Simulation on demand scenarios in the Alqueva watershed: application of the WEAP model

Francisco NAZARÉ FERREIRA[1]; Rodrigo PROENÇA DE OLIVEIRA
Instituto Superior Técnico, Universidade de Lisboa, Av.Rovisco Pais, 1049-001

Abstract

The aim of this study is to evaluate the capacity to satisfy the water requirements from urban and agriculture uses in the Alqueva region, as well to analyze the decision support system for integrated water resource management and policy analysis WEAP.

The research boundary is the Alqueva system and it is divided in three smaller systems: Alqueva, Ardila e Pedrógão. Three scenarios were simulated: the 2012/2013 scenario, where the Alqueva subsystem is working and Ardila is only partially working, the first phase scenario, when all the subsystems are working and the second phase scenario, resulting from an expansion from the first scenario.

The methodology used was WEAP. It was built and designed the Alqueva to understand the capacity to satisfy the necessities, the warranties and other parameters. The results showed that the reservoirs are prepared to satisfy the needs at the 2012/2013 scenario. On the other scenarios the reservoirs are prepared to supply the needs with highly reliability taxes and low flaws. WEAP model is easy to build and design, but they present some flaws, like looping, few performance evaluators and some unknown parameters in the results.

Keywords: water basin simulator, WEAP, water requirements, Alqueva, reservoir management

Introduction

The planning of human activities involving rivers and their floodplains must consider hydrological facts, (…) the flows and storage volumes vary over space and time (Loucks, van Beek, Stedinger, Dijkman, & Villars, 2005). The necessity of predicting the hydrological patterns is essential to the reservoir management. The reservoirs have to insure not only the water quality, but also the human, the industrial and the agricultural consumption. Nowadays the environmental concerns such as the aquatic biodiversity and the environmental pressure have an increase influence in the decision making.

The requirements of the agricultural demand near Alqueva will increase in the next years. The water cannot be allocated to satisfy the agriculture needs without having in count the ecological requirements and the urban consumption, so it is important to define priorities in every study. The Water Evaluation and Planning (WEAP) is used to simulate scenarios. The aim of this study is to understand the satisfaction of the needs and the ecological requirement of Alqueva and to evaluate the WEAP model.

Characterization of the system

The Alqueva system is explored by Empreendimento de Fins Múltiplos de Alqueva (EFMA), they are situated in baixo Alentejo, which is supplied by the watersheds of Guadiana and Sado. The EFMA main goal is to build, maintenance and explore the reservoirs in order to satisfy the water necessities. The

[1] francisconazareferreira@gmail.com,
rodrigopoliveira@tecnico.ulisboa.pt

Alqueva reservoir was finished in 2002, being the main infrastructure of the system, is supplied by the Guadiana River.

The EFMA system is divided in three sub-systems: Alqueva, Ardila and Pedrógão. The Alqueva sub-system acquires water from the Alqueva reservoir to satisfy the water demand. Ardila and Pedrógão sub-systems use the water from Pedrógão reservoir to satisfy the urban and agriculture consumption (Fig 1).

