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Executive Summary

This report synthesises in detail the current water-related security threats for each WASSERMed case study (i.e. Kairouan, Tunisia; Rosetta, Egypt; the lower Jordan River Basin, Jordan; Syros, Greece and Sardinia, Italy), the water-balance models developed for each case study, the results produced for each case study and the implications of those results for each case study and for the wider southern Europe and Mediterranean region. The modelling approaches are not described - these have been described in detail in Deliverable 5.2.2 - Report on modelling tools and techniques to be applied to each case study for water balancing. The aim of the report is to bring together the key results of Work Package 5: Integrated modelling of water-related security threats, the main aim of which was water-balancing. Apart from maintaining to just water balancing, some case study models also predict the potential impacts on agricultural yield, local economies and tourism as a result of changes to water supply and demand, and climate and social change. This therefore allows a more holistic assessment of the water-related security threats throughout the Mediterranean to be made, and recognises the interconnectedness of water, food and the economy, albeit in a somewhat rudimentary, first-order manner. This work is seen as a first and important step towards truly integrated regional modelling and assessment. It is hoped that this work will be taken up as used as inspiration by policy makers and (local) government officials when planning for water-stress mitigation. These results and implications may guide them down a path towards a more sustainable future where local development can continue, and where the population have a safe, clean water supply while not over-exploiting the resource. The report forms WASSERMed Deliverable 5.3.1: Synthesis report on modelling and indicators for policy recommendations.

For the Kairouan case study, Tunisia, at present the Kairouan aquifer is subject to over-exploitation, despite it being the largest permanent water resource in the region. The main cause of over-exploitation is pumping of water from the aquifer to coastal tourist resorts. The other large water demand comes from agriculture. Future changes in living standards and the local climate indicate increasing domestic and agricultural water demand. The complex systems model integrates the simulation of water, crop productivity and economic output to give a full interpretation of the impacts of water shortages. It also accounts for climate and social change and for alterations to pumping to the coast. Modelling for the baseline conditions replicates the current situation of over-exploitation. Simulations for future change with no interventions hint at a worsening of the present situation. A large suite of what-if simulations tested various intervention measures and their effectiveness with respect to improving the water-security situation. Alterations to the agricultural sector gave some improvement, while lowering the volume of water pumped to coastal cities had significant impact, to the point where recharge could be achieved. It is recommended that the proposed plans to reduce pumping by 50% relative to today be pursued, but that other complementary measures, particularly in the agricultural sector are also implemented, introducing redundancy and improving on any savings to be made.

For Rosetta, Egypt, the current water resource is tightly constrained as a result on heavy reliance of Nile river water. About 95% of the water supply derives from the Nile. As a result, there is little opportunity for demand increases of supply decreases. This limitation is potentially hampering local development. Agriculture is the main water user in the case study area, which is also under threat from sea-level rise, population increases and potential changes to Nile inflows, although the direction and magnitude of such change is poorly constrained. The current supply is modelled as being over-exploited. Future simulations, like with Kairouan, suggest increased levels of over-exploitation. A large suite of sensitivity tests was carried out. These suggest that if Nile inflows considerably increase over the baseline, then the water supply could be secure into the future, with surplus possible. However, some models also simulate decreases in Nile flow volumes, and if this were the case, then the situation would be one of potentially severe water scarcity if other measures are not taken. Sea-level rise leads, counter-intuitively, to an improvement to the water balance. This arises because of the displacement of agriculture. As a result, this outcome is seen as a negative impact. A large suite of tests regarding agricultural cropping patterns shows that improvements to the water balance, the agricultural yield, and the local revenue can be made by changing cropping patterns. In addition, the extra crop and revenue can be used to exploit international trade markets, importing water-intensive crops, and thus allowing the growth of a) more profitable crops and b) less water-intensive crops. Through the exploitation of such markets, it is shown that further improvements to the local water-balance situation could be made. However, such policies will have to be reconciled at the national policy level, and the full scope of this is beyond this work. As with the Tunisia work, it is suggested that many policies are implemented in parallel so that their effects are amplified, and so that redundancy is built in the system.

In the lower Jordan River Basin, Jordan, the situation is arguably more critical than in either Tunisia or Egypt. The main water source - the Jordan River - has been consistently over-exploited not just by Jordan but also by neighbouring countries, leading to a significant reduction in annual flow volume and a concomitant decrease in water security and water levels in the Dead Sea. Because of the low availability of water, current agricultural activity is curtailed, not operating at 100% potential, although the domestic supply is still serviceable. However, future climate and social change simulations, which are expected to result in a decreased supply and an increased demand, suggest that the situation is to become more serious than at present. Changes to domestic water policy, while commendable, will only yield small water savings. However, gradual, phased changes to agricultural cropping patterns could lead to local net water surplus. The word local here is particularly stressed. The Jordan is a major transboundary river. While the changes modelled for this case study do indeed suggest local improvement, the overall Jordan River situation may still be critical, particularly if riparian nations do not commit to similar water saving efforts. Despite this, the scenario modelled here is a good start, and could succeed. Because the changes are phased in gradually, and not suddenly imposed, there is more likelihood of acceptance among the local farming community. This will be especially true is farmers can irrigate more of their potential area, thus generating more income.

In Syros, Greece, the water resource (mainly aquifers) is currently not over-exploited, but is being exploited at close to or at 100% capacity for most of the year. As such, there is very little scope for demand increases, and the situation could be serious if climate change led to significant reductions in supply. Agriculture and tourism are the main water users, with demand from the domestic sector likely to increase. Future change is likely to exacerbate the situation, especially with respect to the groundwater exploitation index. The groundwater is predicted to become even more exploited, and potentially over-exploited for some of the year, particularly in the peak summer tourist season. There are two main impacts here: the first is a reduction in water supply for one or more sectors, and the second is salinisation of the groundwater, potentially leading it to become unsuitable for drinking. Syros is currently installing extra desalination capacity, and this extra fresh water is aimed at mitigating over-exploitation of the groundwater resources in the future. The installation of extra desalination capacity is a critical policy measure on Syros, although demand reduction, especially in the tourist sector in the summer months and in the agricultural sector if possible (there is already a high proportion of drip irrigation) should be considered.

Finally, on Sardinia, Italy, the current situation is perhaps the least severe of the five case studies at the present day. The island is reliant mainly on surface reservoirs for its water supply, although there is some contribution from groundwater sources. Severe drought in the early years of the 21st century led to a re-examination of reservoir control and management. As a result, more reservoirs are now interconnected, and more reservoirs are run closer to capacity. Additionally, the regional institute for water management (ENAS) programmed an implementation of the drinking water network based on a simulation of population growth and tourist fluxes for 2040. This means that the water requirements of the domestic, agricultural and intensely seasonal tourist sectors should be fulfilled now and also in the future. Climate change modelling indicates that, on the whole, the current precipitation supply will be sufficient in the future, although some reservoirs/basins will be temporarily over-abstracted, and will therefore rely on transfers from neighbouring connected basins for the extra water. There is some risk here: if all basins are over-utilised, then transfers may not be possible, however due to the reservoirs being filled closer to capacity, and due to improved water management rules, this situation will hopefully not occur, although it could, especially if a very dry summer is coupled with a strong tourist season. Extra desalination capacity could be considered as a backup, and demand management, especially in the domestic and agricultural sectors, should be considered to mitigate against any potential future shortages.

The results and analysis presented in this report, which derive from Work Package 5 of the WASSERMed Project clearly show that through the Mediterranean, there are a wide range of diverse water-security problems, each of which have their own potential solution(s). The severity and complexity of the issues being faced are also very different in different regions. The main message in summary is that there is no single universal, Mediterranean-wide policy solution for overcoming the various water-related security threats being faced. While the overall threats (i.e. population increases, living standard improvements, agricultural demand increases and changes to the climate) are common between the case studies, their impacts are considerably different. As a result, while some policy measures may be applicable across the region, such as curbing domestic and agricultural water demand, and making provisions for 'alternative' water supply where practicable, other measures are far more location-specific. For example, some regions may aim policy at reducing pumping of groundwater to external locales, others may consider considerable, but phased, changes to cropping and exploitation of markets to reduce demand and promote development, while other areas will focus on developing alternative water supply, and others still will consider further improvements to local reservoir operational rules to mitigates against times of water shortage and/or demand spikes. What is common, is that in most regions, a single 'cornerstone' policy should not be implemented in isolation - the risk in the event of failure or underperformance is generally too great in terms of the impact on development opportunities. Multiple policies will a) introduce redundancy should any single policy measure fail or underperform and b) amplify the effects of the other policies, bring about the best chance for a water-secure, sustainable future across the Mediterranean.

Contents

1. Introduction

Although globally there is enough water to satisfy the demand of almost every person on the planet (Savenije, 2000), the spatial and temporal distribution of this freshwater (Oki and Kanae, 2006) and of the global population means that in reality there are areas of the planet that suffer from serious water shortages. Generally, developing nations are more severely affected by these shortages, being located in (semi-)arid locations. However, the recent early-2012 drought in the United Kingdom and the ongoing drought in the American mid-west illustrates that even more developed nations can suffer water shortages, with potential impacts on livelihoods and the economy. It has been shown that globally during the period 1960-2000, more people - from 27% up to 43% of the global population from 1960 to 2000 - have been pushed into more water-stressed situations, mainly due to increasing water demand predominantly from the agricultural sector (Wada et al., 2011) which accounts for c. 85% of the total global consumptive water withdrawal (Hanasaki et al., 2008).

On top of this, are the potential impacts of climate, population and social change in the coming decades. Current model projections of global climate change indicate a general warming trend by the 2050s, particularly over the Mediterranean and North Africa region (Arnell et al., 2004; Christensen and Christensen, 2007; Giannakopoulos et al., 2009; Solomon et al., 2007), although there is some uncertainty in these estimates. In addition, rainfall totals in this region are expected to become either lower or more sporadic (Arnell et al., 2004; Solomon et al., 2007), with a concomitant increase in drought frequency (Giannakopoulos et al., 2009; Solomon et al., 2007). It is recognised however that there is considerable scatter in model results, varying not only by model type but also by the simulation resolution (Christensen and Christensen, 2007). Despite this, the general warming and drying trend over the Mediterranean Basin is still generally observed.

With respect to global population, general estimates to 2050 are that the population will increase from seven billion at present to between c. 8 - 10.6 billion (United Nations, 2010), with a large increase also expected around the Mediterranean. An additional consideration is that as societies develop and wealth increases, household (domestic) water consumption is generally expected to rise (Alcamo et al., 2007; Menzel and Matovelle, 2010) as is agricultural water use as a result of increasing demand for more water intensive products and the effects of increased evapotranspiration demand from crops (Alcamo et al., 2007). Due to increased temperatures, tourism, which is key to some of the case studies being examined here (e.g. Syros and Sardinia) may decrease as temperatures becomes uncomfortable (Giannakopoulos et al., 2009). There are some potential benefits. For example, it is predicted that the growing season through the Mediterranean will lengthen, and may result in increased yield (Giannakopoulos et al., 2009), mainly in the winter months.

The general trend from the above discussion is that as global freshwater supply drops, global demand increases. Globally, there is much variation however. For example, from analysis of 12 global climate models, (Milly et al., 2005) show that while areas such are North America and Eurasia show up to 40% increase in streamflow volume, southern Europe and the Middle East are expected to experience up to a 30% decrease in streamflows, with significant impacts for the local economy and ecosystems. Alcamo et al. (2007), using the WaterGAP model to simulate the physical and socio-economic impacts of future global change, predict either a decrease of water stress by up to 29% or an increase of up to 75% depending on the scenario and the basin. (Alcamo et al., 2007) show that where water stress decreases, this is mainly due to increasing precipitation, while the main cause of increasing stress is growing water withdrawals as a result of income increases and not population increases (which was not as important as improving lifestyles from income increases). In fact, some authors have reported that in the near future, it will be population growth and economic development, not climate change, that will be the main driver that increase water stress generally (Vorosmarty et al., 2000). Likewise, (Shen et al., 2008) estimate that global water withdrawals (i.e. human-driven impacts) may increase from 3800 to over 6000 km^3 yr^{-1}, however the amount of increase depends on the socio-economic development scenario that is modelled (taken from the IPCC SRES scenarios). (Weiss and Alcamo, 2011) show that river basins in southern Europe are the most vulnerable to climate change, and will become far more water stressed than at present. The Mediterranean region has also been described as a global change 'hotspot' and may suffer some of the worst impacts resulting from this change. In addition to surface water, it has recently been shown that globally, many groundwater aquifers have so-called 'footprints' that extend well beyond their planimetric area, indicating that this resource is also being over-exploited (Gleeson et al. 2012).

The impacts of increasing water stress are potentially severe. (Alcamo et al., 2007) estimate that global industrial water demand will increase in response to increasing electricity generation as development improves lifestyles in developing countries. However, if the combined effects of climate change and socio-economic growth are such that overall supply decreases, then the industrial sector may not be able to meet the increase in electricity demand, hampering growth and development. Also, as agricultural demand increases due to population growth and climate change (increasing temperatures are likely to increase the evaporative demand from plants, increasing water requirements (Alcamo et al., 2007)), there is the potential for widespread food shortages unless more efficient irrigation technologies are widely adopted. The fact that water is connected to the sustainability of other critical global commodities has not gone un-noticed. Recently, the 'hyperconnectivity' of global systems has been highlighted (WEF, 2012). This makes reducing water demand and increasing security even more critical because we do not fully understand the potential consequences of sustained, significant, long-term over exploitation of the water resource on food, energy, the economy and social stability.

It is clearly important that a better understanding of global and local water availability around the Mediterranean, and the potential impacts to local development, is required. This element of the WASSERMed Project, Integrated Modelling of Water Related Security Threats, aims to better quantify the local water balance in five case study areas, together with addressing the wider socio-economic implications of changes to the water balance. Through the Mediterranean, just some of the likely consequences of global change are: lower or more sporadic rainfall totals; increased population; improving lifestyles; increased crop evapotranspiration; lower streamflows; and reduced recharge to aquifers. This work has the potential to better inform local policy makers, and make them aware of the options available to them and of the potential impact of these options. Thus, those options or policy measures can be identified which are most likely to have overall long-term beneficial impacts, and to avoid those that are likely to be detrimental.

This report synthesises in detail the current water-related security threats for each WASSERMed case study (i.e. Kairouan, Tunisia; Rosetta, Egypt; the lower Jordan River Basin, Jordan; Syros, Greece and Sardinia, Italy), the water-balance models developed for each case study, the results produced for each case study and the implications of those results for each case study and for the wider southern Europe and Mediterranean region. The modelling approaches are not described - these have been described in detail in Deliverable 5.2.2 - Report on modelling tools and techniques to be applied to each case study for water balancing. The aim of the report is to bring together the key results of Work Package 5: Integrated modelling of water-related security threats, the main aim of which was water-balancing. Apart from maintaining to just water balancing, some case study models also predict the potential impacts on agricultural yield, local economies and tourism as a result of changes to water supply and demand, and climate and social change. This therefore allows a more holistic assessment of the water-related security threats throughout the Mediterranean to be made, and recognises the interconnectedness of water, food and the economy, albeit in a somewhat rudimentary, first-order manner. This work is seen as a first and important step towards truly integrated regional modelling and assessment. It is hoped that this work will be taken up as used as inspiration by policy makers and (local) government officials when planning for water-stress mitigation. These results and implications may guide them down a path towards a more sustainable future where local development can continue, and where the population have a safe, clean water supply while not over-exploiting the resource.

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2. Summary of the Case Studies: water-related security threats

2.1 Introduction

The WASSERMed project comprised five case studies which were to be studied in detail. These are:

- Kairouan, Tunisia
- Rosetta, Egypt
- the Lower Jordan River/King Abdullah Canal, Jordan
- Syros, Greece
- Sardinia, Italy

The case studies were chosen to reflect the different levels and types of water security issues being faced across the Mediterranean basin, thus allowing for a comprehensive overarching analysis to be performed based partially on the results from water-balance modelling in these case studies. Not all the case studies suffer the same level of water stress, and they all have threats arising from different sectors. For example, Kairouan is facing water security threats mainly from groundwater overexploitation, while Rosetta is facing threats from Nile water supply and from sea-level rise. On the other hand, tourism is the major threat on Syros. How these threats impact the water availability situation, to what scale, and the timeframe on which they operate is very different, as is the policy framework which can help to mitigate and potentially avoid the most serious consequences. Therefore, detailed case-study level water-balance assessment was carried out for each of the five case studies using two tools: System Dynamics Modelling and the WaterStrategyMan Decision Support System (see Deliverable 5.2.1 - Literature review and comparative analysis of the existing methodologies for water balance and Deliverable 5.2.2 - Report on modelling tools and techniques to be applied to each case study for water balancing for detailed information regarding the two modelling approaches used).

This section summarises the case studies, and will provide a broad overview to the water security and availability issues being faced in each. These overviews, coupled with extensive dialogue with key case study partners and stakeholders, helped to inform the water balance modelling direction and development, the results of which are presented later in this report. The detail presented in the next sections is compiled from project partner fact-sheets delivered as part of the WASSERMed project (see Deliverable 5.1.2 - Water demand scenarios for the case studies for full details), and from the scientific literature.

2.2 Kairouan, Tunisia

The Kairouan aquifer, Tunisia, is situated in north-central Tunisia (Figure 1). The Merguellil catchment which feeds the large El Haouareb reservoir (Figure 1) is ephemeral, with the rivers only flowing after heavy rainfall. The upper catchment has been heavily modified, with many small dams built for water retention, and also with hillside terraces originally designed to improve the water balance situation. Over the long term however, these terraces had a negative impact on local hydrology (Lacombe et al. (2008).

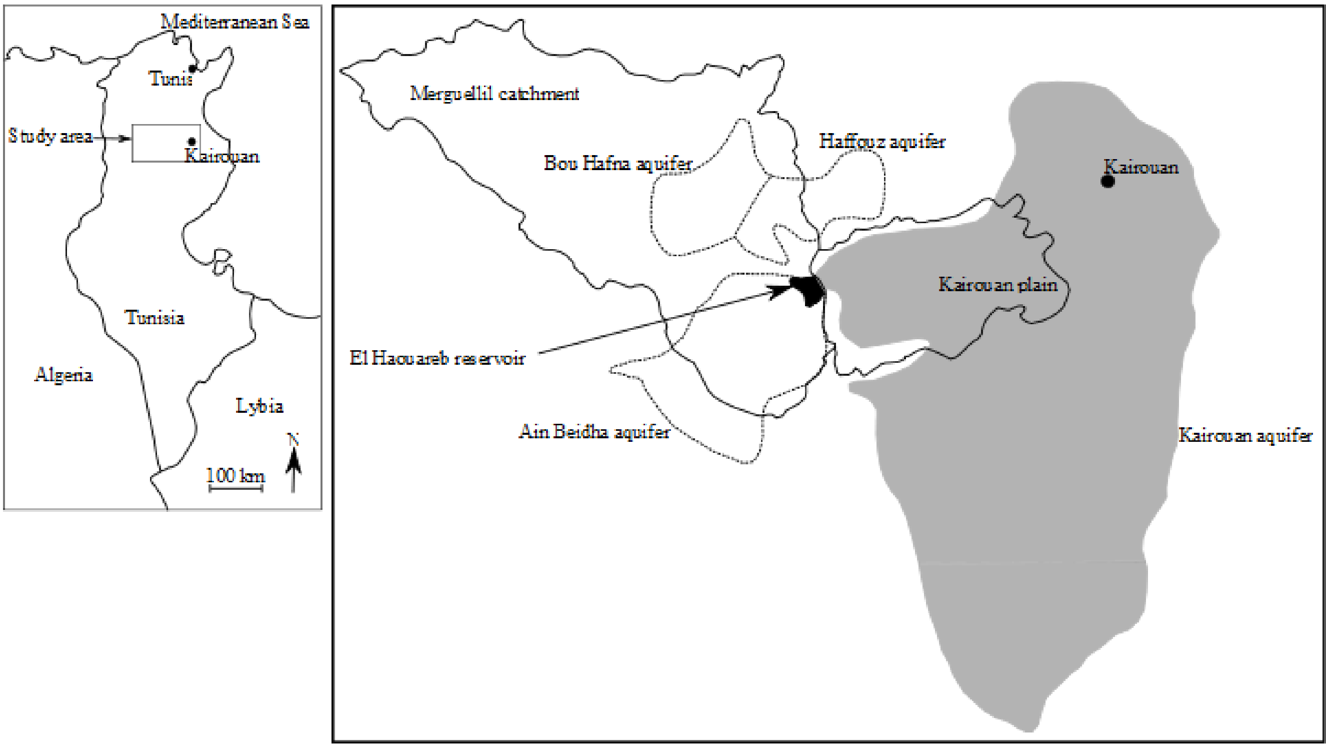


Figure 1: Location map showing the Kairouan aquifer (grey shading), Tunisia.

The El Haouareb reservoir was built to supply water to the region. However, high evaporation, over-abstraction, and more recently, leakage down a fissure have led to this reservoir being significantly more empty than was planned. The leakage, accounting for the loss of up to 50% of the water volume held in the reservoir, actually ends up in the Kairouan aquifer, so rather than being truly lost, it is merely stored in a different location to that planned.

The Kairouan aquifer (Figure 1) water balance, was the main focus of the water balance modelling for this project. It is composed mainly of karstic rock (i.e. limestone-type material) with significant proportions of fluvial sand and gravel (Leduc et al, 2007). This means that transmissivity and storage values are high. From local observations of piezometric levels and from rudimentary mass-balance assessments, the water table in the aquifer is believed to be consistently dropping (Feuillette et al., 2003; Poussin et al., 2008; Le Goulven et al., 2009), hinting at over-exploitation. The exploitation rate can reach as high as 182% of the supply, particularly in hot, dry summers. The current volume of water stored in the aquifer is estimated at c. 59.7 x 10^6 m^3 (Lili-Chabaane, *pers. comm.,* 2010).

The current situation is one of overexploitation of the aquifer water resource. Domestic drinking demand is increasing, as is agricultural demand, which while mostly publicly operated and controlled, also has an unregulated 'private' sector, making accurate estimates of demand very difficult. This is leading to water-conflicts between many sectors: domestic, industrial, agricultural, tourism, etc. The largest water withdrawal from the aquifer is to pump water from Kairouan to coastal cities to satisfy demand there. This is presently the major driver of Kairouan aquifer overexploitation. There is currently a policy in place to reduce this volume by 50% by 2030.

2.3 Rosetta, Egypt

The Rosetta region, is situated on the north-western edge of the Nile Delta, near the city of Alexandria (Figure 2). The study area has an area of 43.3. km^2, and a population of 370600. Agriculture is the dominant socio-economic driver in the region.

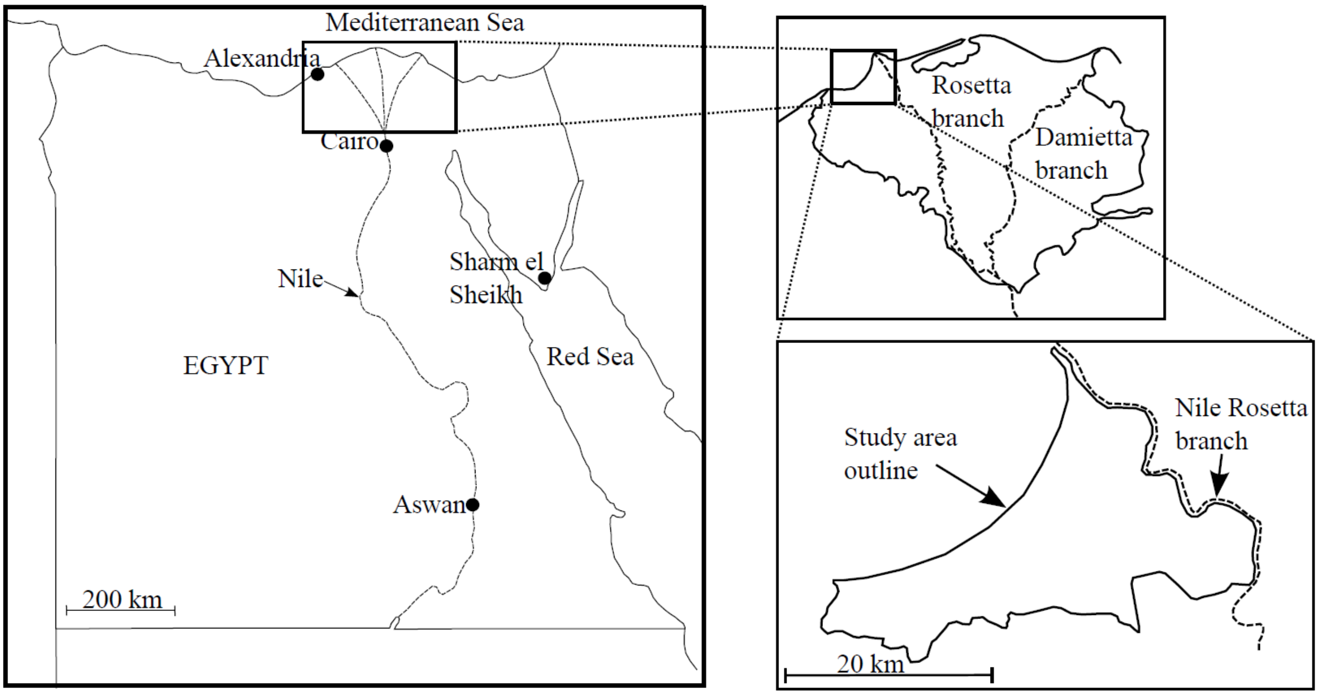


Figure 2: Showing the location of the Rosetta study area.

The water resource in the Rosetta region is largely dictated by a) inflows to Egypt from the Nile River and; b) upstream abstractions of Nile water, particularly along the productive Nile agricultural corridor and from Cairo. Egypt relies heavily on Nile water for national supply, with more than 95% of Egypt's water deriving from this source (Wichelns, 2002). This volume is capped at 55 x 10^9 m^3 yr^{-1} by an international treaty signed with Sudan regarding releases from the Lake Nasser reservoir on the Egyptian border which controls Nile water flow to Egypt. This reliance is also the case in Rosetta, which takes its water from canals which directly feed from the Nile. Therefore, any shortfall in Nile water could mean a shortfall in Rosetta water. The water supply to Egypt is therefore strongly controlled by potential changes to Nile inflow volumes. At present, modelling efforts do not converge on either the direction or magnitude of future changes to Nile flows, with the range of estimated change being from -50 to +60% (Conway, 2005). Egypt does compensate somewhat - there is currently a drive to use more water from treated and re-used waste-water, and there is also an increasing contribution from desalinated seawater.

Water demand is projected to increase into the future from increasing population, improving living standards, agriculture and industry. On top of this, climate predictions for the region show increasing temperatures and lower or more erratic rainfall (Arnell 2004; Christensen and Christensen, 2007; Giannakopoulos et al., 2009), suggesting that the supply could reduce and that demand, especially crop water requirements, could increase. In addition to these issues, Rosetta also faces the threat of land loss resulting from sea-level rise. This loss could potentially reach c. 13% of the total study area by 2050 (ECRI, *pers. comm.,* April 2011). Modelling efforts for this case study focussed on agricultural water use and Nile/canal water supply.

2.4 Jordan River Basin, Jordan

The Lower Jordan River Basin, Jordan (Figure 3) is located in north-west Jordan near the capital Amman, with the study area having a total area of 7600 km^2.

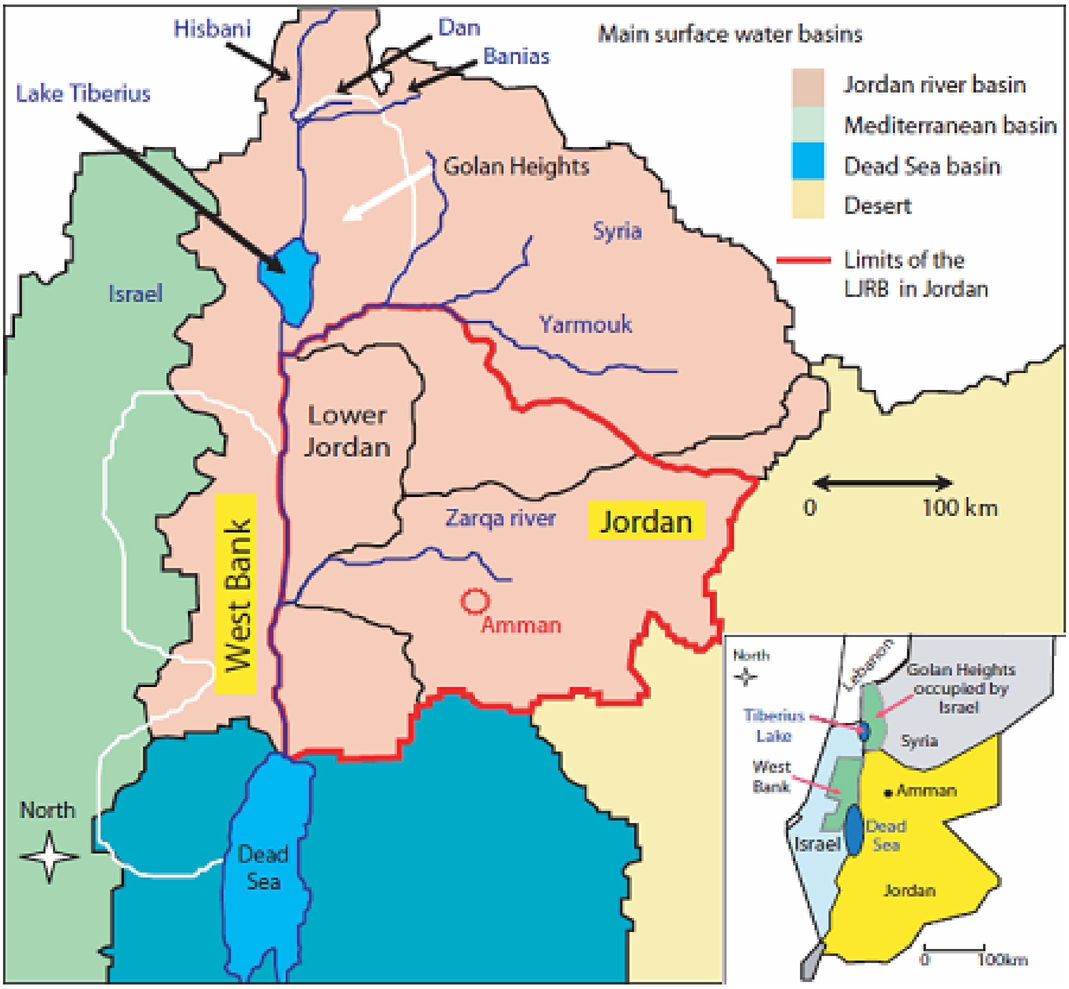


Figure 3: Showing the extent of the lower Jordan River Basin in Jordan.

The study area extends from the southern edge of Lake Tiberius in the north, to the northern edge of the Dead Sea in the south, and encompasses parts of two main tributaries, the Yarmouk and Zarqa Rivers and the city of Amman. The Jordan River throughout this reach is below sea-level.

Jordan River overexploitation has led to a significant decrease not only in Jordan River flow volume (from c. 1550 x 10^6 m^3 yr^{-1} to less than 200 x 10^6 m^3 yr^{-1} today), but also in the level of the Dead Sea itself, threatening the water supply, water quality, and unique ecosystem of the Dead Sea. This over abstraction is largely due to domestic and agricultural demand, both of which are projected to increase into the future. Rainfall is already very low, in some locations < 200 mm yr^{-1}, and is projected to decrease. As a result of water shortages, farmers are being forced to either change their cropping habits, or to reduce their cropping areas, both of which are hampering local development. There is a strong drive towards ever-more efficient irrigation practices in the basin.

In addition to improving irrigation efficiency, a major engineering project aimed at physically transporting water from the Red Sea to the Dead Sea basin is also being considered. While this would reduce dependence of water from the Jordan River (which also has significant transboundary water sharing issues), the cost of the project is very high, and increasing. In the short- to medium-term therefore, most cost-effective, local solutions, particularly in the agricultural sector, for demand management are required in order to address the severe water security and availability issues being faced in this case study.

At present, the water resources are being over exploited by at least 167%, and the supply has fallen by up to 40%. Some reservoirs have never reached full capacity because of the high demand, both from agriculture, and from large cities such as Amman. Groundwater sources are also overexploited. There is however, on top of an irrigation efficiency drive, a drive to treat and re-use wastewater, and also to bring in legislation aimed at reducing demand.

Modelling efforts for this case study focused on future water supply issues, and the various ways to reduce demand through alteration in cropping patterns over time.

2.5 Syros, Greece

Syros Island, in the Cycladic island complex in Greece has an area of c. 84 km^2 (Figure 4). It has a permanent population of just over 20000., with 65% of these people living in the islands capital.

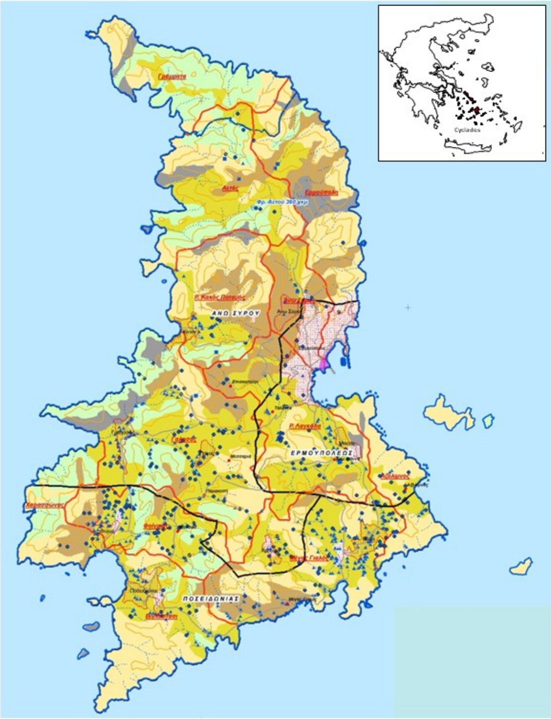


Figure 4: Map of the island of Syros, Greece.

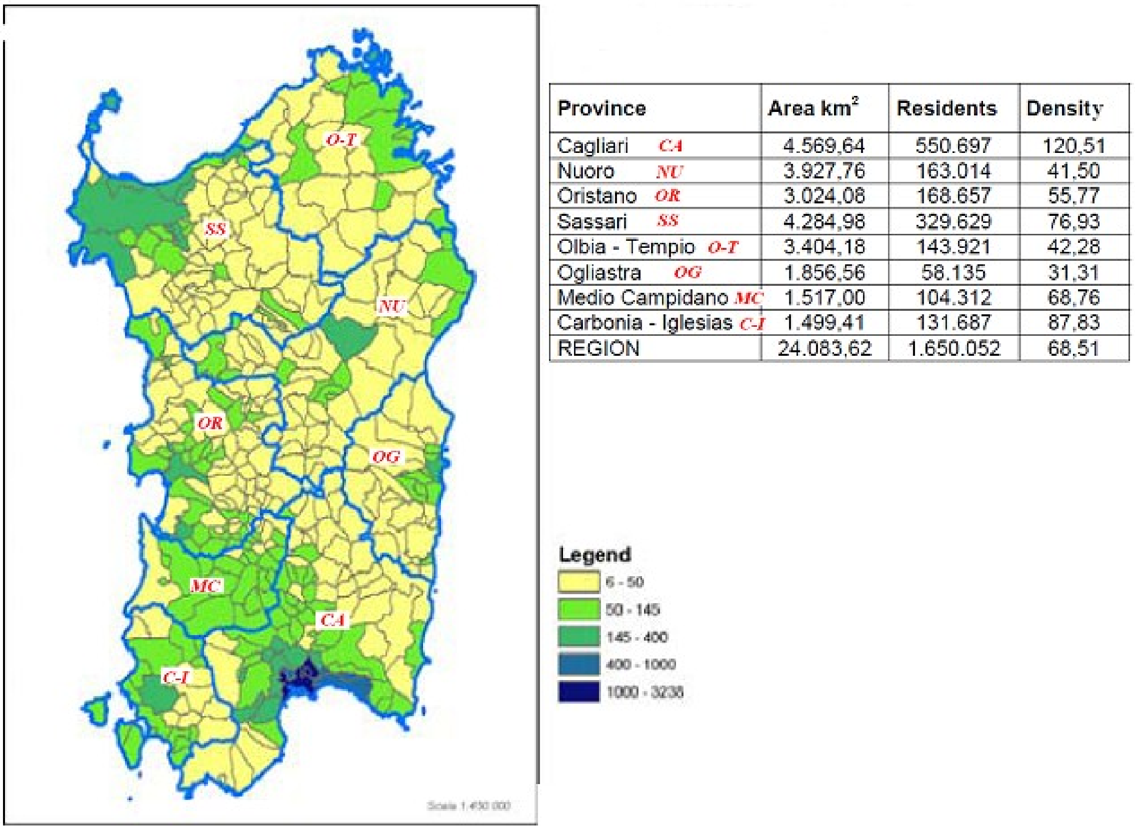
The main water-related pressure that Syros faces is from tourism: in summer, the island population can more than double, putting immense pressure on the local water supply. Despite this huge pressure, tourism is critical to the economy of Syros, and so there is a difficult trade off to make between water availability and the economic viability of the island community. Agricultural activity is also important, particularly for supply to the domestic market.

