MULTI-RESERVOIR MANAGEMENT WITH OPENMI

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EXTENDED ABSTRACT

The paper applies advanced integrated modeling techniques supported by the Open Modeling Interface (OpenMI) standard to optimize water resources allocation for a rapidly growing rural area in Greece. Water uses in a rural basin are significantly affected by urban growth, changes in agricultural practices and industrial needs. This results in a complex water system, whose optimal configuration requires the combination of structural and non-structural approaches. Furthermore, the reliable operation of the water system may be placed under significant stress due to increasing trends of extreme events associated with potential climatic changes which affect freshwater availability. To evaluate and improve the system's operation, a series of specialized models need to be linked and exchange data at runtime. The approach presented in this paper, used OpenMI (an open source, royalty free standard) to facilitate the direct, timestep-by-timestep, communication of models from different providers, written in different coding languages, with different spatial and temporal resolutions. The models were "migrated" to OpenMI and were run simultaneously, linked (exchanging data) at nodes specified by the modeler. The resulting integrated modeling system is tested in the Thessaly Water District, Greece, where growing water demand has often become an issue of conflict between stakeholders. As an example of the type of problems typically faced in the region, a system of two reservoirs receiving flows from different subbassins is designed to satisfy the water demand of the study area. The principal reservoir, the Smokovo reservoir, is a real reservoir, currently in operation, situated on the confluence of two streams, tributaries of the Pinios river. Downstream of Smokovo reservoir, the river flow has to satisfy a series of needs such as ecological flows, increasing irrigation needs, increasing potable water demand of the local municipalities, and production of electricity. The second reservoir introduced in this study is the potential rehabilitation of the Lake Xyniada, as a means to improve the overall resilience of the water system to extreme events and possibly decrease the costs (ecological-economic) of water consumption in the area. The integrated modeling system comprises of three OpenMI-compliant model components: a reservoir model (RMM), a hydraulic model with supporting rainfall-runoff modules (MIKE-11) and a multi-reservoir operational rule component. The models were set-up, calibrated, and linked to exchange data at runtime using data provided by the Public Power Corporation and the Ministry of Environment. The modeling system was run under different operating rules to assess the reliability of the combined reservoir system and compare it with the one-reservoir existing solution against different stakeholder objectives. The paper suggests indicative solutions from the preliminary analysis and concludes with the identification of key future challenges and ideas for further development.

KEY WORDS: Integrated modeling, multireservoir management, OpenMI, optimisation

1. INTRODUCTION

Water uses in a rural basin are significantly affected by urban growth, changes in agricultural practices and industrial needs. This results in a complex water system, often involving multiple reservoirs (natural and man-made) whose optimal configuration and operation requires the combination of structural and non-structural approaches. To evaluate and improve the operation of multi-reservoir water systems, a series of specialized models need to be linked and exchange data at runtime. More often that not, such models are developed for the specific hydrosystem and entail significant development overhead (Koutsoyiannis et al. 2002). This paper presents the development of an integrated model for multi-reservoir management, which was developed by linking existing models through OpenMI. The integrated model is then used for the investigation of the operation of the Smokovo Reservoir and its potential link with Lake Xyniada, as a coherent hydrosystem.

2. THE OPENMI STANDARD

OpenMI is an open source, royalty-free, generic standard developed by an international consortium of major commercial providers, research institutes and universities during the HarmonIT FP5 project (Blind and Gregersen, 2005) with a purpose to facilitate the different model component linking required for integrated analysis (Moore and Tindall, 2005). It is defined by a set of software interfaces that a model must implement in order to become compliant. These interfaces are available today in C# and Java (http://www.openmi.org/). All OpenMI compliant model components can exchange data at run-time with a simple drag and drop approach using the OpenMI Configuration Editor (Figure 2). Hence a modeler may combine the most suitable components available from among both commercial models and research prototypes and tools. The ambition for OpenMI is to become a global standard for model linking. In order to achieve this, it has to prove that OpenMI model compliance ensures interoperability, user-friendliness and improved performance at a reasonable cost. Gregersen at al (2007) recognized three characteristics necessary to a successful standard: (a) the standard has to be technically sound which can be demonstrated through the successful implementation of a large number of test cases that vary in complexity; (b) the standard has to reach a critical level of users which will entice new modelers to adopt it and (c) the standard has to be maintained and continuously developed to address and satisfy the new requests from the modeling community. To be adopted however, such a standard needs to also *demonstrate* that the application of OpenMI at an operational level can solve real-world problems. The following sections will briefly describe such an application and discuss the benefits realized and the challenges encountered when their models were linked in OpenMI.