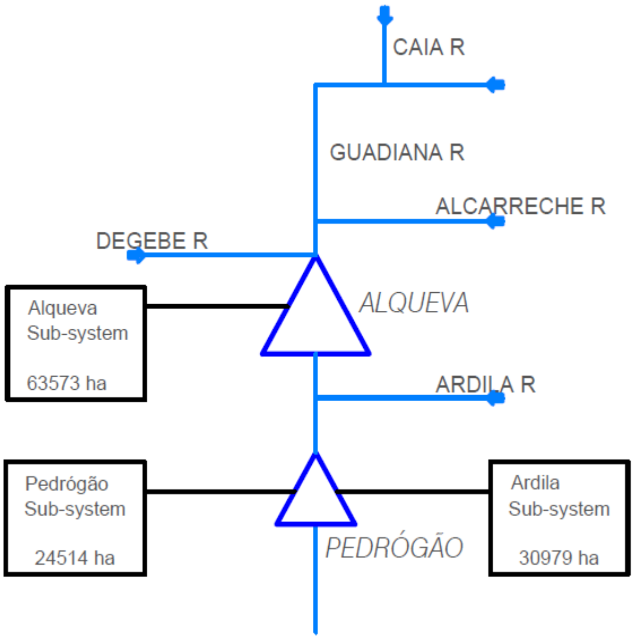

Fig 1 Simplified scheme of Empreendimento de Fins Múltiplos de Alqueva

Hidrography

The Guadiana basin extends from Ruidera lakes, Spain, to Vila Real de Santo António, Portugal, having a total area of 67133 km^2, which 11620 are within Portugal boundaries. The Sado basin is a Portuguese basin that drains to Setúbal having a total area of 7692 km^2.

The watercourses within the sub-basin areas are: Ardila, Degebe, Enxoé, Odearca, Alfundão, Odivelas, Roxo and Xarrama. These areas were estimated with the help of GIS and they are input sections to the EFMA's reservoirs. The flow generated in each one of these area represents the inflow of the system and consequently is an input data.

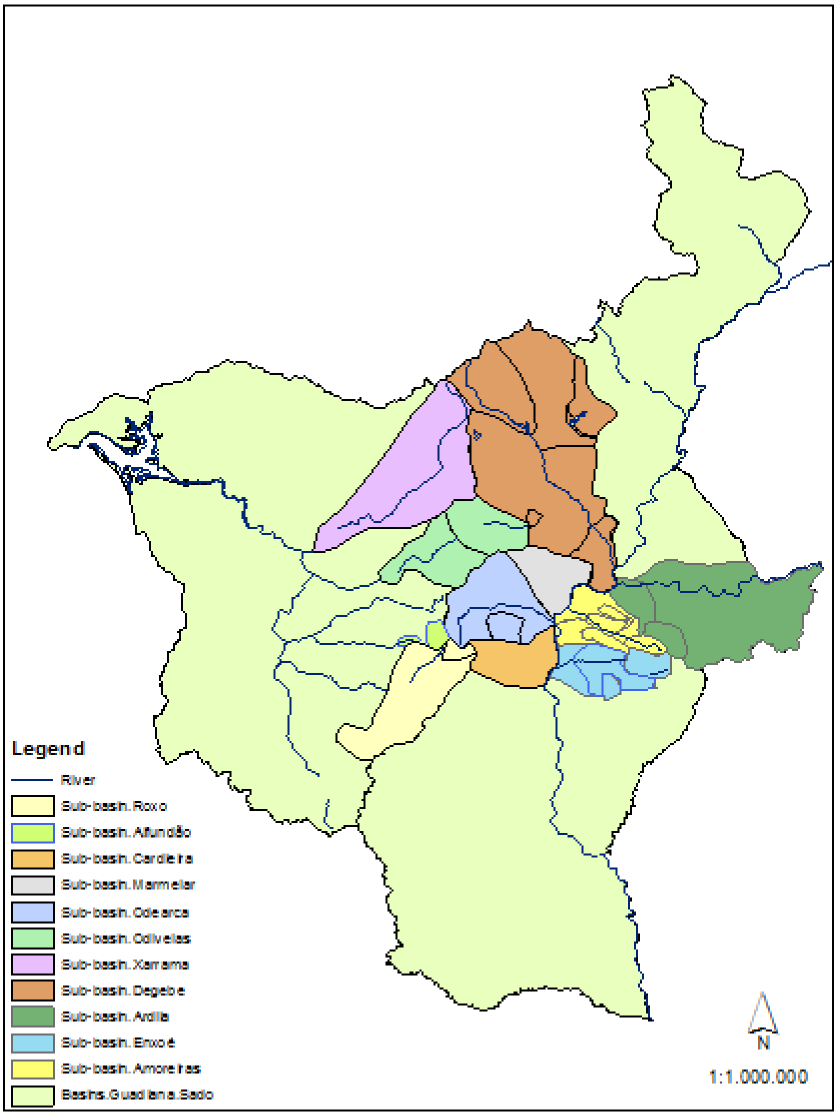

Fig 2 Sub-basins area from EFMA

Runoff

The inflow was calculated based on the on the runoff registers from the hydrometric stations (in SNIRH) and others studies measuring the runoff from Spain untill the hydrometric station or reservoir. Several hydrometric stations were selected at an early stage in order to find the runoff required to the simulation and the period of simulation.

