (nexus: derived from Latin, “the act of binding together”). The optimization will be achieved by means of a proper reservoir, energy, and irrigation management.

The MA-NEX module is the subject of the present study. This module, comprising a part of the NIMA-NEX project, will concentrate on the reservoir and energy management as well as on the water allocation among the competing users. Consequently, it will result in the optimization of the water resource use within the Nile basin. The objective is to optimize the water use in the basin, so as to maximize the ecological, economic and social benefits. Social factors strongly influence water resource use within the Nile River basin. Therefore, the MA-NEX module will optimize the water resource use centered on these social factors.

Keywords: water resources management, optimal water allocation, reservoir optimization

1. Introduction

The Nile, the longest river in the world, is a source of fresh water for millions of people. Eleven African countries share its basin and compete for its resources. Therefore, the Nile basin is suffering from enormous water scarcity as a result of both the continuously growing water demand and the population growth. The concern about the water crisis in the basin is also increasing because of the potential impacts of climate change.

Sufficient and integrated water resource management is required to provide water security in the Nile basin. Integrated management adopts a nexus approach, and therefore, considers water, food and energy as three elements that continuously interact with each other (nexus: derived from Latin, “the act of binding together”).

Within the NIMA-NEX project (NIle MAnagement Nexus EXpert tool), the use of water resources along the Nile River in Ethiopia, Sudan and Egypt will be optimized in terms of a nexus and by means of a proper reservoir, energy and irrigation management. The MA-NEX module is the subject of the present study. Comprising a part of the NIMA-NEX project, it will concentrate on the reservoir and energy management as well as the water allocation among the competing users. Consequently, it will result in the optimization of water resource use within the Nile basin.

2. Study objectives

The NIMA-NEX project aims at optimizing the use of water resources within the Nile basin in terms of a nexus approach. For this purpose, the current study will develop a management tool, the so-called MA-NEX tool. The aims and objectives of MA-NEX are summarized in Figure 1 and described below.

Figure 1: Aims and objectives of MA-NEX.

The MA-NEX tool has two main objectives. The first is the optimization of the system of reservoirs in Ethiopia, Sudan and Egypt. The reason this part of the Nile was chosen is because it brings the most water into the Nile. Furthermore, it is a section that is very interesting from a socio-political point of view. The second objective, which partially depends on the first, is the optimal allocation of water among municipalities and industry as well as energy and food production in these three countries. With these two objectives, MA-NEX aims at maximizing the ecological, economic and social benefits in the Nile basin and ensuring political stability among the countries that share the Nile's waters.

3. Methodolody

To achieve the objectives of MA-NEX, the Nile system will be simulated and optimized to satisfy the water demand among competing users under the threat of climate change. A series of steps is planned to best maximize the ecological, economic, social and political benefits. The methodology is summarized in Figure 2 and described as follows.

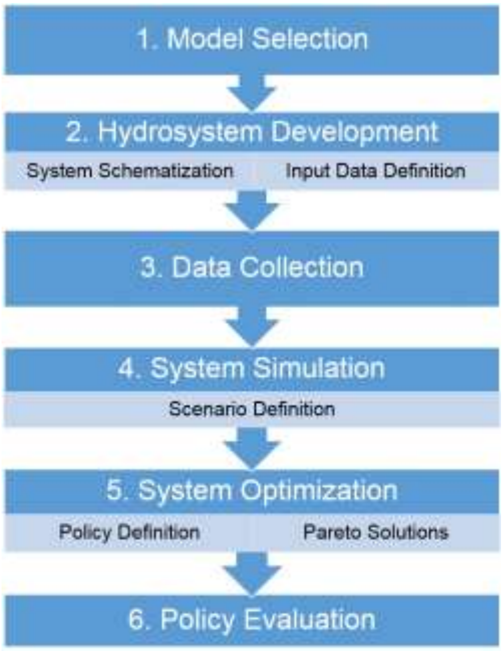

Figure 2: Methodology of MA-NEX.

The MA-NEX module begins with the selection of the proper model for the management of the Nile's water resources. Information on several simulation-optimization models is to be gathered by means of literature review, with the most suitable model selected as a basis for the study (1). In a second step, the model of the hydrosystem is to be developed. Thus, the Nile system is to be schematized and the required input data defined (2). Then, all required information is to be collected (3). The different scenarios to be simulated within the study will be defined, using both the system's schematization and the input data as a basis. The possible impacts of climate change as well as the different water users may be taken into account while defining the scenarios. Subsequently, using the selected model, the system will be simulated for the different scenarios (4).

