OPTEXPLOR – new application for water resources management for private water supply utilities

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Abstract This article presents the steps made for the development of a new water management system (WMS) for a private water utility in the south of Portugal, and its main results. The WMS is composed of a set of models representing the water resources, surface and groundwater, water quality models, economic models, and water allocation optimization models. The system was developed at the request of the regional water utility (Águas do Algarve, S.A.), which is responsible for distributing water to the entire Algarve region (most touristic area in Portugal, with about ten million tourists per year, and a local population of about four hundred thousand). Results clearly show that independently of the amount of water available, inter-annual exploration is always the best solution, if possible. When water scarcity is high, as in consecutive dry years, the water utility will need to call municipalities to use their systems to complement supply. The level of supply deficit is higher, in any case, for annual exploration management, and so are exploration costs. These results clearly show that water resources management needs careful inter-annual planning, even for a private water supply utility with very limited control over water exploration by other competing users.
Keywords water management system; water supply; sustainability; modeling; optimization; Algarve

INTRODUCTION

Groundwater has been seen by national water agencies as "an emergency resource, or for small distribution systems", in opposition to what is now stated by the European Water Framework Directive, which calls for integrated management solutions, such as the R&D OPTEXPLOR project (2005-2009) presented in this article. OPTEXPLOR was financed by the regional water utility, Águas do Algarve, S.A. Its aim was to build a water management system for determining the best resource use under the constraints set by available water in dams and groundwater. These constraints are of two types: i) natural; ii) legal. The first constraint is a reflex of climatic variability and water demand, and requires forecasting - modelling; the second is imposed by the national water institute (INAG), which is responsible for dividing water volumes among users (agriculture and public supply).

The OPTEXPLOR includes modules for modelling surface and groundwater availability, as well as water quality models for estimating the water composition after mixing waters from two or more alternative sources. It also includes a database for storing all historical data and data produced during the modelling phases. During the development of the project two other complementary studies were needed: demand estimation and evolution; and cost of alternative water treatment methods.

EVOLUTION OF WATER USE AND SUPPLY IN THE ALGARVE

Until the first half of the XX century, water demand in the Algarve was entirely satisfied by artisanal shallow wells. The Arade and Bravura dams, built in the fifties, were the first infrastructures made to support demand at the regional scale. These dams supply water for human consumption and for two irrigation perimeters, of 2300 ha and 1747 ha. The following decade saw water consumption rise sharply due to the increase of irrigated areas and tourism. Water demand could only be satisfied due to the generalized use of groundwater, both for human consumption and irrigation. Only in the nineties new dams were built (Odeleite and Beliche), thus allowing the development of a new 8100 ha irrigated perimeter. This area adds up, with the other perimeters, to about 121 km^2, which is the actual irrigated area depending on surface water sources, and corresponds to about 60% of the irrigated areas. Estimates for water demands for agriculture indicate that the dams are capable of supporting 32 million m^3/year, while groundwater supports 186 million m^3/year. With the building of two new dams, Beliche dam in 1986 and Odelouca dam in 2009, the total surface water built storage amounts today to 267 million m^3, with an average usable volume of 170 million m^3. Most of groundwater during the second half of the XX century was managed locally by the municipalities, with no articulation between them, which resulted in sub-optimal exploration solutions. A regional multi-municipal water distribution system (WDS) assures the treatment and bulk distribution of drinking water along the region. The infrastructure is managed by a publicly owned company (Águas do Algarve, S.A., AdA) (Figure 1).

