The water crisis in southern Portugal: how did we get there and how should we solve it

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Abstract

Until very recently, the public water supply in the Algarve region was almost entirely supported by groundwater wells. However, in the last years of the 20th Century, the Portuguese government defined a scheme for the public water supply sector entirely based on surface water from large dams, in order to guarantee the public water supply. The efforts to abandon groundwater as a source for public supply started in 1998, after a large investment in new infrastructures and rehabilitation of some existing ones. However, the practical implementation of this water supply scheme showed that an integrated resource management is needed in order to implement a more economical and reliable solution. The present paper describes the historical background and the evolution of water use in recent decades until the present time in the Algarve, and a proposal for restructuring the management of the water supplies based on the development of a decision support system within an integrated water resources management scheme.

1 Introduction

The Algarve region (5400 km^2) is the southernmost province of Portugal, as indicated in Figure 1. The region is characterized by a warm Mediterranean climate. A mean annual precipitation of 653 mm was calculated for the period 1941/42-1973/74 [1]. Unfortunately the precipitation regime is not regular,

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having intermittent periods with short and sharp floods in the winter and a long dry period in the summer. In addition, there may be extreme events such as inter-annual periods of drought.

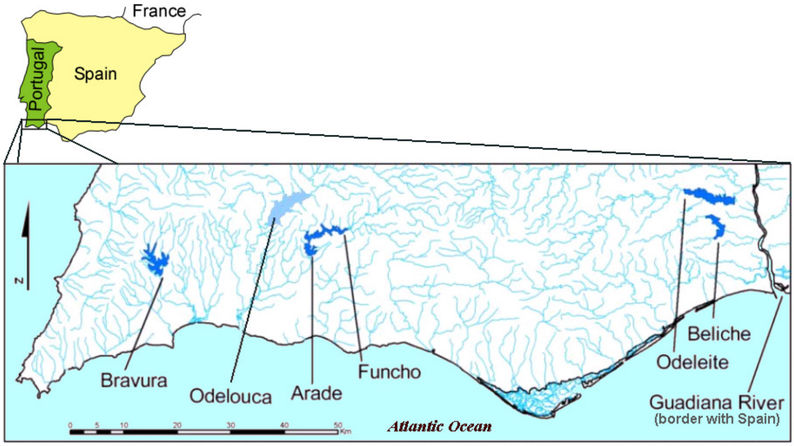

Figure 1: Location of dams in the Algarve region (existing dams in dark blue; dam under construction in light blue).

With such a climate, an integrated management of water resources at the basin scale is needed. With regard to the joint use of groundwater and surface water, Burt [2] remarked: "the inherently random nature of surface water supplies and the natural recharge to an aquifer give groundwater stocks an important role as a contingent supply for times when surface water stocks (*i.e.* dams) are below average. Additionally, optimal intemporal allocation of groundwater used conjunctively with surface water will impute a higher value to the surface water than it would have in an unmanaged basin". Integrated management schemes improve feasibility and reduce systems' vulnerability, and they may also improve the quality of the delivered water and offer important advantages when facing increasing demands, delaying the construction of new and costly infrastructures [3].

At present demand in the region is in the order of 260×10^6 m^3/year, for agriculture (69%), public water supply (27%) and golf activity (10%). This value corresponds to a dramatic rise in the last 40 years, mainly thanks to an increase in the irrigated area (currently about 200 km^2) and tourism (about 10 million visitors per year with an average stay of about 10 days).

Agriculture and golf mostly use groundwater, with much less consumption of surface waters. In the opposite situation, and according to the present policy for the sector adopted by the Portuguese central administration, the public water supply should be guaranteed only by surface waters from large dams (Figure 1 and Table 1). This is a high risk situation for the public water supply system, and its consequences were felt in the last drought that affected Portugal in 2004 and

2005. The dams were almost depleted and restrictions on water use were imposed in all sectors. The economic damage was not greater because groundwater played an important role in helping to cope with the situation.

Table 1: Some characteristics of the large dams in the Algarve region (note: the Arade and Funcho dams are in the same water course).

