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Executive Summary

At present there are over 1 billion people around the world who do not have access to clean drinking water, and 2.5 billion who do not have access to basic sanitation. Many places around the globe are facing water availability and security issues due to either a lack of supply, overexploitation of the supply (i.e. too high a demand) or both. The Mediterranean, which is the focus for WASSERMed has been identified as a hotspot of current and potential future water crises.

Projections of climate change tend to suggest a gradual warming of Earth surface temperatures, leading to increases in evaporation rates. Focusing on the Mediterranean, rainfall totals are expected to decrease across much of the basin, and/or become more sporadic. This will result in lower streamflow totals and less water recharging reservoirs and aquifers. This seems to imply a reduction in the water supply, or at least it becoming more unreliable.

In addition to these climatic changes, are the even more uncertain changes related to socio-economic development, which are impossible(?) to predict as exemplified by the recent Arab Spring and the ongoing global financial crisis. Generally however, the population is predicted to increase (to 9-11.5 billion by 2050) and is expected to become richer overall. Both these factors tend to increase water use per-capita as homes use more water-based appliances and as diets change to incorporate more water-intensive products (especially meat).

This report details the water-balance modelling results for the five WASSERMed case study areas: Kairouan, Tunisia; Rosetta, Egypt; the Jordan River, Jordan; Syros, Greece and; Sardinia, Italy. Two modelling tools were used for the water balance modelling: System Dynamics Modelling, used in Kairouan, Rosetta, Jordan and Sardinia, and the WaterStrategyMan Decision Support System (WSM DSS), which was used in Rosetta and in the Syros case study. For each study area, the water balance model is first described in detail, followed by thorough descriptions of the results and discussion.

Baseline model simulations show the current state of the water availability situation in all case studies. All study areas (except Jordan) show overexploitation to some degree of the local water resource. The situations are simulated to be most serious in Rosetta and Kairouan, while Syros and Sardinia, while still overexploited to some degree, are not as serious. This should not lead to complacency however, and options for mitigating future water shortages should be considered.

Scenarios of the potential situation in 2050 based on the latest climate change data and predictions from local stakeholders were then carried out. In all cases (again, except in Jordan), the situation was predicted to become worse relative to today - that is, the water availability situation becomes more serious, with greater levels of overexploitation expected. When this is coupled to likely increases in population, the consequences could be significant. At the very least, irreversible damage to the water resource and the wider environment could occur. More serious however is the potential impact on peoples' livelihoods (the agricultural sector is likely to be hit the hardest) and on the local economies (and potentially more macro-scale economic impacts are possible) , again due to the large contribution from agriculture. People would probably see their per-capita

allowance decrease, farmers may experience drops in yield and the water supply may become less reliable. Restrictions on water use may be expected, as could increases in tariffs. More aggressive campaigning urging people to use less water and/or use water more efficiently would also be rolled out.

Forecasting to 2050 is inherently uncertain. As a result, various sensitivity tests were carried out, each suited to the individual study areas. The tests showed in all cases that some parameters have a greater impact than others on the local water resource. For example, in Kairouan, reductions in the volume of water pumped out of the aquifer to coastal cities led to significant decreases to the level of overexploitation, while increasing the amount of treated wastewater reuse (mainly for irrigation) led to only marginal changes. The idea of the sensitivity tests is to get an idea of the range of likely impacts to the water resource if one potential policy measure is implemented, and whether its implementation would have overall positive or negative consequences. It is not intended to suggest that such a policy should be taken up, but may act as a guide for future decisions. It is also noted here, that none of the options tested here are actual policies currently in place or proposed to be in place. The simulations have been run for the purposes of sensitivity testing only, and were developed in collaboration with local stakeholders.

In all the study areas, it is suggested that considering only one policy option is too risky. Rather, a suite of measures is more likely to be met with success. By using more than one option, the chances of reversing the current trends of overexploitation are more likely, and the pressure is 'spread' among many parties, rather than being concentrated on just one sector. Also, it means that if the main policy measure fails to meet its target, the impact of other implemented measures may make up this shortfall. Taking the Kairouan example again, the measure of reduced coastal pumping could be coupled with restrictions on irrigation water use, increased domestic tariffs, awareness campaigns and incentives to reduce per-capita demand and allowing the use of treated wastewater for irrigation use. This 'multi-pronged' suggestion is common amongst the case studies, and therefore is likely to be applicable over the wider Mediterranean basin. Also, while some potential mitigating measures are unique to each case study (e.g. reducing coastal pumping in Kairouan, maximising the Nile inflow volume in Rosetta), some are common across all the case studies (e.g. awareness campaigns to save water, changes to tariff structures, restricting use to certain sectors or at certain times of the year and so on).