3. CASE STUDY AREA

Pinios pilot basin belongs to the Thessaly Water District, Greece. The whole Pinios watershed drains an area of approximately 10,500 km^2. It is intensively cultivated with water demanding crops. Agriculture is the main source of income for the greater area (Loukas et al, 2007). It is understood that the sustainability of Thessaly's natural and built environment depends heavily on Pinios water quantity and quality. Available surface water and groundwater has to satisfy the needs of farmers, industry, local municipalities and furthermore, to support the local environmental ecosystems. Fertilizers and pesticides, as well as untreated industrial waste and municipal wastewater directed into Pinios add to local water pollution issues and result to water quality degradation. Climate change impact studies on local water resources forecast decreased monthly precipitations that would lead to decreased streamflows and further water quality degradation (Mimikou et al. 2000). Land use change, deforestation, channel development, and groundwater overexploitation have increased the severity and frequency of extreme events (flood/ drought). Appropriate water management programs should be developed to include mechanisms that ensure effective, economically achievable pollution reduction and secure water that meets the desired standards. The interrelated water quantity and quality concerns of the Pinios basin demand an integrated modeling approach. The OpenMI standard was chosen to facilitate the seamless linking of the most suitable, available models representing the various processes in the area.

The Smokovo reservoir is located in the northwest part of the Thessaly Water District, Greece, and is a part of the Pinios subbasin. The reservoir is situated on the confluence of two smaller streams. A total area of approximately 376km^2 contributes flow to the reservoir. There are many points of unregulated groundwater pumping in the greater area, which have significantly lowered the water table. Due to this situation, no major groundwater resources are estimated as contributing to the reservoir. Smokovo is used to cover a number of demands (urban, energy, environmental and agricultural) in the surrounding area. Specifically, the reservoir has to satisfy the following water uses (see also Koutsoyiannis et al., 2008):

- ❑ Adequate flow to support ecosystems downstream, along Sofaditis river
- ❑ Water to support local municipalities (~55000 permanent residents)
- ❑ Sufficient water for the required energy production at Leontari hydroelectric station
- ❑ And most importantly, enough water volume for the increasing irrigation needs. More specifically, the Smokovo reservoir aims to supply 25000ha of agricultural land, through a pressured pipe network, thus limiting the extensive use of boreholes. Today, only a small part of the network, 1800 ha, is finished and other 3700ha are irrigated through small barrages.

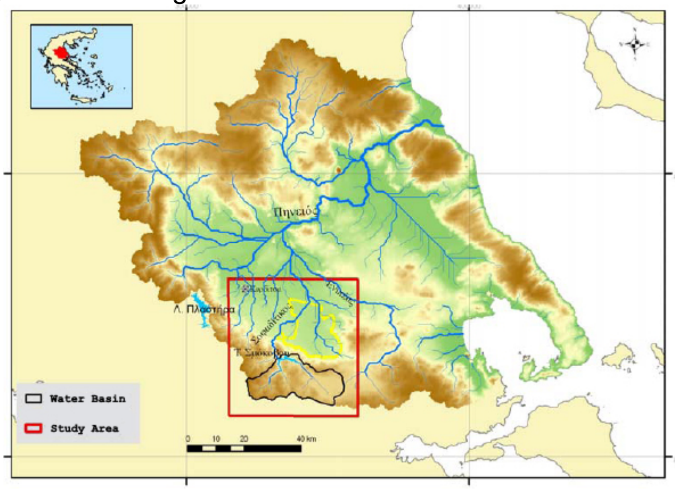

Figure 1: The Pinios Water Basin

There are various concerns related to the optimum operation of the Smokovo reservoir. Future climatic changes may place the operation of the reservoir and its design specifications under stress. Since many different parties benefit and request different reservoir water allocations, investigating an optimum solution accepted from everyone is not an easy task (Kallis et al., 2007). Xyniada, is located 20km to the east of Smokovo reservoir in a water basin of 36,6 km^2 area. Although in the past, Xyniada was a lake, it has been dried up and its current use is simply collect water and irrigate the surrounding agricultural areas. The scenario examined here is to recreate Lake Xyniada to support the Smokovo reservoir (as a combined hydro-system), while still maintain its ability to cover the existing agricultural needs, and possibly provide water for environmental purposes.