Making the issue more difficult is the fact that Syros receives up to 90% of its total annual rainfall from October to March - outside the tourist season, and that most of this rainfall runs off to the sea, and is not stored. The islands main freshwater aquifers are seriously overabstracted, and are subject to saline intrusion. The Cyclades area has recorded the highest annual number of dry days in Greece (Nastos and Zerefos, 2009).

At present, the water infrastructure is relatively basic, with a few small reservoirs providing supply in addition to the groundwater. There is also appropriate water supply and wastewater infrastructure across the island along with four desalination plants, recognising the current water-availability situation, and how it could change in response to regional climate change and social development.

2.6 Sardinia, Italy

Sardinia is located in the Mediterranean Sea off the western coast of Italy (Figure 5). It has a surface area of just over 24000km2 and a population of 1.1 million. At present, agriculture and a summer tourist season represent the main threats to water availability on the island.



Province	Area km²	Residents	Density
Cagliari *CA*	4.569,64	550.697	120,51
Nuoro *NU*	3.927,76	163.014	41,50
Oristano *OR*	3.024,08	168.657	55,77
Sassari *SS*	4.284,98	329.629	76,93
Olbia - Tempio *O-T*	3.404,18	143.921	42,28
Ogliastra *OG*	1.856,56	58.135	31,31
Medio Campidano *MC*	1.517,00	104.312	68,76
Carbonia - Iglesias *C-I*	1.499,41	131.687	87,83
REGION	24.083,62	1.650.052	68,51

Figure 5: Map showing population density in Sardinia.

The Island has a typical Mediterranean climate, which is characterized by mild wet winters and long hot dry summers. The average annual precipitation of the Island is below the 700 mm yr^{-1}, most of which occurs between November and April, while summer temperatures can easily exceed the 35°C. In the summer months, the peak crop water demands coincide with the high tourism season and thus increase the pressure on the scarce water resources of the island and raises concerns to the environment. For the island, tourism from the economic point of view is more profitable than agriculture. As a matter of fact, tourism represents one-third of the Island GDP. However, the environmental impact of the Islands' blooming tourism (around 10 million tourists visit the Island annually) and the pressure exerted on the scarce water resources are immense. The situation is exacerbated with the increase in the drought frequency and intensity that are largely attributed to climate change.

Being an island with limited and confined water resources, Sardinia has to use efficiently each drop of water and where possible to search for alternative and non-traditional sources such as rain harvesting and treated waste water. Winter storage reservoirs are very common in Sardinia, as a matter of fact out of the 32 lakes on Sardinia, 31 are man-made. These reservoirs are designed to store winter water when river flows are high and then conveyed in the summer where demands are high, thus alleviating the pressure on the groundwater abstractions.

Nowadays, the available water resources of the Island for urban, agriculture and industrial sectors depend on the water volume stored in the islands reservoirs or abstracted from the groundwater. Relying excessively on ground water is raising concerns about the use sustainability of such resources. The dry spell of 2004, has led to serious shortage of water. The water stored in the reservoirs reached the reservoir design capacity. A water shortage event to c. 2004 led to a re-designing of reservoir control levels and alarms, ensuring a more reliable supply during dry years. This has led to so-called 'memory loss' among local residents of drought events, which tends to leads to higher domestic consumption with time from the event.

This case study investigates the linkages between three reservoirs designed for different purposes and to serve different sectors. The aim is to demonstrate that changing water-trading rules between these reservoirs can improve the reliability of the Regions ‘water supply. Additionally, the volumetric water demand for agriculture and tourists are projected for the whole island.

3. Summary of the water balance models for the Case Studies

3.1 Introduction

WASSERMed deliverable 5.2.3 - 'Report on water balance modelling for all case studies' presented the latest versions of the water balance models for all the case studies, and also presented the latest results. Since then, some of the models have been modified and the results have subsequently changed. This section presents the most up-to-date water-balance models for all the WASSERMed case studies, while Section 4 will present the latest results based on these models.

3.2 Water balance model for Kairouan

The Kairouan water balance has changed significantly since that reported in Deliverable 5.2.3. The full model, and results derived from the model are described in detail in Sušnik et al. (2012), although a summary based on Susnik et al. (2012) is provided here. Any information that is used from this section should be cited as Sušnik et al. (2012).

For this model, development was carried out in close cooperation with INAT, the local Tunisian project partner. INAT assisted in ensuring that the model boundaries and structure were appropriately representative of the system being studied (i.e. the Merguellil/Kairouan hydrological-social system), and that model results were representing observations. INAT also provided access to essential data when required. Briefly, both the AquaStress model, the focus of which was to model in detail the upper Merguellil Valley, with very little focus on the Kairouan aquifer, and the detailed Kairouan model developed within WASSERMed consist of nine interlinked subsystems:

(a) upper Skhira, which models the very upper part of the catchment;

(b) middle catchment, which models in detail the processes in the mid-Merguellil catchment, including the influence of 35 small dams;

(c) El Haouareb, which simulates the water balance in the large El Haouareb reservoir;

(d) surface water input , which estimates the volume of water infiltrating to the Kairouan aquifer from rainfall (rainfall-recharge in Figure 6);

(e) subsurface water input which models the direct subsurface transfer of water from adjacent aquifers to the Kairouan aquifer (recharge from adjacent aquifers in Figure 6);

(f) coastal pumping which simulates water pumped out of Kairouan to satisfy coastal city demand;

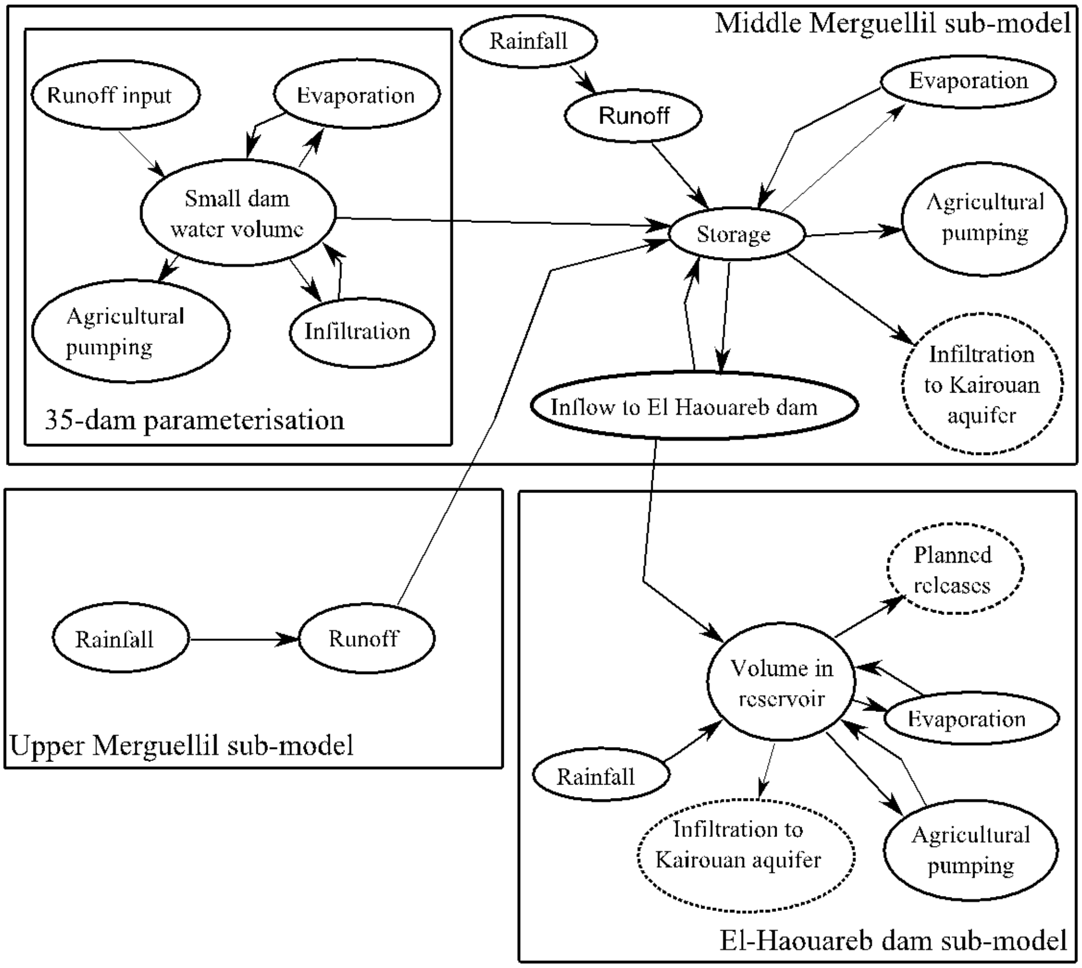
(g) domestic demand;

(h) industrial demand; and

(i) agricultural water demand.

The aforementioned sub-models contribute to a central water balance component which uses all the inputs and outputs to estimate the Kairouan aquifer water volume at each timestep. For each simulation, the initial volume of the aquifer is set to 59.7 x 10^6 m^3 (Lili-Chabaane, 2010). A basic schematic overview of the model interconnections is shown in Figure 6. More details for some of the sub-models are given in this Section and in Figures 7-9.

(a)



(b)

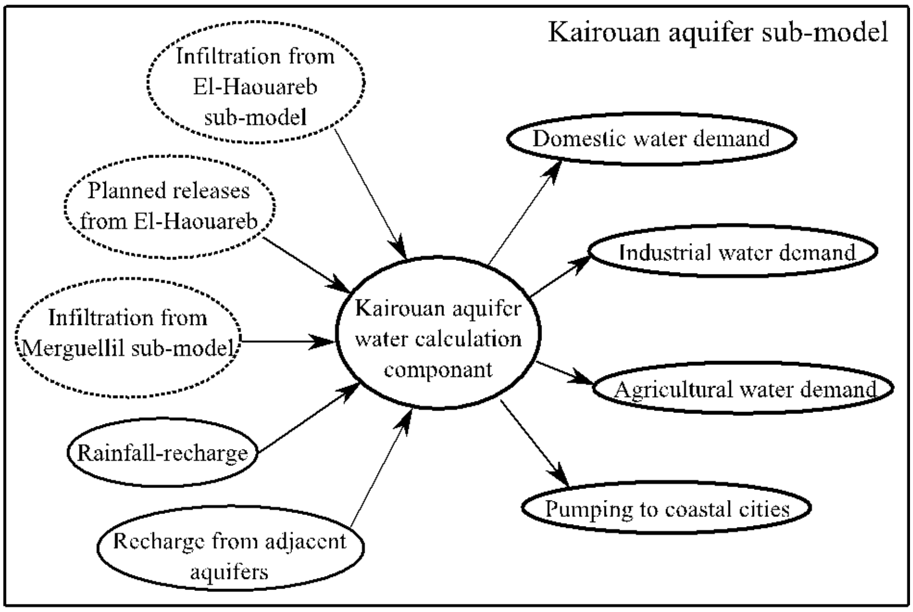


Figure 6: Schematic showing the main interconnections in the SDM developed for this study. (a) illustrates the upper (Merguellil) part of the SDM, while (b) shows the connections between the elements in the newly developed Kairouan aquifer sub-model. This schematic is greatly simplified for clarity here and does not represent the full complexity of the model.

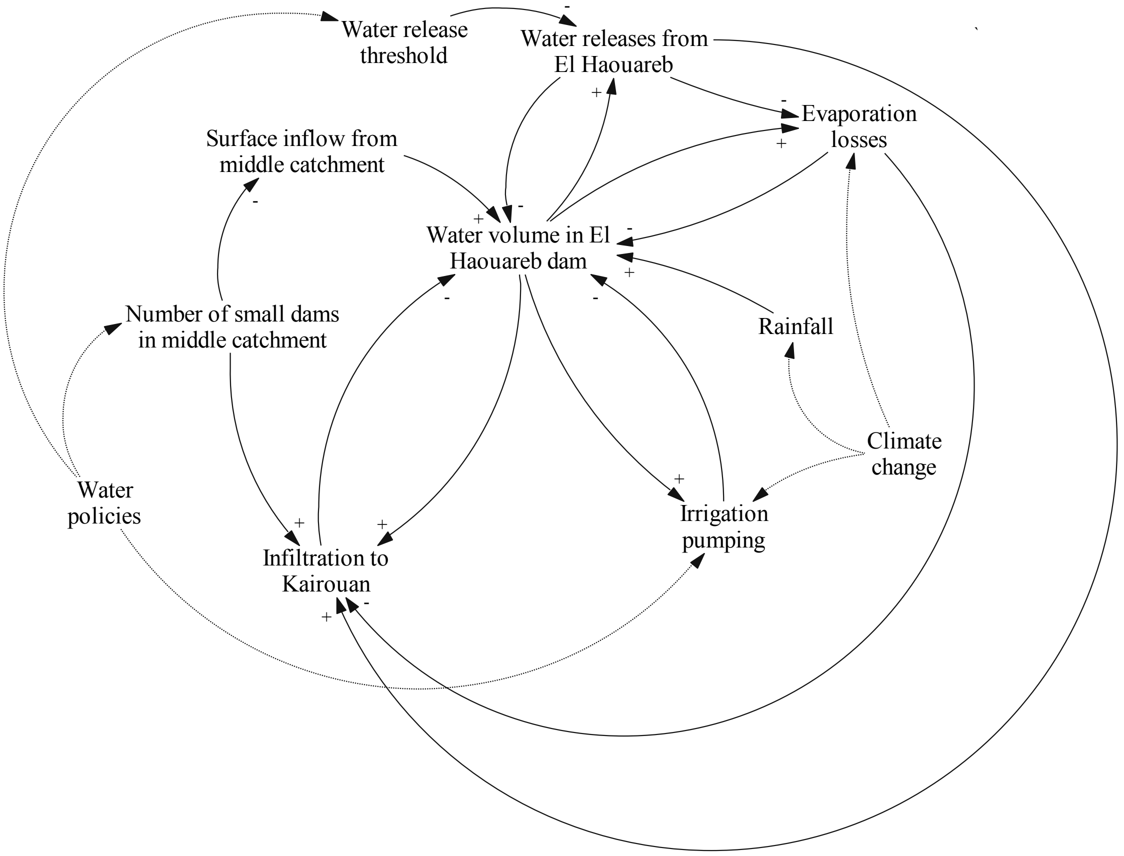


Figure 7: Causal loop diagram for the El-Haouareb sub-model. Polarity of feedback loops is indicated with a '-' for negative (self-stabilising) polarity and a '+' for positive (reinforcing) polarity. Indirect influences are shown as dashed arrows.

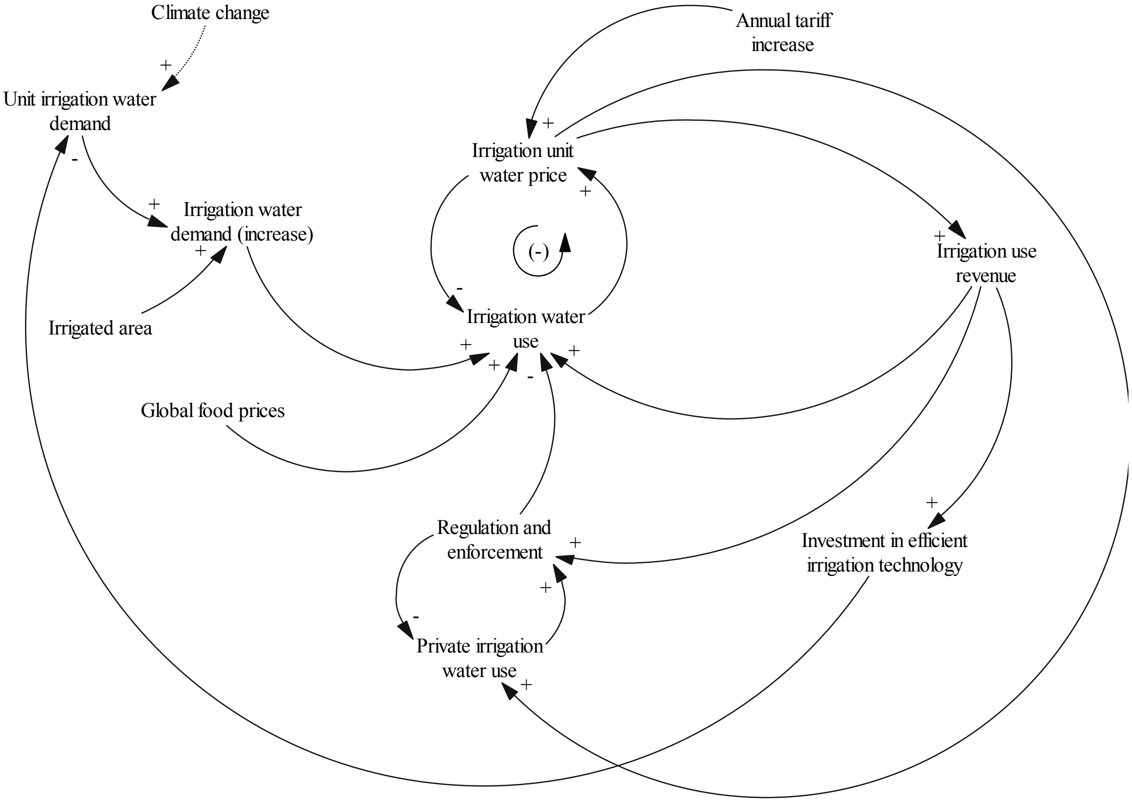
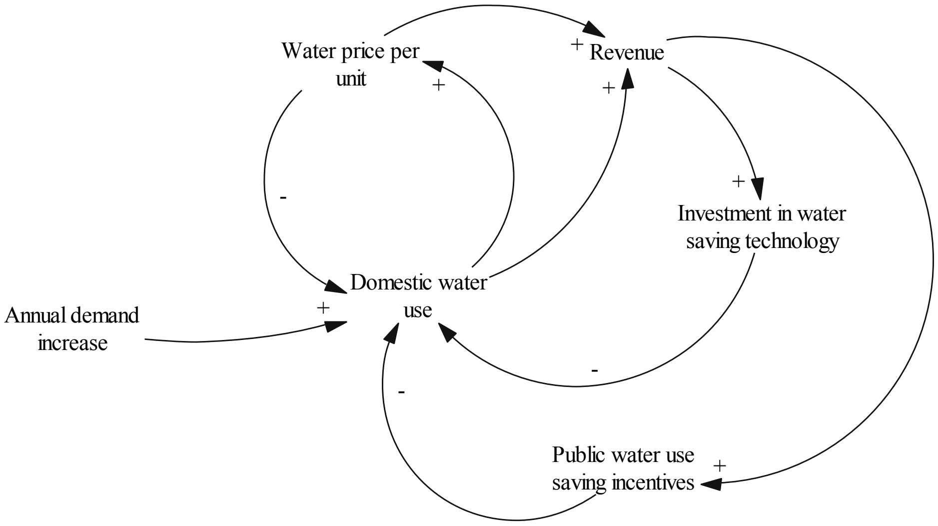


Figure 8: Causal loop diagram for the agricultural demand sub-model. Polarity of feedback loops is indicated with a '-' for negative (self-stabilising) polarity and a '+' for positive (reinforcing) polarity. polarity. Indirect influences are shown as dashed arrows.

(a)



(b)

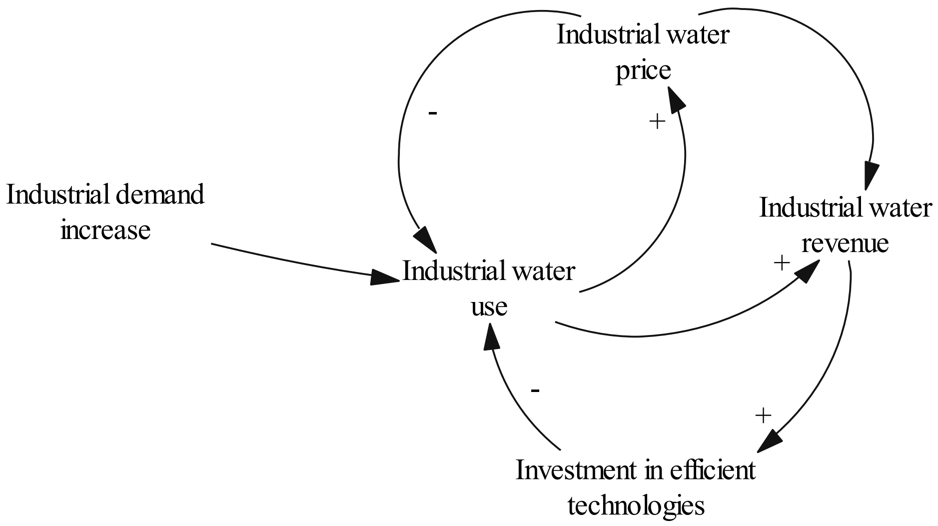


Figure 9: (a) Causal loop diagram for the domestic demand sub-model.(b) Causal loop diagram for the industrial demand sub-model. Polarity of feedback loops is indicated with a '-' for negative (self-stabilising) polarity and a '+' for positive (reinforcing) polarity.

The entire SDM consists of 155 nodes. The model is run continuously for 480 time steps at monthly resolution (i.e. 40 years), taking the simulation to 2050.

The simple Upper Skhira sub-system models the upper Merguellil catchment, with runoff from rainfall contributing to the second sub-system. The main purpose of separating it as an independent subsystem was the existence of flow measurements at its downstream end, which have been used for calibration.

The second sub-system models in detail the middle Merguellil catchment, and includes an encapsulated sub-system describing the water balance of the 35 small dams built for irrigation water supply and groundwater recharge. Infiltration and runoff from the 35 dam sub-system, plus runoff from the rest of the middle catchment region (once evaporative losses and agricultural demand have been accounted for) then feed into the El Haouareb dam sub-system. Some infiltration is routed to small aquifers which in turn recharge the Kairouan aquifer. The middle Merguellil is the most complicated sub-system in computational terms. The characteristics of the encapsulated sub-system have been defined after careful consideration of detailed data on the small dams (Lacombe et al, 2008) and calibration (Vamvakeridou-Lyroudia et al., 2008). At each timestep, the volume of water in the reservoirs is updated, accounting for inflowing water, evaporation, pumping and infiltration losses.

The El Haouareb sub-system includes rules to estimate evaporation based on lake surface area, water releases based on threshold water levels to be applied (this is a reservoir operational control rule to maintain safe water levels, although in practice these happen only very rarely), and a function to represent infiltration into the Kairouan aquifer. Figure 7 shows the causal loop structure in order to illustrate the feedback that is involved within this single sub-model. Also the number of small dams from the Middle catchment subsystem interact with, and affect the water volume in El Haouareb, as well as infiltration to the aquifer. Indirect influences, i.e. climate change, and water policies are presented as dashed lines

The main Kairouan aquifer sub-model, which is the focus of this study, comprises a water-balance model which brings together the calculations performed in each of the six sub-models to simulate the behaviour of the water reserves held in the aquifer. Two of the sub-models represent inputs to the aquifer, including rainfall and the other four represent outflows or abstractions.

The two input sub-models represent surface water recharge and direct aquifer transfers. The surface water sub-model uses continuous monthly rainfall time-series data to estimate the volume of water infiltrating over the area of the Kairouan plain per month from rainfall events. At each timestep, the rainfall depth (m) is multiplied by the catchment area (m^2). This is then multiplied by 0.05 to represent the fact that rainfall only falls over a very small fraction of the catchment area. Of this rainfall, c. 70% is lost to evaporation (Besbes et al., 1978), with the rest recharging the aquifer. In addition, some water released from El Haouareb dam infiltrates to the Kairouan aquifer. The volume of water released from the dam is output from the El Haouareb sub-system and used here as input, thus providing a link between the sub-systems. The sum of the rainfall infiltration and water-release infiltration comprises the surface water input to the Kairouan aquifer. For the direct transfer sub-model two sources are taken into account. The first is water that infiltrates directly beneath El Haouareb dam, as well as water that infiltrates through the small dams in the middle catchment. The second source is direct water transfer from adjacent aquifers.

There are four outflow/abstraction sub-models: a coastal pumping model; a model to represent agricultural demand, and models to represent domestic and industrial abstractions. Each sub-model (except the coastal pumping model) uses a series of feedback loops in order to estimate the respective demands at each timestep. The initial conditions are set to present days values for each of the parameters that require an initial value (e.g. demand, tariff). Over the course of the simulation, the system of feedback loops results in the demand/tariff/etc. being re-estimated at every timestep. For the industrial, agricultural and domestic demands, the demand is influenced both by 'external' factors such as tariff, or predicted annual demand increases, and 'internal' factors such as savings from investment in infrastructure, regulation and water saving campaigns.

The agricultural sub-model is described here in detail in order to give an idea of the complexity involved, and to show how SDM principles have been exploited. The causal loop diagram for the agricultural demand sub-model is shown in Figure 8. It is noted that there is an 'Irrigation water use' node representing the public (regulated) supply and a 'Private irrigated demand' node representing unregulated (sometimes illegal) water use. The initial 'Irrigation water use' value is modelled as constantly decreasing based on the findings by Chahed et al. (2008) that state that the agricultural water demand is predicted to decrease by c. 5% to 2030. We assume that the 5% decrease by 2030 is maintained to 2050. 'Irrigation water use' is influenced by the tariff, which subsequently feeds back to alter the demand at the next timestep. The change in demand due to tariff alterations is controlled by the equation for the price elasticity of demand (Lipsey and Chrystal, 1999):

$$\Delta D = D_{t-1} \times \{PeoD_t \times (\Delta P/P_{t-1})\}, \qquad (1)$$

where D_{t-1} is the demand at time step t-1, P_{t-1} is the tariff at time step t-1, $PeoD_t$ is the price elasticity of demand at time step t. ΔD and ΔP represent the change in water demand and tariff from the previous timestep respectively.

A constant value was chosen to represent an inelastic water market (-0.3) for PeoD. Generally, the industrial, tourist and lower-demand domestic users, who dominate in this area of Tunisia, have low demand elasticity. This value was changed in model testing to test sensitivity of results to different elasticity. The tariff itself is increased by 1.25% per month. Acting alone, this would cause a drop in demand, but this is not the case here. Change in 'Irrigation water use' (i.e. agricultural water demand) is also influenced by 'Global food prices'. The logic is that farmers exploit increases in global food prices to grow more crops for sale abroad, with some of the price increase due to the farmers themselves increasing wholesale costs to recover increased expenditure due to water tariff rises. Thus, tariff increases may not decrease demand as much as expected due to the influence of other feedback loops in the system.

Average global food prices have increased by 11.3% annually from 2000 to 2012 (www.fao.org). It is assumed here that the increase is linear and that this rate of change remains constant through the model simulation.

The 'Irrigation use revenue' node is simply the 'Irrigation water use' multiplied by the tariff per unit consumed. Of the irrigation water use revenue, 10% is invested for improving irrigation efficiency, a reasonable assumption in the absence of more specific data, and was tested with the use of the model. The water efficiency saving from improving irrigation techniques is set at 20% which is very close to the 22% reported by Unlu et al. (2011) when using drip irrigation compared with more traditional irrigation methods. However, it is assumed that a 20% saving of the total agricultural demand can only be achieved if every farmer in the region takes up the technologies. If not, it must be scaled proportionally by farmer take-up. This proportional uptake relies on the investment increasing at each timestep. At present, 21% of farmers use drip irrigation in the Kairouan region (INAT, *Pers. Comm.*) and thus at initial conditions the 20% potential saving is multiplied by the 21% of total farmer uptake (= 0.042). Uptake was capped at 70% of the farmer population because it was assumed that there will always be some farmers who either cannot afford better technology or who resist change to newer technologies. Any water saving calculated is deducted from the total agricultural demand at the next timestep.

Finally, irrigation water use is influenced by regulation and enforcement (a feedback structure currently built into Tunisian water policy, which is in turn governed by the revenue generated. As with the water efficiency savings loop, if revenue increases, there is greater scope for regulation development and for policing water use/extraction. Thus, the unregulated (private) demand will tend to fall with respect to the value at the previous timestep, with a concomitant increase in the regulated water use, and vice-versa. The change in regulation is represented as equal to the proportional change in revenue from the last timestep, but is capped at 10% per year.

The causal loops for the domestic and industrial demand are shown in Figure 4. The logic is similar to the processes described above for agricultural demand, but with various changes made which are specific to each case (e.g. annual percentage change in demand, tariffs, etc). Policies aimed to controlling water demand pertaining to water saving campaigns, increasing utilities' network efficiency and introducing more robust regulation are currently employed in Tunisia.

The exception is the coastal pumping sub-model. Again, data was provided by INAT that lays out how the Tunisian government aim to reduce this pumped volume over time to 2030. This sub-model reduces the pumped volume in a step-wise manner according to the data, creating a downward stepping demand profile over time.

3.3 Water balance model for Rosetta

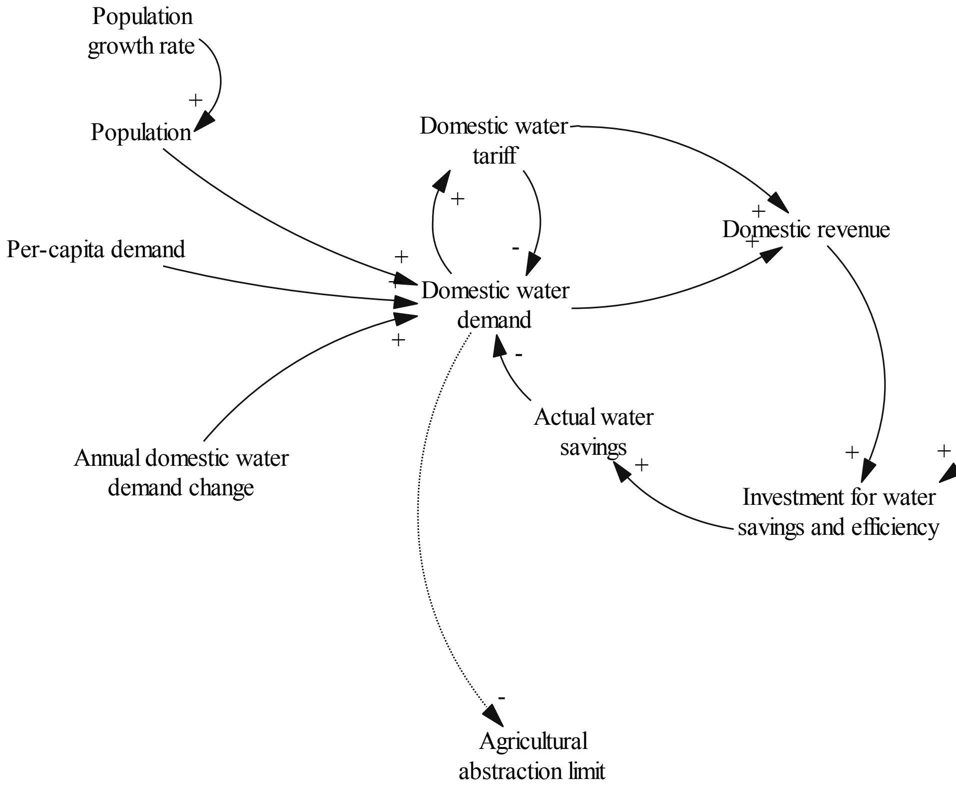
The Rosetta water balance has also changed considerably since that reported in Deliverable 5.2.3 as discussions with ECRI brought to light new challenges that the model was to address. These development were built into the model. The full model, and results derived from the model are described in detail in Sušnik et al. (Submitted), although a summary based on Susnik et al. (Submitted) is provided here. Any information used in this section should be cited as Sušnik et al. (Submitted).

The Rosetta SDM (Figures 10 and 11) was developed over a period of months in close collaboration with local stakeholders and experts (ECRI, Egypt). The base model used here comprises of 15 sub-systems containing 176 model nodes (stocks, flows and converters). The model is run on a monthly timestep for 40 years (480 timesteps).

The water sources for the Rosetta model are calculated in three sub-models: one for canal inflows and one for rainfall contributions. The third sub-model encapsulates the other two, summing relative contributions to give the total supply. For the canal inflow sub-model, data for eight canals supplying the study area were available from ECRI. Data were available for each canal at monthly resolution between 2007-2009 (36 timesteps). After the first 36 timesteps, the average monthly inflow from all canals over the last 12 months of data is used unless a climate change factor, accounting for potential changes to Nile flows, is included. In this case the percentage of inflow change to be implemented by 2050 is divided evenly amongst the remaining 37 years of simulation (444 timesteps) and added up cumulatively during the simulation. For the rainfall sub-model, continuous monthly precipitation data to 2050 were supplied by the Centro Euro-Mediterraneo per i Cambiamenti Climatici (CMCC, Italy). These data were derived from the ETHZ regional climate model forced by HadCM3Q0 using the IPCC A1B emissions scenario. The data are scaled up using the Rosetta study area, and an evaporation coefficient of 70% (Arab Republic of Egypt, 2005) is applied to give an effective rainfall volume, although the 70% evaporation rate may be too low for this region (Kotb et al. 2000). The rainfall and canal contributions are summed to give the total water supply at each model timestep.

The other 12 sub-models pertain to water use. One sub-model deals with domestic use, and another with industrial use. The domestic and industrial sub-models have very similar structures, the main difference being the inclusion of population in the domestic demand model. The logic that applies to both sub-models is that the water demand is influenced by the tariff and by changes to the tariff, with changes to demand subsequently being influenced through the price elasticity of demand equation (see equation 1 above). For this case study, a value of -0.1 was used (Arab Republic of Egypt, 2005), representing low elasticity of demand (i.e. demand does not change much in response to changes in tariff). Such a low value for PeoD is common throughout the Middle Eastern region (Abu Qdais and Al Nassay, 2001). Changes to demand as a result of changes to the tariff affect the revenue generated, which then influences the revenue used for investment in better infrastructure and efficiency measures. Any demand savings made through efficiency measures are applied to the demand at the next timestep. If lower investment is made, minimal demand savings are made at the next time step. Changes to demand feed back through the entire loop in the next timestep. Superimposed on this are expected changes to the domestic and industrial demand to 2050, and for the domestic sub-model, changes in demand due to expected changes to the Rosetta population by 2050. Figure 10 shows the causal loop diagrams for the domestic and industrial demand sub-models to illustrate the nature of the relationships.