The ultimate aims of these results are:

- to feed into the broader integrated water availability and security situation being studied in the WASSERMed project;
- to have useful input into other areas of related research, not just in WASSERMed, but in other EC FP7 and other academic/government studies;
- to reduce some of the uncertainty being faced across the Mediterranean when future forecasts of water availability are to be made;
- to advance the use of SDM and WSM DSS in water balance assessments, and to show their usefulness when undertaking wider, integrated analyses;

- to be useful on the ground in the study areas themselves, and to hopefully be beneficial to policy makers when deciding on appropriate courses of action for the future with regard to the water availability of their region;
- to help achieve a more water secure future for all sectors in all the case study regions and to encourage environmental rehabilitation.

This report forms Deliverable 5.2.3 of the WASSERMed project.

Contents

1. Introduction ... 8

  1.1 General introduction ... 8

  1.2 Context and background ... 8

2. Modelling frameworks used to undertake the water balancing studies ... 11

  2.1 System Dynamics Modelling ... 11

  2.2 The WaterStrategyMan Decision Support System ... 13

3. Water balance modelling for all case studies ... 16

  3.1 Kairouan aquifer, Tunisia ... 16

    3.1.1 The water balance model ... 16

    3.1.2 Model results ... 19

    3.1.3 Discussion ... 25

  3.2 Rosetta, Egypt ... 27

    3.2.1 The water balance model ... 27

    3.2.2 Model results ... 30

    3.2.3 Discussion ... 38

  3.3 Jordan River, Jordan ... 40

    3.3.1 The water balance model ... 40

    3.3.2 Model results ... 41

    3.3.3 Discussion ... 42

  3.4 Syros Island, Greece ... 44

    3.4.1 The water balance model ... 44

    3.4.2 Model results ... 46

3.4.3 Discussion 56

3.5 Sardinia, Italy 58

3.5.1 The water balance model 58

3.5.2 Model results 62

3.5.3 Discussion 65

4. Conclusions 67

5. References 70

1. Introduction

1.1 General introduction

As part of the WASSERMed project, integrated water balance modelling has been carried out in all five case studies (Kairouan, Tunisia; Rosetta, Egypt; Jordan River, Jordan; Syros Island, Greece; Sardinia, Italy). These case studies were selected as they cover a broad range of socio-economic and climate conditions in the Mediterranean Basin, and are all subject to different water-related security threats. For example, the Tunisian case study is heavily impacted by high agricultural water demand and tourism, the Egyptian case study is affected by agriculture water demand and sea-level rise, the Jordan River case study is being impacted by climate change and reserve depletion both within Jordan and from neighboring countries, Syros is greatly affected by tourism and local agriculture and Sardinia is stressed by a large influx of tourist visitors in the summer months, with a large stress being placed on the water supply and infrastructure.

Thus, the selected case studies represent a broad range of water-related security threats that are being experienced throughout the wider Mediterranean Basin. As a result, the outputs of the integrated water balance modelling will be applicable not just to the specific case studies for which it was carried out, but also across the wider Basin, particularly when coupled to outputs from other WASSERMed Work Packages, particularly WP3 and 4. The ultimate aim of this work is to provide a local-to-regional perspective on the water-related threats being posed throughout the Mediterranean Basin, with a particular focus on the diverse WASSERMed case studies.

This Deliverable reports on the water balance modelling that has been undertaken in all Case Study areas. Here, the methods used to carry out the water balance modelling are briefly described (the methods are described in detail in Sušnik et al. 2011). Then, brief introductions to the issues being faced in each Case Study are provided to set the scene and to provide context. Each water balance model is then described, followed by the results generated from model simulations. A discussion is provided and a conclusions section closes the report.

This document forms Deliverable 5.2.3, a requirement of the WASSERMed project.

1.2 Context and background

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 2012 drought in the United Kingdom illustrates that even more developed nations can still 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% 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 backdrop, 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). 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 estimate 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.

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.

It is clearly important that a better understanding of global and local water availability, 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.

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2. Modelling frameworks used to undertake the water balancing studies

To undertake the water balancing studies within the WASSERMed case studies, two different approaches were used: System Dynamics Modelling (SDM) and the WaterStrategyMan Decision Support System (WSM DSS). These will be briefly described here. They have both been discussed in length elsewhere. The reader is referred to Sušnik et al. (2011) for a complete discussion and comparison of the two modelling frameworks. Sušnik et al (2011) also provide a comparison with other modelling tools that were considered but not used in the present project.

2.1 System Dynamics Modelling

System Dynamics Modelling (SDM) is a methodology for studying and managing complex feedback-driven systems. It is typically used when formal analytical models do not exist, but when system simulation can be developed by linking a number of feedback mechanisms in order to define a systems structure. Generally, the structure and behaviour of the system (and the interpretation of this behaviour) are more important than accurate numerical prediction. Visualisation of the system components is via specific software. SDM allows for complex differential/integration equations to be simply solved. The visual nature of the interface allows for a user-friendly, participatory process (Ribarova et al., 2011).