Dam	Year	Height (m)	Watershed (km^2)	Type	Maximum storage ($\times 10^6 m^3$)
Arade	1956	46	224	embankment	27
Bravura	1958	41	75	concrete	32
Beliche	1986	54	99	embankment	48
Funcho	1993	49	211	concrete	43
Odeleite	1996	65	352	embankment	117
Odelouca	2010(?)	96	385	embankment	135

Table 2: Some characteristics of the 17 aquifer systems identified in the Algarve [4].

Aquifer system	Dominant lithology	Area (km^2)	Mean recharge ($\times 10^6 m^3$/year)
M1-Covões	L, D	22.56	6
M2-Almádena - Odeáxere	L, D	63.49	16-24
M3-Mex. Grande - Portimão	L, D, S	51.71	10
M4-Ferragudo - Albufeira	S, L, M	117.10	8
M5-Querença - Silves	L, D	317.85	53-87
M6-Albufeira - R. Quarteira	L, D	54.55	9
M7-Quarteira	L, D, S	81.19	12
M8-S. Brás de Alportel	L, D	34.42	5-6
M9-Almansil - Medronhal	L, D	23.35	6-7
M10-S. J. Venda - Quelfes	C, S, L, M	113.31	9
M11-C. Cevada - Q. J. Ourém	L, D	5.34	2
M12-Campina de Faro	S, L	86.39	10
M13-Peral - Moncarapacho	L	44.07	10
M14-Malhão	L, D	11.83	3
M15-Luz - Tavira	L, S	27.72	4
M16-S. Bartolomeu	L, D	10.60	3
M17-Monte Gordo	S	9.62	3

Legend: C-clays; D-dolomite; L-limestone; M-marl; S-sand.

Groundwater stocks are by far the biggest reservoir in the region and current knowledge about the hydrogeology of the Algarve allows the identification of 17 aquifer systems at the regional scale [4]. The carbonate rocks (mainly Jurassic and Miocene period) are the support of the most important aquifers, both by their extent and by the volume of stored water (Figure 2 and Table 2). Though ground waters in the carbonate rocks have a high natural degree of hardness, it has already been noted that their joint use with softer surface waters may have important advantages in treatment requirements [5].

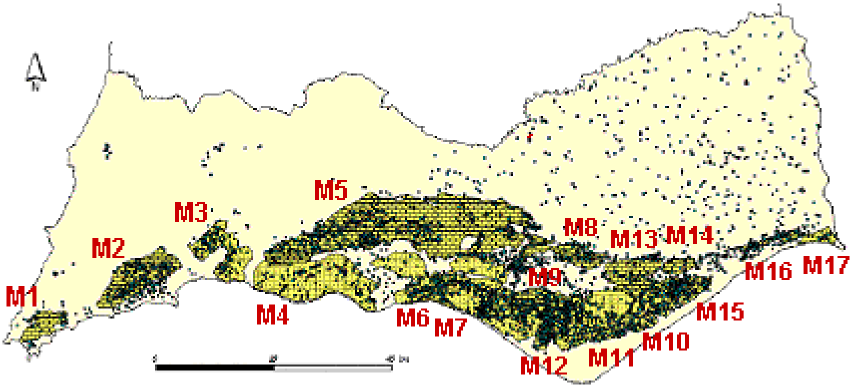

Figure 2: Location of dug wells and boreholes and geometry of the 17 aquifer systems with regional expression in the Algarve.

Recent studies conducted by the company Águas do Algarve S.A. (regional water utility for the public supply) include the use of both surface and ground waters, and the possibility for using desalinated water and treated wastewaters for purposes compatible with its quality The company wants to consolidate the water system to be able to respond to the different possible scenarios, including extreme events like long periods of drought that may periodically happen. Huge investments are required to implement and to operate the different technical solutions. Cunha [6] remarks that planners should use the proper methodological tools to obtain the best response (or a set of good alternative responses) to such problems. The author also argues that decision models can play an important role in dealing with such situation by simultaneously integrating all the relevant aspects (physical, hydrological, technological, financial, etc.). In Section 2 of this paper the authors present a general overview of the changes in the water use during the last 50 years, and in Section 3 they briefly describe the decision support system that is being developed to make the public water supply system more robust and resilient.