The hydrometric stations used were: de Albernoa (26J/01H), Amieira (24L/01H), Ardila (foz) (25M/01H), Barbosa (24M/01H), Entradas (27I/01H), Limas (27L/04H), Monte da Arregota (26K/01H), Monte da Ponte (27J/01H), Monte dos Bravos (24M/02H), Ponte Mourão (23M/01H), Ponte Quintos (26L/01H), Pulo do Lobo (27L/01H) e Vendinha (23K/01H) and Puente Palmas. Energia de Portugal (EDP) developed several previsions about the inflow in the Alqueva reservoir for different Spain water demands (R) and reservoir storages (V). The COBA study represents two inflow series at the border with Spain, one that assumes the natural regime and a future regime that predicts the inflow after the construction of reservoirs. Unfortunately this study only has the annual inflow and not the monthly inflow. Besides, in the study two series were built resulting from the difference between two stations: PM-MV, for Ponte Mourão and Monte da Vinha representing the section beneath the upstream Alqueva reservoir, and PL-PM, for Pulo do Lobo and Ponte Mourão representing the runoff for our system.

After analyzing every series it was decided that the runoff from our system was represented by PL-PM and the Guadiana river flow was represented by the EDP-Alqueva R=4800/V=7000 being completed with Ponte Mourão hydrometric station, since the EDP study end in 1981. The Ardila river has its own hydrometric station, designated as Ardila (foz).

Evaporation

The monthly evaporation rate in the reservoirs from the Alqueva system was based on the evaporation rates from Alqueva and Pedrógão rate (Rodrigo Oliveira, 1994).

Table 1 Distribution of the monthly evaporation rate in the Alqueva system

Monthly evaporation rate (mm)												
Out.	Nov.	Dez.	Jan.	Fev.	Mar.	Abr.	Mai.	Jun.	Jul.	Ago.	Set.	**TOTAL**
97	50	26	33	44	87	116	168	204	167	244	164	**1400**

Infrastructures

Reservoirs

The infrastructures in the three systems incorporate reservoirs, the primary and secondary network distribution and several pump stations. The reservoir characteristics are presented in the annex and are the result from several studies from EDIA, CNPGB and EFMA map (2013).

The Alqueva subsystem presents twelve reservoirs: Vigia, Monte Novo, Álamos, Loureiro, Alvito, Vale de Gaio, Odivelas, 5 Reis, Pisão, Penedrão, Roxo and Alqueva. The Alqueva reservoir is the main and largest reservoir of the system, receiving water from Guadiana River. It has a total volume of 4150 hm^3 and a minimum of 1000 hm^3, with an area at the full storage of 250 km^2. The others reservoirs acquire water from Alqueva to satisfy the necessities of their demand. The system was finished in 2011 and is totally explored nowadays.

The Ardila subsystem incorporates: Pedrógão, Amoreiras, Caliços, Furta-Galinhas, Pias, Brinches, Enxoé, Lajes and Serpa. The Pedrógão reservoir was finished in 2005 and has a total capacity of 54 hm^3 with an area at the full storage of 11 km^2. This reservoir is responsible to supply the Ardila and Pedrógão subsystem. The Ardila subsystem predicts to end the construction of Caliços and Pias in 2016 and Furta-Galinhas in 2017, having the finished reservoirs supplying the actual water requirements. The Pedrógão subsystem presents Almeidas, Amendoeira, Magra and São Pedro. The São Pedro reservoir is the only one in construction, but it is not supplying any water.