(a)


Population growth rate
Population
Domestic water tariff
Domestic revenue
Per-capita demand
Domestic water demand
Proportion invested
Actual water savings
Annual domestic water demand change
Investment for water savings and efficiency
Agricultural abstraction limit

(b)

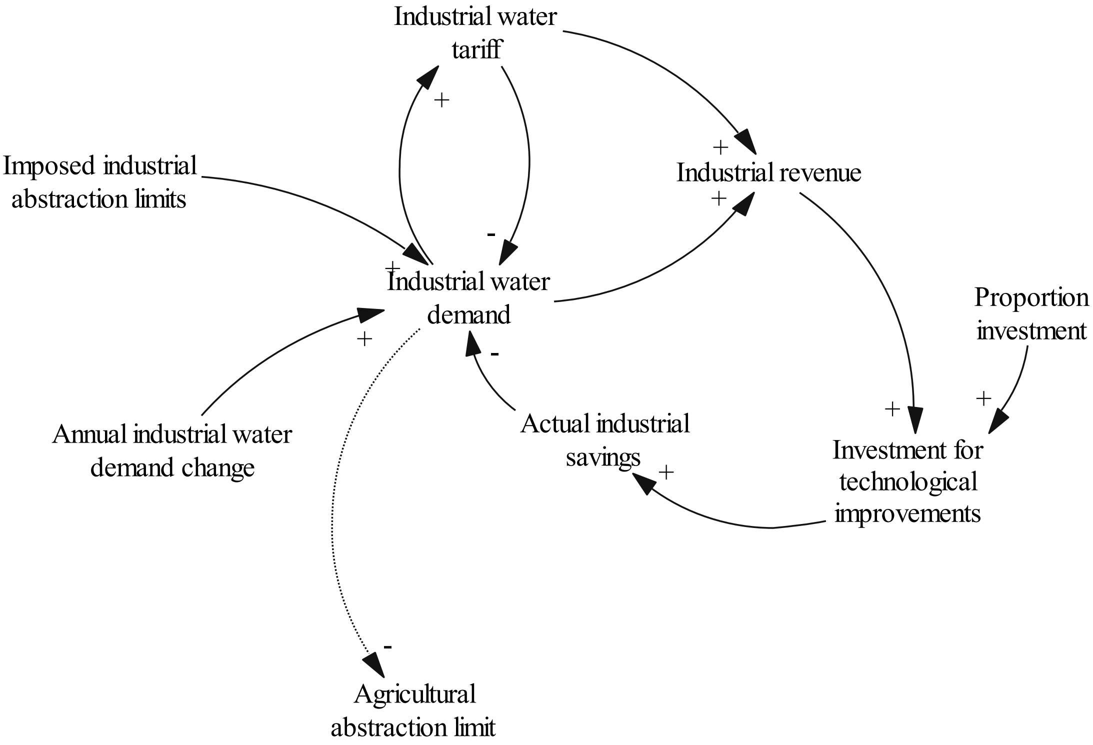

Industrial water tariff
Imposed industrial abstraction limits
Industrial revenue
Industrial water demand
Proportion investment
Annual industrial water demand change
Actual industrial savings
Investment for technological improvements
Agricultural abstraction limit

Figure 10: Causal loop diagrams for: (a) the domestic water demand sub-model and; (b) Causal the industrial water demand sub-models. '+' signs indicate positive relationships (self-supporting), '-' signs indicate negative (self-stabilising) relationships. Dashed lines indicate that the parameter influences the values in a different sub-model.

For the agricultural sector, there are nine sub-models, one per-crop type and a final sub-model encapsulating the nine crop sub-models, summing the results and applying sea-level rise and water supply:demand factors. The nine crops are: alfalfa, cotton, maize, rice, tree crops, summer and winter vegetables, wheat and other crops. For the nine crop sub-models, the model structure within each is similar. At the centre of each crop sub-model is the crop planted area. This is multiplied by crop water requirement (CWR), yield and revenue per unit area. For all crops, estimated changes to the crops' revenue are implemented to 2050. In addition, for cotton, maize, rice and wheat, estimated changes to the yield and water requirements to 2050 are also applied. The per-crop totals are summed to give agricultural sector totals for water requirement, yield and revenue at every timestep. Once the gross totals are calculated, a reduction factor is applied to account for the impact of sea-level rise. For the baseline case, a rise of 2 mm per year (due to land subsidence; El-Raey et al. 1999; OECD, 2004) is applied. Sea-level rise is related to an area of land lost through a regression relationship given in El-Raey (1999). The loss of land is used to reduce the gross crop water requirement, yield and revenue assuming that a percentage land loss corresponds to an equal reduction in agricultural output. The 'sea-level rise adjusted' totals for CWR, yield and revenue are then scaled again. The domestic and industrial water demand are deducted from the total water supply (these sectors have priority of supply) and an agricultural abstraction limit, given as a percentage of the remaining water that may be used for irrigation, is used to calculate the total irrigation water available. If the 'sea-level rise adjusted' CWR is greater than the available irrigation supply, the ratio between supply and requirement is calculated and used to scale down the yield and revenue to give the final values for these parameters. Figure 11 shows the causal loop diagram for the agricultural sub-model and how it relates to the domestic and industrial sub-models.

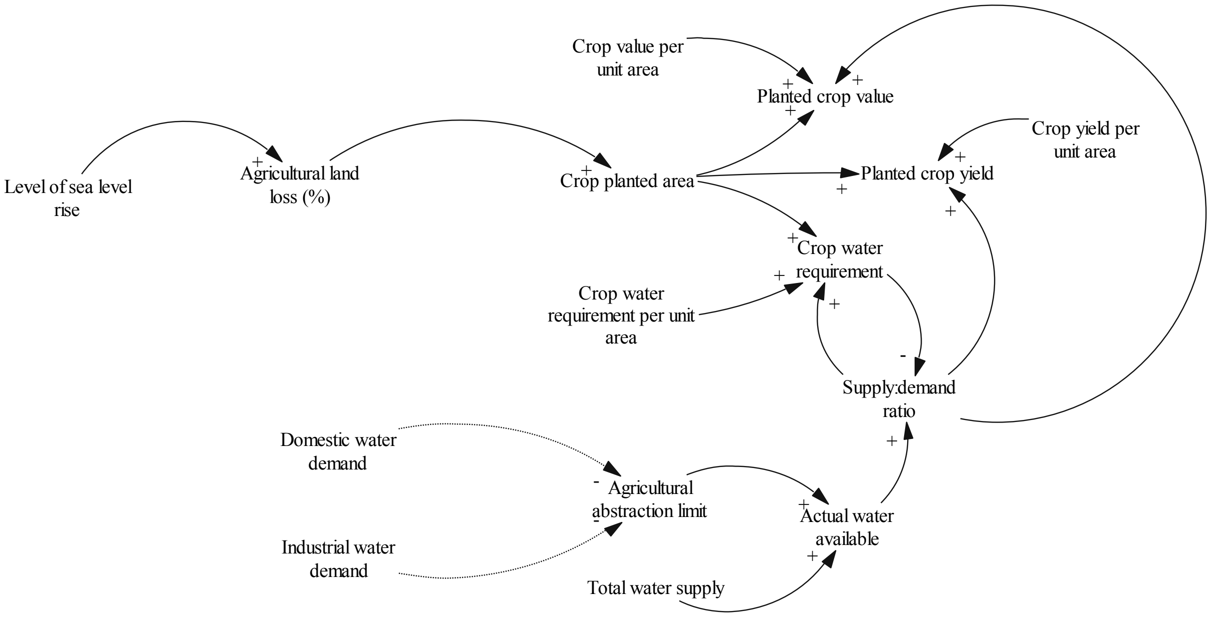


Figure 11: Causal loop diagram for the agricultural water demand sub-model. '+' signs indicate positive relationships (self-supporting), '-' signs indicate negative (self-stabilising) relationships. Dashed lines indicate that the parameter is influenced by the values in different sub-models.

In addition to the modules described above, an addition sub-model was created that attempts to start to quantify the potential impact of a new, beneficial, positive feedback loop described thus. As surplus crop is generated through cropping regime changes, there is the potential to export more product, generating additional income in excess to the extra income already generated by changing cropping regime. Some of this could be used to invest in improved irrigation efficiency, while some could be used to import water-intensive crops such as cotton from the international market. The import of cotton for example could then be used to replace the locally-grown cotton (as well as rice) with crops that are less water intensive, generate more income and that have higher yield. Thus, additional water is saved, and more revenue and yield are generated which results in more surplus product, bringing us back to the start of the loop described in this paragraph. Because this is a positive feedback loop, any beneficial impact is predicted to be amplified over the course of time.

Figure 12 illustrates the casual loop diagram for this additional feedback sub-model. In the first timestep, the extension uses the yield difference between the altered cropping regime (see Results - Section 4.3) and the baseline to estimate for the amount of surplus exported, the amount of crop imported to reduce local water use, and the subsequent implications for changes to total crop water requirements, yield and revenue based on assumed further changes to cropping patterns. After the first timestep, the difference in yield between the cropping scenario and the feedback extension results is used to perform the calculation.

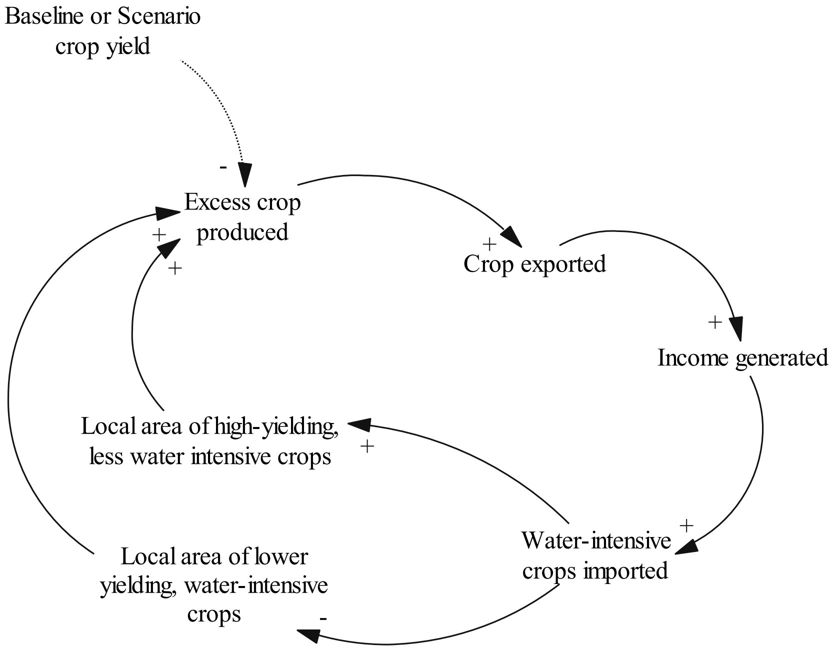


Figure 12: Causal loop diagram illustrating the logic for the feedback-extension sub-model. '+' signs indicate positive relationships (self-supporting), '-' signs indicate negative (self-stabilising) relationships. Dashed lines indicate that the parameter is influenced by the values from a different sub-model.

With respect to further alterations in cropping pattern, it is assumed that as water-intensive crops are imported, a certain area is converted from more- to less-water intensive crops (here, imported mass is expressed as an area-equivalent through a conversion factor). The areas devoted to rice and cotton are decreased by the imported area-equivalent to a minimum of zero, while cash crops with a high yield and lower water requirements (summer and winter vegetables and wheat) are increased by the converted area-equivalent to a maximum of 1.5 times their currently planted area. Updated values for yield, crop water requirement and revenue are calculated based on the new cropped areas.

In addition to the SDM, a WSM DSS representing the Rosetta water system has been developed (Figure 13).

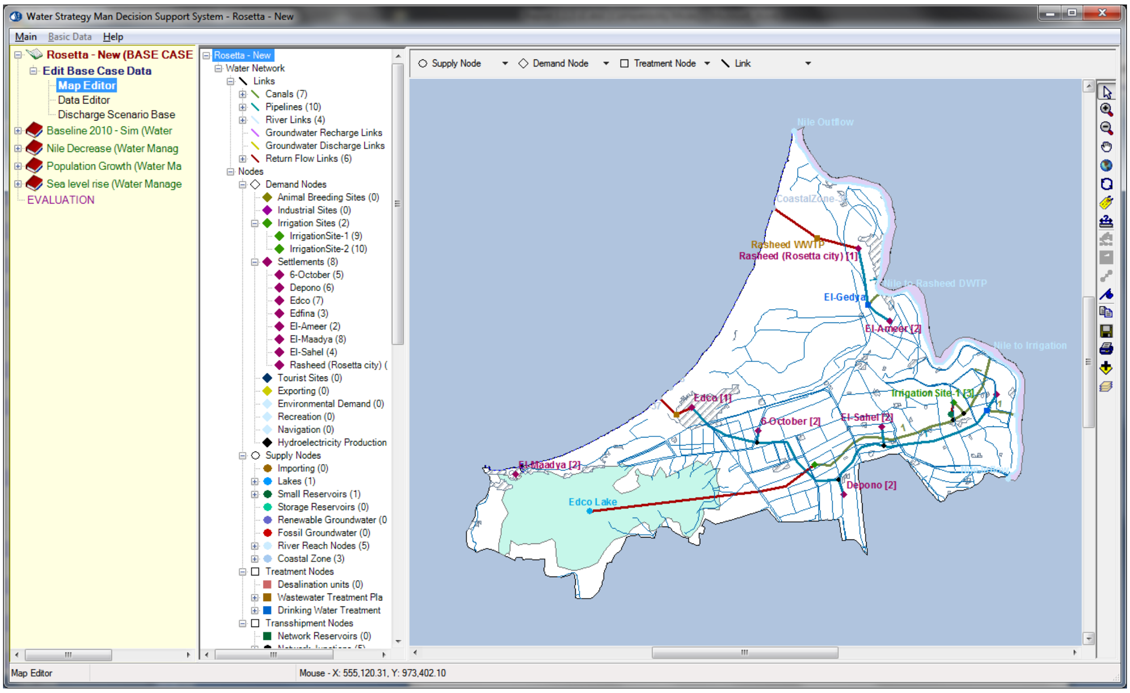


Figure 13: The baseline representation of the Rosetta water system, using the WSM DSS

The model distinguishes between different water uses (urban vs. irrigation) and different water supply sources in irrigation water supply (freshwater vs. drainage water). It has been developed using data provided by ECRI and includes:

- All major urban water uses in the area, which are modelled as 8 settlements/urban agglomerations. Of those:
    - El Rashid (Rosetta) and Edco cities have the highest priority in terms of water supply;
    - The remaining 6 settlements (6-October, Depono, Edfina, El Ameer, El Maadya, El Sahel) have a lowest priority (equal to 2).

  All settlements receive freshwater from the Nile, treated in the local drinking water treatment plants. Wastewater from Rosetta and Edco cities is treated in the corresponding wastewater treatment plants and discharged to the sea and the Edco lake respectively, whereas wastewater from the remaining agglomerations is discharged to irrigation/drainage canals.

- Water use for crop irrigation is divided in two demand nodes, according to the water supply source, with priorities lower than urban water supply. The first node corresponds to freshwater use, directly from the Nile canal system. The second node receives also drainage (return flows from irrigation with freshwater) as the primary water supply source, and deficits are complemented with freshwater supply from the Nile. Drainage ends up in Edco lake.

- The Nile section of the Rosetta area is modelled through a set of river reach nodes, of which the first receives as run-off the share of Nile water that enters the area.

In addition to the baseline representation of the system, the following scenarios have been built for further development and validation:

- A scenario for the decrease of Nile inflows to the area. As the water system of Egypt is highly centralized, the inflow to the upper river reach of the Nile segment pertaining to Rosetta will depend on future, national, water allocation policies, which will be influenced by: (a) population growth and land reclamation schemes upstream, (b) potential changes in the Nile quota allocated to Egypt, as a result of transboundary agreements between riparian countries, and (c) climate change affecting run-off and inflows to the High Aswan Dam.
- A scenario on population growth. Due to the increasing salinity of soils, further agricultural development seems unlikely. Nevertheless, there are plans for urban expansion along the Mediterranean coast.
- A scenario on land loss, due to sea level rise, particularly affecting the maximum cultivable area.

3.4 Water balance model for the lower Jordan River Basin

As with the previous models, this was developed closely with Jordanian partners NCARE. The model consists of a water source sub-model, a demand sub-model accounting for demand from 7 sources and three separate sub-models that account for the agricultural crop water demands from three regions. The focus of this study is to study the cumulative water balance of the King Abdullah Canal - a key water stock in the region.

Starting with the water source sub-model, 11 water sources are accounted for. These are: Tiberia Lake, the Yarmouk River, Mukiehbeh Wells, Wadi Arab dam, side-wadis (ephemeral, narrow, steep-sided channels), Wadi Sheib dam, Kafrein dam, King Talal dam, Shrhabiel dam, the Shuneh groundwater source and 'new' dams. For all of these sources, data were provided at an annual resolution only. Therefore, all the annual values were divided by 12 to obtain average monthly supply values. Finer resolution supply data (e.g. at monthly scale) would have been preferable, but were not available. The sources are assumed constant over time. Figure 14 shows the SDM representation of the supply sub-model.

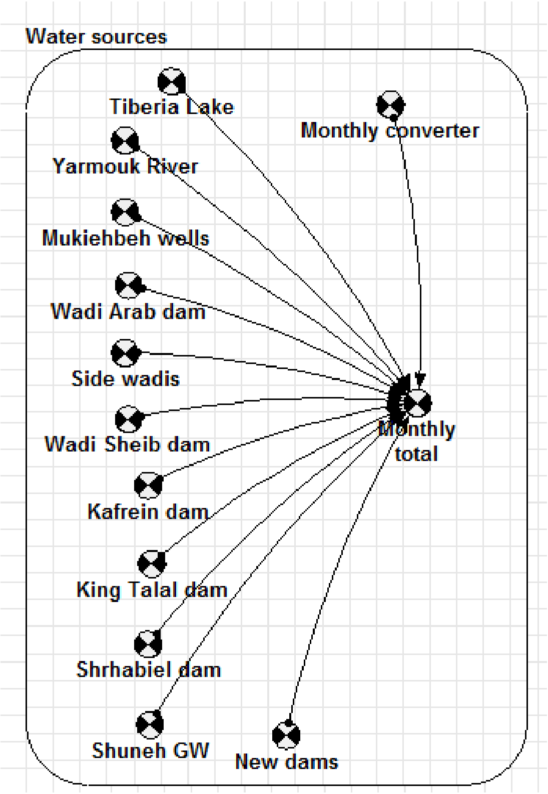


Figure 14: SDM representation of the Jordan water supply sub-model.

For the demand sub-model that does not account for agricultural demand, seven water demands are accounted for. There are Jordan Valley drinking water demand, industrial water demand, irrigation from groundwater sources, side wadi water rights (for villages, farming communities, etc.), drinking water demand for the city of Amman, the pumping of water to Wadi Arab dam and losses such as due to leakage and evaporation. As with the supply data, the demand data were only available at annual resolution, and so all values were divided by 12 to give average monthly values for demand. Also, all these demands are assumed constant over time as no better data were available.

For agricultural water demand, the demand from three regions was aggregated: Karameh, Dier Alla and Sharbabeel. These three regional agricultural sub-models were also used to alter cropping patterns into the future according to comprehensive data provided by NCARE. It is in these regional cropping sub-models that the power of SDM as a scenario modelling tool was captured and fully exploited. The structure of each region is the same. For each, three crop types are accounted for - tree crops, other crops and vegetables. In tree crops, citrus, banana, palms and other are modelled. In other crops, field crops and protected crops (those grown under cover) are accounted for. Finally, in vegetables, tomatoes, eggplants, squash, potato, peppers, onions, cabbage, cucumber, beans, lettuce and other vegetables are accounted for. For each crop, the specific water requirement per unit area, and the area over which it is planted in each of the three regions was provided by NCARE, thus, the total crop water requirement for each area, and the CWR per crop and per crop type could be calculated by taking the product of area and CWR per unit area. Figure 15 illustrates the model structure for one of the three regions, though it is noted that all three have the same structure.

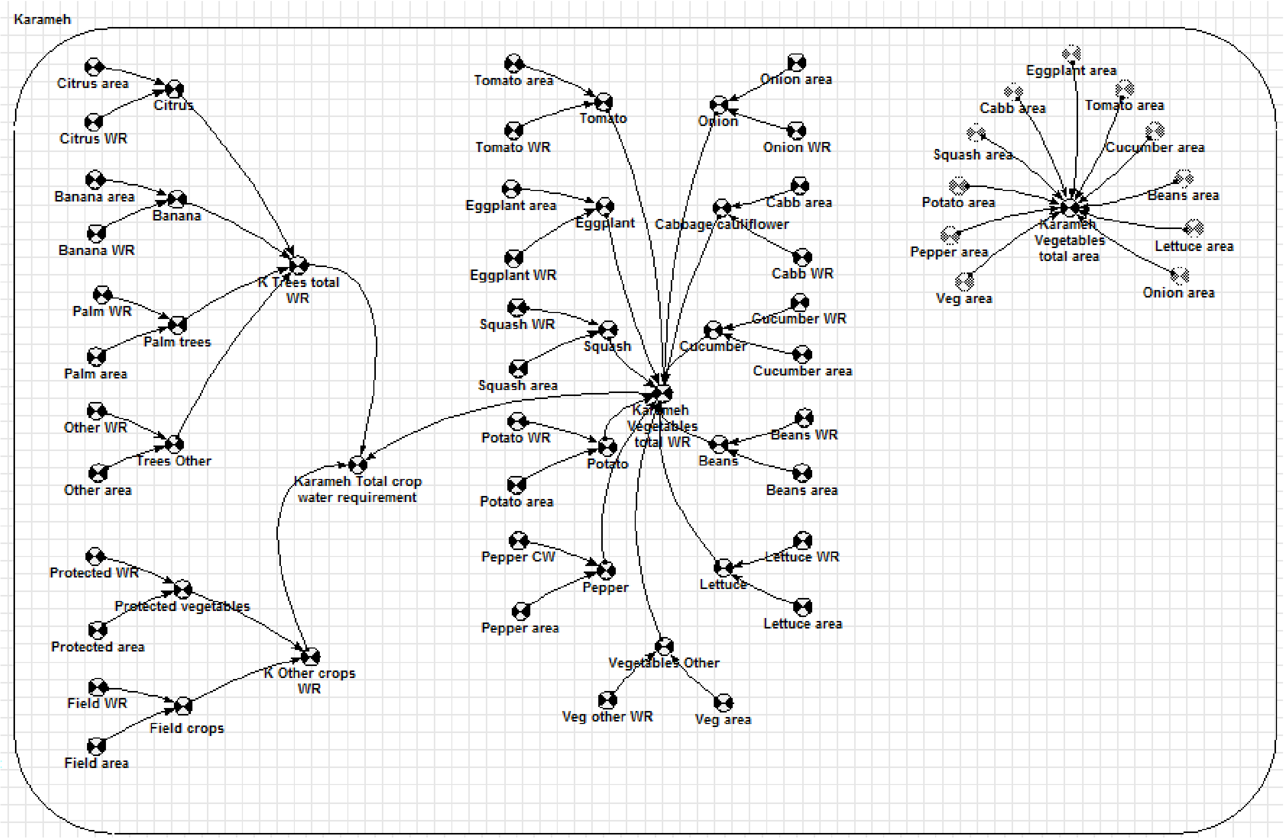


Figure 15: Structure of the agricultural water demand SDM sub-model for the Jordan case study.

In addition to calculating the present day crop water demand, another sub-model has been developed that calculates crop water demand into the future based on alterations to the cropping patterns in the region. This additional sub-model allows for changes in cropped areas to be implemented over time. For example, vegetables may be decreased by 1% per year to a maximum decrease of 10% relative to today, or the tree crops may be increased by 5% per year to a maximum increase of 25% relative to today. In doing this, policy makers can test many what-if scenarios quickly in order to identify those alterations to the cropping pattern that will have the best outcome for the regional water resources. Future improvements to the model could include allowing changes to the supply and domestic and industrial demands to be made to give a more realistic future outlook regarding the water resource.

3.5 Water balance model for Syros

Unlike the three previous water balance models, the model to Syros was constructed using the WaterStratgeyMan decision Support System (WSM DSS), and was developed by NTUA, Greece. The description of the model presented her can also be found in Deliverable 5.2.3.

Water balance modelling for Syros Island, Greece was developed by the NTUA, using the WaterStrategyMan Decision Support System. Following from the workshop on “Water-related security threats, climate change and adaptation options for Syros Island, Greece" (Hermoupolis, Syros, 17-18 June 2011) and a working meeting with local stakeholders, the initial model, described in Deliverable 5.2.2 "Report on modelling tools and techniques to be applied to each case study for water balancing", was substantially revised to allow a more accurate representation of the Syros water system.

The final schematization of the Syros water system in the WSM DSS is presented in Figure 16.

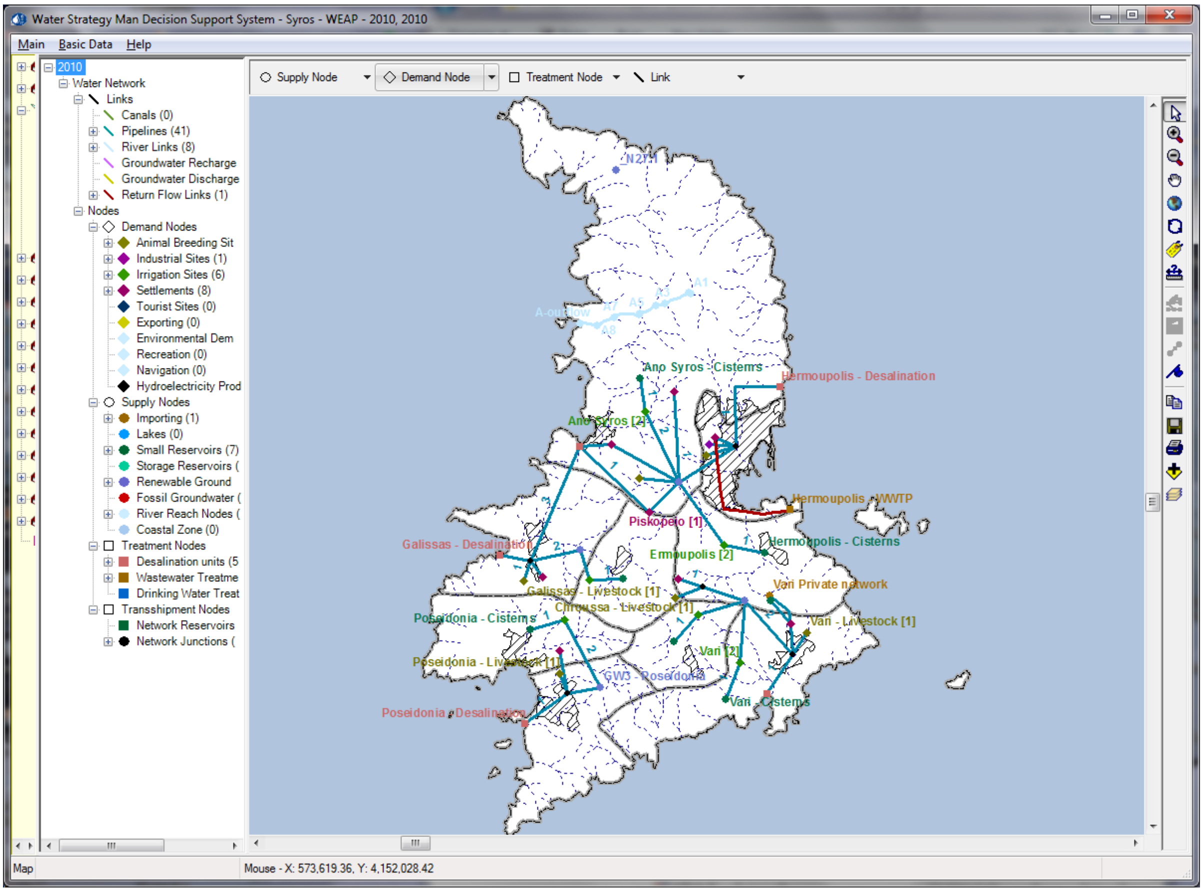


Figure 16: The schematization of the Syros water system in the WSM DSS

The main water supply sources in this system comprise desalination and groundwater, whereas the main water uses concern domestic (urban) water demands and crop irrigation. Other (minor) demands that have been included in the model concern animal husbandry (livestock breeding) and industrial activities in the city of Hermoupolis. Five desalination nodes aggregate the existing installed capacity. These are the first priority water supply source for domestic water supply in coastal agglomerations and in the city of Hermoupolis. Four main hydro-geological units are also modelled, from where groundwater is used to meet crop irrigation requirements and is a supplementary source for domestic water supply. In general, domestic water demands, livestock breeding and industrial water use have a higher priority than crop irrigation.

In total, four sub-systems can be discerned, according to the main hydro-geological units of the island:

- The first subsystem corresponds to the hydro-geological unit of Ano-Syros-Hermoupolis. Groundwater from this system is extracted to meet crop irrigation demands in the former municipalities of Hermoupolis (Manna area) and Ano Syros[i], and domestic water demands in the agglomeration of Ano Syros and Piskopeio. The main water supply source for the city of Hermoupolis and the agglomeration of Kini is desalination (capacity of 4,700 and 750 m^3/d respectively), with the latter unit also supplying 30% of domestic water requirements in the agglomeration of Piskopeio, and a small share of domestic demands in the agglomeration of Galissas. Groundwater can also used as a supplementary resource for domestic water supply in Hermoupolis and Kini.

- The second sub-system corresponds to the hydro-geological unit of Galissas (south-eastern part of the island). Groundwater is used for crop irrigation in the wider area of Galissas and Pagos, and as a supplementary resource for domestic water supply in the agglomeration of Galissas.

- The third sub-system corresponds to the hydro-geological unit of Poseidonia-Foinikas and also includes the corresponding desalination unit of Poseidonia (main domestic water supply source). Groundwater is mainly abstracted to meet crop irrigation requirements.

- The fourth sub-system concerns the hydro-geological unit of Vari. In addition to crop irrigation, groundwater is the main water supply source for the inland agglomeration of Chroussa; desalination is the main water supply source for the coastal agglomerations of Vari and Megas Gialos.

In addition to the above, cisterns are also used as a supplementary water supply source for crop irrigation, accounting for about 15% of irrigation water supply. To account for the practice of rainwater harvesting in irrigated agriculture, cisterns have been modelled as small surface storage reservoirs of an adequate (aggregate) capacity to meet the corresponding share of water demands. Data used for the baseline representation of the system are presented in Table 1.

Table 1: Type of data and data sources for the Syros water balance model

Type of node	Type of data	Source of information & Assumptions
Domestic water requirements (agglomerations)	Actual Permanent Population	Data from the population census of 2001 and 2011 (intermediate results) Source: Hellenic Statistical Authority

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[i] Before the 2010 administrative reform, the island of Syros was divided in three municipalities (Hermoupolis, Ano Syros and Poseidonia). After this reform, the entire island constitutes a single municipality.

Type of node	Type of data	Source of information & Assumptions
	Overnight stays	Estimates, based on room occupancy and number of beds Data Sources: Hellenic Statistical Authority and "CYCLADES" Tourist Apartments Federation
	Per capita consumption	Data from the Hellenic Ministry of Development, 2008
	Physical water losses	Information by the Municipal Enterprise of Water Supply and Sewerage of Hermoupolis/Syros
	Income from tourism	Data from the Association of Greek Tourism Enterprises
Crop Irrigation	Cropping pattern	Data from the Hellenic Statistical Authority (2007 Agricultural Census)
	Irrigation efficiency	Data from the Hellenic Ministry of Development, 2008
	Unit economic output and cultivation costs	Data from the Hellenic Ministry of Development, 2008
Livestock Breeding	Number of animals	Data from the Hellenic Statistical Authority (2007 Agricultural Census)
Desalination	Capacity	Information by the Municipal Enterprise of Water Supply and Sewerage of Hermoupolis/Syros
Groundwater	Capacity	Data from the Water Management Study for the Cyclades Complex, Prefecture of Cyclades, 2001
	Natural Recharge	Estimates based on groundwater model, adapted from Kumar, 2002 and Kumar, 2004, and information by the Water Directorate of the Region of South Aegean
Cisterns for crop irrigation	Capacity	Estimates, based on information on current demand coverage by Local Farmer Associations
	Volume of rainwater harvested	Estimates, based on information on current demand coverage by Local Farmer Associations and precipitation pattern

3.6 Water balance model for Sardinia

Sardinia is the final WASSERMed case study. This model was developed largely by the Sardinian stakeholders, but with some outside assistance from UNEXE, especially with respect to model structure and data processing capabilities.

The Sardinia model has been developed by CMCC and a local stakeholder (ENAS), who provided key data and assisted in model development and calibration. The model was built to represent six different aquifers with different water inflows and demands. However, three of these aquifers are interconnected and were grouped together to form the “scheme 3C”. The model is organized in four submodels accounting for the inflows and water demands of each reservoir.

The water budget is simulated on a monthly basis and its components are discussed in the below sections.

3.6.1 Inflows and evaporation

The basin surface contributing to each aquifer was calculated using the FlowAccumulation tool (ESRI), which also defines the cumulated streamflow (i.e. inflow to the reservoir) from the catchment area upstream of the dam.

The total inflow to the reservoir is calculated as precipitation over the upstream catchment area times the annual average runoff coefficient.

The runoff coefficients, specific for each aquifer, were provided by ENAS.

Evaporation (mm per month) from the reservoir water bodies is calculated using a version of the Penman-Monteith approach for open water (Jensen, 2010) and multiplied by the surface of the reservoir. The surface of the reservoirs a function of the water volume, and each surface-volume relationship is reservoir specific and derived from measured data.

Monthly mean climatic data predicted for the period between 1980 and 2050 were downscaled from GCM and corrected by climate synopsis based on climate stations placed on each dam using a dataset from 1980 to 2010.

Monthly total precipitations and evaporation from the GCM for the periods 2008-2010 and 2048-2050 are used as input. The runoff coefficient is assumed to remain constant over time.

3.6.2 Water outflows

ENAS, the local water authority, is in charge of the reservoirs management and therefore it keeps monthly records of the volume distributed to each sector. Water for domestic use is delivered to ABBANOA which purifies the water and distributes it to households. Water for irrigation is delivered to each of the seven “Consorzi di Bonifica”, which are responsible for its distribution to farmers. The industry instead, has a direct access to the water and it is charged based on consumption. ENAS also monitors the water level in the reservoir to i) keep the dam within the legal security levels (some of the dams have not being tested for their full potential) and ii) to deliver enough water to sustain the downstream ecosystems.

Each SD model for each sector takes into consideration the water demands of each sector based on the ENAS data. Each reservoir supply one or more sectors; Pedra e’ Othoni reservoir for example has hydropower demand. ENAS water management policy is included in the model and is used to limit the water supply for each sector based on Marchs’ stored water volume.

Domestic use was calibrated to match the size of the population served by the reservoir as well as the tourist flows. The number of tourists visiting the island is registered and divided by the four major regions of the Island. However to estimate the number of tourists served by reservoir, the number of beds in the accommodation structures was used as proxy indicator. The daily water consumption per capita was estimated to 600 liters, a slight higher than the normal 400 liter average. The extra 200 liters were used to account for the water losses in the water distribution networks.

The future projections of the domestic use will be based on the Touristic Climate Index (TCI) which accounts of population growth and change in the touristic flows. Note that population growth rate is low in Sardinia (1.04 per year) and that TCI suggest an overall increase in the number of tourists and the length of the tourist season to cover both spring and autumn.

Irrigation water demand was estimated using SIMETAW. The model was used to calculate the water requirement of the cropping area served by each reservoir. The major crops grown on the Island are Olive trees, vineyards and a mix of horticultural crops. The application efficiency of the on-farm irrigation system was also taken into consideration.

The future crop water demand (2050’s) was calculated under the assumption that current cropping pattern will remain unchanged. On average, the future irrigation needs is predicted to slightly decrease in the future regardless the warming. As a matter of fact, the increase in the future atmospheric CO2 concentration is projected to improve the water use efficiency of the plant (process better known as CO2 fertilization). The change in the industrial and Hydropower demand were not assessed in this study and hence were estimated to remain the same as present. Future scenarios assume that the structure of all dams were tested and found suitable to work at full storage capacity. Water discharges were reduced for eventual overflows that can occur both in the 2008-2010 and the 2048-2050 periods.

The developed water balance model is shown in Figure 17.