2 Evolution of water use in the Algarve during the second half of the 20th century

Until the midway through the 20th century water demand in the Algarve region was entirely supported by mechanical means. Groundwater was exploited through hand-dug wells with large diameter and depths usually less than 30 meters. Surface waters were exploited in small earth dams and water was channelled through sluices. The Bravura and Arade dams (Figure 1 and Table 1), built in the 1950s, are the first man-made structures supporting the use of surface waters with expression on a regional scale. The water in these two dams was used initially for the irrigation of agricultural areas in two public areas of 23 km^2 and 17 km^2. In the 60s, a period of exponential rise in the water demand began, mainly due to the introduction of many and new irrigated agricultural areas and to the growth in tourism. Rough calculations indicate that by the end of the 20th century demands were ten times higher than in the early 50s.

It was only possible to meet increasing demands thanks to the introduction of drilling technology that allowed the construction of thousands of boreholes in the region. These boreholes, often more than 100 m deep, were implanted without the support of adequate regional planning, that should have been based on the existing knowledge of the hydrogeology of the region. Despite the efforts of the regional office of the National Water Authority, the inventory of the existing boreholes is still far from being exhaustive, although more than 8000 wells and boreholes have already been mapped (Figure 2). At that time, the public water supply was locally and independently dimensioned by each of the 16 municipalities of the Algarve. Only a few of the boreholes operated by the municipalities were established taking in account the characteristics of the aquifers and backed up with pumping tests and technical reports. However, most of the boreholes, in particular those that were built for agriculture, were implemented without any technical or scientific support.

The intensive augmentation of groundwater use during this period was certainly one of the reasons contributing to the large number of scientific contributions related to the characterisation of groundwater resources in the Algarve region. The first contributions to the characterization of groundwater at a regional scale appeared in the early 80s [7–9]. However, due to the lack of technical capacity, those studies did not lead to visible improvements in the efficiency of the regional water management. In practice, the knowledge contained in those works was not used to support current water management. Increasing pressures on the groundwater resources resulted in the exposure of serious problems. High levels of groundwater abstraction were at least partly responsible for high nitrate contamination in irrigated areas [10] and for the displacement of the fresh water-salt water interface in some sectors of coastal aquifers [11].

These situations, together with the relentless increase in water demand, led to the present policy defined by the Portuguese government, which consists of the construction of a multi-municipal system, entirely based on surface waters from large dams to guarantee the public water supply and to replace all the individual municipal systems. The efforts to abandon groundwater as a source for public water supply started in 1998, after a large investment in new infrastructures (Funcho, Odeleite dams; water treatment plants, regional distribution system) and in the rehabilitation of others ones (Beliche and Bravura dams). The Arade dam is used only for irrigation. One dam is missing to complete the system: the Odelouca dam. This dam should already have been built but a series of delays related to the environmental impact assessment procedure have reduced its maximum capacity and postponed its commissioning until 2010, at least. The

Odeleite and Beliche dams support a multi-purpose system. Besides public water supply these dams allowed the creation of a new irrigation area of 81 km^2. This new area, together with the aforementioned area irrigated by the Bravura and Arade dams, allows a total of about 120 km^2 to be irrigated with surface waters.

At a first glance, the immediate benefits associated with the implementation of the multi-municipal system seem evident. From the environmental point of view, it was often claimed that reducing the exploitation of the coastal aquifers, plus with the abandoning of many boreholes used for public supply in urban areas, would lead to the attenuation of the effects of saltwater intrusion. However, as water use for urban supply constitutes only 27% of the total water use, this is not necessarily true, because the effects of these phenomena are strictly conditioned by the pumping schedules at the scale of the aquifer sectors where boreholes were in use. The major benefits were felt in the quality of the water delivered for human consumption and in the control of water quality because all surface water is properly treated for use, and it is far easier to control water quality in a few dams than in a large number of boreholes.