The reservoirs Álamos, Loureiro, Monte Novo, Alvito, Odivelas, Pisão, Vale de Gaio and 5 Reis present their own storage curves acording to (EDIA/COBA, s.d). For the other reservoirs, which do not have storage curves, the storage curves were designed assuming a linear regression between storage area and minimum volume and area at the full storage.

Distribution network and culture areas

The distribution network has the primary network, that makes the connections between reservoirs and takes the water from the reservoir to the demand site, and the secondary network, which distributes the water in the demand site, to farms, houses and industries. In the study, the interest is in the primary network, meaning that there is no need to evaluate the characteristics of the channels.

The three scenarios simulated are the 2012/2013 scenario, where the Alqueva subsystem is working and Ardila is only partially working, the first phase scenario, when all the subsystems are working and the second phase scenario, resulting from an expansion from the first phase scenario.

The distributions of the cultures were done according to the EDIA studies and are presented on the Table 2. On the second phase scenario the Monte Novo bloc is amplified by 1100 ha, keeping the same percentage of the cultivations, and it is created a new bloc designated as Degebe with 4000 ha, which as the same distribution as Ardila subsystem (60% olive, 10% corn and 30% mix).

Table 2 Distribution of the cultivations on the scenarios

Subsystem	Bloc	Water Course	2012/13 area (ha)	First phase area (ha)	Second phase area (ha)	First phase scenario cultivations			
						Olive	Corn	Vineyard	Mix
Alqueva	Monte Novo[1]	Loureiro, Monte Novo	7875	-	1100	0	1415	1100	5360
Alqueva	Loureiro-Alvito	Loureiro	1100	-	-	0	550	400	150
Alqueva	Vale de Gaio	Vale de Gaio, Alvito	-	3939	-	0	1415	0	2524
Alqueva	Degebe	Monte Novo	-	-	4000	0	0	0	0
Alqueva	Infra-estrutura12	Odivelas	5645	-	-	5645	0	0	0
Alqueva	Alvito-Pisão	Alvito	9256	-	-	3114	0	3600	2542
Alqueva	Beringel-Beja	Alvito	-	5106	-	5106	0	0	0
Alqueva	Pisão-Alfundão	Pisão	6622	-	-	6622	0	0	0
Alqueva	Ferreira-Figueirinha-Valbom	Pisão	4943	-	-	4943	0	0	0
Alqueva	Ervidel	Penedrão	7896	-	-	0	1415	0	6481
Alqueva	5 Reis-Trindade	5 Reis	-	5615	-	0	1415	0	4200
Alqueva	Roxo-Sado[2]	Roxo	1176	4400	-	0	1420	0	4156
Total area			44513	63573	68073				
Ardila	Orada-Amoreira	Amoreira	2646	-	-	1588	265	0	794
Ardila	Amoreira-Caliços	Amoreira	-	2134	-	1280	213	0	640
Ardila	Caliços-Moura	Caliços	-	1530	-	918	153	0	459
Ardila	Caliços-Machado	Caliços, Furta Galinhas	-	4668	-	2801	467	0	1400
Ardila	Brinches I	Pedrógão	5506	-	-	3304	551	0	1652
Ardila	Brinches II	Brinches							
Ardila	Pias	Pias	-	4698	-	2819	470	0	1409
Ardila	Brinches-Enxoé I	Brinches	5114	-	-	3068	511	0	1534
Ardila	Brinches-Enxoé II	Enxoé, Lajes							
Ardila	Serpa	Serpa	4683	-	-	2810	468	0	1405
Total area			17949	30979	30979				

[1] Second phase total area in the Monte Novo bloc 8975 ha
[2] First phase total area in the Roxo-Sado bloc 5576

Subsystem	Bloc	Water course	2012/13 area (ha)	First phase area (ha)	Second phase area (ha)	First phase scenario cultivations			
						Olive	Corn	Vineyard	Mix
Pedrógão	Pedrógão-Selmes	Pedrógão	4668	-	-	4668	0	0	0
Pedrógão	São Matias	São Pedro, Almeidas	-	5806	-	0	720	980	4106
Pedrógão	São Pedro Baleizão	Amendoeira	-	6035	-	4775	280	980	0
Pedrógão	Baleizão-Quintos	Magra	-	8005	-	4775	720	0	2510
Total area			4668	24514	24514				
EFMA total area			67131	119066	124166				

Water Requirements

It was considered two different types of requirements: urban consumption (Table 3) and agricultural consumption (Table 4).