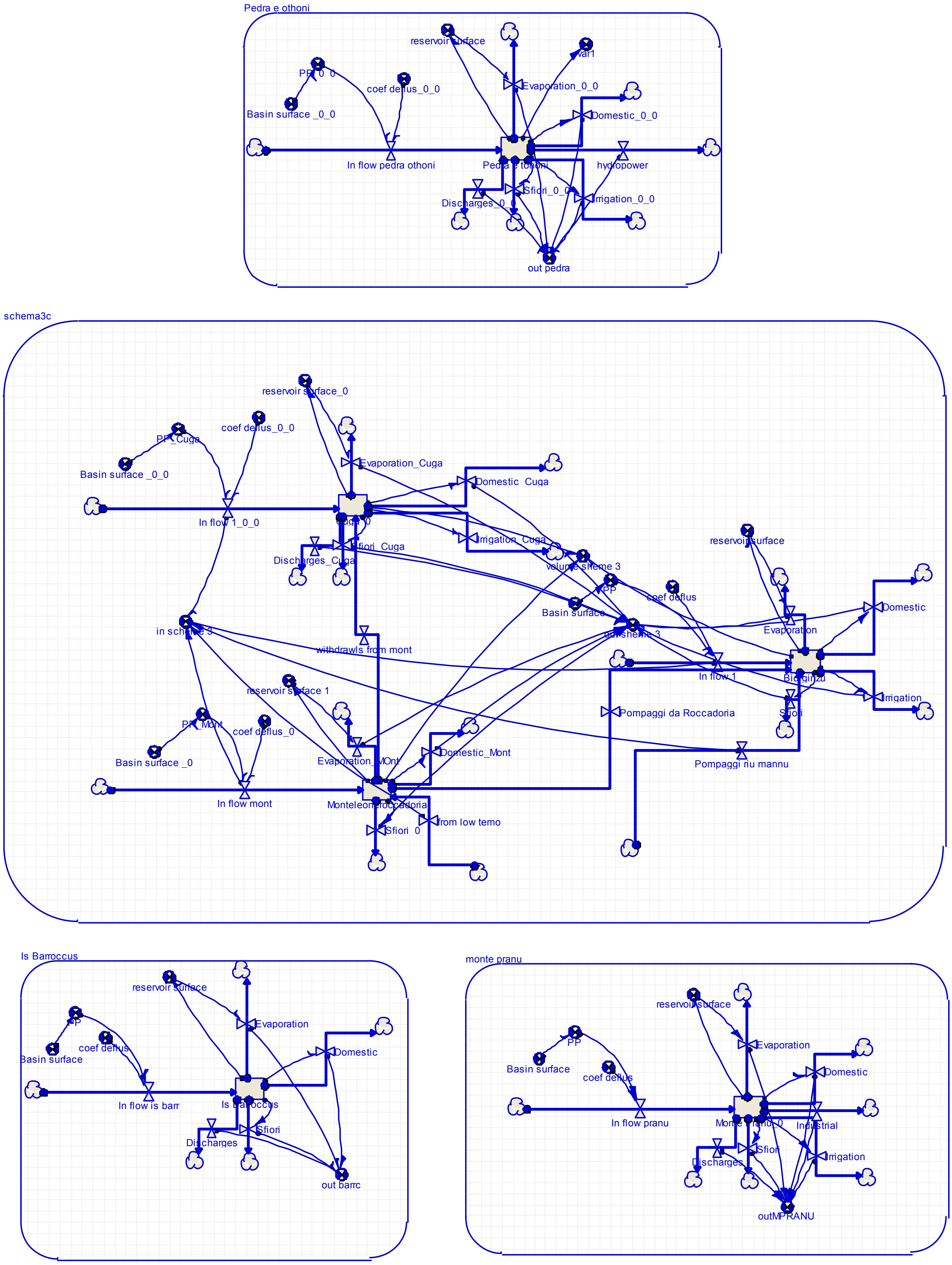


Figure 17: The developed SDM for the Sardinia case study.

Additional information on the approaches used to evaluate possible water security issues for the whole island

An SDM for the whole island proved to be a highly complicated task for two main reasons: 1) The high interconnectivity of the reservoirs and the multiple sources of water for the same end user with no standardized management protocol; 2) Data for agricultural land use, irrigation, and domestic water use are often lacking. The two points together yield a high uncertainty on the simulations. However, total irrigation needs for the island and simulations of the domestic demands were calculated for the whole island following a different approach in order to highlight possible water shortages in the future.

The volumetric irrigation need of Sardigna Region has been estimated using a one dimensional soil water balance model. Using map windows components, the GIS based software integrates monthly gridded climate data with soil and land cover maps. The soil system is divided into two connected subsystems. The upper subsystem represents the water dynamics in the root zone while the lower subsystem represents the natural groundwater recharge (Figure 18). Since the aim of this work is to estimate the crop water needs, the lower soil subsystem has been neglected. The change in soil water content (δw) at end of each month *I* can be summarized with the following equation:

$$\delta w_i = P_i - ET_{C\,i} - RO_i + I_i$$

where:

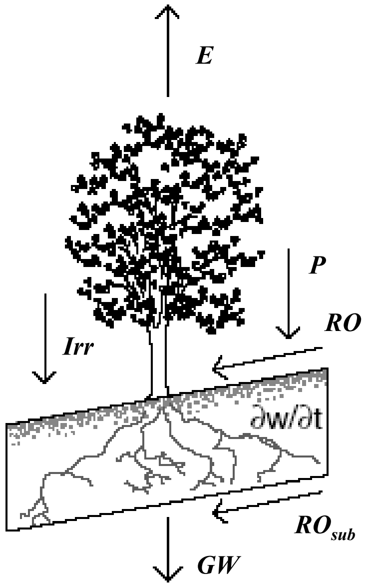
P_i: Precipitation in month *i* (mm);

ET_c: Crop evapotranspiration (mm);

RO: surface runoff (mm);

I: Irrigation applied in month *i* (mm).

Figure 18: Schematic representation of the water balance



The effective rainfall (P_{eff}) for month *i*, represents the proportion of the rainfall that is potentially available for crop. The empirical formula of the USDA– Soil Conservation Service (1967) has been used to separate the monthly rainfall ($P_{(i)}$) into effective rainfall ($Peff_{(i)}$) and surface runoff ($RO_{(i)}$) as following:

$$Peff_{(i)} = \left(\frac{P_{(i)}}{125}\right) * (125 - 0.2P_{(i)}) \quad \text{for} \quad P_{(i)} < 250 \text{ mm}$$

$$Peff_{(i)} = 125 + 0.1P_{(i)} \quad \text{for} \quad P_{(i)} > 250 \text{ mm}$$

Crop evapotranspiration (ET_c) is defined as the water flux to the atmosphere through soil evaporation and plant transpiration. The crop coefficient (K_c) method described by Allen et al. (1998) has been used to calculate crop evapotranspiration (ET_c) by adjusting the reference evapotranspiration (ET_o) as following:

$$ET_c = K_c * ET_0$$

K_c depends mainly on the crop type, variety and it also changes with the plant growth stages. The coefficient factors assume that plants are under optimal nutrient and water conditions. This does not necessarily reflect the actual farming practices where plants can deliberately (i.e. for quality reasons) or unintentionally (i.e. bad irrigation management) subjected to water stress.

The CORINE land cover maps (European Environment Agency 2000) and the FAO global soil datasets were used to identify the spatial distribution of the agricultural lands and their soil characteristics. Within CORINE, each land cover units *j* (i.e. vegetable/ fruit trees….) encloses a series of individual crops *i* (tomato, potato, lettuce… / apple, peach…) that can have different growing season, cropped area and water requirement.

To overcome this limitation and for better calculation accuracy, the grown area for each crop at Province level was obtained from the national agricultural census (ISTAT, 2010). Accordingly, a weighted average was used to generate a crop coefficient (Kc_j) and a root depth (PR_j) for each land cover unit *j* as following:

$$\overline{Kc_j} = \frac{\sum_{i=1}^{N} Kc_i * A_i}{\sum A_i} \tag{1}$$

$$\overline{PR_j} = \frac{\sum_{i=1}^{N} PR_i * A_i}{\sum A_i} \tag{2}$$

where:

$\mathrm{PR_i}$: root depth of crop i within the land cover unit *j* (m);

Kc_i : crop coefficient (Allen et al. 1998) of crop *i* within land cover unit *j*;

N: number of different crops *i* within the land cover unit *j*;

A_i : Surface area occupied by each crop *i* within the correspondent Province (ha).

The water balance model starts in January assuming the soil is at maximum field capacity. By iterating to the consecutive months, the total volumetric need for each land cover unit will be estimated. In this work, the total volumetric irrigation need has been calculated for the baseline (1961-1990), 2005 to 2010 and for the future 2045 to 2050 period.

Four different strategies were used to evaluate the viability of future policies for irrigation expansion: Business-As-Usual (BAU) where irrigated areas are unchanged; or a 20% expansion of irrigated areas (15,000 ha) for dominant irrigated crops (IWS) or for selected water efficient crops (ISC) over the entire island, or for dominant irrigated crops just in the central plains (ICP).

Meanwhile tourist presences for 2048-2050 were simulated according to four development scenarios.

Both in terms of overall destination attractiveness and changes in seasonal flows composition, climate change effects on regional tourism patterns represent an indication for the development potential of Sardinian sector. To this end, future changes in arrivals and overnight stays have been estimated assuming that tourist preferences and regional relative attractiveness (relating to different investments in tourist facilities) will not change over time.

However, in the light of multiple forces which nowadays drive and rapidly change the international and national tourism market, long-term tourism demand forecasting under specific socio-economic conditions could result unreliable if projected on an excessively wide timeframe, even if developed through qualitative methods[ii].

In fact, although it could be provided for many years ahead in line with climate knowledge environment (in this case 40 years), under a market-driven approach and due to the large number of factors involved in macro and micro related environments (world economy, fuel prices, political stability, natural disasters, air and sea transports public and private companies policies, tourist infrastructures, tourist accommodations prices, etc.), long-term forecasts tend to present relevant confidence limits, in antithesis with stakeholders' expectation to rely on accurate and reliable predictions in order to adjust their respective operational strategies. Thus it might result a theoretical exercise if we don't consider policy needs coming from

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[ii] Related research distinguishes three different time horizons in tourism forecasting (Dwyer et alii, 2010), among others the long range over 5 years for tourism planning and policy development purposes.

current competitive arena and orienting strategic planning and sustainable tourism development.

Recent literature outlines the role of tourism activities in regional economic growth, developing with better performances than other sectors. However, it has not still properly defined in which extent tourism growth represents a sustainable process in the long-term. In a more or less intensive way, tourism production and consumption patterns exploit social, natural and structural destinations' resources, producing positive impacts on local societies but also various negative pressures which can compromise present and future functionalities. Individuals face alternative combinations of attributes describing a specific choice object (holidays for tourists and quality of life for residents) and modeling alternative tourism development scenarios, among which comes the need to design and manage development processes, flexible and detached from choices too restrictive in terms of reversibility (Biagi e Pulina, 2007; Usai e Vannini, 2007).

On this basis, the analysis addresses the need of defining alternative regional scenarios to an adaptive logical scheme, i.e. in terms of which strategies regional public sector should adopt and what related possible outcomes would be in comparison with tourism-related impacts by climate change in Sardinia. To this aim, predicted values for overnight stays under climate change conditions (and related implications in terms of water consumption) will be assumed as a target "dimension", to be reached through modulation of tourism supply and demand side figures into different combinations, in order to select the most suitable one.

In this context, analysis will focus, on quantitative and qualitative basis, some of the most relevant factors influencing tourism supply chain in terms of infrastructures (primarily accommodation and distribution channels) and governmental role at a destination level (governance and marketing functions), and will also project potentials related to tourism market segments on the demand side, from which drawing suitable flows for the destination.

On this basis, four development scenarios are designed through the description, under different conditions, of alternative profiles assumed by single components selected:

1. "Business As Usual (BAU) Scenario". A laissez faire or do-nothing approach has been evaluated, moving from basic values for 2010 up to 2050 through the addition of the average value of annual absolute variations calculated for the reference period 2007-2010.

2. “Intensive Tourism Growth (ITG) Scenario”. In order to identify a reliable growth path but also to minimize the increasing spread among supply and demand growth rates (with particular respect to the hotel sector), 2005-2010 has been selected as a suitable reference period in order to represent a local-based scenario by adding the average value of annual absolute variations observed over time.
3. “Strictly Controlled Sustainable Tourism (SCST) Scenario”, where tourism development for heritage purposes (natural and cultural resources-based products) is the sole focus in the whole regional context. To this aim an unchanged accomodation capacity has been assumed until 2050, reflecting current values and relative distribution levels. On the contrary, overnight stays are predicted to change in order to reach present average gross occupancy rates and to reproduce relative flows patterns in terms of nationality already observed in 2010 in the National context for that kind of destinations (namely cultural, hill and mountain locations) (ISTAT, various years).
4. “Balanced Competitive and Sustainable Growth (BCSG) Scenario”, inspired to stimulate a progressive diversification approach for tourism facilities, attractions and products in order to attract and develop multiple targets and segments (aged people, accessible, family tourism) over the year. To this end a drastically reduction in average annual growth rates has been supposed on the supply side (about one third of average values for the period 2007-2010 both for hotels and other establishments), jointly to low-scale dimension (under 25 rooms per unit) and up-level standards (4-5 stars) for new hotel developments. The latter will mostly involve the regional coastline, on the contrary other collective units will continue to find a privileged location mainly in internal districts. On the demand side, overnight stays are predicted to change in order to reach present average gross occupancy rates observed in the Italian context for maritime destinations on one side, and cultural, hill and mountain destinations on the other, respectively for coastal and internal Sardinian locations (ISTAT, various years).

Among others, all scenarios have been described on the basis of most common indicators used in literature for structural analysis, and they have been also defined in the light of most probably demographic trends for Sardinia, designed by the National Institute of Statistics through the so called “Central Scenario” (ISTAT, 2011), assuming proportional variations in coastal and internal districts.

By representing hypothetical situations and related values for selected variables, outcomes can thus be compared in order to evaluate which scenario fits better with climate predictions. Scenarios are developed to focus on some key differences resulting from alternative choices, thus they also incorporate choices or indications already shared by local stakeholders and defined into regional policies, plans and programmes.

4. Synthesis of results for the Case Studies

4.1 Introduction

WASSERMed deliverable 5.2.3 - 'Report on water balance modelling for all case studies' presented the latest versions of the water balance model results for all the case studies. Since then, and as a result in changes to model structures and philosophies, some of the results have changed since this report. This section presents the most up-to-date water-balance results for all the WASSERMed case studies.

4.2 Water balance modelling results for Kairouan

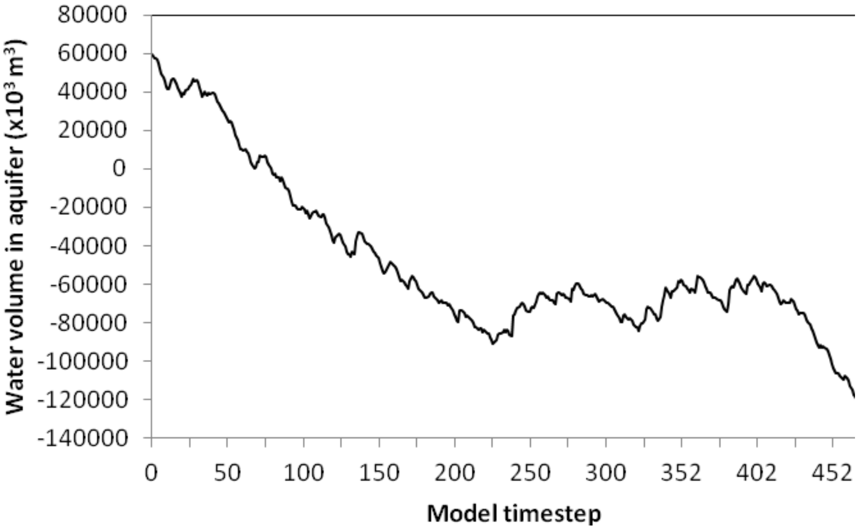
The results for the Tunisia case study have changed significantly since Deliverable 5.2.3 in response to the further development of the water balance model. These results have been extensively reported and analysed in Sušnik et al. (2012). The results presented here are based on the results in Sušnik et al. (2012), but the reader is referred to that paper for further details.

The SDM was run continuously using a temporal resolution of one month for 480 timesteps (i.e. 40 years), taking the model from 2010 to 2050. The aim is to reproduce credible behaviour characteristics that pertain to the aquifer water volume. Previous studies of water table levels (e.g. Leduc et al, 2007), which can tentatively be used as a proxy for determining general aquifer volume behaviour, are used to verify that the model behaviour is generally sensible. It is noted that model behaviour patterns are more important than absolute numbers. The aim is to show which, if any, alterations to the baseline parameters may lead to favourable aquifer behaviour in the future (i.e. potential water volume recovery, and an end to over-exploitation). Such results may be used as a guide by policy makers to make their efforts more directed towards those options that will likely have the greatest impact in preserving the water resource.

4.2.1 Baseline run

Figure 19 shows the results. The aquifer is being over-exploited, with aquifer supply being lower than demand through most of the run, with intermittent periods of increased supply due to climate (rainfall) variability. The rate of over-exploitation is c. 10×10^6 m^3 yr^{-1}, which is lower than the 17.4×10^6 m^3 yr^{-1} estimated by Luc (2005) based on rudimentary mass balance calculations. The overall pattern is one of aquifer stored volume decline, which closely mimics observed water table patterns since the 1960's (Le Goulven et al., 2009), other model simulations of the depth to the Kairouan aquifer water table (Feuillette et al., 2003) and more recent field observations (Leduc et al., 2007). Based on the baseline run, and assuming that current social and policy behaviour continues, the model shows that the aquifer undergoes significant depletion (becoming virtually 'empty' in seven years). It is predicted that industrial and agricultural revenue will both increase, whereas revenue from domestic water use will decrease. Revenue increases are mainly due to increasing tariff, which in the case of agriculture offsets the predicted decline in demand. For revenue from domestic water use, the decrease is due to the demand falling over time as a result of the impacts of the savings from improving infrastructure (i.e. reduced water losses) and from public water saving measures. Negative simulation values signify "deficits" in the stocks (the storage computational elements in System Dynamics). In reality this means that there is not enough water to fulfil the required demands, that there is no viable supply. If this situation occurred in reality, abstraction would be significantly curtailed and restricted, and the energy costs would increase dramatically.

(a)



(b)

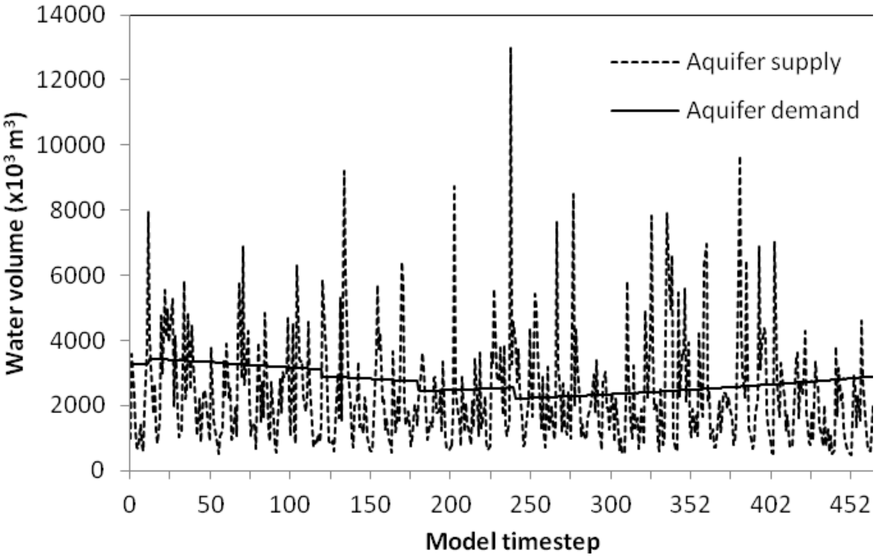


Figure 19: (a) Showing the simulated stored water behaviour in the Kairouan aquifer under baseline conditions; (b) showing the volumes of water input to and abstracted from the aquifer during the standard run.

4.2.2 Sensitivity analysis

During these tests, only the value under investigation was changed in order to observe the impact on model response. All other values were as in the standard run. Table 2 details all the simulations that were carried out for the scenario testing. Although mostly hypothetical, it is noted that at present, Tunisia has active policy procedures aimed at reducing water demand in various sectors through a combination of public awareness campaigns, tariff structures, increasing regulation and investment in more efficient irrigation technologies.

These tests aim to identify which parameters have the greatest impact on aquifer behaviour and therefore may act as a future guide or focus for policy decisions. It is noted that the behaviour, once the water volumes become 'negative' in the model, is indicative only, and should be seen as an indication/trends of collateral problems (e.g. occurrence of 'hypersalinity', environmental degradation, severe water scarcity).

Table 2: Sensitivity tests summary

Test number	Tested parameter	Relevant sector	Baseline value	Value tested	General result - water volume trend
1.	Per-capita demand	Domestic demand	2.28 m^3 $month^{-1}$	Baseline x 0.5	Declining
2.	Per-capita demand	Domestic demand	2.28 m^3 $month^{-1}$	Baseline x 2	Declining
3.	Population increase rate	Domestic demand	0.00083	Baseline x 0.5	Declining
4.	Population increase rate	Domestic demand	0.00083	Baseline x 2	Declining
5.	Annual domestic demand increase	Domestic demand	0.0004583	Baseline x 0.5	Declining
6.	Annual domestic demand increase	Domestic demand	0.0004583	Baseline x 2	Declining
7.	Price elasticity of demand	Domestic demand	-0.3	-1	Declining
8.	Price elasticity of demand	Domestic demand	-0.3	-1.5	Declining
9.	Fraction of revenue invested for infrastructure upgrades	Domestic demand	0.385	Baseline x 0.5	Declining
10.	Fraction of revenue invested for infrastructure	Domestic demand	0.385	Baseline x 2	Declining

	upgrades				
11.	Fraction of revenue invested for public water saving initiatives	Domestic demand	0.165	Baseline x 0.5	Declining
12.	Fraction of revenue invested for public water saving initiatives	Domestic demand	0.165	Baseline x 2	Declining
13.	Monthly demand increase	Industrial demand	0.0095416	Baseline x 0.5	Declining
14.	Monthly demand increase	Industrial demand	0.0095416	Baseline x 2	Declining
15.	Price elasticity of demand	Industrial demand	-0.3	-1	Declining
16.	Price elasticity of demand	Industrial demand	-0.3	-1.5	Declining
17.	Fraction of revenue invested to improve efficiency	Industrial demand	0.01	Baseline x 0.5	Declining
18.	Fraction of revenue invested to improve efficiency	Industrial demand	0.01	Baseline x 2	Declining
19.	Price elasticity of demand	Agricultural demand	-0.3	-1	Recharge
20.	Price elasticity of demand	Agricultural demand	-0.3	-1.5	Recharge
21.	Monthly change in demand	Agricultural demand	-0.00015	Baseline x 0.5	Declining
22.	Monthly change in demand	Agricultural demand	-0.00015	Baseline x 2	Declining
23.	Monthly global food price increase	Agricultural demand	0.009416	Baseline x 0.5	Recharge
24.	Monthly global food price increase	Agricultural demand	0.009416	Baseline x 2	Declining
25.	Tariff increase	Agricultural demand	0.0125	Baseline x 0.5	Declining
26.	Tariff increase	Agricultural demand	0.0125	Baseline x 2	Declining

27.	Proportion of revenue invested to promote efficient irrigation	Agricultural demand	0.1	Baseline x 0.5	Declining - stable
28.	Proportion of revenue invested to promote efficient irrigation	Agricultural demand	0.1	Baseline x 2	Declining - stable
29.	Potential water saving from efficient irrigation	Agricultural demand	0.2	Baseline x 0.5	Declining
30.	Potential water saving from efficient irrigation	Agricultural demand	0.2	Baseline x 2	Declining - stable
31-33.	Reduction in pumped volume over time	Coastal pumping demand	See Table 3	See Table 3 for tested values.	Tests 31 and 33 - recharge. Test 32 - declining

4.2.2.1 Domestic demand sub-model tests (Tests 1-12)

Figure 20a shows the Kairouan aquifer water volume behaviour for Tests 1-6 and Figure 20b for Tests 7-12. Domestic demand changed non-linearly in response to changes in the parameters during these tests. For example, Test 1, which halved the per-capita demand shows a gradually increasing demand pattern, while Test 2, in which the per-capita demand was doubled shows an exponentially decreasing demand profile. These changes subsequently have significant impacts on the aquifer volume profiles (Figure 20). Despite this, water in the aquifer is still projected to decrease (virtually 'emptying'), with the time at which this occurs varying from 7.5 years (Test 1) to 4.5 years (Test 2).

Changes to various domestic demand parameters have, when acting alone, relatively little impact on the simulated behaviour, with all the tests resulting in net over-exploitation and eventual 'emptying' of the aquifer. The main reason for the relatively small impact observed is that these sectors consume the least water in the Kairouan region. Despite this, given the current state of the aquifer behaviour, it would be unwise to neglect any potentially fruitful water-saving policy aimed at these sectors. In terms of policy-realistic actions, changes to water-efficiency/saving investment rates and/or campaigns to change social behaviour and promote better water use efficiency, together with more aggressive tariff increases (though this would prove less popular) could be targeted in an effort to reduce overall demand.

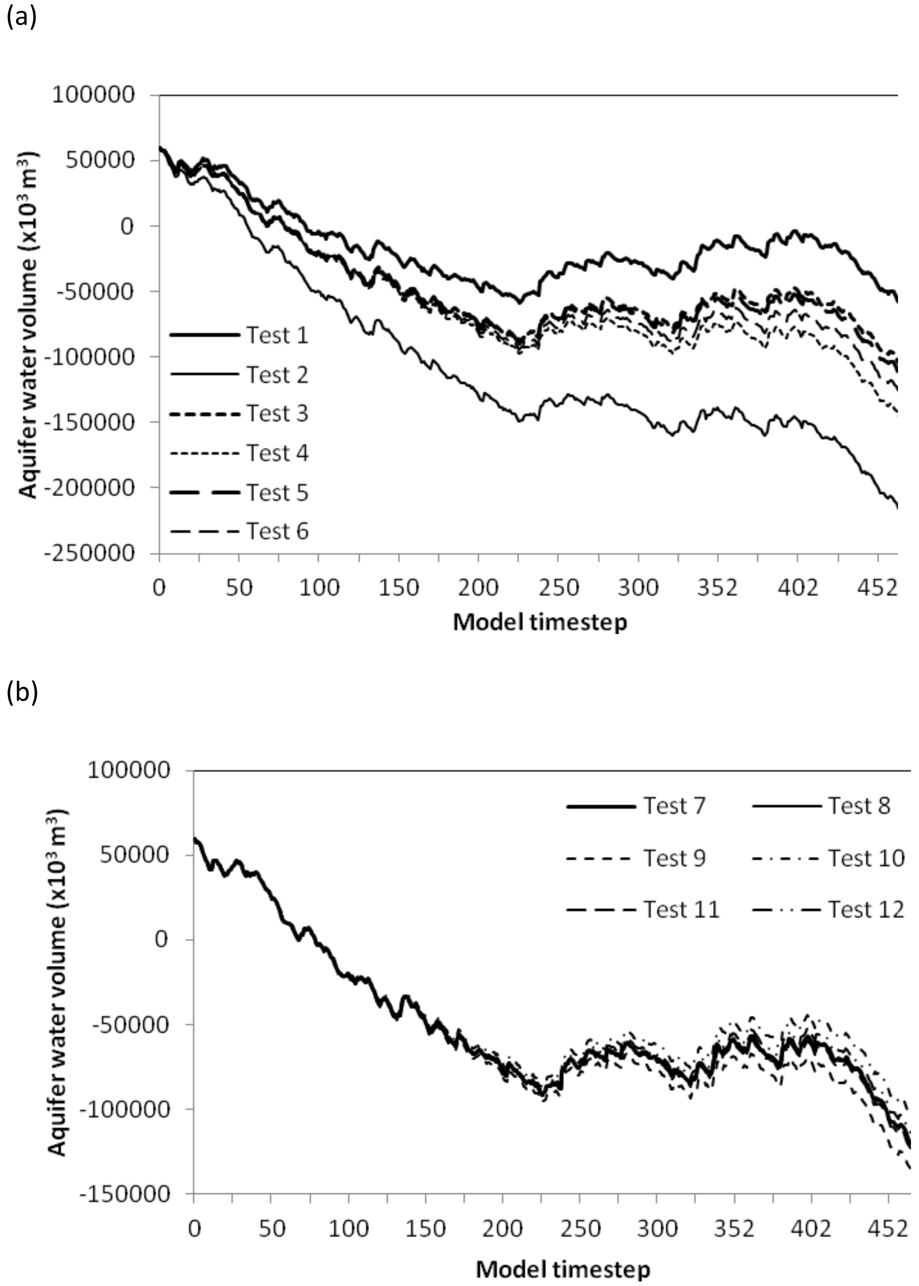


Figure 20: Results for the domestic demand series of tests (Tests 1-12) showing (a) the aquifer water pattern for Tests 1-6; (b) the aquifer water pattern for Tests 7-12.

4.2.2.2 Industrial demand sub-model tests (Tests 13-18)

As with the domestic tests, these results show highly non-linear response to changes in the model parameters, with Test 14 showing an exponential increase in demand, leading to an exponentially decreasing aquifer behaviour. It is recognised that this is inherently unrealistic, but again, it is the behaviour mode that is more important than the numerical result. In all model simulations, the aquifer becomes virtually 'empty' in about seven years.

For the industrial sector, like with the domestic sector, all tests resulted in net over-exploitation and eventual 'emptying' of the aquifer. As with the domestic sector, this is mainly due to the very small volumes of industrial demand having a negligible impact on the overall regional water budget. But again, it would not be prudent to neglect any potential water-saving policy aimed at the industrial sector.

4.2.2.3 Agricultural demand sub-model tests (Tests 19-30)

Figure 21a shows the aquifer stored water volume evolution for Tests 19-24 and Figure21b for Tests 25-30. Test 24 results in exponentially increasing demand (note logarithmic ordinate) with concomitant exponential decrease in the aquifer water volume. The kink in the demand profiles at timestep c. 186 is a result of the tariff being capped at ten times the present day value. After this has taken effect, the other feedbacks dominate the behaviour, leading to the renewed increase in demand. In these Tests, Test 19, 20 and 23 allow for aquifer recovery, and by the end of the simulation, there is a substantial quantity of stored water in Kairouan aquifer (Figure 21). Test 30 also hints at the potential for recovery. This is due to a decrease in agricultural water demand through the simulation period in response to increased demand elasticity (Tests 19 and 20) and halving of the rate of food price increases (Test 23). The time at which the simulation suggests that the aquifer will become virtually 'empty' ranges from five years (Test 24) to 15 years (Test 20), although this is only temporary, as this simulation suggests significant recharge later in the model run.

The tests conducted on the agricultural sector had more of an impact on aquifer behaviour. Agricultural water demand is by far the main local stress on the aquifer. Some tests, particularly 25-30, which relate to alterations to the tariff increase, the amount of revenue invested and the potential saving from water efficiency measures, all had relatively negligible impact, and none prevented depletion of the aquifer, although Tests 28 and 30 are more encouraging. Tests 19-24 had a greater impact on simulated behaviour. For example, Test 24 shows exponentially increasing demand as a result of doubling the average historic global food price increase. Of course, in the real world this behaviour is grossly unsustainable in the long term. Once aquifer yields begin to decline, water demand must fall (to the limit of zero if the aquifer were actually allowed to become empty, which is unlikely). However, the point here is to illustrate that such a real-world change would be an unfavourable scenario, as it could bring about a change in the Kairouan aquifer system that brings about severe water shortage much faster than expected, reducing the timeframe to initiate mitigating or adaptation measures. Such a scenario as in Test 24 would, in the long term, likely lead to rapid environmental degradation, drastic reduction in aquifer water quality, and hinder socio-economic development in the region as agricultural activity suffered due to the water shortages.

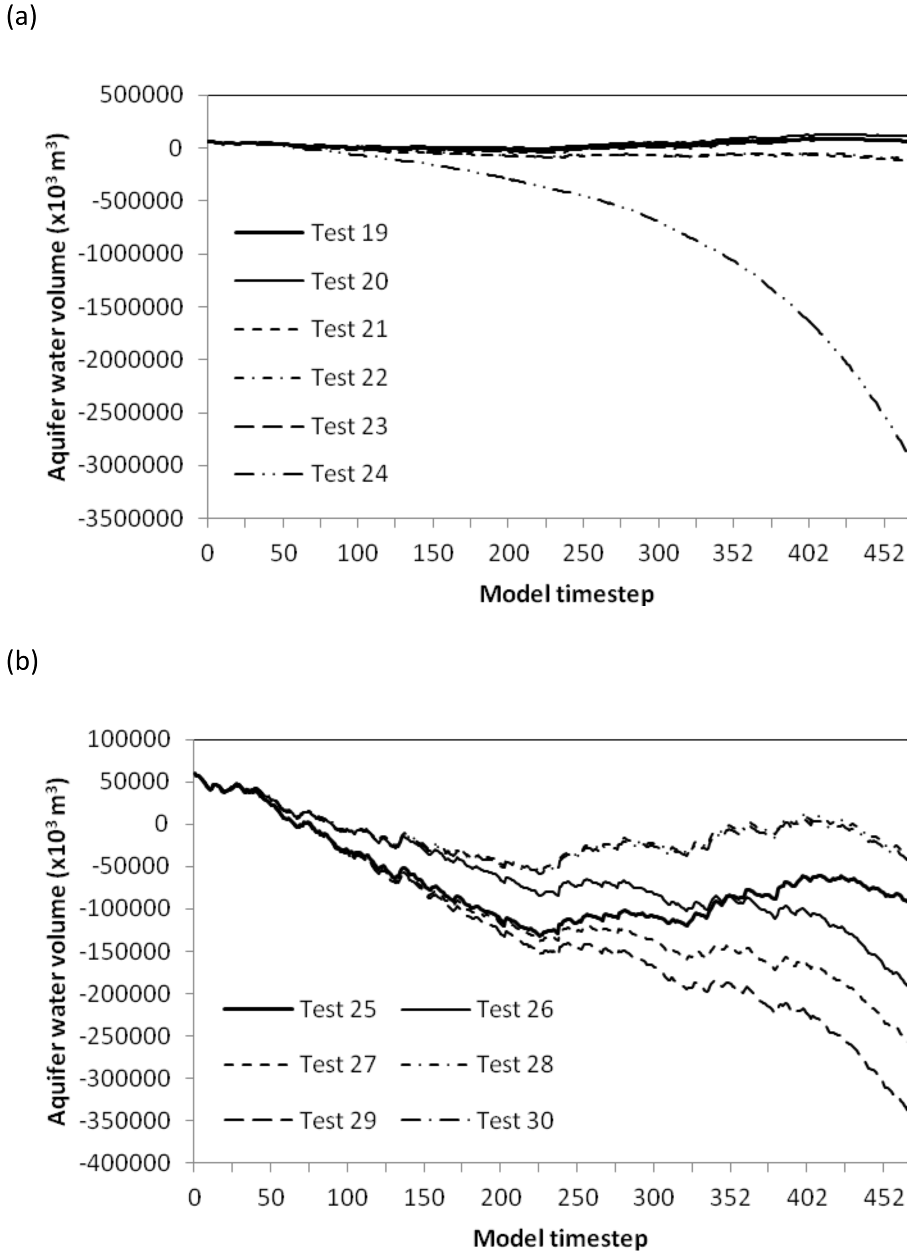


Figure 21: Results for the agricultural demand series of tests (Tests 19-30) showing (a) aquifer water patterns for Tests 19-24; (b) aquifer water patterns for Tests 25-30.

Conversely, Tests 19 and 20 indicate that the aquifer would initially be overexploited, but then demand drops sufficiently to allow for net recharge, especially in the second half of the simulations. These two tests pertain to altering the value for the price elasticity of demand, which was initially set at -0.3, representing fairly low elasticity (demand does not change much in response to price changes). The tests both assumed greater elasticity - unitary elasticity and elastic demand response for Tests 19 and 20 respectively. While these changes altered the behaviour in the most encouraging way with respect to aquifer water volume, demand elasticity is probably one of the parameters least ably controlled by local policy decisions as it can depend on many socio-economic and psychological factors (e.g. amount of income spent on the commodity, brand loyalty and necessity). Furthermore, demand elasticity would probably be slow to change and difficult to directly influence through policy changes.