(Forrester, 1961) introduced SDM in the early 1960’s as a modelling and simulation framework for long-term decision-making in dynamic industrial management problems. Since then, SDM has been applied to various business policy and strategy problems (Barlas, 2002; Sterman, 2000). Subsequently it has proven to be very useful for the simulation and study of complex environmental (Ford, 1999; Mazzoleni et al., 2004; Mulligan and Wainwright, 2004) and water systems (Chung et al., 2008; Simonovic, 2003) in an integrated way, and has been applied at a range of scales from local (Khan et al., 2009) to global (Kojiri et al., 2008; Simonovic, 2002). More recently, it has been successfully used to convey system behaviour to the public in order to get them more involved and enthused in important local decision making (Stave, 2003; Tidwell et al., 2004).

Building an SDM follows an iterative approach, involving both the modeller and the stakeholder/local expert, and is thus ideal for use in a project such as WASSERMed. The first step in developing an SDM is defining the causal relationships linking system processes and the basic system structure (Figure 1). From this initial guide, quantitative models with few feedback loops and little detail are built, so as to allow the construction of an initial working numerical simulation model (Atanasova et al., 2006). The working SDM model is then be modified and improved to show the desired level of detail and complexity (Haraldsson and Sverdrup, 2004).

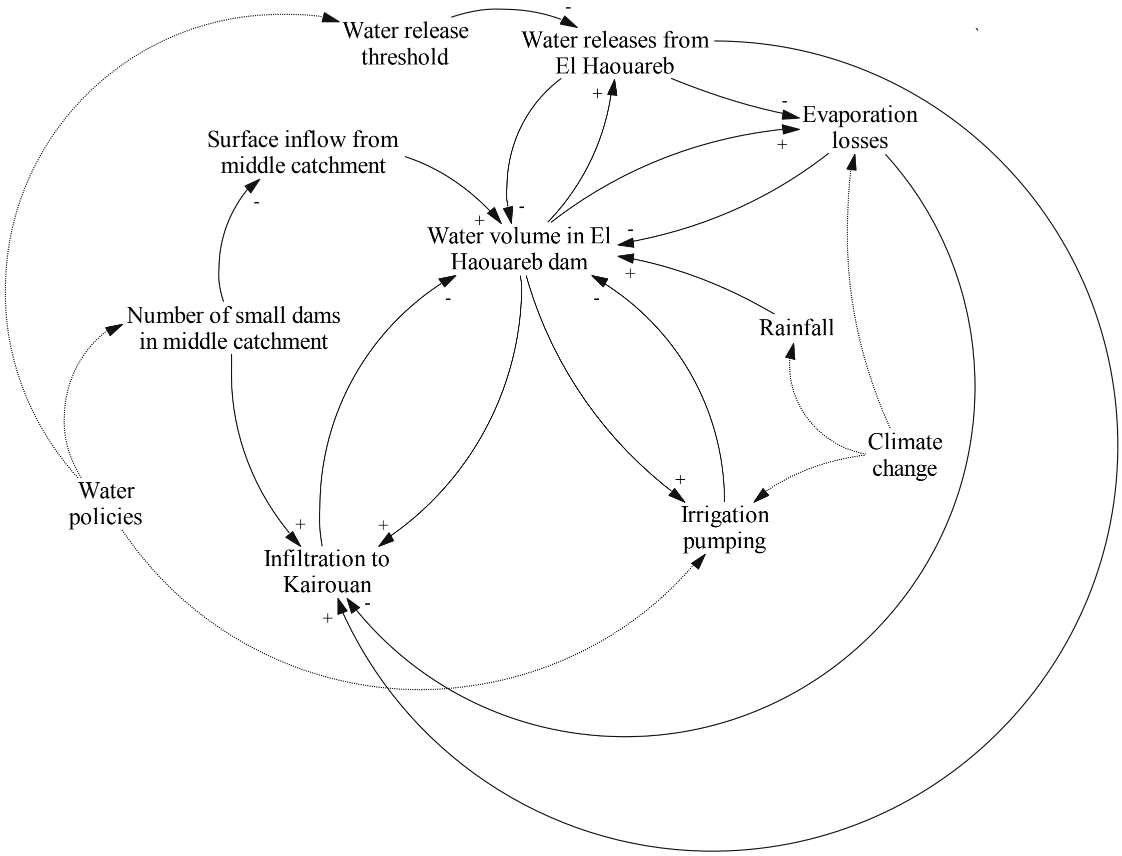


Figure 1: Causal loop diagram for the El Haouareb sub-model of the Tunisian SDM in the WASSERMed project. Positive ('+') symbols represent reinforcing links/feedbacks while negative ('-') symbols represent self-stabilising links/loops.