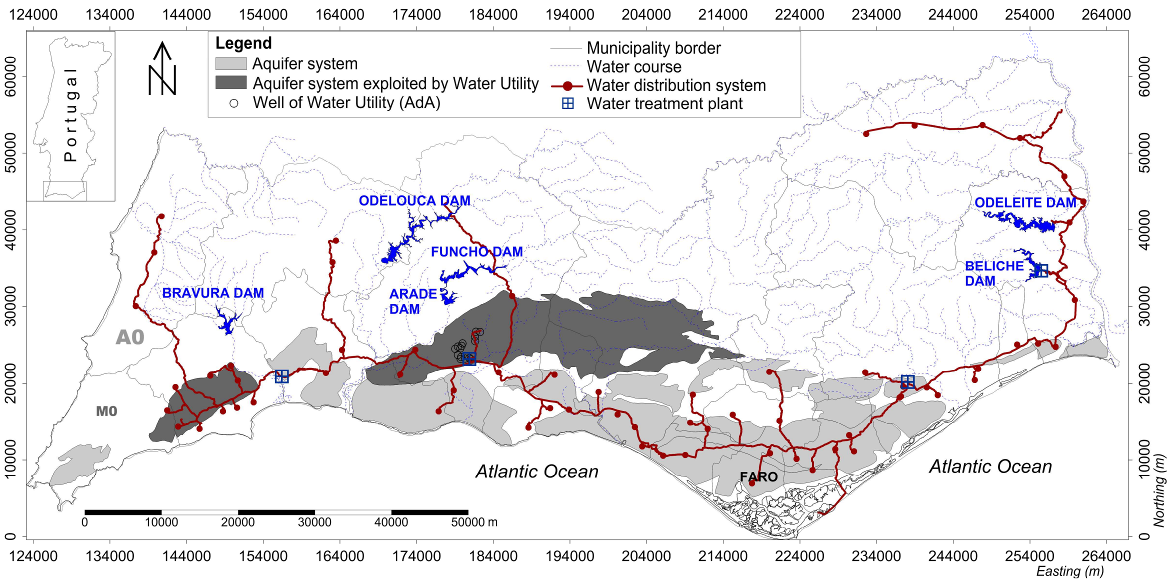

Figure 1. Multi-municipal drinking water distribution system

The main water sources for the WDS are three multi-purpose dams (Bravura, Funcho, and Odeleite/Beliche), fifteen wells in the Querença-Silves aquifer, and three wells in Almádena-Odeáxere aquifer. Emergency wells to cope with critical scarcity periods are available in six different aquifers. These are owned by municipalities and can only be used under AdA authorization and with continuous monitoring of quality and levels.

OPTEXPLOR

By 2005 it was very clear that the production of drinking water in the region would have to include both surface and groundwater. The fundamental question was how to define the amount of one and the other. By that time there was still limited information as to the correct volumes available at all sources (mainly in groundwater) and to the volumes demanded at each delivery point (mainly the minimum contingency volumes needed for hospitals, fire-fighting, etc.). The water utility had already studied the possibility of blending surface and groundwater to obtain water of higher quality at a lower cost, but the sustainable volumes of groundwater with appropriate quality had still to be determined. Would it be advisable to mix waters from different origins and quality in the same distribution system – what quality would the mixed water have? Also, would it be more cost effective, in some locations, to treat water in small treatment plants (WTP) near the source, or convey all water into the large WTP? Finally, what volumes of water should be used of each source such that exploration costs were minimized and resources sustainability maximized? The water utility and a team from the Universities of Algarve, Coimbra and Technical University of Lisbon, set up a R&D project in 2005, designated OPTEXPLOR to answer these questions.

The result of the project should be a water management system (WMS) capable of allowing the water utility to evaluate the consequence of decisions about operational exploration, namely on the amounts of water that should be used from each source, guaranteeing the distribution of high quality water and the preservation of the resources.

The project started by evaluating inter-annual water availability (drinking water consumptions and water availability). Surface and groundwater models were built to simulate annual water volumes at six dams (Arade, Bravura, Beliche, Funcho, Odeleite, Odelouca), and two aquifers (Almádena-Odiáxere, and Querença-Silves). In the surface models, the monthly natural runoff included in the water balance of reservoirs was calculated by the Temez (1977) model for each basin (Nunes et al. 2009). The monthly minimum discharges for downstream ecosystem were set to 15% of the monthly natural runoff, considered the appropriate value by Alves and Bernardo (2003). Groundwater was modeled in transitory conditions by the finite element method, with 14533 elements and 7494 node in the first aquifer, and 22409 elements and 11663 nodes in the second. All models were calibrated and validated against real series. Groundwater models also allowed the establishment of minimum sustainable piezometric heads, i.e., the minimum water level that did not affect negatively other groundwater functions (for irrigation, and preservation of ecosystems). On the other four aquifers, where hydrogeologic information was not enough to build numerical models, minimum piezometric heads were established by expert judgment based on historic piezometric head series. An exhaustive analysis of all municipal wells used for public consumption (340 wells) to identify if water quality fulfilled water quality criteria was made. Water was considered of good quality if water had been classified as of good quality according to Portuguese legislation in all historic records, and if yield was higher than 15 l/s. Only 18 wells fulfilled both criteria and therefore included in a list of possible water sources. Water demand was determined by a second team and incorporated in the project. Average annual demand was estimated to be 72.5 million cubic meters, highly concentrated during summer months from July to September.