4.2.2.4 Coastal pumping sub-model tests (Tests 31-33, Table 3)

Figure 22 shows the evolution of the aquifer stored water. The three tests performed here represent more or less stringent caps on the volume of water that would be allowed to be pumping out of the Kairouan aquifer to cities on the coast then the currently proposed regime of downward-stepping limits. Test 31 represents a significant decrease to pumping volumes relative to the proposed regime, Test 32 represents an initial improvement over current proposals but achieves lower reductions in the later years, and Test 33 is a case intermediate between the two, but with the limits being lower than are currently proposed. Both Tests 31 and 33 indicate that the aquifer never becomes 'empty' (all other parameters held constant), while Test 32 shows 'emptying' of the aquifer in approximately eight years.

Table 3: Tests conducted for coastal pumping

Year	Baseline	Test 31	Test 32	Test 33
2011	2050000	2050000	2050000	2050000
2012	2168333	2000000	2100000	2100000
2013	2141667	1800000	2000000	1900000
2014	2102500	1600000	1900000	1750000
2015	2075833	1400000	1800000	1600000
2020	2036667	1200000	1700000	1450000
2025	1826667	1000000	1600000	1300000
2030	1550833	800000	1500000	1150000
> 2030	1209167	600000	1400000	1000000

The coastal pumping tests had significant impacts of recharge behaviour due to the substantial volumes of water involved. These tests showed that, by altering current policy to reduce pumped volumes by greater amounts than presently committed to, but not by so much as to be unrealistic or unobtainable (Test 33), net recharge behaviour is simulated for the Kairouan aquifer. However, if the targets are missed by only a relatively small amount, then aquifer overexploitation, environmental degradation and negative impacts to socio-economic development are still probable.

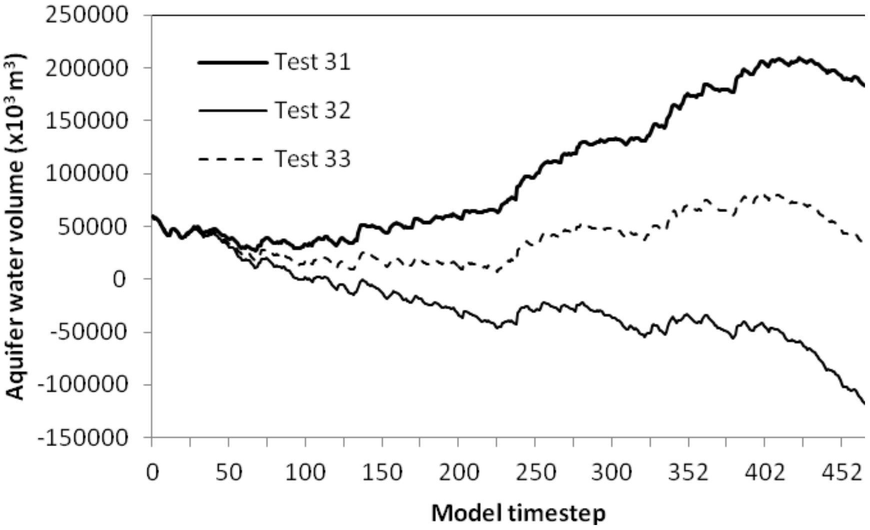


Figure 22: Results of the coastal pumping series of tests (Tests 31-33) showing the aquifer water patterns for Tests 31-33.

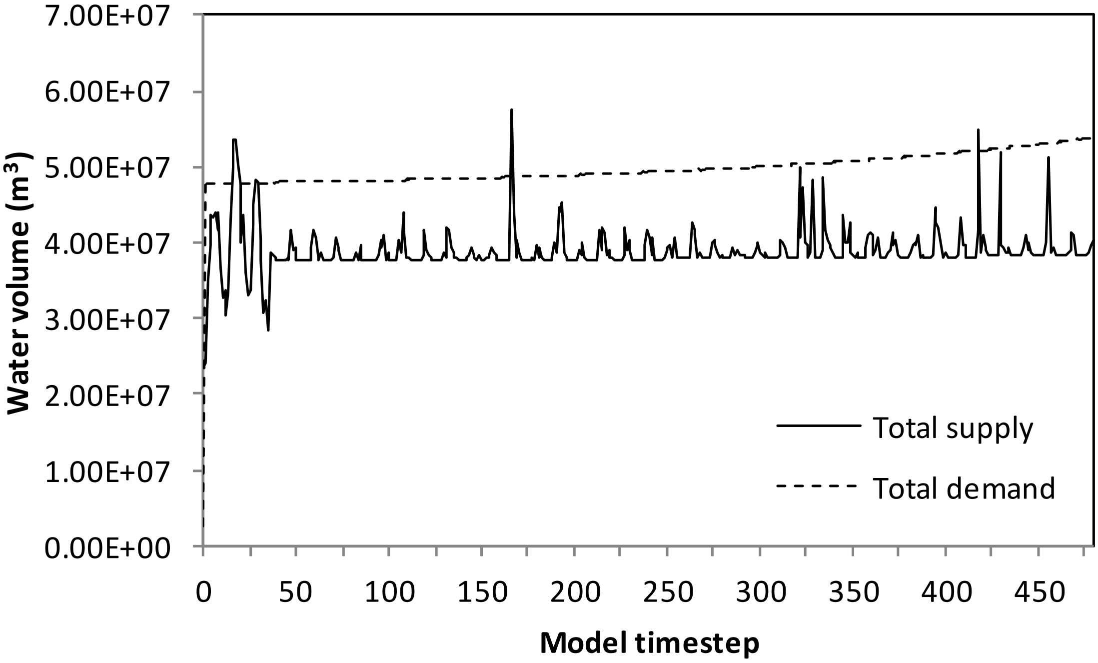
4.3 Water balance modelling results for Rosetta

The results for the Egypt case study have also changed since Deliverable 5.2.3 in response to the further development of the water balance model. These results have been extensively reported and analysed in Sušnik et al. (Submitted). The results presented here are based on the results in Sušnik et al. (Submitted), but the reader is referred to that paper for further details. Sušnik et al. (Submitted) also provides full details of the Scenarios and Simulations, and to save space, the reader is referred to the paper for further details.

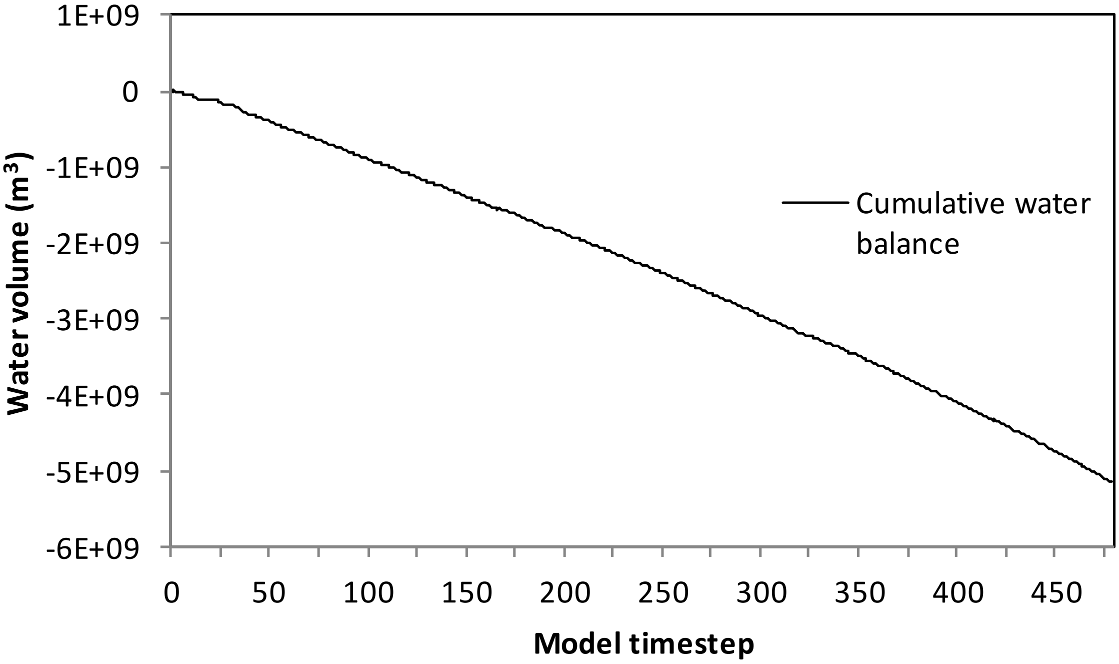
4.3.1 Baseline and 'best' and 'worst' case futures (Scenarios 1-3, Simulations 1-3)

Figure 23 shows the baseline cumulative water balance, supply and demand, and crop yield and revenue under the baseline scenario (Sušnik et al. Submitted). If current trends continue, it is predicted that net water resource over-exploitation will continue into the future (Figure 23). It is noted that the spikes observed after timestep c. 300 in Figure 23 are driven by spikes in water supply (i.e. in rainfall input, Figure 23). The explanation for the spikes in yield and revenue is that the extra supply means that the potential can be more closely met (Figure 23).

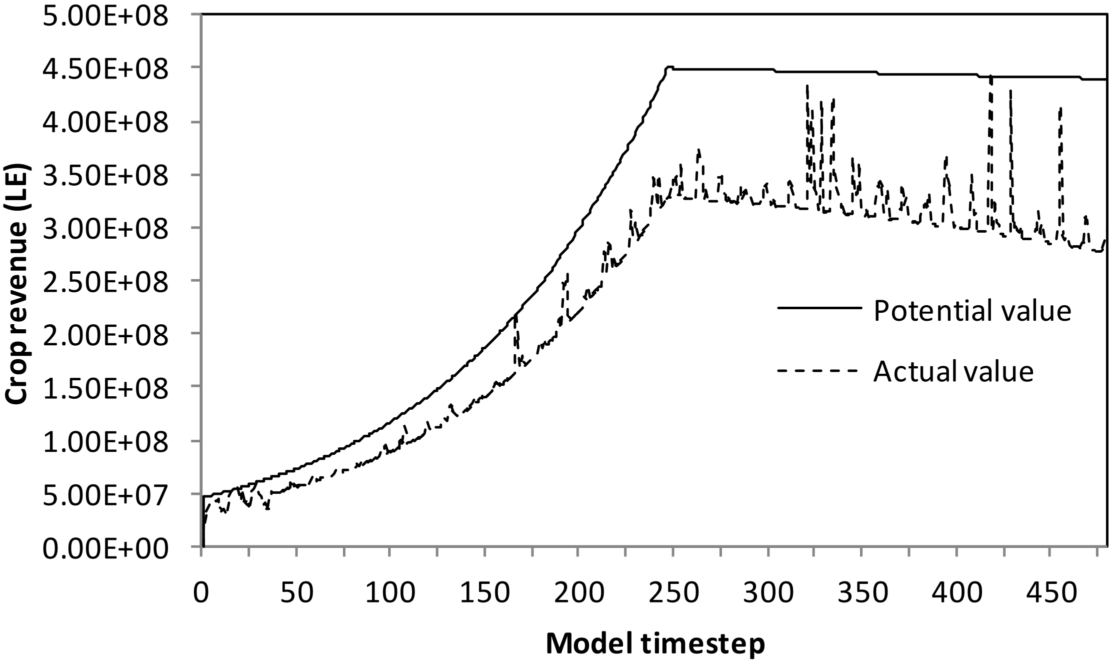
(a)


7.00E+07
6.00E+07
5.00E+07
4.00E+07
3.00E+07
2.00E+07
1.00E+07
0.00E+00
Water volume (m³)
0
50
100
150
200
250
300
350
400
450
Model timestep
Total supply
Total demand

(b)


1E+09
0
-1E+09
-2E+09
-3E+09
-4E+09
-5E+09
-6E+09
Water volume (m³)
0
50
100
150
200
250
300
350
400
450
Model timestep
Cumulative water balance

(c)



(d)

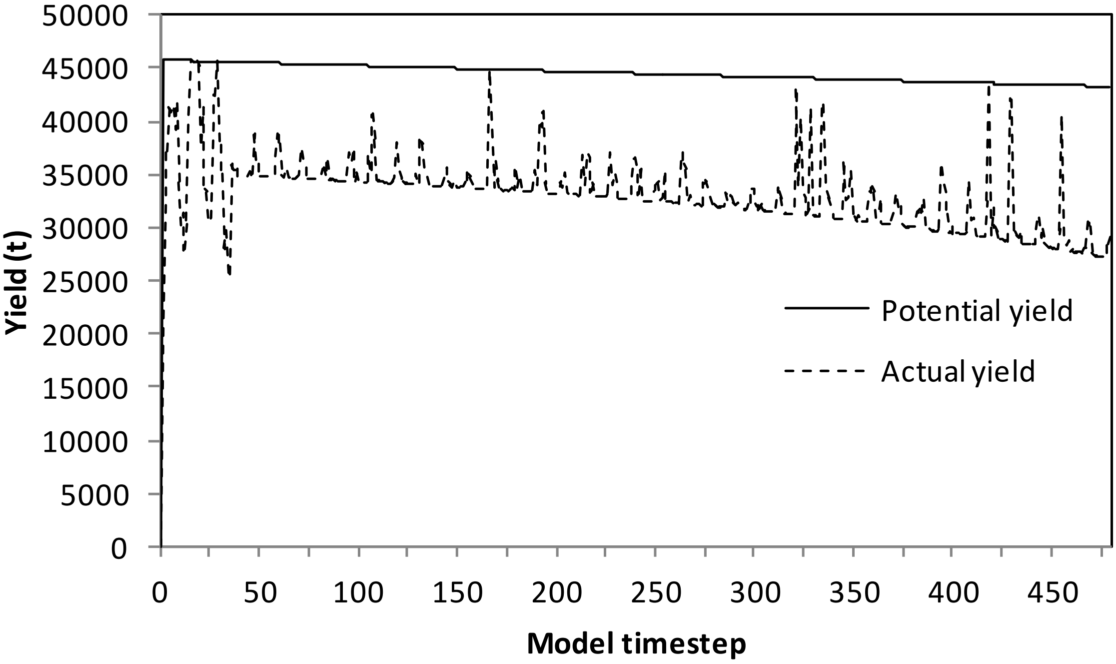


Figure 23: Results for the baseline scenario showing: (a) water supply and demand; (b) the cumulative water balance; (c) the potential and actual crop revenue and; (d) the potential and actual crop yield.

Scenarios 2 and 3 (the best and worst case respectively) show diverging water balance characteristics. The worst case scenario shows a worsening of the baseline situation over time (i.e. the resource is being over-exploited to a greater degree than at present), particularly near the end of the simulation. In contrast, the best case cumulative water balance appears to shows a flattening trend over time, hinting that the level of over-exploitation is decreasing year-on-year.

4.3.2 Uncertainty in Nile inflows (Scenario 4, Simulations 4-12)

The water-balance profiles for Simulations 6, 8 and 12, representing a 40% increase, a 60% increase and a 50% decrease to the total canal inflow volume respectively are shown in Figure 24. It is shown that a 50% decrease would be potentially devastating for the region (note the order of magnitude increase in the cumulative water deficit at the end of the simulation compared with the baseline). A 40% increase to the supply shows more promising profile. After timestep c. 350, the cumulative water balance levels out, indicating net water balance stability (no deficit, no surplus). If the supply is increased by 60%, net water surplus after the first half of the simulation is indicated. The severely restricted water supply is shown to have a marked impact on revenue, particularly in the latter half of the simulation when crop prices are not allowed to increase further due to modelling assumptions. If the water supply is vastly increased, then the crop revenue almost matches the potential, only being reduced slightly due to land loss resulting from sea-level rise.

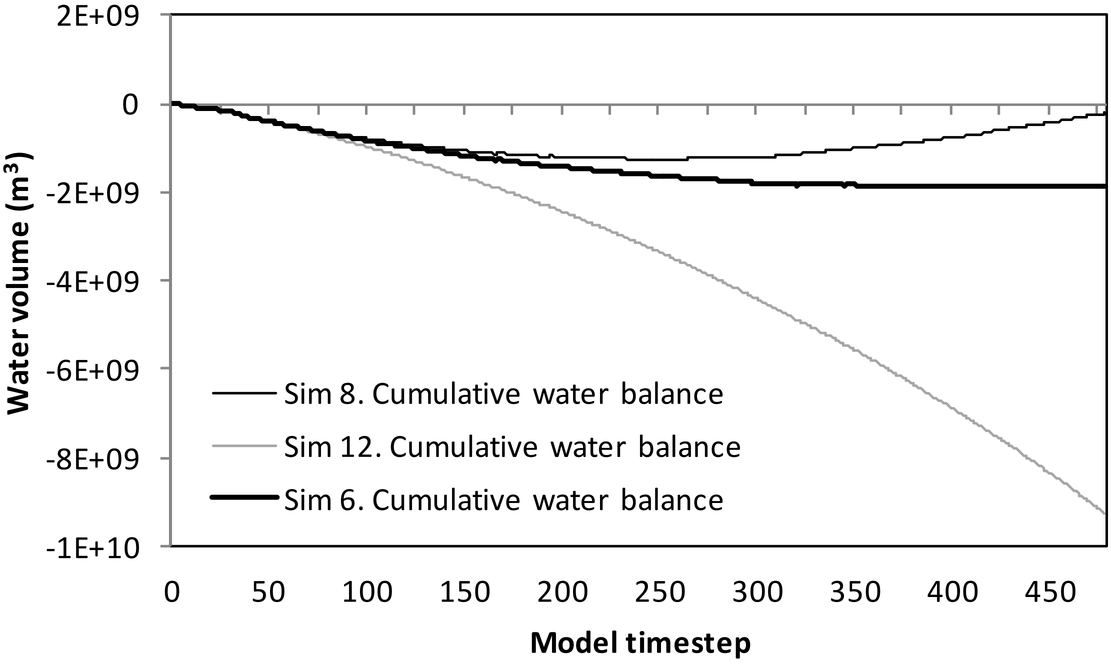


Figure 24: Results showing the impact of changing Nile flow volumes (Simulations 6, 8 and 12, Table 2) to the cumulative water balance.

4.3.3 Uncertainty in sea-level rise (Scenario 5, Simulations 13-17)

Greater levels of sea-level rise resulted in increased areas of agricultural land loss, leading to gradually improving cumulative water balance profiles. The inundation of agricultural land means less crops are grown and thus, less water is used. The downside is that the local economy is adversely affected, and is thus seen locally as a negative impact due to the economic impacts.

4.3.4 Sensitivity in the domestic sector (Scenario 6, Simulations 18-30)

Halving and doubling the per-capita water demand had the greatest impact to the cumulative water balance by making it considerably better or worse than the baseline respectively. All other simulations showed very little impact to the final results, mainly due to the relatively small water volumes involved when dealing with local Rosetta domestic demand when compared with agricultural demand. All results indicate a worsening water deficit over time, with any savings not sufficient to lead to water-balance stability.

4.3.5 Sensitivity in the industrial sector (Scenario 7, Simulations 31-35a)

Figure 25 shows the results of Simulations 31 and 32 which halve and double the rate of industrial demand change respectively. By halving the rate of change of demand, there is a slight improvement to the cumulative water balance over time, while a doubling leads to a significant worsening of the situation, with the amount of over-exploitation increasing at every timestep (exponential behaviour.

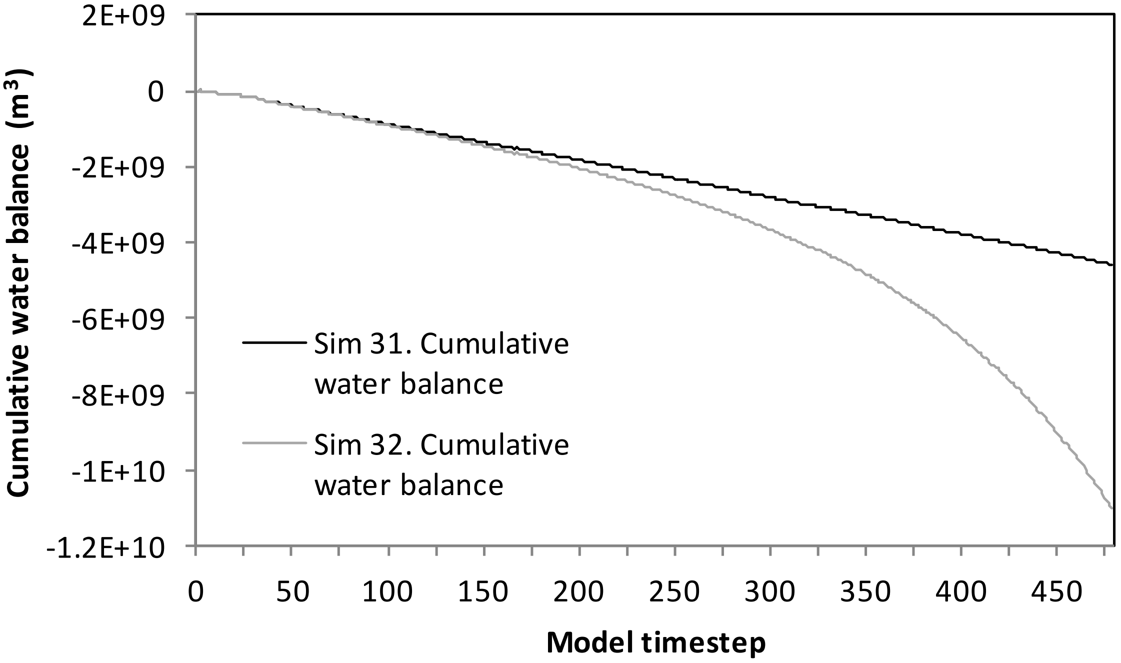


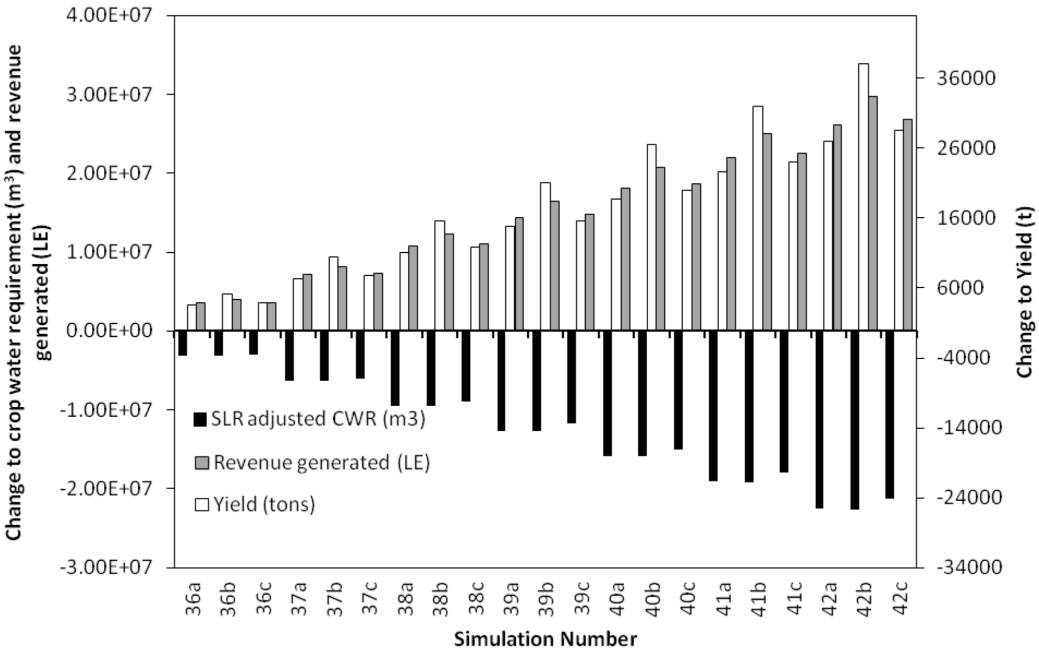
Figure 25: Results from Simulations 31 and 32 altering the rate of industrial water demand change, showing the impact to the cumulative water balance.

4.3.6 Impact of cropping regimes changes (Scenario 8, Simulations 36a-42c)

The results of the 21 cropping regimes changes are summarised in Figure 26 which shows the change in total crop water requirement, total crop yield and total crop revenue for each scenario relative to the baseline. Figure 26a shows the cumulated change at the end of the first 12 months of simulation (i.e. at the end of year 2010), while Figure 26b shows the cumulated change at the end of final 12 months of simulation (i.e. at the end of year 2049). The main feature in both figures is that the performance of each scenario improves from left to right on the x-axis (as more rice is replaced), and that the economic ('b') pathway is the best performing of the three pathways in that it saves the most water per timestep, and results in the best gains in terms of yield and revenue.

The cumulative water balance for the baseline simulation and for Simulation 42b (all rice replaced with the economic pathway) is plotted in Figure 27. While there is an improvement, long term over-exploitation is still observed. The amount of water saved at the end of the simulation relative to the baseline is 21%.

(a)



(b)

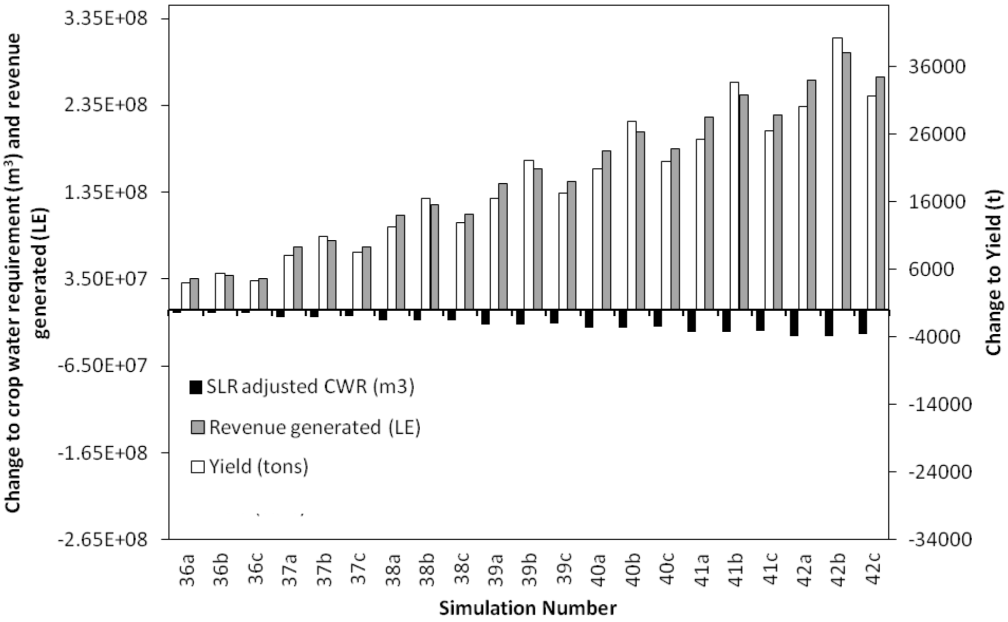


Figure 26: Results for the cropping regime scenarios (Simulations 36a-42c) showing: (a) the change relative to the baseline in crop water requirement, yield and revenue at the end of the first 12 model timesteps (i.e. the end of 2010) and; (b) the change relative to the baseline in crop water requirement, yield and revenue at the end of the last 12 model timesteps (i.e. the end of 2050).

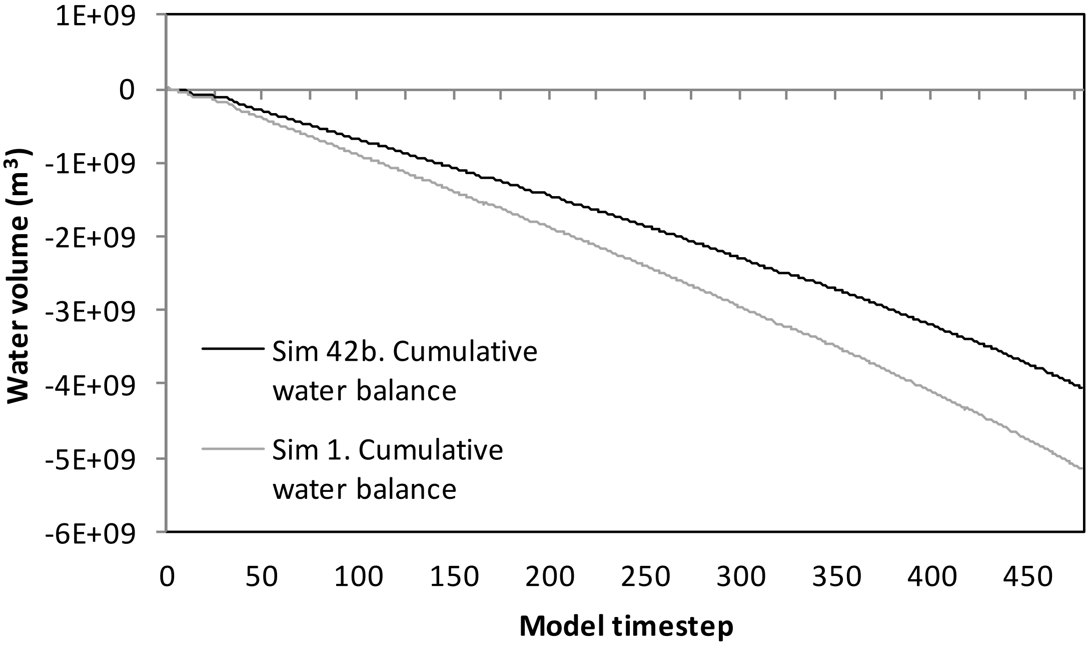


Figure 27: Comparing the cumulative water balance for the baseline scenario and for cropping scenario Simulation 42.

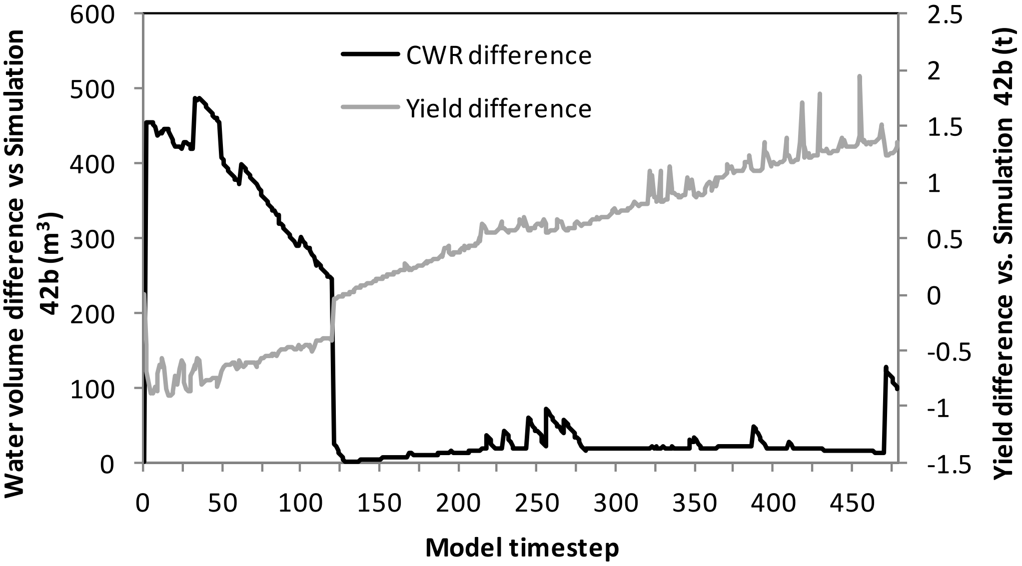
4.3.7 Modelling the impact of using alterations to cropping patterns to exploit international trade.

Figure 12 illustrates the casual loop diagram for the feedback extension, the logic of which is as described in Section 3.3. In the first timestep, the extension uses the yield difference between the altered cropping regime (results from Simulation 42b) and the baseline to estimate for the amount of surplus exported, the amount of crop imported to reduce local water use, and the subsequent implications for changes to total crop water requirements, yield and revenue based on assumed further changes to cropping patterns. After the first timestep, the difference in yield between the cropping scenario (Simulation 42b) and the feedback extension results is used to perform the calculation.

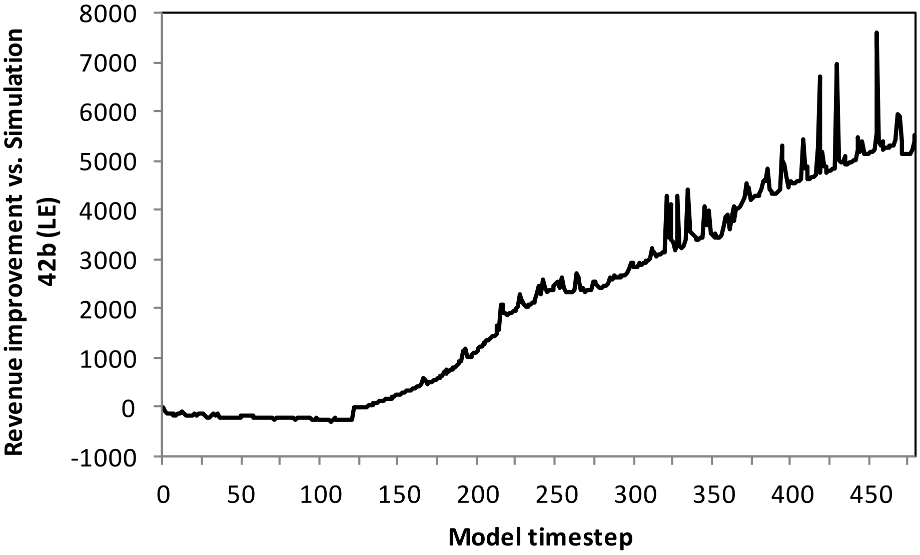
With respect to further alterations in cropping pattern, it is assumed that as water-intensive crops are imported, a certain area is converted from more- to less-water intensive crops. The areas devoted to rice and cotton are decreased by the imported area-equivalent to a minimum of zero, while cash crops with a high yield and lower water requirements (summer and winter vegetables and wheat) are increased by the converted area-equivalent to a maximum of 1.5 times their currently planted area. Updated values for yield, crop water requirement and revenue are calculated based on the new cropped areas. Here, the Rosetta SDM was set to run Simulation 42b (Table 3) as it generated the best water saving, yield and revenue improvements from the cropping regime simulations, offering the best starting point.

Figure 28 shows the results from this simulation. It is shown that further improvements can be made to the Rosetta crop water requirement and yield and revenue when compared with the best-performing cropping scenario (Simulation 42b). Figure 28 also compares the newly calculated yield to that produced under the baseline simulation in order to highlight the potential benefit that a change in cropping pattern coupled with exploitation of international trade could bring, additional to water savings and revenue improvements.

(a)


CWR difference
Yield difference
Water volume difference vs Simulation 42b (m³)
Yield difference vs. Simulation 42b (t)
Model timestep
600
500
400
300
200
100
0
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
0
50
100
150
200
250
300
350
400
450

(b)


Revenue improvement vs. Simulation 42b (LE)
Model timestep
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
0
50
100
150
200
250
300
350
400
450

(c)

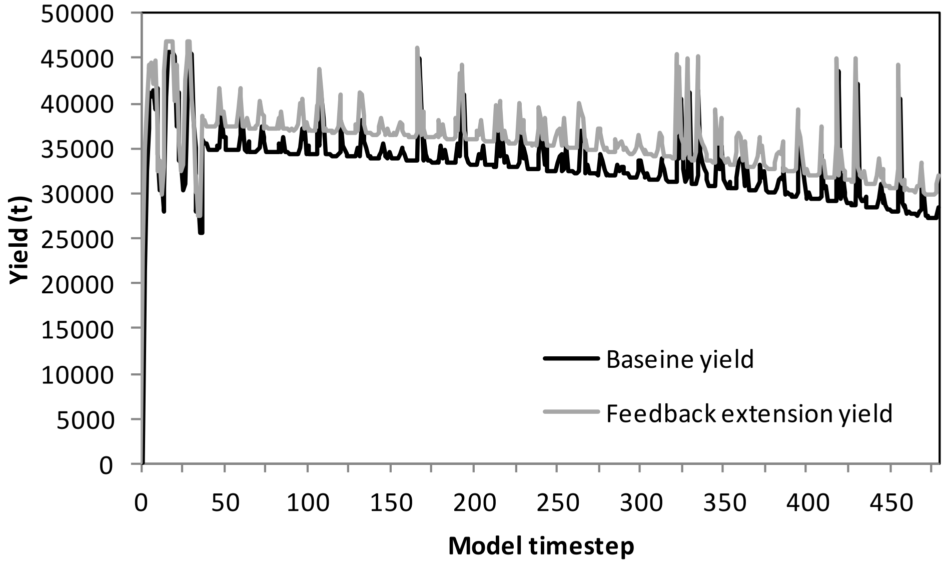


Figure 28: Differences between the 'extension' sub-model and Simulation 42b (Table 3) results for: (a) total crop water requirement and yield. Peaks in CWR difference curve after timestep 300 are explained by the changes in cropping patterns and water supply peaks; and (b) revenue. (c) Comparing the yield profiles for the baseline and feedback extension simulations.