Table 3 Urban Consumption in the Alqueva system

	Volume consumption (dam^3)		
	Monte Novo	Alvito	Odivelas
Total/Year	9662	3272	6200

The Table 3 represents annual urban consumption supplied by the Alqueva subsystem according to EDIA/COBA (s.d).

The Table 4 has the annual agricultural requirements for the three scenarios. The Monte Novo bloc in the second phase scenario has the same ratio of water requirement per hectare as in the 2012/2013 scenario, and the Degebe bloc has the same ratio as the Ardila bloc.

Table 4 Agricultural consumption in the Alqueva system in dam^3

Subsystem	Actual requirement (hm^3)	Future requirement (hm^3)	Expanded requirement (hm^3)
Alqueva	181478	271382	292658
Ardila	69991	120663	120663
Pedrógão	13350	93032	93032
Total	264740	485077	506353

Ecological Requirement

The ecological requirement is an environmental obligation, created to preserve the ecosystems from important negative impacts, like losses of ecosystems. The environmental flow from Pedrógão reservoir was calculated using the Texas method by the european commission in 1996, according to Alves, 2003. The other environmental flows are 15% of the average inflow in a reservoir (only at the important water courses).

Description of the WEAP model

The WEAP model was developed by Stockholm Environment Institute and it was designed to help in the planning and management of a river basin. The WEAP uses a monthly step to calculate the hydrological balance between the supplies (rivers, groundwater aquifers, WWTP and reservoir) and the demand sites (agriculture, industrial and urban areas). The WEAP model is a supply driven model, since at every time step the volumes delivered obey the operation rules and are distributed upstream to downstream, having the available water as limitation factor. This model may study the water quality and financial analysis.

WEAP organization

WEAP is organized in five different sectors: schematic, data, results, scenario explorer and notes. In the schematic map is possible to design watersheds, reservoirs, demand sites or others elements, with the help of Geographic Information System. The transmissions links and return flows require the confirmation of the places to which they are connected.

The data view allows inserting the characteristics of the elements from schematics, giving the possibility to import and export from excel. The data is organized by demand site, hydrology (presenting the Water Year Method), supply and resources (having the water courses and the reservoirs, water quality and others assumption). The results present the outcome from the calculation, with the scenario explorer allows drawing several assumptions from the results and with the data allows taking quick notes.

Description of the WEAP components

The WEAp model uses the inflow, as input data, storing the water in reservoirs or groundwater aquifers. The transmission links connects the reservoirs to the demand sites or to others reservoirs and the return flows reconnect the water not consumed to the WWTP, reservoirs, groundwater aquifers or even rivers.

The user can control the priorities from the program, this way it can be choosen the demand site priorities, environmental requirements and reservoir refilling. The priority system is 1 for the most important and first to satisfy and 99 for the less important. In the standard conditions the demand sites, the environmental requirements, the transmission links and the return flows are 1 and the reservoirs are 99. The financial analysis is only calculated after the distribution of the water requirements, this way it will not interfere with priorities system.

The Water Year Method uses the inflow from the 0 year to simulate the next years by changing the inflow, allowing to understand the influence of the climate. The hydrologic years can be designated as: extremely dry, dry, normal, wet and extremely wet. The normal inflow is represented by a coefficient 1, as for the others coefficients the user can add or subtract a percentage.

Performance indicators from WEAP

The WEAP has few performance indicators and for the study it was selected monthly reliability, monthly coverage for the demand sites and environmental flows. The coverage is defined as the quotient of water supply and water requirement, as for the reliability is represented as the quotient of the months totally satisfied and total months.