In order to build a model using standard SDM techniques, system components are described as interlinked compartments (stocks), flows (directed links) and converters (influences) (Ford, 1999). Stocks are to be thouht of as storing a material, for example a bath-tub, or a bank account. If all inflows and outflows to this stock are set to zero, or if they exactly equal each other, then the level in the stock will not change. Flows move material into and out of stocks. For example the flow of water into or out of the bath tub, or money being deposited into or withdrawn from a bank account. Finally, the converters control the flow rates. For example, they can act to control the evaporation rate from the bath tub, or can control the interest paid on the bank account. The control can be external or can be set according to the level in the stock. As such, converters also act to form feedback loops within SDMs. Converters may represent simple ratios, or they may form more complex non-linear equations. Many specialised SDM software packages have been developed. The most prominent include: SIMILE (Muetzelfeldt and Massheder, 2003); www.simulistics.com), VENSIM (www.vensim.com), STELLA (www.iseesystems.com) and SIMULINK – an add-on to MATLAB (www.mathworks.com). These provide a graphical interface which adds to the participatory process, and is especially useful for those unfamiliar with conventional programming (e.g. the C programming language). SIMILE and VENSIM have both been used successfully in previous EU Framework Programs, namely the EU FP6 project 'AquaStress' (Ribarova et al., 2011; Vamvakeridou-Lyroudia and Savic, 2008; Wintgens et al., 2009). Mathematically, most existing SDM visual environments are similar. SIMILE (Muetzelfeldt, 2010; Muetzelfeldt and Massheder, 2003) (www.simulistics.com) has been selected as the primary software platform for implementing the quantitative (numerical) model for the case studies within WASSERMed. More details about SDM framework, its advantages and disadvantages, and its application can be found in Sušnik et al. (2011).

2.2 The WaterStrategyMan Decision Support System

The WaterStrategyMan Decision Support System (WSM DSS, Figure 2) was one of the main final outputs of the WaterStrategyMan Project ("Developing Strategies for Regulating and Managing Water Resources and Demand in Water Deficient Regions"), funded by the EC through the 5th Framework Programme.

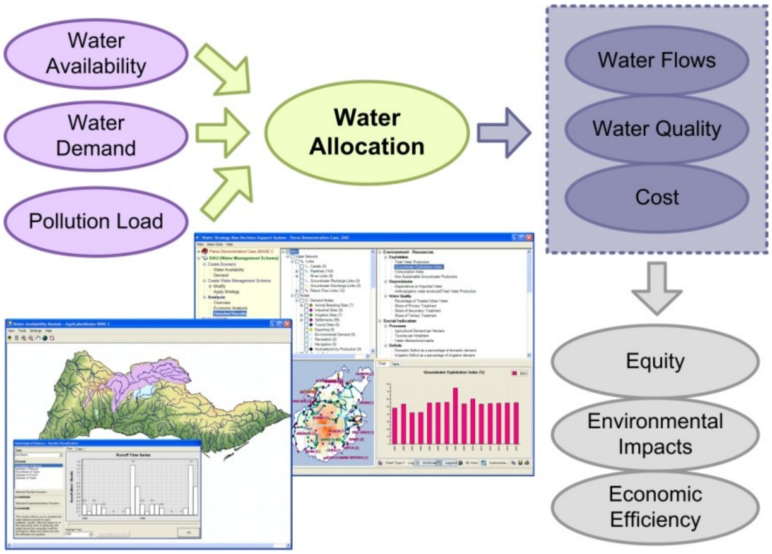


Figure 2: A schematic overview of the WSM DSS capabilities

The WSM DSS was developed with the objective to support the assessment of the state of water resource systems and to facilitate the simulation and evaluation of different scenarios and water management options in areas facing permanent or temporary water scarcity (Todini et al., 2006). It combines a hydrological model, a water demand and pollution load estimation model, and a simulation model for water allocation that minimizes water shortage under limited water availability (Manoli et al., 2001). It further includes models for economic water value and gross benefit assessments, and cost estimations. All the above components are integrated in a holistic environment, which allows the representation of water systems as networks of nodes, representing water supply sources, infrastructures and demands, and links, which stand for their physical or conceptual interconnections.

The WSM DSS is a GIS-based package that emphasizes the conceptual links between the different components and aspects of water resource systems. The overall approach and modules were conceptualized and formalized under the **"Drivers-Pressures-State-Impacts-Responses"** structure of indicators (DPSIR, Figure 3). Two pre-processors (modules) of the DSS are used to assess freshwater availability and demand, in order to estimate pressures exerted on the water system by external driving forces.