It is recognised that the assumed values used here are open to criticism, however prediction of variables such as how much surplus crop a region will export, or the value of exported crops is inherently uncertain. The idea here is to indicate that the establishment and careful maintenance of a positive feedback loop that exploits international trade could be used to further benefit local, regional or even national development, and could help lower the water demand from the agricultural sector.

4.3.8 Results using the WSM modelling tool

Figure 29 presents water demand estimated through the application of the WSM DSS vs. freshwater availability and total supply delivered to use for the baseline conditions. Water demand includes irrigation water requirements and domestic water demand for the main agglomerations. Supply delivered to use includes the total freshwater used, as well as the reuse of drainage water in irrigation. Both water demand and supply present a seasonal pattern, with irrigation demand peaking during July and August. Water supply, particularly during those months, is significantly lower than the estimated demands; on an annual basis, the total deficit (monthly sum) ranges between 76 and 112 million m^3/yr.

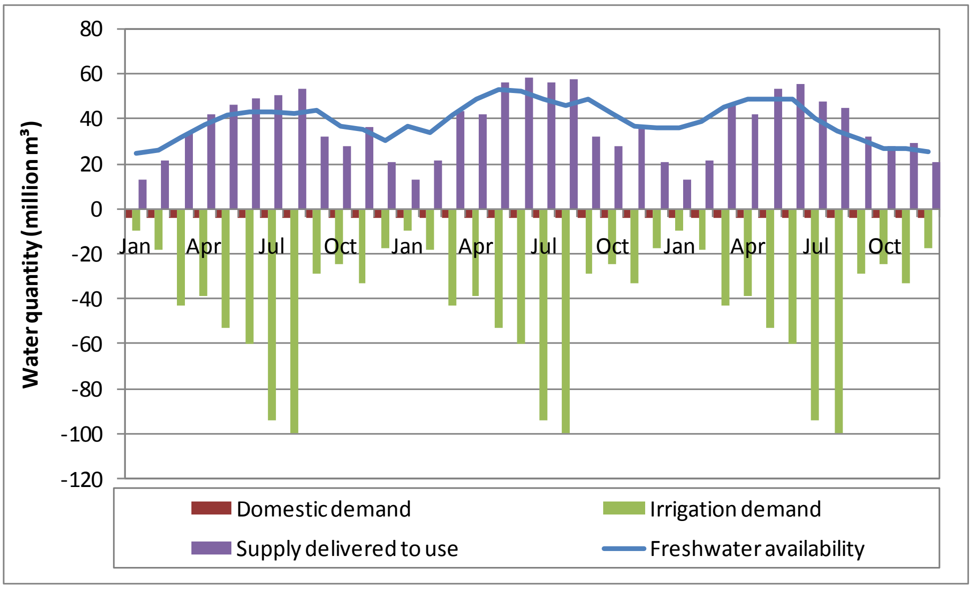


Figure 29: Water demand, freshwater availability and supply delivered to use in Rosetta, as estimated by the WSM DSS for the baseline conditions

Due to the priority setting, domestic deficits are equal to 0 throughout the simulated period. Figure 30 presents in more detail water supply sources, demand and deficit in the agricultural sector. Overall, the reuse of drainage water alleviates water shortage, contributing by 20% to water supply for irrigation.

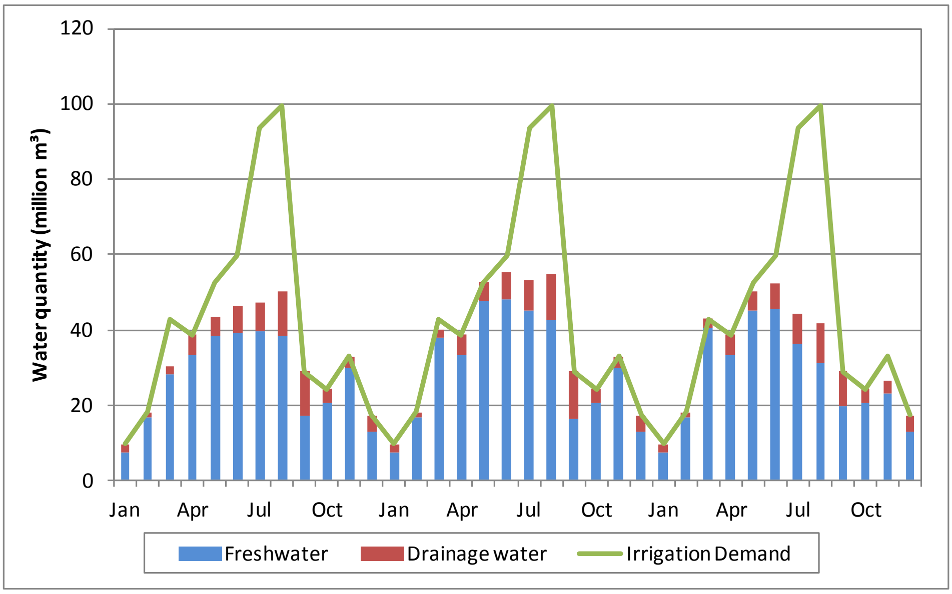


Figure 30: Water demand, supply sources and deficit in the agricultural sector of Rosetta, as estimated by the WSM DSS for the baseline conditions

Future scenario simulations in the WSM DSS concerned the best and worst case scenarios, as described by ECRI for WASSERMed Deliverable 5.1.2 (Sušnik et al., 2011b). In summary:

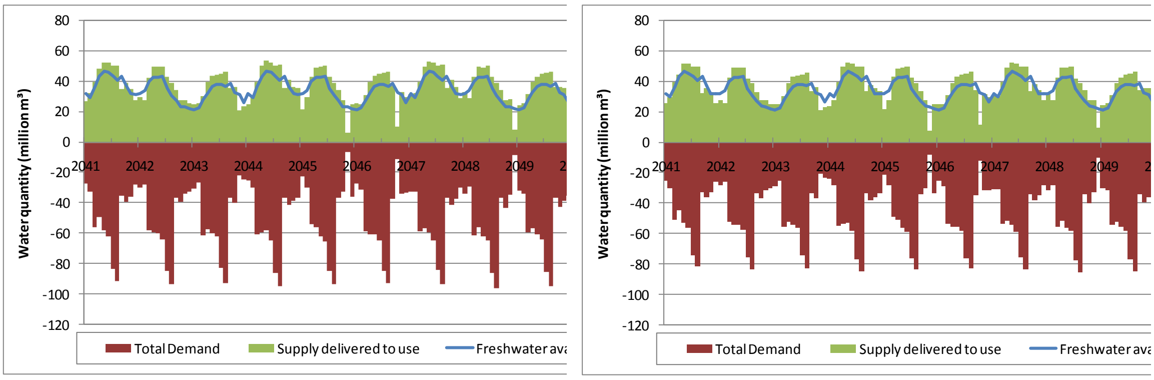
- The best case scenario (BS) foresees a mild population growth rate of 1.54%/yr and the implementation of measures to address sea level rise. As a result, crop acreage remains at the current level of 66,248 feddans. A 10% water saving is achieved in the domestic sector, as a result of increased awareness on water conservation.

- The worst case scenario (WS) foresees a more intense population growth (1.88%/yr). No measures are implemented for sea level rise, resulting in a decrease of cultivated land of 13% by 2050. Per capita consumption is not reduced.

Both scenarios incorporate climate projections provided by the CMCC, derived from the ETHZ regional climate model, forced by the Hadcm3Q0 GCM and for the A1B IPCC scenario. Data used from the climate dataset concern precipitation and temperature. As the dataset did not include information on relative humidity and wind speed, future evapotranspiration was calculated based on the Blanney-Criddle method, which requires data only for temperature.

In addition to the above, a critical parameter which can determine future water balance in the area concerns Nile water availability. This depends on inflows and outflows to and from the High Aswan Dam (HAD), but also on socio-economic developments upstream of Rosetta (e.g. population growth in Cairo, plans for agricultural expansion etc.), which can influence the allocation regime of Nile water throughout the centralized water system of Egypt. Beyene et al. (2010) provide detailed hydrological simulation results for the entire Nile Basin, and for releases from the HAD, based on multi-model long-term averages for three future periods (2010-2039, 2041-2069 and 2070-2099) and different IPCC scenarios. Simulations have been based on the current agreement between Sudan and Egypt on the sharing of Nile waters, and thus consider also how potentially higher Nile flows can be shared among countries. According to the estimates of Beyene et al. (2010), releases for irrigation from the HAD for 2041-2069 can be reduced around 11-13%, with regard to the historical average (1950-1999). As irrigation is the dominant water use also in Rosetta, and assuming that the current allocation regime among the irrigated lands of Egypt remains the same, an average decrease of 12% in canal inflows to Rosetta was also incorporated in the scenarios.

Figure 31 presents a comparison of the monthly water balance between the two scenarios for 2041-2050.



(a) Best Case scenario (b) Worst Case scenario

Figure 31: Water demand, freshwater availability and supply delivered for the Best and Worst Case scenarios,
as estimated by the WSM DSS [2041-2050]

In both cases, and despite the reduced demand in the WC scenario, a significant deficit still exists, which varies, according to the precipitation pattern and canal inflows. On an annual basis, the annual deficit for 2041-2050 is ranges between 90 and 154 million m^3/yr for the Best Case scenario (average value of 122 million m^3/yr) and between 71 and 150 million m^3/yr for the Worst Case scenario (average value of 112 million m^3/yr). Similarly to the results presented for the SDM model, the positive water balance change for the WC scenario is due to the reduction of crop acreage, which reduces agricultural water demand.

Figure 32 provides an interesting snapshot on how economic output from agricultural activities can evolve, depending on the scenario. In general, the average yearly economic output for the BC scenario is somewhat higher than that of the WC scenario. However, in years when crop water requirements are higher, the gross economic output is higher for the WC scenario. The internal algorithm in the WSM DSS estimates changes in crop yield (quantities produced), as a result of reduced water made available for irrigation. Thus, in years of higher rainfall, when the deficit per ha is lower for specific crop types (e.g. 2043, 2046 and 2047 in the graph of Figure 32), the economic output can be higher for the Worst Case scenario, offsetting the loss of agricultural land.

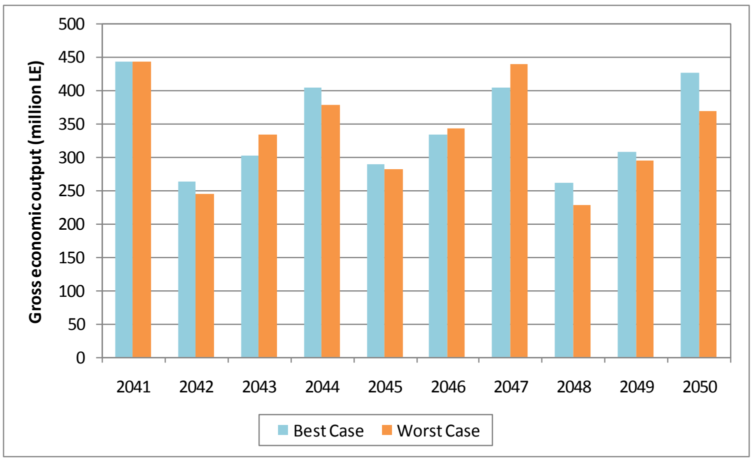


Figure 32: Gross economic output from agriculture for the Best and Worst Case scenarios, as estimated by the WSM DSS [2041-2050]

Results presented above correspond to scenarios without potential adaptation measures. This means that besides the changes included in the scenarios, all other parameters (levels of wastewater reuse, cropping pattern, irrigation efficiencies) remain the same and equal to those corresponding to the baseline conditions. The analysis developed through the WSM DSS will be further enhanced to address the effectiveness of measures in alleviating potential threats, and the assessment of their costs and benefits. Potential measures, as described by ECRI, can include an adaptation of cropping patterns, but also enhancement of wastewater reuse (through volumes made available from other regions, e.g. Alexandria), and improvement in irrigation methods. The relevant results will be included in Deliverable 5.3.1.

4.4 Water balance modelling results for the lower Jordan River Basin

The results from the Jordan case study have also changed since those in Deliverable 5.2.3. The model has been significantly improved, and as such, the results are now more informative. For the baseline simulation and for Scenarios 1-4, Table 4 details the input data used, allowing for quick comparison to be made as to how the scenarios differ. It is noted that for Scenarios 1-4, there are 'best' and 'worst' case versions for each of these, making eight simulations. All the details can be found in Table 4.

Table 4: Detailing the input data for the baseline and for Scenarios 1-4 used in the Jordan case study simulations. Those values in bold text have been altered from the baseline.

Time/ Name	**Baseline (2007)**	***Scenario***			
		1	**2**	**3**	**4**
Available Water Resources					
Tiberia Lake: Restore water right through River Jordan (additional 25 MCM)	40.6	40.6	40.6	**65.0**	**65.0**
Yarmouk river: restore water rights from Yarmouk river (additional 50 MCM), decrease due to climate change	31.8	**16.0**	**81.8**	**16.0**	**81.8**
Mukiehbeh wells (GW), decrease due to climate change	31.8	**20.0**	**20.0**	**20.0**	**20.0**
Wadi Arab Dam	9.9	9.9	9.9	9.9	9.9
Side Wadis	12.8	12.8	12.8	12.8	12.8
Wadi Sheib Dam	6.1	6.1	6.1	6.1	6.1

Kafrein Dam	10.6	10.6	10.6	10.6	10.6
King Talal Dam: Increase is expected to rise from 100 MCM at the present to 200 MCM by 2020	82.1	**100.0**	**200.0**	**150.0**	**200.0**
Shrhabiel Dam, decrease due to climate change	5.1	**3.0**	**3.0**	**3.0**	**3.0**
Shuneh GW, decrease due to climate change	24.0	**12.0**	**12.0**	**12.0**	**12.0**
Building new dams of 35 MCM		0.0	**35.0**	0.0	**35.0**
Total available:	244.9	231.0	431.8	305.4	456.2
Water Uses - ***Best Case***					
JV drinking, population growth by 1.08%	9.0	**9.7**	**9.7**	**9.7**	**9.7**
Industrial, population growth by 1.08%	6.0	**6.5**	**6.5**	**6.5**	**6.5**
Irrigation using GW	20.0	20.0	20.0	20.0	20.0
Side Wadis Rights	20.0	20.0	20.0	20.0	20.0
Driniking Water, pumped to Amman	40.6	**43.8**	**43.8**	**43.8**	**43.8**
Pump to wadi Arab	8.4	8.4	8.4	8.4	8.4
Losses	10.0	10.0	10.0	10.0	10.0
Total demand	114.0	118.4	118.4	118.4	118.4
Available Water for Irrigation purpose	139.1	112.6	313.4	187.0	337.8
Deficit in Water available for Irrigation purpose *	-60.9	-87.4	113.4	-13.0	137.8
Water uses - ***Worst Case***					
JV drinking , population growth by 2%	9.0	**18.0**	**18.0**	**18.0**	**18.0**
Industrial, population growth by 2%	6.0	**12.0**	**12.0**	**12.0**	**12.0**
Irrigation using GW	20.0	20.0	20.0	20.0	20.0
Side Wadis Rights	20.0	20.0	20.0	20.0	20.0
Driniking Water, pumped to Amman	40.6	**81.2**	**81.2**	**81.2**	**81.2**
Pump to wadi Arab	8.4	8.4	8.4	8.4	8.4
Losses	10.0	10.0	10.0	10.0	10.0
Total demand	114.0	169.6	169.6	169.6	169.6
Available Water for Irrigation purpose	139.1	61.4	262.2	135.8	286.6

Deficit in Water available for Irrigation purpose*	-60.9	-138.6	62.2	-64.2	86.6

4.4.1 Baseline case

Using the model set to baseline parameters (Table 4), the cumulative water balance in the King Abdullah Canal stock element shows a consistent long-term decline (Figure 33). This indicates chronic over-exploitation of the water resource, which is not surprising. It is well known that the water situation in Jordan at the present day it critical. It is important to note that Figure 33 shows the cumulative water demand over time, and not the absolute water volume held in the canal at any point in time.

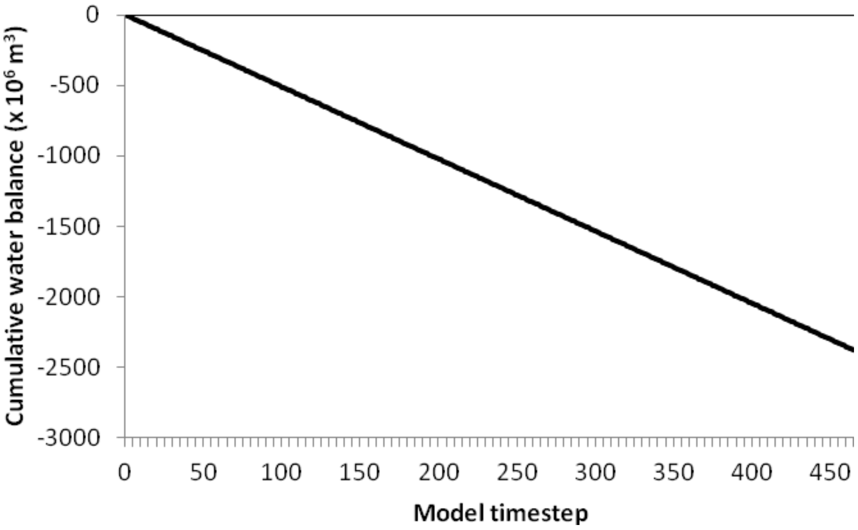


Figure 33: Baseline cumulative water balance in the King Abdullah Canal stock element.

4.4.2 Scenario simulations 1-4

Scenarios 1-4 each comprise of a best and a worst case situation (Table 4), resulting in eight modelling simulations. The Scenarios account for hypothetical differences in, for example, expected water demand, changes to water legislation and volumes pumped into neighbouring basins. Figure 34 shows the cumulative water balance in the King Abdullah Canal stock for all eight simulations, and also shows the baseline curve for comparison.

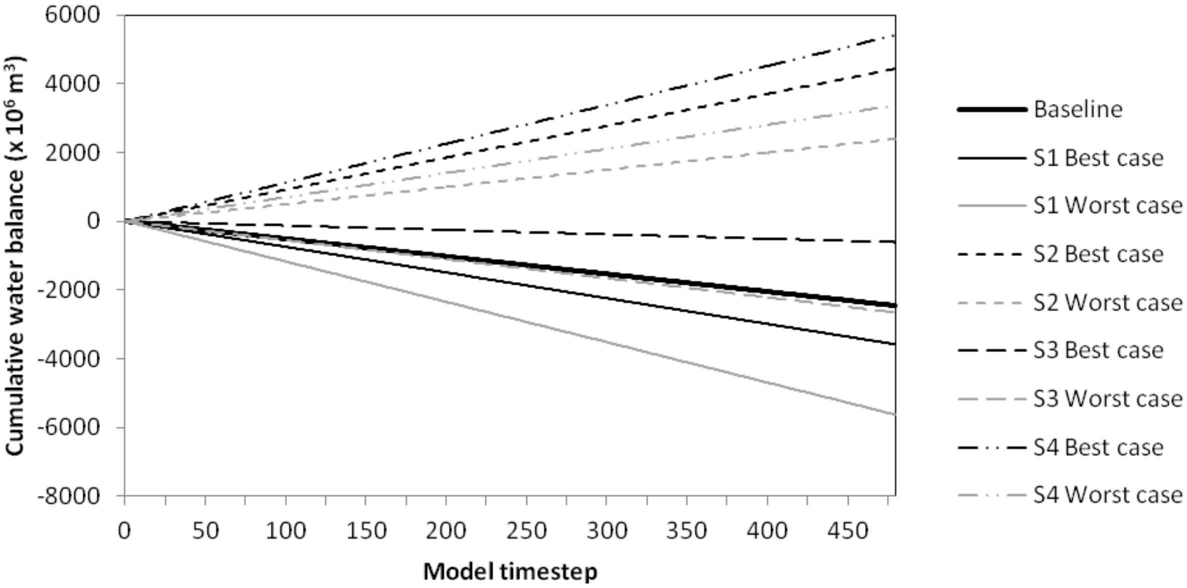


Figure 34: Comparing the cumulative water balance trends of the King Abdullah Canal from Scenarios 1-4.

As shown in Figure 34, some scenarios lead to a worsening of the current situation (Scenarios 3 worst case, 1 best and worst case). While Scenario 3 best case leads to an improvement, overall water deficit is still indicated. However, Scenarios 2 (best and worst case) and 4 (best and worst case) all show cumulative water surplus. This surplus is achieved not through demand reductions but through supply increases - particularly from the Yarmouk River and the King Talal dam.

4.4.3 Testing future cropping changes

Under this simulation, a number of potential changes to cropping patterns were implemented over the course of the situation. These changes are aimed at lowering overall water demand in the area and ultimately securing the water resource for the future in order to mitigate the impacts of climate change. The changes that were implemented over the baseline are:

- the area of bananas planted was reduced by 2.5% per year to a maximum reduction of 50% over the baseline.
- the area of palm trees was increased by 3% a year over the simulation.
- the 'other' category of tree types was reduced by 3% per year to a minimum of zero.
- the area of all vegetables was reduced by 1% per year to a minimum of zero.

These changes were implemented in parallel, and not one-at-a-time. This scenario represents a broad scale change in agricultural behaviour, and was specified by colleagues at NCARE.

Figure 35 compares the cumulative water balances of the King Abdullah Canal for the baseline and the cropping scenario. It is shown that while initially the Canal is over-exploited, as the implementation of the cropping changes progresses, and more land is converted between crop types, the stock eventually reaches water balance (input = output) and ultimately surplus, with demand being lower than supply. Model results suggest that it would take c. 30 years for supply to become lower than demand within the assumptions of the model (Figure 36).

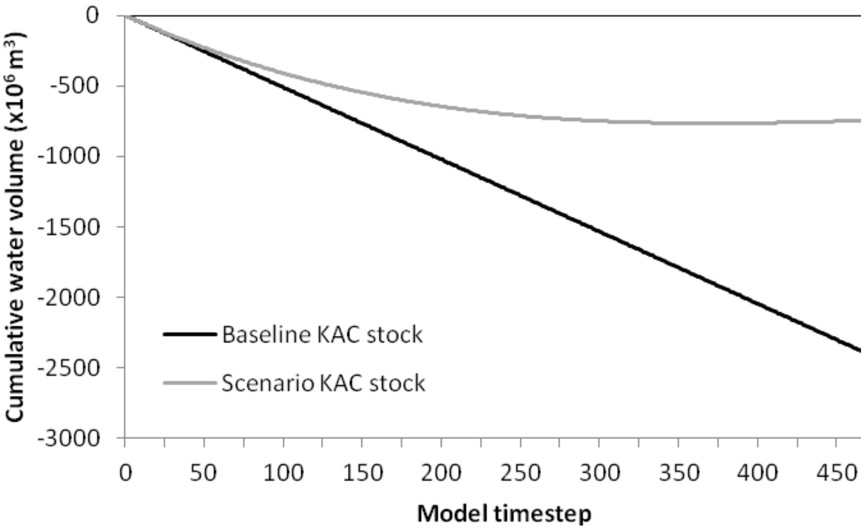


Figure 35: Comparing the cumulative water balances of the King Abdullah Canal stock for the baseline and for the cropping scenario.

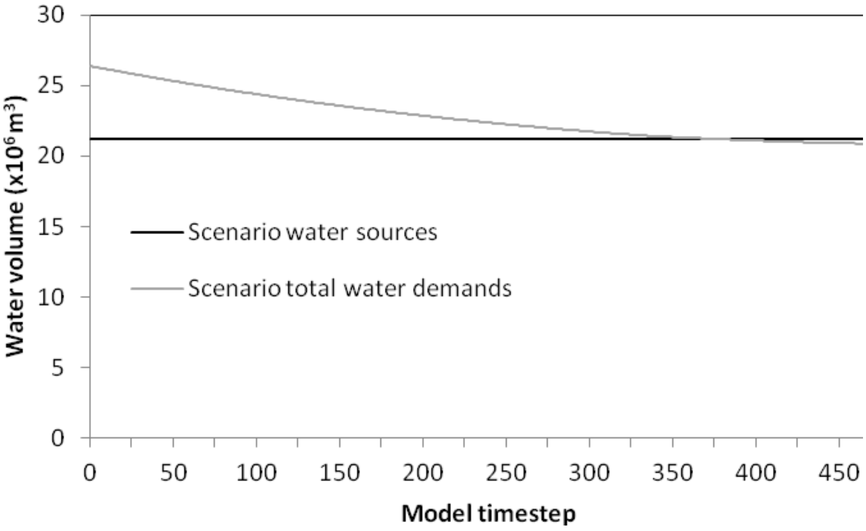


Figure 36: Evolution of Jordan case study water demand over time under the cropping simulation. The time taken for supply < demand is c. 30 years.

Figure 37 shows both the total crop water requirement in the study area over time and the study area irrigation water deficit over time for the baseline and the cropping scenario. It is shown that as time progresses, the CWR and the irrigation water deficit diverge from the baseline simulation. In the case of CWR, the cropping scenario shows a lower water volume being required over time as the crops are altered. For the irrigation water deficit, this is shown to reduce over time (Figure 37), which has promising implications for the region into the future.

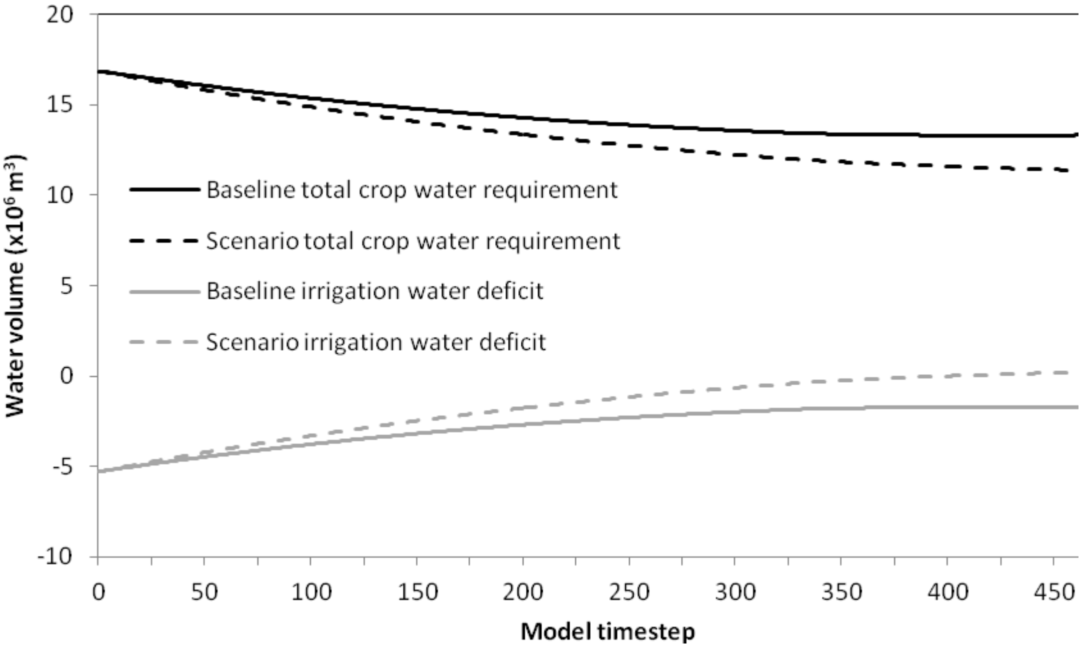


Figure 37: Comparing the CWR and irrigation water deficit between the baseline and cropping simulations over the 40-year model simulations.

4.5 Water balance modeling results for Syros

This section presents the results of the Syros water balance model. Results are presented for the baseline conditions (2010) and for future scenarios (2011-2050). These results are also summarised in Deliverable 5.2.3

4.5.1 Baseline conditions

The analysis of simulation results for the baseline conditions is aimed at assessing whether the developed water balance model can provide a realistic overview of the current conditions. For this purpose, the basic set of indicators presented and commented upon concern water deficits in the urban and agricultural sectors, the production of desalinated water and the current levels of groundwater exploitation. Furthermore, sensitivity analysis is employed to evaluate how assumptions relating to input data influence the model results (uncertainty associated with data used and modelling assumptions).

Figure 38 presents the 2010 deficit in the urban and agricultural sectors. As evident, urban water demand is fully met throughout the year. A small deficit is experienced in the agglomeration of Chroussa, which relies only on groundwater supply. On the other hand, the deficit in the agricultural sector is not as significant as described by local authorities and stakeholders (yearly coverage ranging between 80 and 90%). This is in line with results from previous studies, which indicate that in most cases farmers resort to deficit irrigation, to cope with the limited supply. Figure 38 reveals that the water deficit is more pronounced in September, whereas a smaller deficit is experienced in November. The September deficit is due to the fact that both groundwater storage and stored rainwater reach their lowest level at the end of August; thus, at the end of the hydrological year, freshwater availability is at its lowest value, and not enough water is available to meet irrigation demands.

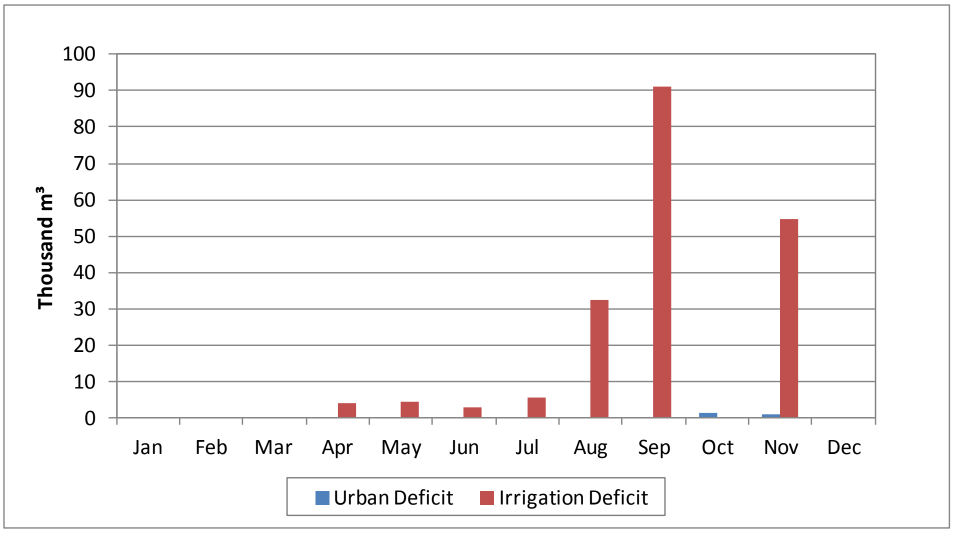


Figure 38: Water deficit in the urban and agricultural sectors for the 2010 baseline

Figure 39 presents the desalinated water production in the 5 major units of the island. Of the simulated values of water production from individual units, desalinated water production in Hermoupolis is in full agreement with the data obtained by the Municipal Enterprise for Water Supply and Sewerage of Syros-Hermoupolis.

It is further worth noting that during the summer peak the installed capacity is adequate to meet water needs in all agglomerations. The highest levels of capacity exploitation concern Hermoupolis, Poseidonia and Vari (90%, 74% and 70% respectively), whereas the lowest are observed in the agglomerations of Galissas and Kini (63 and 46% respectively).

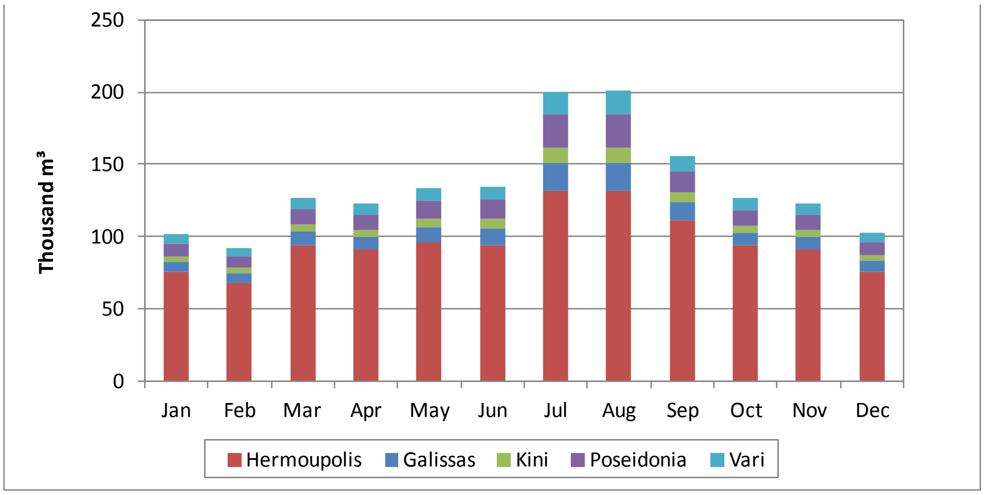
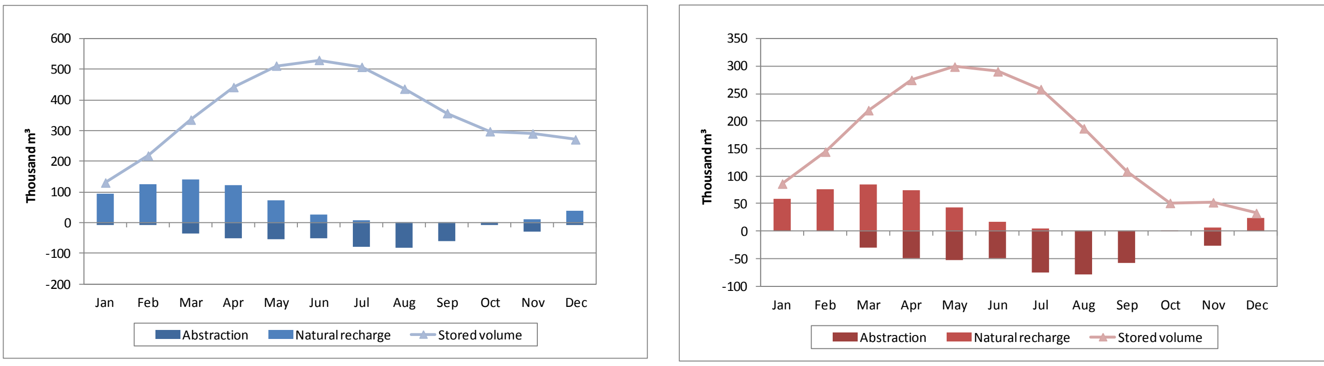
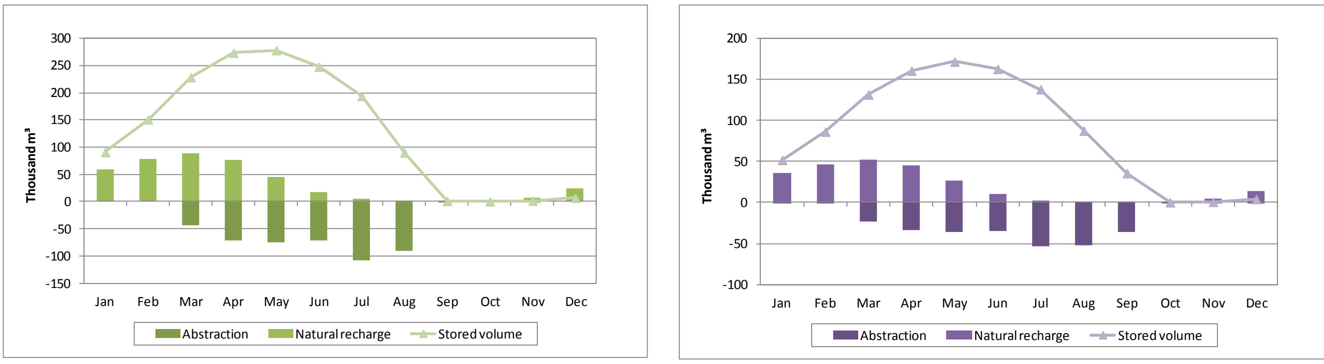


Figure 39: Desalinated water production for the 2010 baseline

Figure 40 presents results on groundwater extracted from each hydrogeological unit vs. stored volumes. On an annual basis, and in the case of all hydro-geological units, abstractions are almost equal to the estimated annual recharge, indicating a very high exploitation rate of groundwater bodies.