4. MODELING APPROACH

An integrated modeling approach was selected to allow taking into account all essential water balance components of the hydrosystem and improve the understanding of water availability and demand in the area. OpenMI was used to link a commercial model (Mike-

11) to an in-house reservoir management model (RMM-NTUA) to support the objectives of the analysis. Mike-11 was OpenMI compliant at the beginning of the study. The RMM-NTUA model was migrated into OpenMI by the authors. An additional component to the RMM-NTUA model was also developed and migrated (a "rule component"), which adds the volumes of all reservoirs present in the system to make the operational rules applicable to the whole reservoir system.

Mike-11 was used to simulate open channel flow in a canal, linking two reservoirs models for the purposes of the study. Rainfall-runoff was simulated using the NAM module[1] available within Mike-11. The NAM module is a lumped, conceptual rainfall-runoff model, simulating the overland-, inter- flow, and base-flow components of catchment runoffs as a function of the moisture contents in four storages. NAM includes a number of optional extensions, including an advanced snow-melt routine and a separate description of the hydrology within irrigated areas. RMM-NTUA is a reservoir model, which includes operational rules. The rules specify the water level of the reservoir, as a function of the total water volume available in the reservoir system. The models were linked as model components in the OpenMI Editor[2] (Figure 2).

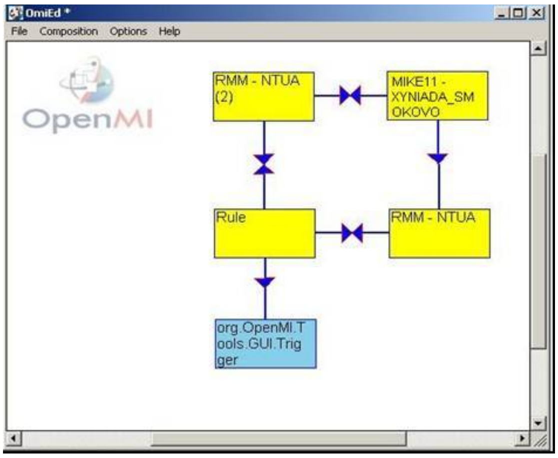

Figure 2: The OpenMI Editor

Specifically:

- Discharge calculated from Mike-11 is sent as input to Xyniada Reservoir (RMM2)
- Outflow from Xyniada Reservoir is sent back to Mike-11, where it is added to the discharge from Smokovo catchment, supplying the input to Smokovo reservoir (RMM)
- The volume in the two reservoirs is sent to the rule component, and the total volume is calculated, sending the information back to both reservoirs, in order to correct the volume allocation

5. MODELING THE CASE STUDY

The open channel connecting the basins of Smokovo and Xyniada was modelled using Mike-11. Rainfall data from nearby hydrometeorological stations were used to calibrate the NAM rainfall-runoff module within Mike11. Input parameters for the modelling exercise were:

- Time step and time horizon of simulation
- Level-storage and level-surface data (given as point- series)
- Characteristic levels (minimum, maximum, initial)
- Upstream watershed area
- Time series of precipitation and evaporation depths
- Leakage function coefficients (monthly)

[1] An OpenMI compliant version of MIKE-SHE was not available at the beginning of this work.

[2] See also: Gregersen et al (2005).

- ❑ Water uses properties (priority order, demand time series, operational rules)

The reservoir properties used can be seen in Table 1.

Table 1: Reservoir Properties

	Smokovo	Xyniada
Minimum Level	+285m	+450.5m
Intake Level	+331m	+451m
Spill level	+375m	+454m
Dead Storage	28.4hm3	10.7hm3
Total capacity	237.6hm3	42.9hm3
Useful storage	209.3hm3	32.2hm3
Maximum area	8.4km2	31.6km2
Upstream watershed area	260km2	100km2

The following demands were required from the Smokovo Reservoir:

- ❑ Water release for environmental preservation, 10 hm^3 /y
- ❑ Abstractions through Leontari tunnel for water supply, 15 hm^3 /y
- ❑ Abstractions through Leontari tunnel for irrigation, 150 hm^3 /y
- ❑ Additional water release for irrigation, 20 hm^3 /y

The operational rule which defines water allocation in each reservoir is of the form seen in Figure 3 and it is the optimization of this rule that is made possible through the integrated modeling approach in this study.