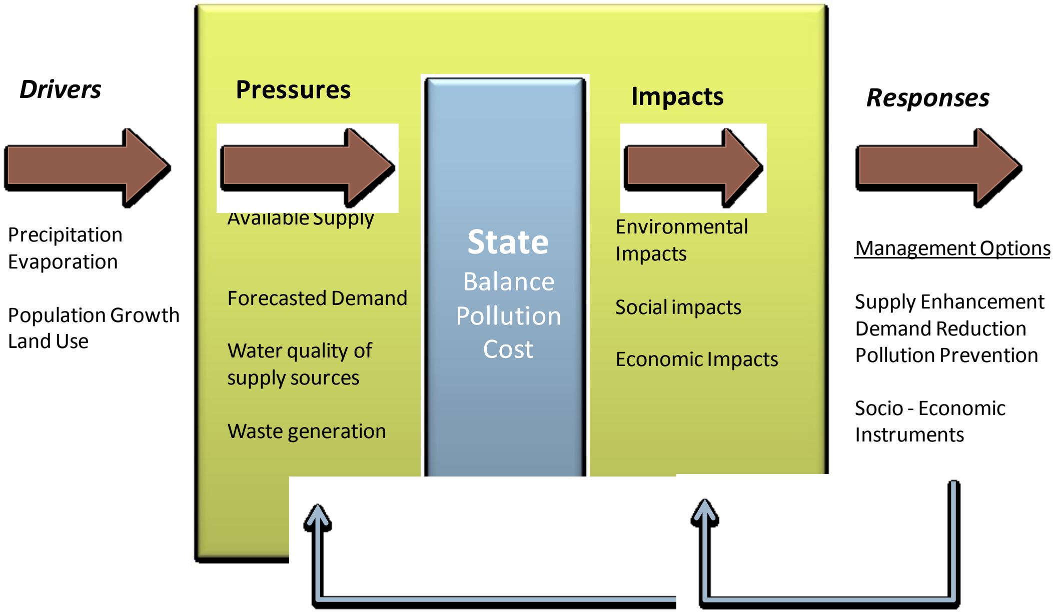


Figure 3: The analysis framework of the WSM DSS

The simulation of the state of the water resource system under different scenarios on pressures is performed by two modules, **water allocation** and **water quality estimation.** The assessment of impacts is based on the computation of different sets of indicators, which are further processed to assess the overall sustainability of the system, through the estimation of statistical criteria for reliability, resilience and vulnerability, for individual indicators. Through this approach, alternative scenarios, water management options and integrated plans can be compared and evaluated through multi-criteria analysis, based on user-defined weights.

The WSM DSS consists of four main calculation modules (water availability, water demand, water allocation, economic assessment) and a statistical evaluation and multi-criteria analysis module. These are all described in detail in Sušnik et al. (2011), but a brief summary is provided below:

- *Water Availability Module:* The pre-processor for water availability estimations is used for computing the amount of water available at each water supply node, focusing particularly on freshwater supply sources (surface or groundwater). The assessment is based on a lumped water balance at the watershed scale, based on the hydrological modeling approach known as the ARNO Rainfall-Runoff Model (Todini, 1996). As alternative, water availability scenarios can also be generated by assuming variations of freshwater availability compared to a normal (average) year for each water supply node, thus avoiding hydrological balance estimates. A stochastic option is also available.

- *Water Demand Module:* The water demand module produces forecasted monthly time series of demand for all uses, based on user-defined trends on the driving forces that are most likely to have an effect on water demanded for various purposes. In addition to this a priori estimation, a demand feedback loop is also incorporated in the WSM DSS, which can be used to simulate responses to demand management options, or the impact of socio-economic reactions to measures restricting the allocation of water supply to specific uses.

- *Water Allocation Module:* Water allocation is the kernel of the WSM DSS, and is performed through a simulation model, which minimizes water shortage under limited water supplies. For distributing the water available from the various supply sources to the connected uses under shortage conditions, two user-defined priority rules are applied. First, competing demand sites are treated according to specified priorities (e.g. social preference or constraints)

- *Economic Analysis Module:* The assessment of costs in the WSM DSS expands beyond financial costs for the operation of the current water system and capacity expansions, to include also external environmental and resource costs. On the basis of the water allocation performed by the core model, the DSS can provide estimates on economic output from the different water use sectors and on financial, environmental and resource costs linked to water management interventions and allocation. These are further allocated to water use(r)s, allowing for the estimation of cost recovery levels.

- *Statistical analysis, Evaluation and Multi-criteria analysis:* The evaluation of alternative options or allocation schemes is based on their performance against a predefined set of indicators describing economic efficiency, equitability and environmental sustainability. Statistical analysis is used for the calculation of reliability, resilience and vulnerability criteria for the selected indicators, based on user-defined thresholds, describing the desired range of values that the indicator can assume. Through weights provided to the individual indicators an overall index is calculated, in order to rank potential interventions and integrated plans according to their performance over an extended time horizon.

Further details on all the modules and the indicators are provided in Sušnik et al. (2011) and in Todini et al. (2006).

3. Water balance modelling for all case studies

This section will describe the models (both SDM and WSM DSS for those case studies where both approaches were used) and the key model results. Discussion is provided in Section 4. Each case study will be treated in a separate sub-section.

3.1 Kairouan aquifer, Tunisia

3.1.1 The water balance model

In this case study, part of the model developed for 'Aquastress' is used in a slightly modified form. Essentially, the Upper and Middle catchment elements and the El Haouareb reservoir sub-models have been retained (see Vamvakeridou-Lyroudia et al., 2008). The Aquastress model is outlined briefly below, but full details can be found in Vamvakeridou-Lyroudia et al. (2008). The major modification here is the total redevelopment of the Kairouan aquifer water balance sub-model. This new sub-model, including all the components, is outlined later in this section.

The portion of the Aquastress model that has been retained comprises of three main sub-models (Figure 4). The first sub-model represents the upper, and relatively simple, part of the Merguellil basin. Rainfall is distributed over the area, some of which is converted to runoff and routed to the middle catchment sub-model. No water is stored within or abstracted from the upper catchment sub-model.