(a) Hydrogeological unit of Ano Syros-Hermoupolis (b) Hydrogeological unit of Galissas



(c) Hydrogeological unit of Poseidonia (d) Hydrogeological unit of Vari

Figure 40: Water balance in the hydro-geological units of Syros for the 2010 baseline

Table 5 summarizes the results from the sensitivity analysis for the baseline conditions.

Table 5: Sensitivity analysis results on baseline parameters for the Syros water balance model

Parameter	**Baseline value**	**Range of values tested**	**Results**
Water losses (leakage) in distribution networks	15%	15-25%	Domestic demand coverage: 100% (No change) Irrigation demand coverage: 89.6-89.7% Desalinated water production: 1.62 -

			1.82 million m^3/yr Groundwater exploitation index[iii]: 97-99%
Share of irrigation demand met through cisterns	15%	5-20%	Domestic demand coverage 100% (no change) Irrigation demand coverage: 87.5%-92% Desalinated water production: 1.62 million m^3/yr (no change) Groundwater exploitation index: 99%-94%
Overnight stays	383,577	± 20%	Domestic demand coverage: 100% (No change) Irrigation demand coverage: 89.6% (No change) Desalinated water production: 1.60-1.64 million m^3/yr Groundwater exploitation index: 97% (No change)

With regard to the sensitivity analysis results, the following are noted:

- Domestic demand coverage is not affected by the change of the corresponding parameters. The higher allocated priority assigned to domestic water requirements results in full coverage of the corresponding demand, despite changes in the actual quantity needed.
- Desalinated water production is affected by potential water losses, and to a lesser extent by overnight stays. The first result is expected, as desalination is the primary source of water supply for most agglomerations. With regard to the latter, the rather small change in desalinated water production is due to the fact that domestic water demand is dominated by permanent population requirements. Thus, the impact of small deviations in overnight stays and peak demands does not significantly affect the use of desalinated water.
- The overall groundwater exploitation rate is always about 100%, as, under all tested cases, there is deficit in the agricultural sector. Increased cistern capacity can have a minor effect, both in terms of irrigation demand coverage and in terms of groundwater overexploitation (a 5% increased capacity results to about 3% improvement in both indicators).

[iii] The groundwater exploitation index is defined as the ratio of groundwater abstractions vs. groundwater recharge.

4.5.2 Future scenarios

The analysis of simulation results for different scenarios is aimed at assessing how the water balance of Syros will be affected by climate change and other socio-economic developments. The simulation of scenarios was based on the baseline model, incorporating climate projections provided by CMCC, and on assumptions for future socio-economic developments. Future climate projections concern temperature and precipitation data for the 2011-2050 period from the HIRHAM5 Regional Climate Model, forced by the ECHAM5 GCM for the A1B IPCC scenario. It should be noted that based on this data, natural recharge and crop irrigation requirements are calculated by the corresponding modules of the WSM DSS, and thus the corresponding results provide an integrated assessment of climate change impacts. For the purposes of future simulations, the contribution of all other water sources was considered equal to the baseline conditions. Socio-economic scenarios for Syros describe alternative futures for the island for the 2050 time horizon, and have been selected to formulate a best and a worst case alternative so as to adequately represent the range of future uncertainties.

From the scenarios described in Table 6, the “Balanced economic development – Environmental protection (BE - EP)” and the “Unilateral economic development – Environmental degradation (UE-ED)” scenarios represent the best and worst case alternatives, and have thus been used as the basis for the simulations. Overall, this analysis concludes that climate change can create the potential for tourism enhancement throughout the year, despite the fact that slight decreases can be expected during the summer season. Enhancement potential corresponds to the “flattening” of the tourist season towards spring and autumn; the exploitation of this potential would however require supporting changes and investments. Thus, two more scenarios were developed to simulate this type of alternative, based on the initial BE-EP and UE-ED assumptions. According to the sensitivity analysis results, tourism water demand can affect desalinated water production and potentially domestic deficits. In this regard, results presented for these two scenarios focus on domestic water demand, domestic demand coverage and desalinated water production.

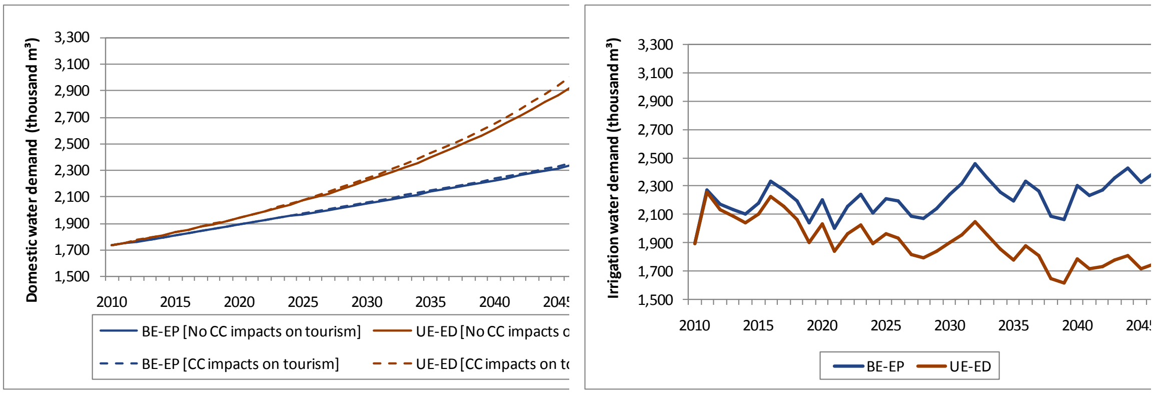
Scenario simulations were run for the entire 2011-2050 period. Indicative results on domestic and irrigation demands and deficits, desalinated water production and groundwater exploitation for the entire period are presented in Figures 41 to 44.

Results are further summarized through a basic set of indicators concerning water security, environmental security and economic security (Table 7). Indicator values are provided over decadal time spans [2011-2020; 2021-2030; 2031-2040; 2041-2050], in order to better illustrate their evolution, according to climate projections and socio-economic developments, and for the entire simulation horizon [2011-2050].

Table 6: Parameters of socio-economic scenarios for Syros

Category	Parameter	Balanced economic development – Environmental degradation (BE-ED)	Balanced economic development – Environmental protection (BE - EP)	Unilateral economic development – Environmental protection (UE-EP)	Unilateral economic development – Environmental degradation (UE-ED)
Population (permanent and seasonal)	Population growth	0.8% per year			
	Tourism growth (overnight stays)	3% per year	2% up to 2020, 1% onwards	3% up to 2020, 1% onwards	5.9% per year
	Change in the number of people with holiday residence	According to population growth estimates			
Land use	Urban expansion	According to population growth and current population density			
	Change in total cultivated land	No change		Reduction by 30%	
Agriculture	Cropping patterns	20% decrease of the area of arable land and corresponding increase of the area of vegetables	20% decrease of the area of arable land and corresponding increase of the area of vegetables	30% decrease in the area of all crops	30% decrease in the area of all crops
Livestock breeding	Change in livestock types/number	No change	No change	Only cattle breeding	Only cattle breeding

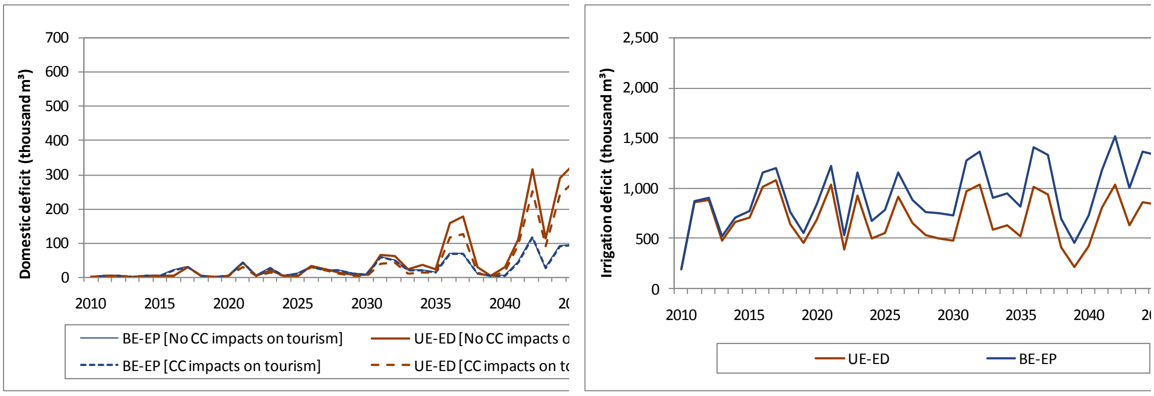
Figure 41 presents the annual domestic and irrigation requirements for the scenarios for the entire simulation period. Domestic water demand is dominated by permanent population water requirements, and is not significantly affected by climate change impacts on tourism. This is particularly true in the case of the BE-EP scenario, which describes a pattern of light tourist development. Irrigation demand is significantly affected both by climate change (reduction in precipitation and increase of evapotranspiration) and by scenario parameters. An abandonment of agricultural activities, as described in the UE-ED scenario, would result in an average decrease of irrigation requirements of about 25% during the 2041-2050 period.



(a) (b)

Figure 41: Domestic and irrigation water requirements for the BE-EP and UE-ED scenarios for 2010-2050

Figure 42 presents deficits in the domestic and agricultural sectors. Starting from 2015, minor deficits are experienced in the domestic sector, which become more pronounced towards the end of the simulation period. From 2030 and onwards, the domestic deficit is significantly more pronounced and gradually affects all agglomerations. Thus, domestic water supply becomes much more dependent on variations in groundwater availability, and demand coverage is significantly reduced towards 2050, when rainfall values, and thus groundwater availability, are extremely low. As expected, deficits are higher for the UE-ED scenario; if climate change impacts on tourism are also included ("UE-ED [CC impacts on tourism]" case), the deficit is somewhat lower. On the other hand, deficits in the agricultural sector are significantly more pronounced. The average coverage of water demand towards the end of the simulation period, when a significant decrease of precipitation is foreseen in the HIRHAM dataset, ranges between 40 and 60%, depending on the scenario and the consequent decrease in irrigation demand. This is a combined result of (i) reduced precipitation and increased evapotranspiration, (ii) reduced groundwater availability, and (iii) increased groundwater abstractions for domestic use, which has a higher priority than irrigated agriculture.



(a) (b)

Figure 42: Domestic and irrigation deficits for the BE-EP and UE-ED scenarios for 2010-2050

Figure 43 presents desalinated water production. Although desalination capacity is not increased, currently, units are designed to meet peak water demands. To that end, and as water supply requirements gradually increase also for the rest of the year, desalinated water production increases. This increase is more pronounced in the case of the UE-ED scenario, and particularly for the case when climate change impacts on tourism are considered, as in this case, water supply requirements are more evenly distributed during the year.

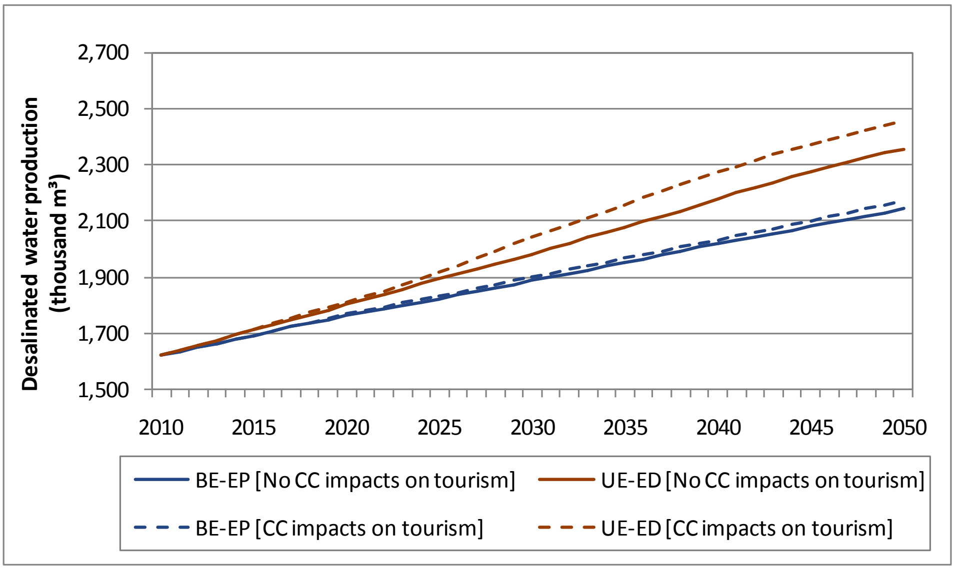


Figure 43: Desalinated water production for the BE-EP and UE-ED scenarios

Finally, Figure 44 presents the groundwater exploitation index for the entire water system (sum of abstractions vs. total natural recharge). Overall, the level of groundwater exploitation does not change much over the entire simulation horizon, as in all cases, available supply is inadequate to meet domestic and irrigation water requirements, and groundwater bodies are exploited in the fullest possible extent. Minor differences between the scenarios are attributed to the reduction of cultivated area and irrigation demand in the UE-ED scenario, which allows replenishment of the aquifers in years when precipitation in the HIRHAM5 dataset is higher than average.

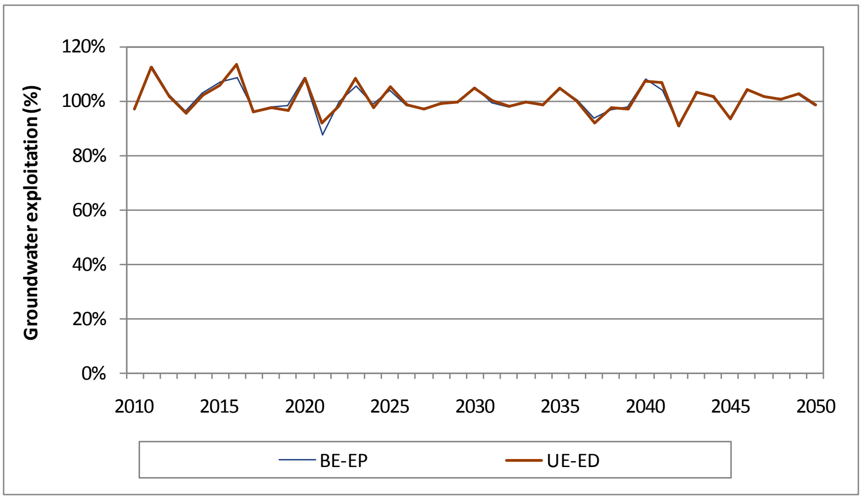


Figure 44: Groundwater exploitation index for the Syros water system in the BE-EP and UE-ED scenarios

Table 7: Range of values of indicators on water-related security threats for future scenarios (without adaptation measures)

Security aspect	**Indicator**	**Value range**				
		2011-2020	**2021-2030**	**2031-2040**	**2041-2050**	**2011-2050**
Water security	Average domestic demand coverage	100%	99%	98-99%	93-97%	**97-98%**
	Reliability in domestic demand coverage [threshold: 95%]	0.96-0.98	0.86-0.93	0.8-0.86	0.61-0.68	**0.82-0.84**
	Average irrigation demand coverage	68-70%	67-73%	63-70%	49-56%	**62-67%**
	Reliability in irrigation demand coverage [threshold: 80%]	0.51-0.53	0.55-0.6	0.5-0.57	0.34-0.48	**0.48-0.54**
	Resilience in irrigation demand coverage [threshold: 80%]	0.15-0.16	0.17-0.19	0.18-0.19	0.1-0.14	**0.15-0.18**
Environmental security	Groundwater exploitation index [average]	103%	99-100%	99-100%	100%	**100%**

Security aspect	Indicator	Value range				
		2011-2020	**2021-2030**	**2031-2040**	**2041-2050**	**2011-2050**
Economic security	Yearly average of total economic value from domestic water use, incl. tourism (M€/yr, current values)[iv]	156-190	180-317	190-541	186-699	178-434
	Yearly average of gross economic output from agriculture (k€, current values)	246-292	44-163	61-113	0-1	**93-141**

From the range of indicator values summarized in Table 7 the following can be summarized:

- Water security gradually deteriorates in the simulation for both water use sectors, both in terms of average coverage of water demands and in terms of reliability. During the 2041-2050 period, domestic demand coverage exceeds 95% at only 60-68% of months. The situation is considerably worse for the agricultural sector, where both reliability and resilience in meeting 80% of irrigation water requirements is very low.

- Groundwater exploitation is always very high, with total abstractions equaling available recharge.

- As irrigation water demand coverage is very low, economic output from agricultural activities is low, and equals almost 0 towards 2041-2050, even in the case when irrigation demand is considerably reduced (UE-ED scenario). In turn, this implies that the preservation of agricultural activities would necessarily require supporting measures, to ensure that agriculture is not abandoned. As further improvements in irrigation efficiency are not possible (micro-drip irrigation systems are already employed by most farmers, and efficiency is currently estimated at 95%), adaptation measures would need to focus on the supply-side, through the introduction/enhancement of non-conventional water supply sources.

- There are substantial differences among scenarios on total economic value from domestic water use, due to the very different projections in terms of overnight stays. Lower values correspond to the BE-EP scenarios, whereas higher values to the UE-ED

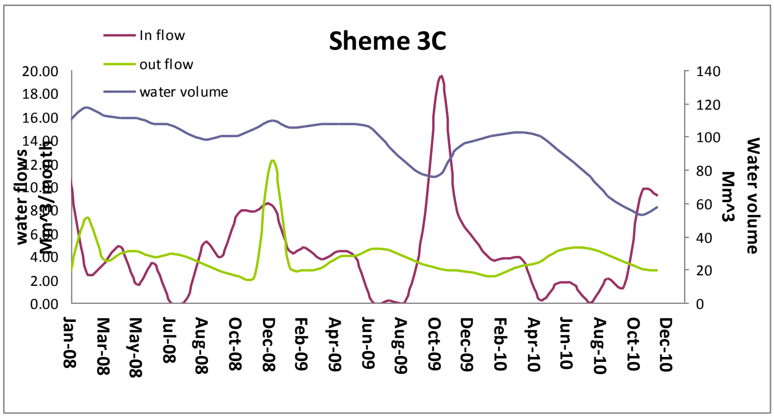
[iv] The WSM DSS offers different possibilities for the estimation of the total economic value from domestic water use. In the Syros water balance model, the indicator is estimated as the sum of the marginal water supply cost (i.e. the cost of the most expensive water supply source under use) for residential water demand [households], plus the economic output generated as a result of overnight stays that can be sustained [tourism].

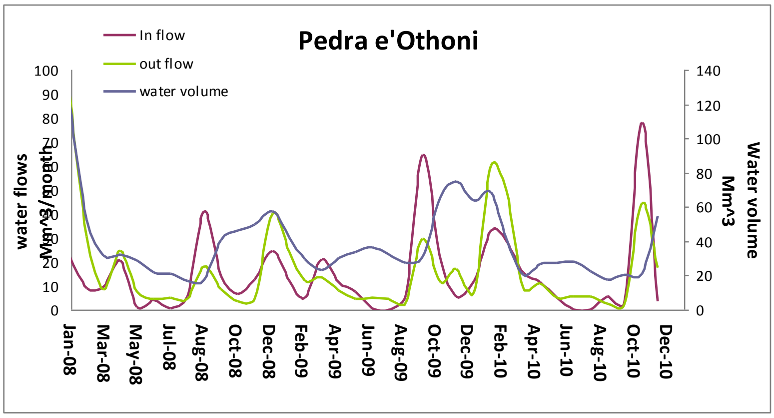
alternatives. The highest value is obtained when climate change impacts are considered, as in this case, the more evenly distributed overnight stays can be sustained by existing supply sources.

4.6 Water balance modelling results for Sardinia

These results for Sardinia are also summarised in Deliverable 5.2.3.

The results for the baseline scenario (i.e. 2008-2010) are shown for each of the four submodels: SCHEME 3C, Barroccus, Monte Pranu and Pedra e’ Othoni (Figure 45).





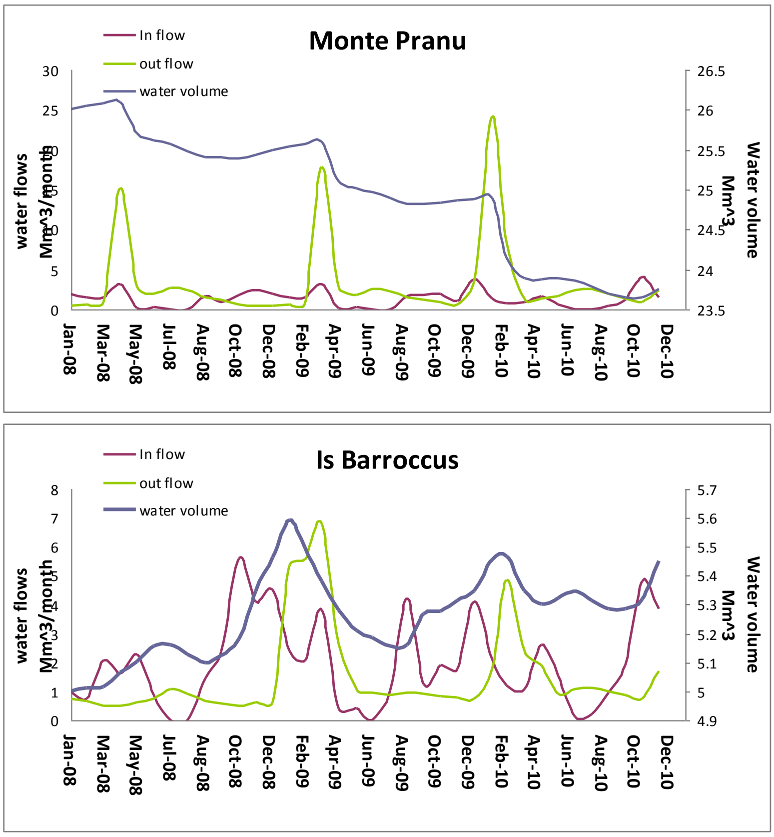
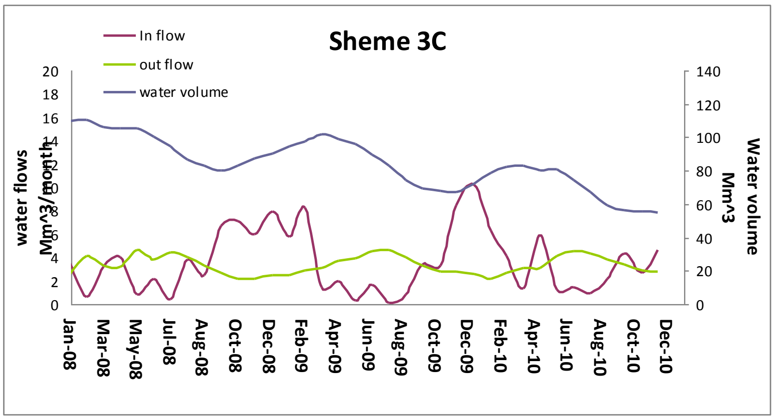
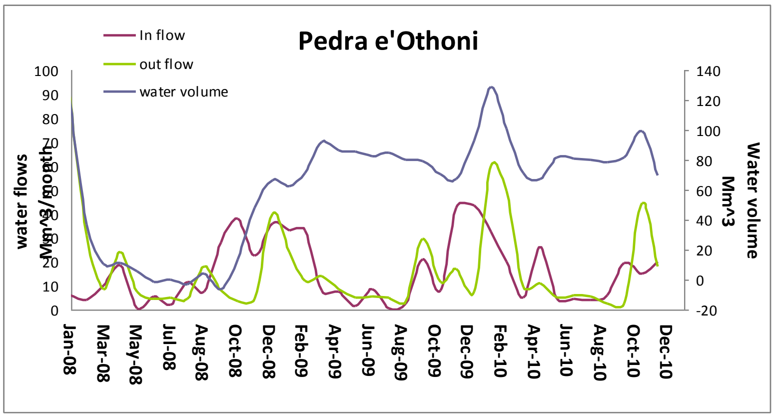


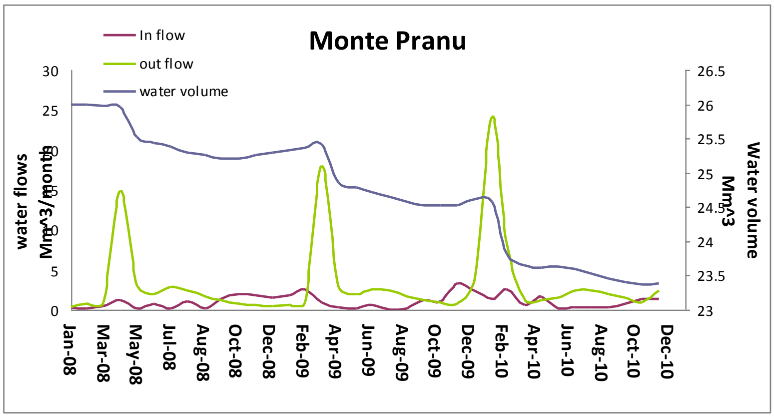
Figure 45: Baseline model results for the four modeled areas in the Sardinia case study

Scheme 3C, composed of three interconnected reservoirs, remains fairly stable during the three modeled years. The system serves a low population for domestic use and the rest is supplied to irrigation. However, the system has an important “safety role” as it can serve the large population and tourist flows in the nearby city of Alghero in case of water emergency. The Pedra e’ Othoni basin is one of the largest reservoir and serves multiple uses. The dam is currently under stress tests and also functions for hydropower production, which explains the winter outflow peaks. The water balance remains fairly stable throughout the year. In the Monte Pranu basin the demand slightly out-strips the supply and, as such, this basin show slightly decreasing water volumes over the years. However, the orography of the basin is complex and a better analysis may show that the subsurface catchment area is actually larger. Barroccus shows a slightly increasing trend of water volume in the reservoir, largely explained by low water demand mainly for domestic and touristic uses. In general, the trend of the water balance follows a high variability of precipitation.

Figure 46 shows the 2048-2050 scenarios where water inflows decrease by about 15%, dams can reach their full potential and overflows add directly to water discharges once total water storage capacity is reached. Thus, simulation for scheme 3C and Monte Pranu show a clear decreasing trend in water storage, which is very similar to the present. Pedra e’ Othoni shows a clear increasing trend, which is due to allowing the dam to reach its full volume storage capacity. Is Barroccus maintains a steady stored water volume. It should be noted that the allowed increases in water storage capacity will compensate for the predicted losses of water inflows, but that downstream ecosystems may be affected by the reduced flows.







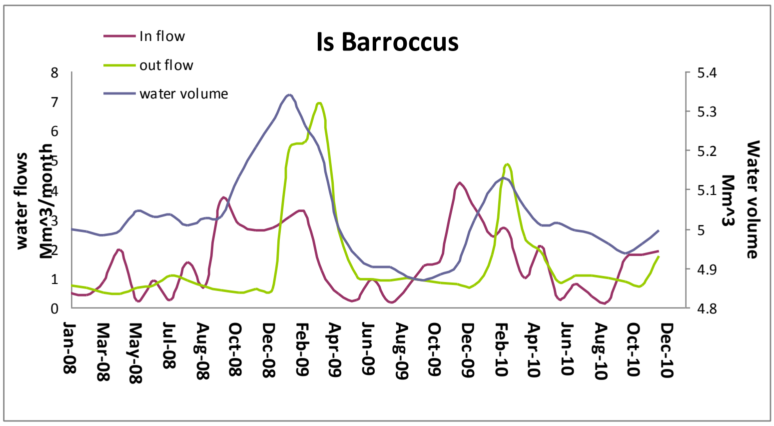
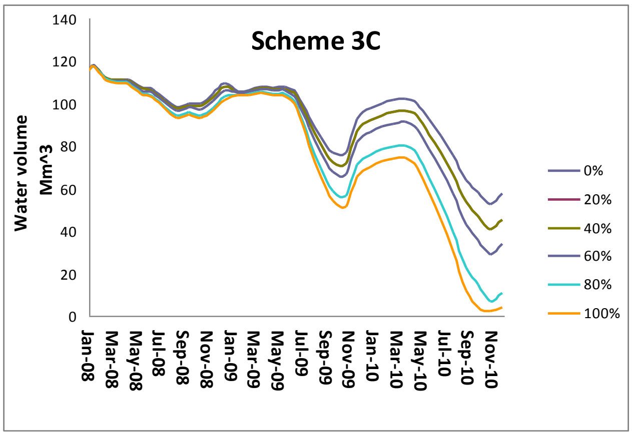


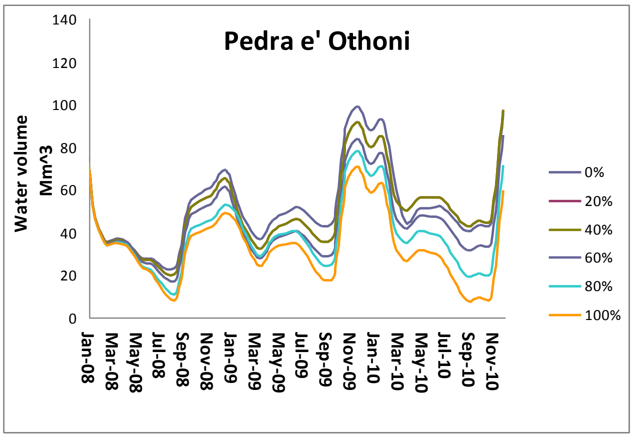
Figure 46: 2050 model results for the four modeled areas in the Sardinia case study

4.6.1 Sensitivity test for irrigation use

Simulations were run assuming the most water efficient irrigation system (drip irrigation) and the sensitivity test corresponds to percentage increases in irrigated land (Figure 47). Model outputs suggest that Scheme 3C cannot withstand a large increase in irrigated land as this would worsen the decreasing trend of the stored water in the reservoir.

Monte Pranu only satisfies a limited irrigated area and is not particularly sensitive to a change in irrigation demand. Pedra e' Othoni, can satisfy an increase of irrigation demand up to 40% without reaching a safety margin set as the water volume able to satisfy 70% of the annual demands under a scenario of 400mm of precipitation for three consecutive years.





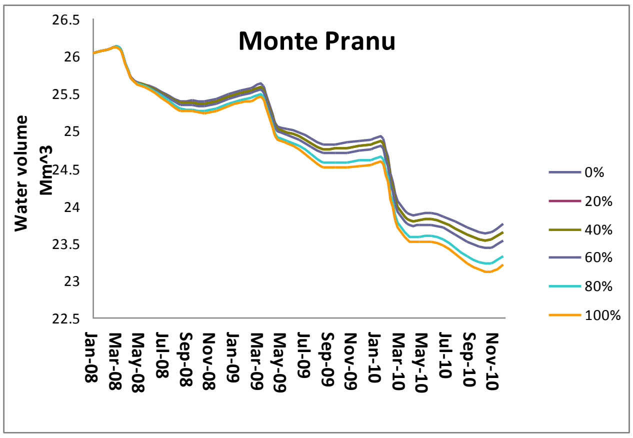


Figure 47: Sensitivity test for irrigation

4.6.2 Sensitivity for domestic use

Figure 48 shows the sensitivity test for domestic use assuming an irrigated area equal to present. An increase in domestic demand would worsen the water balance of scheme 3C, but this could be compensated for using more water efficient irrigation systems. It should be noted that in 2050 the chance for an emergency demand by the city of Alghero will increase. As for irrigation, Pedra e’ othoni could satisfy a large increase of water demands for domestic use. Monte Pranu and Is Barroccus are not strongly affected by increased domestic use.

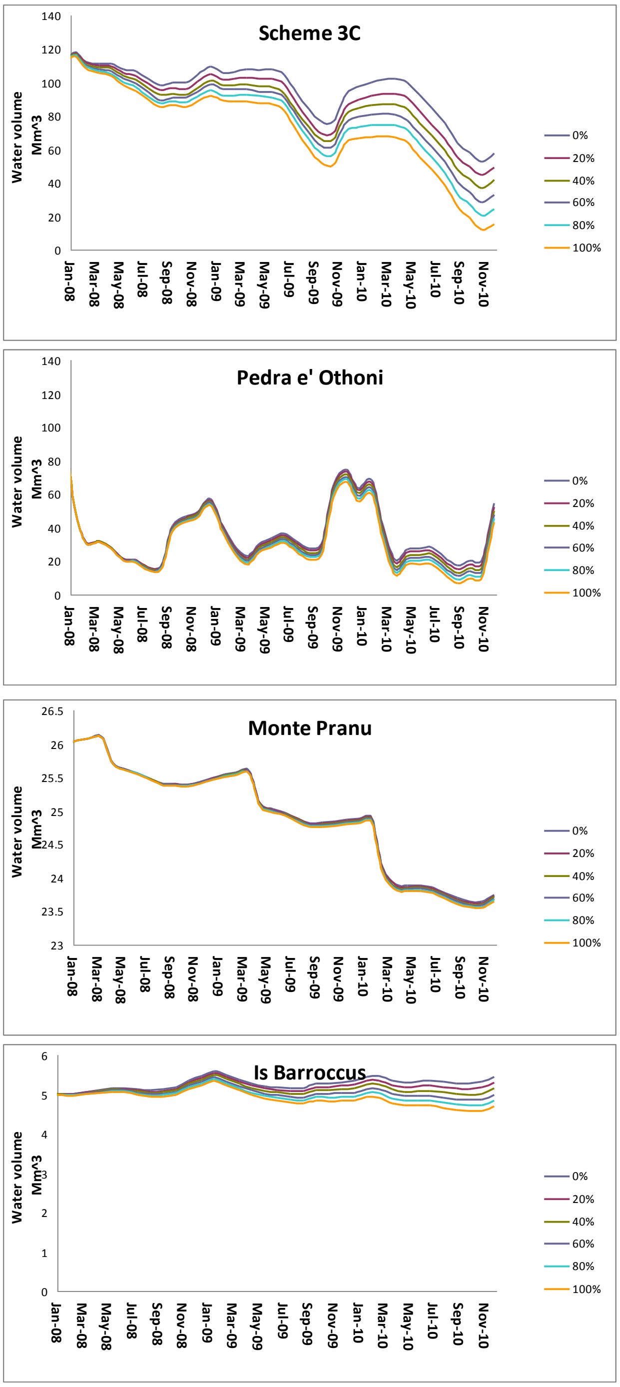


Figure 48: Sensitivity test for domestic demand

4.6.3 Water abstraction for irrigation at island level

Using the monthly water balance described in section 3.6.2, the potential irrigation need of the island under current climate (2005-2010) and current cropping pattern was estimated to be around 265 Mm^3. The irrigated area in each region was obtained by combining the national statistical data (ISTAT) with the CORINE land cover map and accordingly the total volume of water required by each crop in each Province is presented in Figure 49. Cagliari (24% of total) and Oristano (22% of total) are the two largest agricultural water demanding Provinces, followed by Medio Campidano (18%) and Sassari (17%). In terms of crop, vegetables and olive trees potentially are potentially the highest water consuming crops with one third each of the total crop water consumption of the island. Note that in this study, olive trees of the island were all considered irrigated at full requirement. Vineyards and fruit trees are estimated to consume 19% and 10% of the total irrigation water need of the island.