Total Volume	Smokovo	Xyniada	Total Volume	Smokovo	Xyniada	Total Volume	Smokovo
0	0	0	110	90	20	210	170
10	5	5	120	100	20	220	180
20	10	10	130	110	20	230	190
30	20	10	140	120	20	240	200
40	30	10	150	130	20	250	210
50	40	10	160	140	20	260	220
60	40	20	170	150	20	270	230
70	50	20	180	150	30	280	240
80	60	20	190	160	30	290	250
90	70	20	200	160	40	300	260
100	80	20					

Figure 3: The operational rule of the system of reservoirs.

6. RESULTS

The simulated period was between July 2002 and December 2005, using a daily timestep. Hydrological inputs included:

- ❑ Inflow time series from the upstream watershed, provided by Mike11/ NAM after calibration
- ❑ Rainfall depths from nearby stations
- ❑ Evaporation depths, estimated on mean monthly basis and uniformly disaggregated

Figure 4, presents the simulated operation of the Smokovo reservoir.

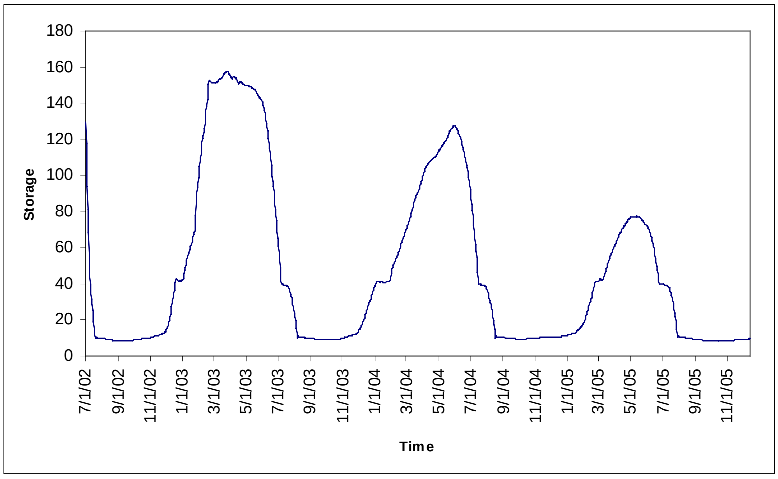

Figure 4: Smokovo - Reservoir operation

Similarly, Figure 5 presents the operation of the Xyniada (potential) reservoir.

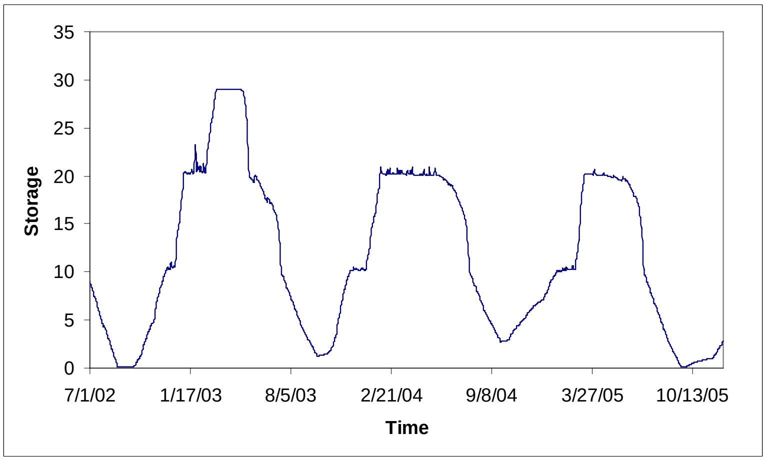

Figure 5: Xyniada - Reservoir operation

The correlation between demand and supply from the combined system, which is the result of a specific (non-optimal) operational rule (the one presented in Figure 3) can be seen in Figure 6.

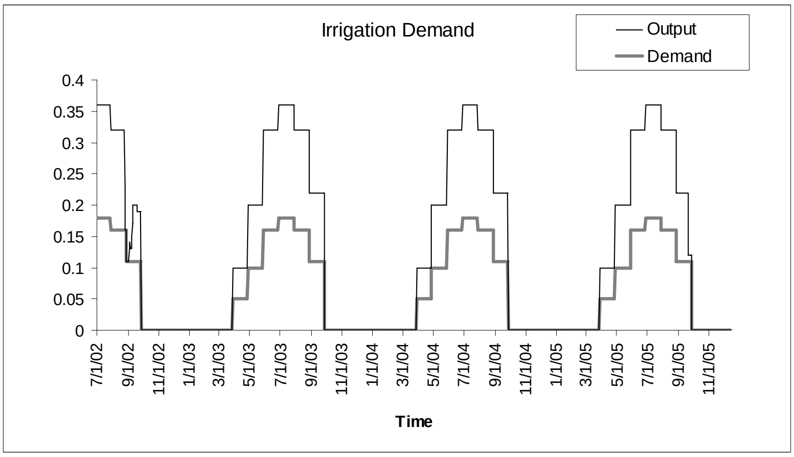

Figure 6: Demands versus supply for the system (Operational Rule No 1)

The correlation between demand and supply for primary and secondary irrigation uses of the Smokovo reservoir resulting from a (more optimized) operational rule for the system can be seen in Figure 7. It can be observed that although primary irrigation uses are satisfied, some secondary uses are not. There is hence room for defining a more optimal rule.