The next sub-model represents the complex middle catchment of the Merguellil system (Figure 4). It receives water as input from the upper catchment sub-model. It also receives rainfall input, some of which is converted to runoff and routed either as infiltration into aquifers or into one of the 35 small dams represented in the middle catchment sub-model as a self-contained sub-model. At each model iteration, the reservoir surface area is updated according to rainfall input. Evaporative losses are calculated along with withdrawals for agricultural use and infiltration. Then, the surface area is assessed again and a final volume at the end of that iteration is given. The rest of the middle catchment sub-model accounts for rainfall input and evaporative and infiltration losses. Some water is routed to aquifers that recharge the Kairouan aquifer directly.

The El Haouareb dam sub-model works in a similar way to the small dams sub-model contained within the middle catchment sub-model. The reservoir surface area is given for the start of each model iteration and linked to volume. This is then updated for rainfall input. Evaporation is accounted for. However, the majority of the water volume (c. 50%) is lost through down a fissure. Most of the water remaining is pumped for agriculture. The volume is then updated again after all the outputs have been accounted for. The causal loop diagram for the El Haouareb sub-model is shown in Figure 1.

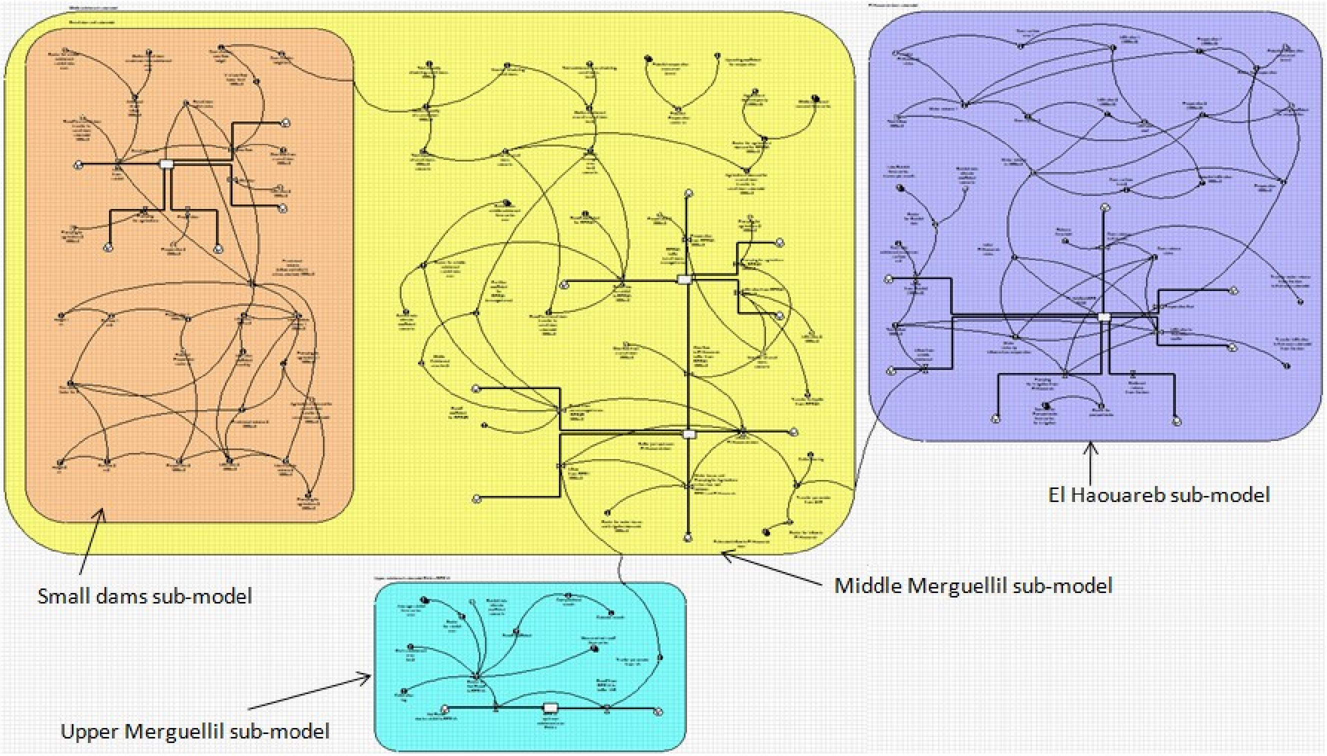


Figure 4: Section of the current model for the Merguellil valley, based on the previous model from the Aquastress project.

The Aquastress model did incorporate a very rudimentary sub-model to account for the Kairouan aquifer. However, as this was not the focus of that study, it was lacking in detail and realism. For WASSERMed, the old Kairouan sub-model has been completely redeveloped. The new Kairouan aquifer sub-model (Figure 5) consists of two input sub-models, six output/abstraction sub-models and a separate sub-model for the selection of rainfall data. These inputs and outputs all feed into the main water balance component of the model (Figure 5). The new aquifer model was developed closely with the local partner INAT.