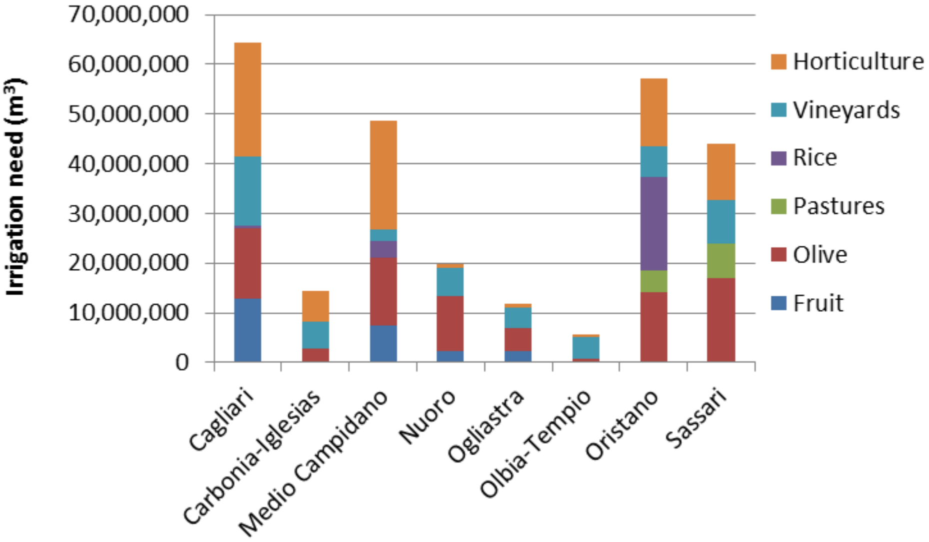


Figure 49: Irrigated volume required for each crop in the 8 Provinces of Sardinia

In the future, the total volume of water needed is estimated to be 258 Mm^3 which is slightly lower than the current demand (2005-2010) for the same cropping pattern. Figure 50 shows a reduction in crop water need in the south while the water demand in the north increases. Future climate projections, shows a general increase in temprature affecting the crop transpiratiuon but the summer rain for the Island (mainly june and July) is expected to slightly increase in the future especially in the Southern part of the Island. Consequently, the future total volumetric irrigation water is expected to be slightly lower than current for the Island. This variation is not unifrom across the Island, but is more noticeable in the South while the North a further increase in the crop water demand is expected.

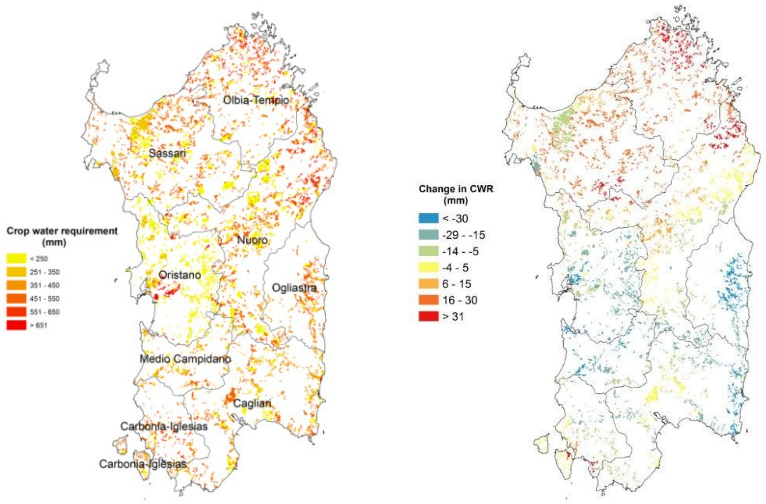


Figure 50: Estimated potential crop water need of Sardinia Island (2005-2010) and the projected future change (2050 period)

Figure 50 shows the cumulative water requirements in 2050 for the agricultural sector according to the four possible development scenarios.

Table 8. Total irrigation needs under historical and present conditions and future scenarios.

Period	Development Scenario	Total Irrigation Needs (million m³/yr)
1960-1990	-	295.2
2005-2010	-	303.1
2050	BAU	294.6
	IWS	353.6
	ISC	345.4
	ICP	351.4

4.6.4 Water abstraction for domestic use for the whole island

Estimating the direct impact of long-term climatic changes on tourist preferences and flows, TCI’s projections predict an enhanced overall tourist attractiveness of Sardinia and a positive trend of related overnight stays, with a cumulative increase of about +13% in 2050 mostly concentrated in shoulder and low seasons. At the same time, on the socioeconomic side comparison between alternative scenarios (Tab. 8) underlines the wide range of predicted values that, under different conditions, characterize both establishments’ capacity and tourism flows, as well as the evolutionary paths of regional water consumption levels (Fig. 51 and 52).

Considering present structural constraints which afflict regional tourism supply and demand (in terms both of market potentials and sustainability issues) as well as potential conflicts regarding alternative uses of water resource by different economic activities (among others, the primary sector), a suitable, joint prediction might be capable to manage tourism capacity and flows in order to qualify services, destinations and products, and simultaneously to shift towards more profitable and better distributed clients in time and space over the year.

In these terms, **BAU** and **ITG** scenarios turn out as incapable to explain tourism-related impacts of climate change in Sardinia. A neutral relationship between climate predictions and socioeconomic trends for tourism parameters is testified by a progressive consolidation of recent regional dynamics. The already unsustainable seasonal concentration of operational figures and overnight stays is worsened by an unbalanced evolution of tourist flows (respectively, +0.8% and +2.1% on annual basis), mostly concentrated during the summer months, with a falling role of the hotel sector and despite of increasing shares for international tourists; as a result, especially ITG scenario suggests a rising overcrowding effect with respect to residents’ number.

A relevant beds’ growth (respectively, +1.6% and +2.0% in terms of average annual rate) and an increasing interest for internal locations, in association with a deeper role of the hotel sector and bigger average dimensions of establishments, exacerbate present pressures on demographic and territorial dimensions. Due to a deeper gap between supply and demand growth paths, gross occupancy rates for the hotel sector consolidate the negative evolution path, leading to the disappearance of tourist flows during shoulder seasons or at least to a significant downsizing of respective volumes. At the same time, exponential increases both for coastal and internal districts suggest huge costs for regional community in order to expand water infrastructures to cater to the rising tourist demand.

On the contrary, under feasible projections towards average occupancy rates already observed at National scale for similar destinations, **SCST** and **BCSG** scenarios reveal demand growth rates and flows' relative compositions in line with climate strictly-related effects on a regional tourism dimension. Recognizing Sardinia as a mature destination and identifying the need to develop new alternative segments in order to prevent high and/or irreversible pressures on basic resources (as the main tourist attraction of tourism regional products), coherent results have been obtained in terms of average annual growth rates (respectively, +1.2% and +1.0%) and more than proportional increases in shoulder and low seasons. It explains a slight increase in tourist pressures but also avoids augmented overcrowding effects on the destination. These results come out mainly from stimulating a better flows distribution in time and space and focusing on diversified motivational issues, exploiting key "megatrends" of international market and attracting new and qualified tourists (in particular foreigners).

On the supply side, the first case translates a strictly controlled ecotourism development into unchanged accommodation profiles; moving from key elements resulting from legislative and political framework, the second one adopts a more competitive and sustainable approach and envisages requalification processes as well as a slight increase of existing stocks (an average annual growth rate of +0.3% in terms of beds). As a consequence, an overall expansion in terms of gross occupancy rates is expected for the hotel industry, in particular during spring and autumn months. On this basis, new water systems will probably need moderate financial investments by local authorities, in particular when additional supply initiatives will be oriented to qualify current unofficial establishments.

Overall, last scenarios capture, translate and valorize cumulative climate projections as part of a wider enhanced attractiveness of the destination, reached through a progressive modulation of infrastructural and market figures and in which seasonal water demand shows a more sustainable distribution over the year (Fig. 53), in line with climate predictions and basic resource availabilities in time and space. At the same time, despite of common trends, SCST scenario would imply a radical shift of present connotations with a new market positioning in a very short period of time. On the contrary BCSG scenario outlines a progressive transition for regional tourism sector, suitable in the light of present supply stocks and seasonal connotations on the demand side, and broadly consistent with TCI predictions. In this case, climate conditions would justify part of expected changes in tourist motivations, also induced by a renewed institutional perspective aimed to explore new products and market channels.

In addition to a more balanced seasonal and geographic distribution of tourist flows, water consumptions will also benefit from several effects relating to supply management schemes. Among others, both coastal and internal areas tourism management will refer to controlled small-scale units, with stringent requirements and guidelines for establishing new activities or qualifying the old ones, relying on the maintenance of the integrity of heritage resources and focusing on self-contained environmental impacts. Moreover a growing ecolabelling industry will shift operational processes and will hire customers' awareness towards sustainability issues.

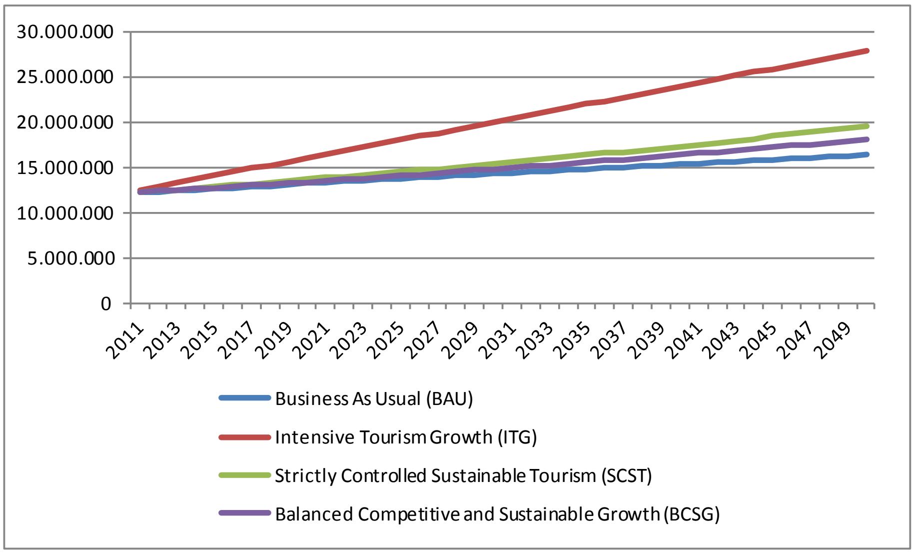


Fig. 51 Total overnight stays evolution paths, by scenario (2011-2050)

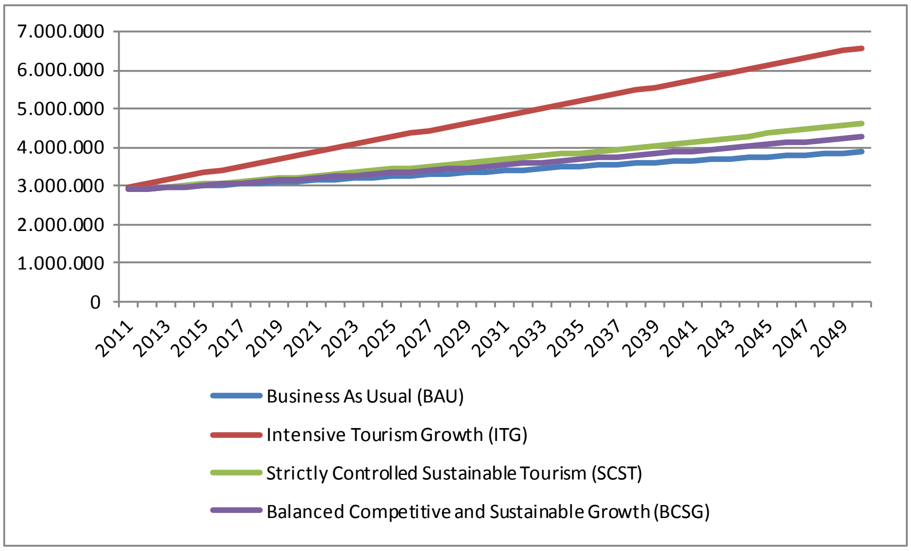


Fig. 52 Evolution paths for water consumption levels relating to tourism flows, by scenario (2011-2050) (*thousands of liters)*

Tab. 8 Scenarios in comparison

Indicator	Unit	Current value	BAU	ITG	SCST	BCSG
Total beds	n°	202.491	379.184	455.643	202.491	232.084
Total beds in coastal districts	%	92,5	84,8	84,6	92,5	86,6
Total beds in hotel establishments	%	52,6	61,1	54,8	52,6	51,3
Total beds per 1000 inhabitants	n°	120,9	255,3	306,8	136,3	156,3
Total beds per 1000 inhabitants in coastal districts	n°	216,4	419,4	502,6	244,1	262,0
Total beds per 1000 inhabitants in internal districts	n°	18,9	80,0	97,6	21,3	43,4
Total beds per100 km2	n°	840,6	1.574,0	1.891,4	840,6	963,4
Total beds per 100 km2 in coastal districts	n°	2.507,4	4.308,4	5.163,4	2.507,4	2.691,2
Total beds per 100 km2 in internal districts	n°	91,9	345,8	421,7	91,9	187,3
Average beds per hotel establishment	n°	116,3	136,0	134,1	116,3	87,2
Average beds per hotel establishment in coastal districts	n°	133,8	141,0	157,7	133,8	98,3
Average number per hotel establishment in internal districts	n°	41,6	36,6	41,0	41,6	37,4
4-5 stars hotels weight on total hotel beds	%	55,6	96,7	97,6	55,6	60,2
4-5 stars hotels weight on total beds	%	29,3	59,1	53,5	29,3	30,9
Website avalibility among secondary and tertiary firms with more than 10 employees	%	45,7	100,0	100,0	100,0	100,0
Ecolabel certified beds	n°	128	128	128	10.686	12.248
Total overnight stays	n°	12.172.923	16.462.390	27.929.099	19.597.147	18.147.861
Foreigners overnight stays on total flows	%	33,1	37,8	45,0	53,0	35,5
Hotel overnight stays on total flows	%	68,3	36,1	54,0	73,1	67,2
Total overnight stays in winter season	%	2,6	2,7	0,9	21,6	6,6
Total overnight stays in spring season	%	24,2	14,4	24,3	22,4	25,7
Total overnight stays in summer season	%	68,3	80,6	71,3	38,1	60,8
Total overnight stays in autumn season	%	4,9	2,3	3,5	17,9	7,0
Total overnight stays per inhabitant	n°	7,3	11,1	18,8	13,2	12,2
Gross occupancy rate in hotel establishments	%	21,4	7,0	16,5	36,8	27,3
Gross occupancy rate in hotel establishments in spring season	%	22,6	0,0	16,8	33,4	30,6
Gross occupancy rate in hotel establishments in autumn season	%	5,2	0,0	2,5	28,8	9,1

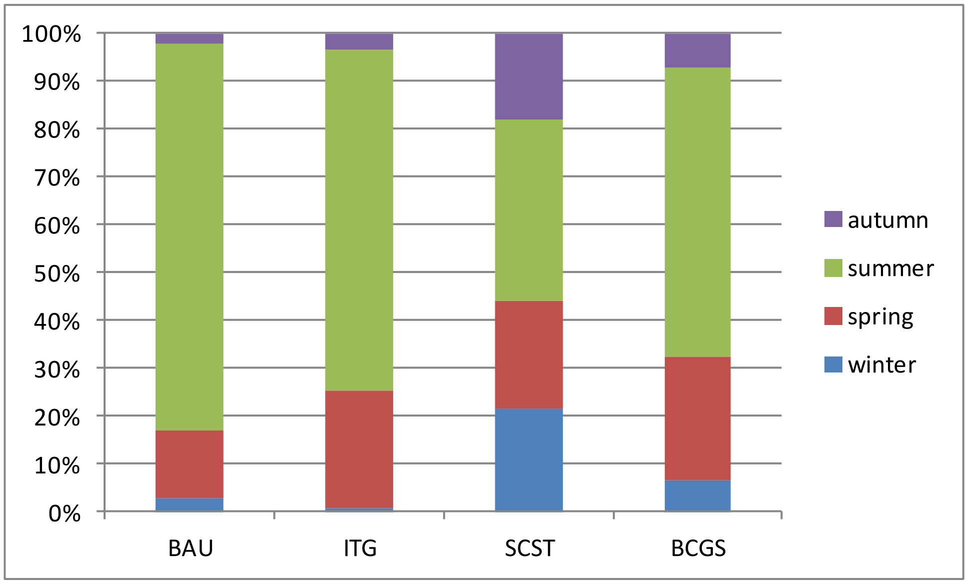


Fig. 53 Seasonal distribution of water consumption levels relating to tourism flows (2050), by scenario (*in % of total use)*

5. Implications of the results: towards indicators for policy development

The WASSERMed water balance models and the results for each case study have been presented in detail. These results have important implications for the individual case studies, but also for the wider southern Europe and Mediterranean region. We note here that no specific policy options are suggested. The implications here are intended as 'signposts' for further investigation for policy makers and local government to consider more fully.

5.1 Case-study specific implications

This section will briefly discuss the results in terms of the individual case studies and what they mean for the local water supply now and into the future as a result of global change.

For Tunisia, the current situation is one of water resource over-exploitation that is being driven by pumping of water out of the Kairouan aquifer to coastal cities to supply water for tourism. If current water behaviour continues, the water resource in the region will be highly stressed, potentially leading to shortages of supply, deteriorating water quality of the aquifer and of surface water bodies, and severe environmental degradation, particularly the loss of the fragile sebkha areas. Analysis showed that by reducing the coastal pumping element by 30-40% (in terms of volume) the water resource would be much less exploited, and a situation of surplus could be attained. The shortfall at coastal cities could be made up for example by developing 'new' water resources such as from desalinated seawater, the cost of which could be paid through a 'tourist-tax'. While this option delivers the most immediate and significant water saving measure, it is suggested that reductions in local demand are also attempted. This 'multi-pronged' water saving strategy would allow for redundancy to be built into the policy landscape. Therefore, if one policy failed to provide the savings expected, other policies could fill the gap. Also, by engendering water-saving behaviour, there is a better chance of long-term environmental sustainability and water availability, thus allowing continued growth, particularly in the dominant agricultural economy, which would be less likely to be targeted for water restrictions.

In Egypt, the situation is somewhat different. Here, the water supply is largely controlled by Nile River inflows, and is therefore vulnerable to potential reductions of this flow in the future, although it is noted that current model forecasts are highly uncertain regarding future Nile flow volumes, with some models predicting a significant increase. For the time being, the resource can be thought of as being limited throughout much of the country, and in the Rosetta case study. In addition, Rosetta is also facing the threat of land loss resulting from sea-level increases. Demand is also expected to increase as the population increases and as living standards improve. As with Kairouan, the current water resource is being over-exploited, with demand outstripping supply. This is hampering agricultural income due to irrigation water restrictions, and potential local development. Analysis shows that if Nile flows significantly increase over the present value, then water surplus will be attained. However, this must be taken with caution. The opposite is also possible - Nile flows could decrease, leading to greater issues regarding the water supply. Nile water flows into Rosetta, and indeed Egypt, are controlled by many upstream factors, and cannot be controlled. Therefore, relying on increases to inflows should not be relied upon to improve the current situation. The results show that by reducing demand in the domestic and industrial sectors, improvements can be made, although water surplus can not be achieved. Implementing savings in both sectors in parallel will of course amplify the effect of any savings that are made. Detailed analysis of the agricultural cropping pattern showed that by developing policy to encourage the planting of less water-intensive crops, not only is it possible to save considerable quantities of water (up to 21% when compared with the present day), but also to improve the yield of crop harvested and the agricultural income, helping to further local development. By growing more surplus crop, there is the potential to use this surplus to exploit international trade to further help the situation. Water-intensive crops can be imported using the profits from the sale of surplus crop, thus lowing the regional crop water requirement. As such, water-intensive crops can be substituted for less water-intensive, high yielding cash crops, creating a positive feedback loop whereby extra surplus is sold to import water-intensive crops, allowing for more high-yielding cash crop to be grown which provides more surplus and so on. It is shown in Section 4.3.7 that by exploiting such markets, improvements to the crop water requirement, yield and revenue can be made. By implementing domestic and industrial demand reduction with cropping pattern changes and market exploitation, there are potential opportunities to retain a secure water supply and give the chance for regional development. However, any such policy would have to be carefully managed, be considered at the national strategy scale, and would possibly only yield beneficial consequences after a number of years.

In Jordan, the situation and pressures being faced are very different again. Agricultural and domestic water availability is largely dependent on supply from the King Abdullah Canal and on small contributions from groundwater. At present, waste-water treatment and re-use is employed. Due to chronic, widespread over-abstraction of the Jordan water resource by many countries that has reduced the annual flow volume by over 80% from the historical baseline, the water supply is at a critical level, and in many communities, agricultural activity is curtailed as a result of the low water supply. The supply in the study area is also being unsustainably over-abstracted (Section 4.4.1). Predictions of water demand increase in response to social and climate change will likely increase the water stress in the region. Those simulations that predict moderate population and water demand increases together with substantial water supply improvements suggest that the water balance can be in surplus in the future, while those simulations that predict the opposite indicate a worsening of the present situation (Section 4.4.2). Although some of the results are optimistic, at present it is difficult to see where the significant supply increase will derive from, especially when the current over-abstraction (including that by neighbouring nations) and low rainfall totals in the region are considered. The cropping change simulation in Section 4.4.3 is possibly a more realistic scenario looking to the future as significant increases to the supply are not required to lead to water surplus. Rather, by gradually changing those crops with a high water requirement for those with lower water requirements, the regional water balance is gradually brought towards a situation of water surplus. Because the changes are gradual, there is no sudden 'shock' to local farmers, and this will help such a measure be more readily accepted. The downside is that while the current water situation will gradually improve, water surplus may not be observed for a number of decades, assuming that water supply and demand volumes do not change much from the present day. The scenario in Section 4.4.3 is a realistic one for mitigating future water shortages, and this and other similar and complementary policies should be seriously considered at the governmental level.

In Syros the water availability situation is not as immediately pressing as in the previous three case studies, however, the water resources are being almost completely exploited. For example, the exploitation rate of most of the groundwater bodies on the island is very close to, or at, 100%, with desalinated seawater making up any shortfall in supply. At present the water demand is fully met by supply year-round, however, change to climate and tourist influx may stress the system to an unsustainable level. All future scenarios lead to a gradual and consistent increase in both domestic and irrigation water demand, and as a result, water deficit increases. Despite this, the groundwater exploitation index remains at about 100%, never being significantly over-exploited. The shortfall is made up for by an almost linear growth in water supply from desalinated seawater. This is based on the assumption that the finances and energy are there to a) build the desalination plants and b) to run the desalination plants - desalinating seawater is an energy-intensive process that will likely lead to water-bill increases for local residents. The scenarios all agree on the prediction that the water security for Syros generally deteriorates into the future, with greater reliance on alternative sources of water. If these alternative sources are not built to full capacity, then the water-availability situation on Syros in the future may be very fragile, with shortages becoming a real possibility. Therefore extra capacity and demand reduction should be viewed as the key concerns and as priorities for policy.

Finally, water balance modelling for Sardinia shows that at the present day, the water balance and security situation is stable. The four basins analysed are, overall, able to meet demand needs. Because some of the basins are connected, if one basin is struggling to meet demand, water can be pumped from a neighbouring basin. Improvement water management rules over the past 5-10 years have meant that even in times of drought, there is more available water, and that less is wasted. New reservoir operational rules mean that the reservoirs are increasingly near-capacity, which is especially important considering that reservoirs provide a large share of Sardinia's water supply. In the future, increases to the domestic demand are not so critical. While one basin would not be able to cope with the increase, this could be alleviated by pumping water in from a connected basin. However, substantial increases in irrigation water demand is likely to have a larger impact. In this case, two basins are likely to be unable to meet the requirements. This would mean that they would have to be supplemented with water from other basins. However, these neighbouring basins would also be more water stressed, and would struggle to meet the shortfall. Therefore, future increases in demand, especially in the agricultural sector need to be carefully managed, and it may be wise to make plans for the provision of water from alternative sources. In addition, these simulations did not account for the impacts of extreme climate events. This could worsen the situation, for example by increasing the frequency and severity of drought events. This too must be carefully accounted for when planning the future water supply. The projections for future water demands for the whole island show that the present system, with some implementations to reduce water losses, will be able to satisfy the water demands for tourists under different development scenarios leaving enough water to also expand the irrigated areas. However, the intensive development scenarios for tourism will require high investments to implement the network well beyond those planned by the regional government.

5.2 Synthesis of implications for the wider Mediterranean region

The case studies illustrate the vast complexity and diversity of the issues being faced throughout the Mediterranean region. Some areas are facing water-related security threats as a result of groundwater shortages, others due to river water supply issues, sea-level rise, trans-boundary water sharing issues, tourism increases and demand increases. On top of these issues, social and climate change will probably lead to increasing demand across sectors while the supply either remains stable or falls. Many areas are facing more than one problem, making mitigating more challenging. This is especially the case for those areas which rely on water from transboundary sources as the volume of water entering their territory cannot easily be controlled (e.g. Egypt, Jordan).

This implies that there is no single 'quick-fix' option for managing water security and related threats in the region. Much of the research carried out in these case studies suggests that not only are multiple policy options implemented in parallel that complement each other required, but also that many of the options may not start to produce noticeable benefits for a number of years or even decades. In addition, many of the options must be well managed and regulated if they are to work effectively, and therefore require social and political will and support at national levels. By implementing many options in parallel, redundancy is built into the policy landscape, reducing reliance on one cornerstone measure, and building resilience should any particular measure be unsuccessful. Because these conclusions were found to be consistent across the case studies, it is probably also the case throughout the Mediterranean, though of course the exact type of measure(s) required and the extent to which certain measures need to be implemented will vary widely depending on the particular area under consideration.

5.3 Indicators for water-related security threats

In many cases, it is impossible or unfeasible to directly monitor the water balance with good accuracy for any given area. As a result, good quantitative assessment of the actual water resource can be very difficult to obtain, and if it is obtained, it can be associated with considerable uncertainty. In addition, many policy makers may not be familiar with the hydrological concepts that are attached with water balance assessments. Therefore, sets of indicators are usually used either as surrogates for accurate quantitative assessment and/or as communication tools to non-expert stakeholders such that they can get a quick, clear understanding of the past, present and potential future situation.

Through this research, it is clear that a number of indicators could be used for each case study and for the whole Mediterranean region. In Tunisia, rather than attempting to measure the absolute volume of water being moved into and out of the Kairouan aquifer, there are a number of indicators that can reflect the overall water balance situation. The concentration of pollutants in aquifer water can be measured easily. If the concentrations are observed to be increasing over time, this may reflect decreasing water stored in the aquifer (it could also reflect increasing pollutant loads entering the aquifer). So pollutant concentration is a potential indicator. The volume of water pumped to coastal cities has been shown to be critical in this region for the status of the water resource. Therefore, the annual/monthly pumped volume could be another indictor. Because water is essential for agricultural productivity, the volume or weight of crop produced in the region could also be another indicator of water supply - large decreases in production could indicate lower water availability. Finally for Tunisia, the coastal cities depend on water from Kairouan for a lot of their supply. If this supply was to be curtailed, the shortfall would probably be made up using desalinated seawater. The volume of freshwater supplied to coastal cities could therefore be another indicator. Increases in this volume could represent a decrease in pumping from Kairouan.

In Rosetta, the situation is difference, and therefore, suitable indicators are also different. Here, one crucial indicator is likely to be the volume of water that Egypt is entitled to under the Treaty signed with Sudan. This will have direct consequences for the Rosetta region, and is therefore important to monitor closely. Another critical indicator could be the amount of land lost to sea-level rise. This should be easy to assess from high-resolution satellite imagery. As with Tunisia, the amount of crop grown and more importantly, it's value/revenue can both be used as indicators for water security, with downturns potentially hinting at water scarcity. If these trends were to be observed, the situation could be monitored much more closely. Another more subtle indicator could be proportion of farmers moving to more efficient irrigation practices. An yet another could be the area planted with certain types of crops - as water becomes more scarce, farmers may switch to less water-demanding crop types. As with Tunisia, a suite of indicators should be used to give as clear a picture as possible regarding the water security situation.

In Jordan the volume of water held in the King Abdullah Canal is a critical indicator. Because this is a man-made structure, the volume can be much more accurately assessed, and as much this indicator is a realistic and important one. In a similar manner to Rosetta, the amount and type of produce grown in the region may also reflect the water availability situation. If less crop is produced, or if there is a switch to less water intensive crops, this could suggest lower water availability. However changes in crop type could be due to policy incentives aimed at reducing water demand by encouraging farmers to switch crop types. This would have to be investigated in detail if such a trend was observed. One final indicator could involve a potential large-scale engineering project in Jordan - the Red-Dead Water Transfer project. This involves the construction of a pipe/canal that will transfer water from the Red Sea basin to the Dead Sea basin to top-up the supply there. The indicator could show the volume of water transferred to the Dead Sea basin as a result of this project. The results here suggest however that such a project is not necessarily required to improve the water availability situation - changes to cropping patterns can have the same effect. However, the project may also help to restore the ecosystem functions in the lower Jordan River.

Probably the most important indicators of water security in Syros are the groundwater exploitation index and the volume of freshwater supplied from desalinated seawater. Currently, the groundwater resource is exploited at, or very close to 100%, so there is not much opportunity for further development of this resource without considerable over-exploitation. Monitoring the exploitation index is critical therefore, and will likely become more critical in the future as a result of climate-change impacts to the hydrology on the island. Because of the expected increases in domestic and irrigation water demand, and the fact that groundwater is unable to meet this extra demand, desalinated seawater looks to be the best option for supplying the shortfall. As a result, the volume of freshwater derived from desalinated seawater is another key indicator on Syros, and will reflect how much the islands water demand is increasing.

Finally, on Sardinia, the single most important indicator is the volume of water that is stored in each of the four reservoirs. Like in Jordan, because these are man-made structures, the volume can be assessed much more accurately than for a natural system. The volumes of water stored should always be above a critical threshold. Therefore possible indicators are i) the absolute volume of water stored in each reservoir and ii) the number of times in a given time period that the volume drops below the threshold. If this frequency was observed to be increasing, it may be suggested that the water security situation was getting worse. Another potentially useful indicator is the volume of water that is transferred between basins. If this volume is observed to increase, it could indicate that one basin is struggling more than the others to meet the total water demand, and is therefore more reliant on water from neighbouring basins.

It is clear that there is no one single indicator to assess water security across the southern Europe and Mediterranean region. This is due simply to the diversity of the challenges and situations being faced. Some places will require indicators for groundwater levels/water quality, other for economic output of agricultural activity or for land-loss. Still others will require indicators for reservoir levels or inter-basin water transfers. With regard to the whole Mediterranean region, there are only a few indictors which may be useful in assessing region-wide water availability and security. One is population change. Increasing population usually leads to increasing water demand, and so national and regional statistics of population change could help inform predictions of future water demand. Model predictions of rainfall and temperature change throughout the region may also help in assessing the direction of change to water security in the future. By having a better understanding of the large-scale changes to the climate, more robust assessments of future water supply can be derived. As such, indicators may include the change in average daily, monthly and/or annual temperature relative to today, or the changes to precipitation (e.g. changes to annual, monthly totals, number (non-) rainy days, etc.). These would all help to build a better picture of the potential challenges being faced in the future. These broad-scale indicators must however be coupled with more locally specific indicators such as those proposed here for the WASSERMed case studies in order to get a comprehensive picture of the future water availability and security trends.

6. Summary and Conclusions

The work presented throughout this synthesis report has consistently highlighted some common themes. The first is that areas throughout southern Europe and the Mediterranean are suffering from some form of water security and availability issues, and that these issues are likely to change into the future in response to climate and social changes. The second is that, locally, the nature of the stresses being faced is very different, meaning that there is no single broad-scale solution to water security and availability in the region. Thirdly, there are a few common issues across the region, irrespective of the location. For example, population increases and water demand increases are two such common themes. This leads to an over-arching, Mediterranean wide analysis but highlighting local variations that are essential for a full analysis of local water-resources problems.

The work presented here for the WASSERMed project also shows how two different modelling approaches, here SDM and the WSM DSS, can be used together to draw complementary results and analysis of water-related security issues between case studies. While the approaches are different in their philosophies and in their mathematical background, both have been used to great effect here to analyse in detail the current and potential water-related security issues in each of the five WASSERMed case studies.

The general current situation throughout the Mediterranean region, as interpreted from the results generated in WASSERMed, shows widespread, chronic water-resource over-exploitation. The magnitude of the over-exploitation is very different between locales, and in some areas, the resource is in fact not being over-exploited, generally however, there is over-exploitation of water-resources throughout the Mediterranean. As hinted at, there is considerable variation on this general situation. For example, in Tunisia, Egypt and Jordan, the water resource is being considerably over-exploited, potentially leading to severe water shortages in the future. However, of these three, Tunisia has a single option that could be employed that would significantly improve the situation (i.e. reducing or limiting pumping from the Kairouan aquifer to coastal cities). In Egypt and Jordan, there are other policy options being explored in order to lower the level of exploitation. These options mainly consider changes to the agricultural sector. However, because the changes also implicitly involve the cooperation of local farmers (e.g. to agree to changing cropping patterns), there is a greater chance of policies not meeting their potential reductions as a result of farmer resistance to change for example. In Sardinia and Syros however, the water resource is not currently being over-exploited, but is very close to that threshold, particularly in the case of Syros, where the groundwater exploitation index is close to 100% for much of the time. Sardinia is currently the best-placed case study in terms of its water resource. However this situation has come about in response to major, island-wide droughts that occurred in the early 2000's. As a result of the droughts, more redundancy was built into the system, and reservoirs are now managed better, meaning that they are generally closer to capacity year-round, and that they are interconnected, meaning that if one reservoir experiences low volumes, it can be topped-up from neighbouring reservoirs. Despite this, there is still concern about what impacts climate change and population increases will have on the future water resource.

The current over-exploitation is potentially hampering local and regional development, as shown particularly well in the Tunisia and Egypt case studies. At present, the local economy of these areas is unlikely to be meeting its full potential as a direct result of farmers not being able to properly irrigate crops due to water restrictions and/or shortages. There is anecdotal evidence that a similar situation is occurring in Jordan, with many farmers unable to irrigate all their land, thus reducing crop yields, sales and exports, all of which will negatively impact the economy and development opportunities.

All modelling efforts also broadly agree on future scenarios, and again, there is considerable local variation on the general trend. Most future scenarios with respect to climate change suggest that rainfall totals will be lower and/or more erratic (less reliable), and that temperatures will increase, lengthening the growing season, but at the same time increasing plant evaporative demand, leading to increased agricultural water demand. Social changes are generally reflected by assumed increases in population and in living standards, both of which hint at increasing domestic water demand. Generally, future scenarios including climate and social change point to worsening water-resources situations in the case studies, with greater levels of resource over-exploitation, potentially leading to water restrictions, severe water shortages, impacts to agriculture and/or hampered development opportunities.

As a result of the potentially detrimental impacts of climate change to the case studies, a series of hypothetical mitigating policy options were modelled for each case study, representing 'what-if' analysis of potential changes to impacts if various policies were to be implemented. These measures included: policies aimed at reducing domestic and industrial demand, changes to cropping patterns aimed at reducing irrigation water requirements, policies to reduce pumping to external users, and so on. These policies generally had positive impacts, but again the impact of the policies on the water resource varied considerably across the case studies. For example, in Tunisia, the policy to reduce pumping out of Kairouan had a large impact, helping to reverse the current trends, while in Egypt and Jordan, changes to cropping patterns aimed at lowering the irrigation water requirement, also had a significant impact. However, measures to reduce domestic and/or industrial demand generally had a lesser impact due to the lower volumes involved.

Despite this, another common theme across all the WASSERMed case studies was that multiple initiatives should be implemented in parallel such that a) redundancy in built into the policy landscape, so that if one policy fails, or does not bring its potential savings, other policies can fill the deficit; b) the responsibility of water saving is spread across sectors, leading to less chance for resentment by any particular sector and; c) if all policies do succeed, the savings could be substantial, and provide for a water-secure future.

To conclude, while the present water security situation may look serious, there is considerable room for water-balance improvements, and these improvements can be made with relatively little change in lifestyle habits. Political will is the main object that is required. Through a suite of subtle changes and demand management, a more water-secure future throughout southern Europe and the Mediterranean is feasible, and with it, environmental protection, healthy lifestyles and economic development.

7. References

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