Even without the Odelouca dam, which will be exclusively operated by Águas do Algarve for the public water supply, all needs were satisfied until the last long drought that occurred in 2004 and 2005. In that period all the dams were almost depleted and restrictions on water use were imposed for all economic sectors, with exceptional measures being taken to avoid the total disruption of the public water system. When the public water supply could not be ensured by surface waters “emergency boreholes” were made and the old municipal boreholes were reactivated. Unfortunately, the last solution was not completely successful. In too many cases, the infrastructures (*i.e.* boreholes, pumps and pipes) had been abandoned and were in a bad state of repair. Figure 3 shows some images that confirm the abandonment of infrastructures that represented huge investments in the relatively recent past. One may think that if the Odelouca dam had already been built there would not have been any problems meeting all demands in the last drought. With a maximum storage capacity of 135×10^6 m^3 and mean annual inflows of 121×10^6 m^3, the Odelouca dam will contribute significantly to solving major water scarcity problems and will release the Funcho and Bravura dams for almost exclusive irrigation purposes. However, the measured inflows to the Odelouca dam are between a minimum value of 4×10^6 m^3/year and an extreme value of 309×10^6 m^3/year. The inflows series show that there will be many years when the demand cannot be satisfied. Even with inter-annual regularization due to the construction of the dam, it will be hard to meet the demand in the long term (projected to be 75×10^6 m^3 in 2025) in long periods of drought.

As claimed by Monteiro and Costa [12]: (1) after a period (in the past) in which public water supply was almost entirely supported by groundwater; (2) there is a (present) period characterised by large investments in replacing groundwater by surface waters from dams; (3) but there will be a (future) period where the prevailing hydrological conditions and the conflicts between users will force the administration to define an integrated management scheme to guarantee the public water supply at basin scale.

Figure 3: Abandoned sluices, pumping stations and boreholes (São João da Ourém, March 2006 – Photos by José P. Monteiro).

3 A decision support system for the public water supply system of the Algarve

From the description of the evolution of water use in the Algarve, it can be accepted that the public water supply system in the Algarve must include new water sources under an integrated resources management scheme. New infrastructures have to be sited, designed and operated in order to have a more robust and resilient system. To accomplish those tasks, the development of a decision support system based on an optimisation model is being built in conjunction with regional water supply utility (Águas do Algarve, S.A.).

The decision-support system should help with the following decisions:

- Different sources to be mobilized: surface water, groundwater, desalinated seawater or even treated wastewater;
- The location and the size of water intake and water distribution infrastructures;
- The location, size and technologies for water treatment, wastewater treatment, water desalination infrastructures;
- The operating policy of such infrastructures for different scenarios.

The framework for the development of the decision-support system is presented in Figure 4 and it will be designed to promote the efficient, economic and sustainable use of the different sources. The decision model is being built for cost minimization (the cost functions are being tailored to take into account the Water Framework Directive recommendations [13] on environmental costs, recovery costs, etc.) of interventions, but the decisions taken will have to be sustainable and promote the efficient distribution of water among users. This can be achieved by considering various constraints. The fulfilment of such constraints is evaluated through the use of different simulation models:

- A groundwater simulation model to allow the effects of the pumping policies to be assessed, both in terms of costs and also considering that one is working in a coastal area and saltwater intrusion should be avoided;