There are two input sub-models: a surface water input sub-model and an infiltration input sub-model (Figure 5). The surface water input takes the rainfall time-series and any water released from the El Haouareb dam as inputs. For the water releases, 70% is lost to evaporation (Besbes et al., 1978). Rainfall is not distributed evenly over the catchment. As such, a reduction factor of 95% is used to better represent actual rainfall input. Of this volume, 70% is lost to evaporation. The infiltration input sub-model takes into account direct recharge from adjacent aquifers upstream of Kairouan and of the water that infiltrates down the fissure in El Haouareb dam.

There are six output/abstraction sub-models: a model accounting for natural losses; a model accounting for anthropogenic transfers of water directly out of the aquifer; and models accounting for agricultural, domestic, industrial and tourist water use (Figure 5Figure). All these models, except the natural out-transfer model, have been designed with the same structure, allowing easier interpretation and use by non-experts. The natural out-transfer model takes the volume of water naturally lost from Kairouan aquifer to other downstream aquifers and to a nearby Sebkha region.

All output sub-models have, as the basic data, the baseline water abstraction data. In order to allow for the testing of the future scenarios, a scaling coefficient is used that multiplies the baseline data according to future projections estimated by the local partner. By changing just one value in the sub-model for each sector, the modeller can choose to use as input either the present day data, the future data (i.e. present day scaled by the coefficient), or a policy option which is just another scaling coefficient which can be changed by the modeller to whatever value is desired in order to explore the impact of different policy measures.

Finally, the model incorporates a feedback loop which accounts for the reuse of treated waste water. A proportion of the abstracted water for each sector is assumed to be treated and re-used. The sum from each sector contributes the total treated waste water re-use volume. This goes back into the main aquifer storage unit as a recharge that can be used again in the next model iteration.

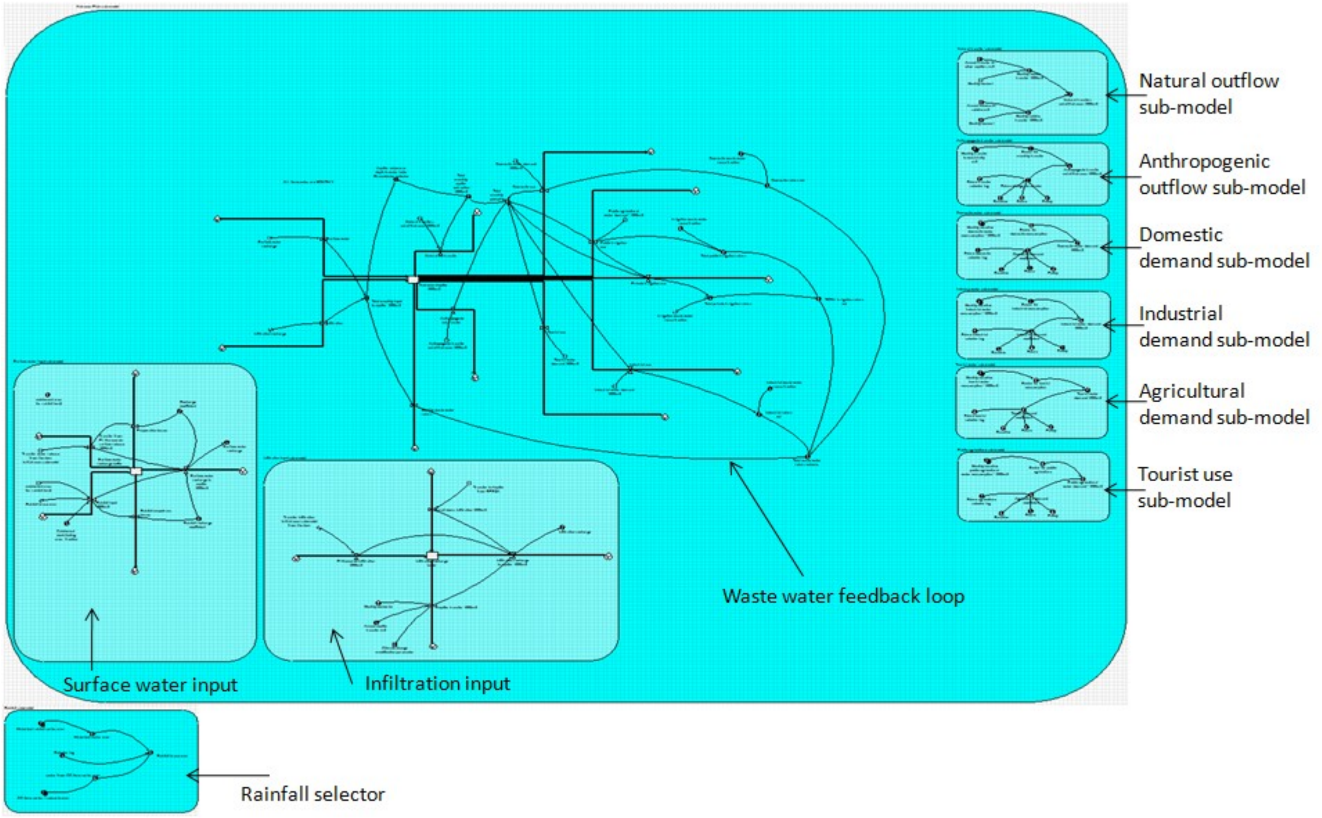


Figure 5: The newly developed Kairouan aquifer sub-model used in WASSERMed.