Other performance indicators

The WEAP model presents large options in the demands, requirements or unmet demands or even a good control in the reservoirs and water courses. Unfortunately, the performance indicators are few, restricting the study. To better understand the warranties and flaws of the scenarios, several indicators were calculated: annual reliability, duration of the flaws, average volume of the flaws and resilience.

The annual reliability is calculated as in the WEAP indicators, the duration of the flaws is the month average per flaws and resilience can be defined as the number of flaws with one month per total of flaws.

Scenario Analysis

Synthesis of the Scenarios

The three scenarios have the same simulation period from 1953/1990, corresponding to the inflow stream data. The reservoirs characteristics are the same in the scenarios and the missing reservoirs top of inactive volumes were calculated using the minimum level exploration. The transmission links and return flows present 10% losses and the consumptions of the urban requirement and agriculture demand are 20% and 80%.

After performing a first simulation, loopings occurred in some areas. As a solution, the priorities were changed from the standard: the urban consumption, environmental flow, the transmission links and return flows present priority 1, agricultural consumption 2, reservoirs 98 and an environmental flow downstream the system 99. This fictional environmental flow is a monthly demand with the same value as the maximum flow rate value from Guadiana river.

Scenario Results

The annual balance is a simple way to understand the simulations. On the first and second phase scenarios the agricultural requirements increased almost to the double when compared with the 2012/2013 scenario, as a result the increase of transmission link and return flows losses. On the 2012/2013 scenario the local reservoirs of Magras, Amendoeiras e Almeidas are not finished, explaining the 0 value in the overflow parameter. The reservoir annual balance represents the refilling and draining in the reservoirs, getting highest values when the consumptions are lowest. The 2012/2013 scenario presents the lowest environmental flow because the Ardila river does not present any reservoir, being only influenced by its on inflow (Table 5).

Table 5 Annual balance in the scenarios

	2012/13 scenario	First phase scenario	Second phase scenario
Annual inflow average	3415,7	3415,7	3415,7
Reservoir annual balance	65,4	59,2	58,5
Annual evaporation average	354,9	335,8	333,9
Local reservoir annual average overflows	0	1	1
Annual environmental flow average	408,6	427,8	427,8
Annual urban consumption average	19,2	18,8	18,8
Annual agricultural consumption average	264,7	481,7	499,4
Annual transmission link losses average	141,4	231,2	239
Annual return flow losses average	6,8	11,1	11,5
Outflow calculated	2631,6	2388,3	2368,5
Annual outflow average	2631,6	2388,3	2368,5

In the 2012/2013 scenario the monthly reliability for the urban and agricultural consumption and the environmental flows are 100%, except the Ardila environmental flow that is 74% and 21% for the annual reliability. The resilience in the Ardila river is 44% and the average volume of the flaw is 18 hm^3.

The first and second phase scenarios present some flaws resulting in a decrease of the monthly reliability into 99.1% and 98.6 in all the agriculture, except Vale de Gaio that has 99.6% and 99.2% because the high inflow from Xarrama. The resilience in the agricultural consumption is 0%, except for Vale de Gaio with 50%, showing that normally the flaws are longer than 1 month. The urban consumption presents a decrease in the monthly reliability for 98,7% and 98%, in the first and second phase scenarios, with a 0% resilience.

Lastly, for the environmental flows, it exists an increase in the monthly reliability of the Ardila river and a small decrease in the others to 99%. This increase in the Ardila river results from the construction of the Furta-Galinhas reservoir. The resilience varies between 33% and 0%, with the average volume of the environmental flow always beneath 3 hm^3, except Pedrógão that presents 14,1 hm^3 in the first phase scenario and 16 hm^3 in the second phase scenario.