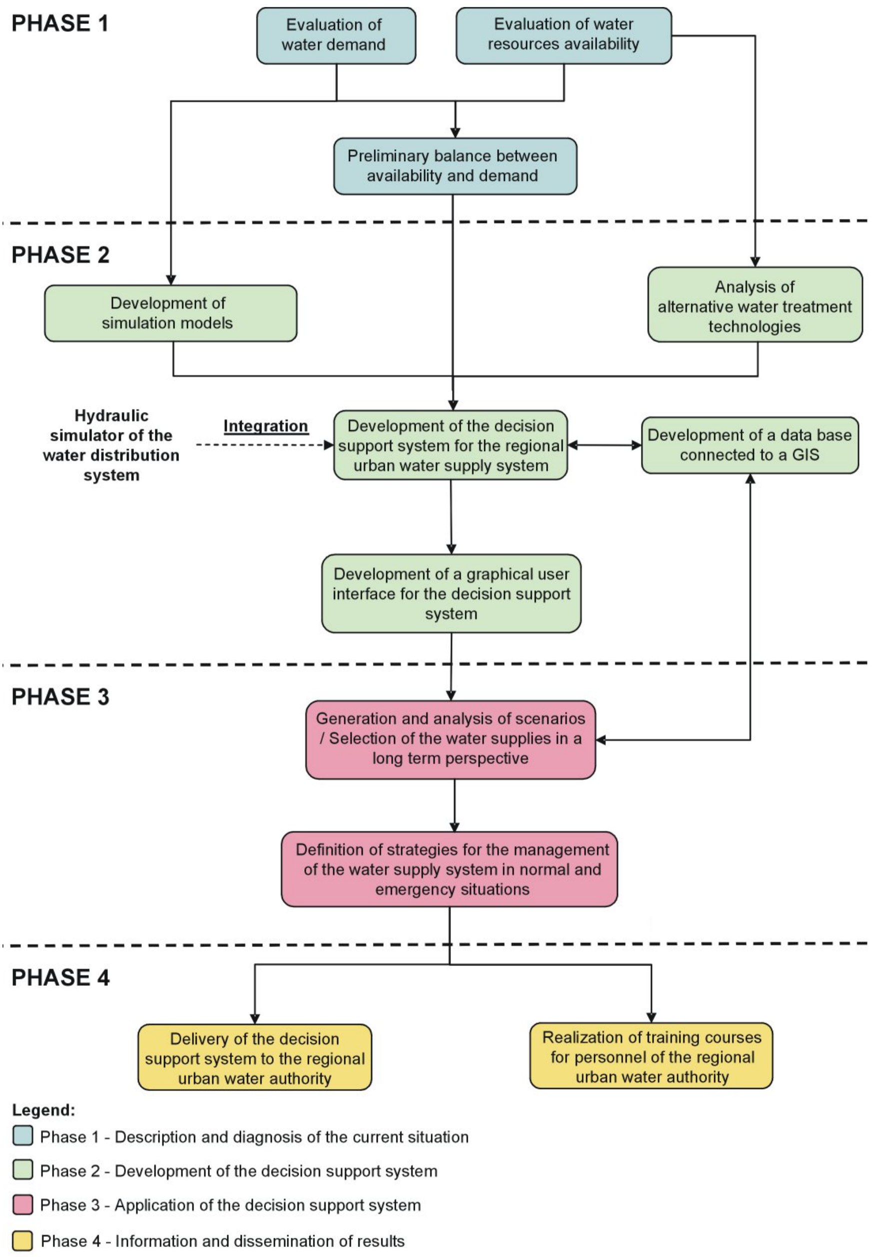

Figure 4: Framework for the development and application of the decision support system.

- Simulation models for dams, to quantify inflows and outflows for different climate scenarios (e.g., due to induced climate changes, and during drought periods);
- Water quality simulation models that will allow the definition of the percentage of each type of water in the final mixture to be supplied, because of the different physical and chemical characteristics of the water coming from surface or groundwater origins;
- Water distribution simulation models to allow assessment of the performance of the distribution system for different scenarios (e.g.: pressure, velocity, etc.).

The integrated model is a non-linear mixed integer one, and a new algorithm based on heuristics optimisation techniques is under development.

4 Conclusions

The analysis of the evolution of the water use in the Algarve during the second half of the 20th century and the casuistic interventions of the central water authority shows the reasons for the water crises faced by the Algarve region in times of drought. History has shown that water supply cannot rely on a single origin, surface or groundwater (or even desalination, or treated wastewater). In this article we have presented a decision-support system that will help to manage the allocation of resources (extractions from each source) by one of the major stakeholders in the region. It is hoped that future (next three to four years) operational results will make the remaining stakeholders and central administration follow the path of integrated water resources management, by including all stakeholders and all available sources, with the least environmental impact, lowest social cost, and greater sustainability.

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