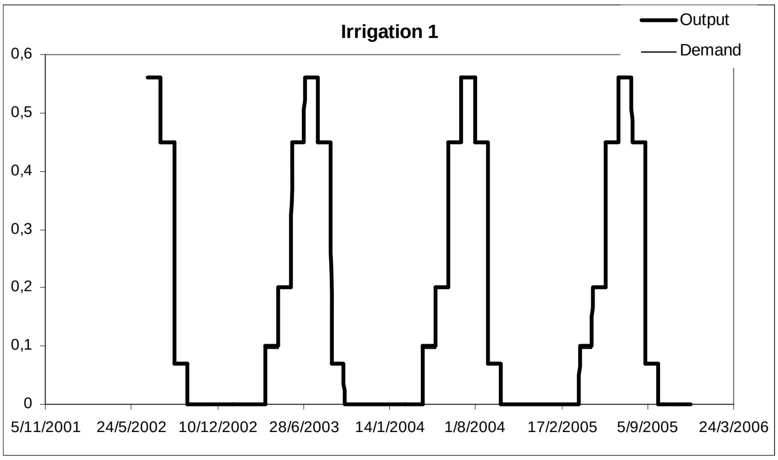

Figure 7: Primary irrigation demand versus supply for Smokovo

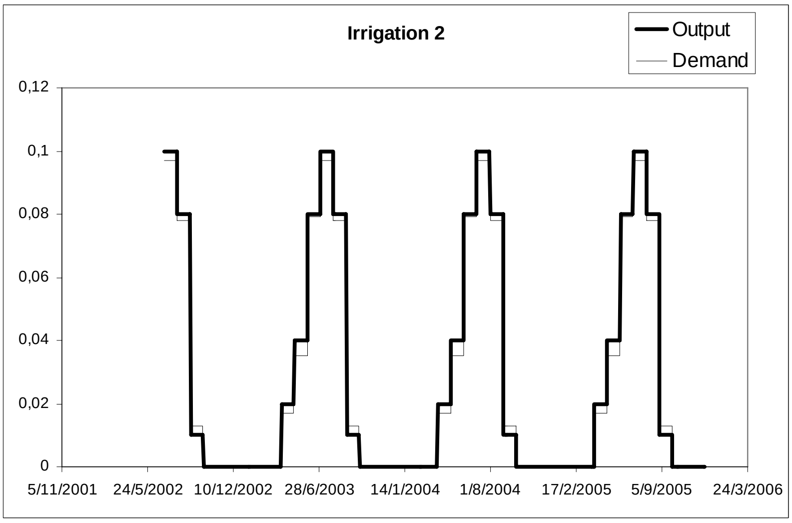

Figure 8: Secondary irrigation demand versus supply for Smokovo

7. CONCLUSIONS

- A number of in house and commercial models were made OpenMI compliant, and were successfully run and made to exchange data at run time.
- A multiple reservoir system was set up from existing model components which is taking into account the interactions between reservoirs and the catchments, and manages reservoir operation to balance supply and demands.
- An additional rule component was developed which allows for the optimization of the multi-reservoir system operation, assiting the design and operational decision making process. A formal optimization component for the system is currently under development.
- It is suggested that the set up of such scenarios using OpenMI saves substantial time, by allowing the models to exchange data at run time, instead of running the models consecutively and separately.

- The next steps of this study will be to provide different design parameters to test the system under different circumstances, provide different rules for water allocation in each reservoir, according to the demands and reservoir operation and add new models, including an additional reservoir
- It is further suggested to develop and test a multi-objective optimization component to support decision making for the whole system (Makropoulos et al., 2006).
- Finally it is suggested that through this work a possible restoration of Lake Xyniada could be considered, to be used both as an additional reservoir for the supply of Smokovo, as well as to cover needs of the Xyniada area, including environmental objectives.

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[3] http://www.openmi-life.org/