Storage volume in Alqueva

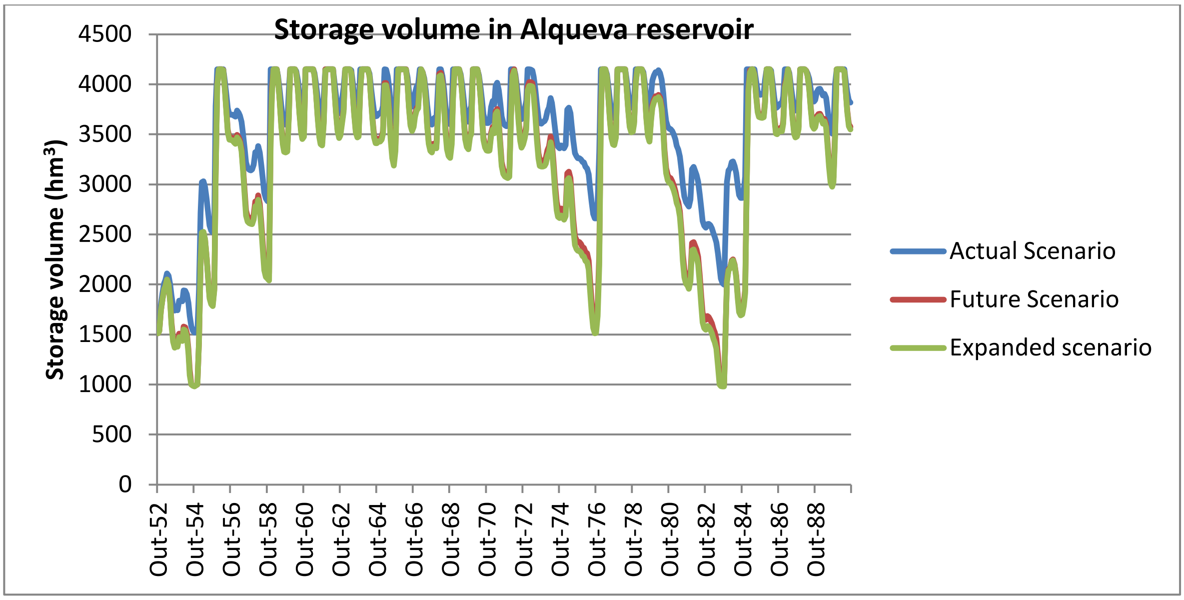

Fig 3 Storage volume in Alqueva reservoir

In the Fig 3, it is possible to understand the storage in the Alqueva reservoir during the simulation period. The peaks in the figure are the result from the variation of the inflow, since the water requirements do not change with the years. It was concluded four dry period times: 1953-1955, 1957-1959, 1972-1976 and 1980-1986.

The 2012/2013 scenario satisfies the water requirements having a minimum of 1500 hm^3. The difference in the requirements from the 2012/2013 scenario to the first and second phase scenarios are 220 and 242 hm^3. This variation during the dry crises makes the storage volume reach till 1000 hm^3. After getting to the minimum value, the supply stops but the monthly evaporation still exists.

Analysis of WEAP and Conclusions

The study has for main results the satisfaction of the water requirements in the Alqueva system in the several scenarios. In the 2012/2013 scenario the monthly reliability are 100% and in the others scenarios the reliability are always over 98% with a resilience normally with 0%. This resilience can be explained by the low number of flaws during the scenarios and for presenting always consecutive months. The Alqueva reservoir in the 2012/2013 scenario the storage volume is always over 1500 hm^3, but in the first and second phase scenarios the volume can be beneath 1000 hm^3.

The WEAP model has an easy design and a simple way to build the river basin. The possibility to desegregate the demand sites in new divisions, or the supplies, from the main river into secondary rivers and reservoirs, allows for a simple way to control the system. The results exposure is simple and allows the relation between scenarios, years or demand sites.

During the present study some negative critics where related with the general balance in the reservoirs, because they do not specify the inflows when making the global balance, calling it inflow from upstream. Besides that, it is not possible to only select one parameter. Other negative aspect is that in the local reservoirs the net evaporation and overflows are in the same aspect, when they could easily be separated. The main critic is the looping problem, because it generates water in the system.