The overall goal is to propose different policies that will satisfy the water needs of conflicting uses and users. Through the optimization of the system, objective functions will be defined and pareto solutions will be developed for each policy (5). The last step of the study is to evaluate the different policies. The key point during this step will be the societal effect of these policies on the different users (6). Throughout the entire study, with emphasis on the fifth and sixth step, the main focus will address effective ways to integrate the social factors into the optimization procedure.

4. Study challenges

The first challenge of MA-NEX is to properly choose the model that will be used for the simulation and optimization of the Nile system. The Nile is the longest river in the world. The part that flows from Ethiopia to Sudan and Egypt will be simulated and optimized within this study. Nevertheless, this part of the Nile includes many reservoirs and contains various water uses and targets that not every model is able to simulate and optimize.

The second challenge is the collection of the data required for the simulation and optimization of the Nile system. Table 1 shows the basic categories of information to be gathered for Ethiopia, Sudan and Egypt. It is worth mentioning that, due to the political situation in the region, the data collection is a major difficulty.

Table 1: Basic information categories for the Nile system.

Supply/Demand	Category
Water supply	Reservoirs/dams
	Groundwater
Water demand	Public water supply
	Irrigation
	Industry
	Hydropower

The third and biggest challenge of MA-NEX is the integration of the social factors into the optimization procedure. From the socio-political point of view, the Nile River is a very interesting case because it is a transboundary river that flows through many countries that compete for its resources. The optimization procedure will take into account various social factors that affect water use and will seek to maximize social benefits.

5. Model selection

Throughout recent decades, different models have been developed to enhance the management of water resource systems. A literature review was carried out in order to choose the most appropriate model to use for the simulation and optimization of the Nile system. The research conducted concentrated on 15 different models (see Table 2). These models share two main characteristics: they include both the aspect of simulation and optimization (so-called simulation-optimization models), and they are generalized models that may be used for different case studies.

Table 2: Selected models and their main field of application.

	Simulation-optimization model	Field of application
1	AQUATOOL	Water resources planning and management
2	AQUATOR	Tool for water resources modelling
3	HEC-ResPRM	Optimization of reservoir system operations
4	HYDRONOMEAS	Simulation and optimal management of water resource systems
5	MIKE HYDRO BASIN	Integrated river basin analysis, planning and management
6	MODSIM	River basin Decision Support System and network flow model
7	OASIS	Operational Analysis and Simulation of Integrated Systems
8	REALM	REsource ALlocation Model
9	RiverWare	Modeling river systems
10	WARGI-DSS	WAter Resources Graphical Interface
11	WASP	Water Assignment Simulation Package
12	WaterWare	Water resources management
13	WEAP	Water Evaluation and Planning System
14	WRIMS	Water Resources Integrated Modeling System
15	WRMM	Water Resources Management Model

From these 15 models, HYDRONOMEAS was chosen as the most appropriate one for the purpose of this study for the following reasons. Five of the models, namely MODSIM, REALM, WEAP, WRIMS and WRMM, were excluded because of their optimization procedures. Specifically, MODSIM is primarily a simulation model in which optimization is conducted as a means of accurately simulating the allocation of water resources (Labadie, 2010). REALM uses a fast network linear programming algorithm to optimize the distribution of water for each time-step of the simulation period (Perera *et al*., 2005). Likewise, WEAP and WRIMS do not include a separate optimization module (Sieber and Purkey, 2011; Parker, 2012). Finally, WRMM finds an optimal water distribution policy for each time step individually (Ilich, 2000).

Furthermore, six other models, namely AQUATOOL, AQUATOR, Hec-ResPRM, MIKE HYDRO BASIN, OASIS and RiverWare, were excluded because no modifications are allowed on their source code (UPV, 2015; Oxford Scientific Software Ltd, 2015; O'Connell and Harou, 2011; DHI, 2015; HydroLogics, Inc., 2009; UCB, 2014). Although WASP has the capability of readily modelling a wide range of water supply systems, it is not able to model those with hydropower (Kuczera and Diment, 1988). WaterWare was excluded because it is a web-based system (ESS GmbH, 2010). Finally, between the last two models, HYDRONOMEAS and WARGI-DSS, HYDRONOMEAS was chosen. The reason is that it belongs to a system of co-operating software applications which the user may take advantage of (e.g. CASTALIA for the generation of synthetic time series) (Karavokyros *et al.*, 2001).

6. Conclusion

Within MA-NEX, the water use in the Nile basin in Ethiopia, Sudan and Egypt will be optimized using as a basis the model HYDRONOMEAS to maximize the ecological, economic and social benefits in the region. The tool that is being developed for this purpose, will propose policies, among others for the reservoir management in the region, and will address the social factors that affect the water use.

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