A hydrochemical model was developed to determine water quality after mixing waters with different origin. It simulates the mixing of raw surface water from the Funcho dam and groundwater from the Querença-Silves aquifer at the Alcantarilha WTP. The main objective of the model was to calculate hardness and calcite saturation after the mixing of the two waters, under variable water temperature, as mixing is non-conservative. It can also simulate the effect of mixing on the values of pH, chloride, nitrate, iron, and manganese.

Several alternative water treatment technologies were compared to evaluate the costs of treating water in small WTP. Cost functions were obtained in a per unit of parameter removed basis, and per water source. The following parameters were analysed: i) iron and manganese; ii) hardness; and iii) microbiological parameters. These values helped the water utility to choose for keeping the system concentrated in large WTP, as costs could be kept lower and were easier to operate than several smaller units.

All information collected and produced during the project was stored in a relational database programmed in Microsoft Access, with supporting files in Microsoft Excel. The selected software has the advantage of allowing the search by queries and exportation of selected data very easily, which facilitates data transference between team members and results in a very useful tool for other projects as well.

The decision about what volumes to use from each water resource according to water availability, environmental restrictions (e.g., minimum piexometric levels), minimum water quality, and operation costs, was solved by a deterministic optimization model, based on a representation of water systems as a modified multicommodity flow network (Yang et al. 2000). Water system components were represented in the flow network as eleven supply nodes, sixty four transshipment nodes, sixty five demand nodes and one hundred and fifty eight arcs. The linear piping main piping system was divided into two subsystems, a western and a eastern. Two-way flow pipes are used to transfer water between the two. Three water treatment plants (WTP) only receive surface water (Tavira, Fontaínhas and Beliche), while in Alcantarilha WTP surface water is previously mixed with groundwater to improve treatability and water chemical quality. The planning objective was to minimize the value of operation costs. These were penalized if demand was not fully satisfied, if water mixture was out of given boundaries, and if emergency wells had to be activated.

RESULTS FROM THE PROJECT

At the end of the project, the water utility received two fully operational groundwater models (Querença-Silves, and Almádena-Odeáxere aquifers), one hydrochemical model for assessing the quality of water mixtures, five fully calibrated surface water models, a set of water treatment cost functions, one database, and one optimization decision model.

Due to the very high climatic variability in the Algarve, common to Mediterranean climates, precipitation is distributed very unevenly over time. Periods of two or three consecutive years of very low precipitation are frequent, as occurred in the years 1975-76, 1981-1983, and 2004-2005. During these periods water availability decreases significantly, putting a lot of pressure on water utilities. The analysis of consequences of management decisions during (and before) these periods are very useful when planning inter-annual use of water resources. The water utility had the opportunity to evaluate different climatic scenarios. Results from the simulations indicate that if a year per year operation is use, in the event of two consecutive very dry years, the water utility would have to allow municipalities to activate their wells to equal demand, as water deficit may reach as high as 65%. If inter-annual operation is used, i.e., planning ahead and distributing water resources and demand for longer periods, deficit is much lower, of only about 17%. These water deficits are compensated by exploration of groundwater resources at the municipal wells. As the water utility can only charge for water that it supplies, deficits correspond to high revenue losses.

Exploration costs are similar for annual and inter-annual management during normal hydrologic years, as optimal water allocation is an even annual distribution. Whereas, during extreme water scarcity periods, optimization leads to lower exploration costs as it forces allocation to be more even than is usually made (depleting first surface water sources and only after exploring more groundwater).

Inter-annual management presents some obvious advantages: i) water sources are better used – stored volumes are more even; ii) water scarcity is much lower; iii) water quality at surface water bodies is better due to larger water depth. There are, however, some disadvantages: i) larger volumes at surface water bodies increase losses by evaporation and ecological yields; ii) other water users may compete for the same resource; iii) may be misleading as to the real water budget – as groundwater levels are being lowered at the same time – and therefore increase water waste.

The model was used by the water utility to study scenarios of water availability since its finalization in November 2009. Future developments will include its integration with other water simulation models (EPANET, AQUASAFE), daily operation management tools (NAVIA), and models for the efficient use of energy (to be developed).

CONCLUSIONS

Results clearly show that independently of the amount of water available inter-annual exploration is always the best solution, if possible. When water scarcity is high, as in consecutive dry years, the water utility will need to call municipalities to use their systems to complement supply. The level of supply deficit is higher, in any case, for annual exploration management, and so are exploration costs. These results clearly show that water resources management needs careful inter-annual planning, even for a private water supply utility with very limited control over water exploration by other competing users.

ACKNOWLEDGEMENTS

The writers wish to thank the water utility Águas do Algarve S.A. for funding the research reported herein under project OPTEXPLOR (2005-2009).

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