The measures presented to improve WEAP model are to rename the inflow from upstream and to separate the net evaporation for the overflow in the local reservoirs, in this way is simple to understand which part is the net evaporation and which is the waste of water. The main problem could be resolved by inserting a price for the cubic meter so the water would stop pumping after the fulfilling the requirements. This solution it is not the preferable one, so probably the main equations have to be re-designed. The WEAP model could include some of the indicators used on this study.

References

Projeto EDIA (2013). Características de temperaturas e precipitações médias anuais. (retrieved in http://www.alqueva.com.pt/pt/oportunidades/potencial-produtivo/6, june 2014)

Alves, M.H. & Bernardo, J.M. (eds) (2003). Caudais ecológicos em Portugal. INAG. Lisboa.

Brandão, C., Rodrigues. R. (2000), Hydrological simulation of the international catchment of Guadiana River, *Physics and Chemistry of the Earth*, *Part B: Hydrology, Oceans and Atmosphere* 25(3):329-339.

CNPGB (n.d). Características das barragens de Portugal. (retrieved in http://cnpgb.inag.pt/gr_barragens/gbportugal/, january 2014)

Deltares (2012). RIBASIM- River Basin Planning and Management. (retrieved in http://www.deltares.nl/en/software/101928/ribasim, february 2014)

DHI (2011). Mike BASIN- integrated river basin planning. (retrieved in http://mikebydhi.com/Products/WaterResources/MIKEBASIN.aspx, february 2014)

EDIA & COBA (n.d.). Modelo de simulação e Optimização do Funcionamento do Subsistema do Alqueva.

EDIA (2013). Características de albufeiras e perímetros de rega na região do Alqueva. (retrieved in http://sigims.edia.pt/alqueva_storymap/, march 2014)

EDIA (2004). Estudo de impacte ambiental da barragem do Pisão.

EDIA (2006). Estudo de impacte ambiental dos blocos de rega Alvito-Pisão.

EDIA (2002). Barragem dos Álamos e ligações associadas.

EDIA (2011). Projeto de exucução e estudo de impacte ambiental dos blocos de rega de Beringel-Beja.

EDIA & COBA (2010). Blocos de rega de Ervidel.

EDP (1988). Escalão de Alqueva. Projecto. Estudo das disponibilidades hídricas. Electricidade de Portugal.

Glintz, M. (2000). Improving the quality of requirements with scenarios.

INAG & COBA (1985). Recursos hídricos do rio Guadiana e sua utilização. Instituto da Água & COBA consultores. Lisboa.

IWA Water Wiki (2011). Water Rights Analysis Package (WRAP) (retrieved in http://www.iwawaterwiki.org/xwiki/bin/view/Articles/WaterRightsAnalysisPackageWRAP, february 2014)

Loucks, D. P., van Beek, E., Stedinger, J. R., Dijkman, J. P. M., & Villars, M. T. (2005). *Water Resources Systems Planning and Management: An Introduction to Methods, Models and Applications*. Paris : UNESCO.

Oliveira, R. (1994). *Simulação do empreendimento de fins múltiplos de Alqueva*. Lisboa.

Prado & Paulo (n.d.). Automatização do canal Loureiro Monte Novo

Simões, J., & Oliveira, R. (2010). Modelos de gestão de bacias hidrográficas: o desempenho dos modelos IRAS-2010 e AQUATOOl na simulação do aproveitamento hidroagrícola do Vale do Sorraia.

SNIRH (2013). Shapefiles da RH7 e RH6.
(retrieved in http://geo.snirh.pt/AtlasAgua/#, january 2014)

Universitat Politècnica de València (2010). Proyecto Aquatool.
(retrieved in http://www.upv.es/aquatool/, february 2014)

WEAP (2014). Características do modelo WEAP- Water Evaluation And Planning.
(retrieved in http://www.weap21.org/index.asp?action=202, february 2014)