3.1.2 Model results

For the baseline conditions, the aim is to verify that the model gives a broadly realistic view of the current water situation of the Kairouan aquifer. Figure 6 shows the time series for the total volume of water being input to and output from the Kairouan aquifer over the 36 month baseline simulation period.

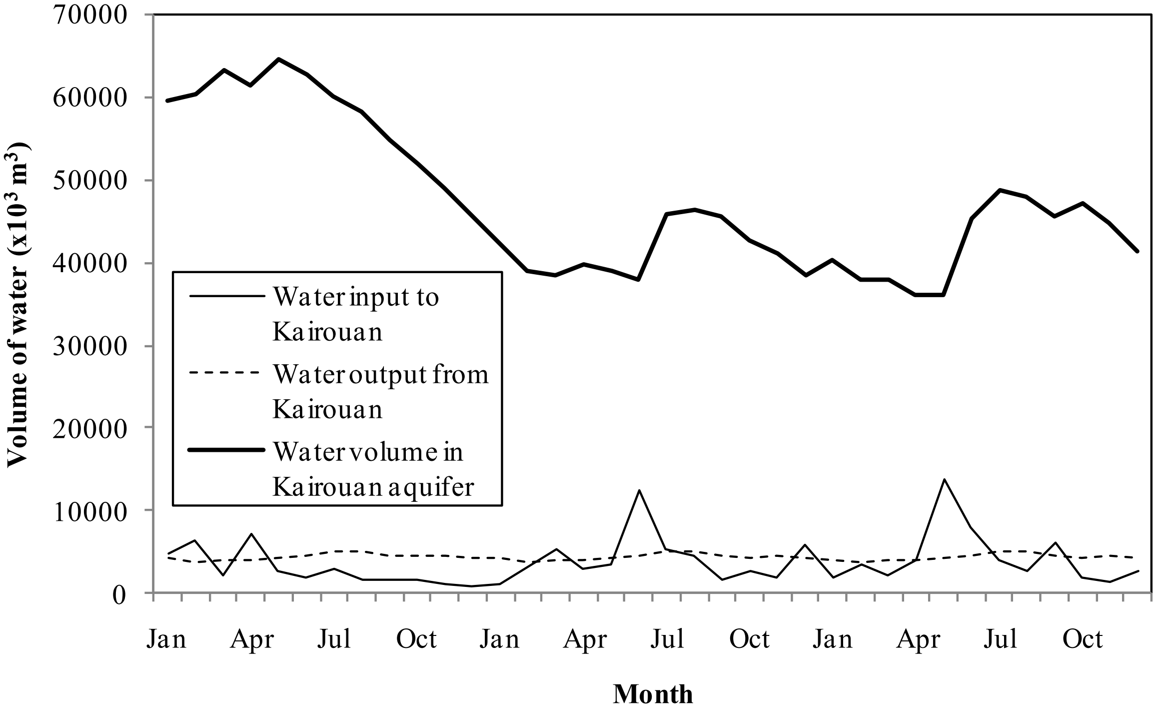


Figure 6: Baseline results for the Kairouan aquifer case study.

The main feature is the relative 'spikiness' of the input series when compared with the output series (Figure 6). Analysis of model outputs showed this to be due largely to contributions from infiltration down the large fissure at the downstream end of the El Haouareb reservoir. Output behaviour is more damped, but can be observed to follow seasonal trends, with greater water demand occurring in the summer months, a realistic pattern as it would be expected for water demand to peak in summer, due to increased seasonal irrigation water use. The quasi-cyclic abstraction pattern is due to some of the abstraction time series being repeated over three cycles. Figure 6 also shows the total volume of water in Kairouan aquifer and suggests that over the long term, Kairouan aquifer is being overexploited, with short periods of recharge, in line with current observations (Feuillette et al., 2003; Le Goulven et al., 2009; Leduc et al., 2007; Luc, 2005). Starting with a value of 59.7 x 10^6 m^3 , Figure 6 shows a steady decline in water volume, broken only by the two periods of recharge. The average annual volume loss predicted by the model is c. 7 x 10^6 m^3, roughly corresponding with the 17.4 x10^6 m^3 a^{-1} water deficit reported by (Luc, 2005), suggesting that the model is representing the Kairouan aquifer water system reasonably well.

Next, the 'unmitigated' 2050 model simulation with no additional policy elements superimposed was modelled. Figure 7 presents the time series' showing the total volumes of water input to and output from the Kairouan aquifer. This behaviour is unsustainable in the long term, and if it carries on into the

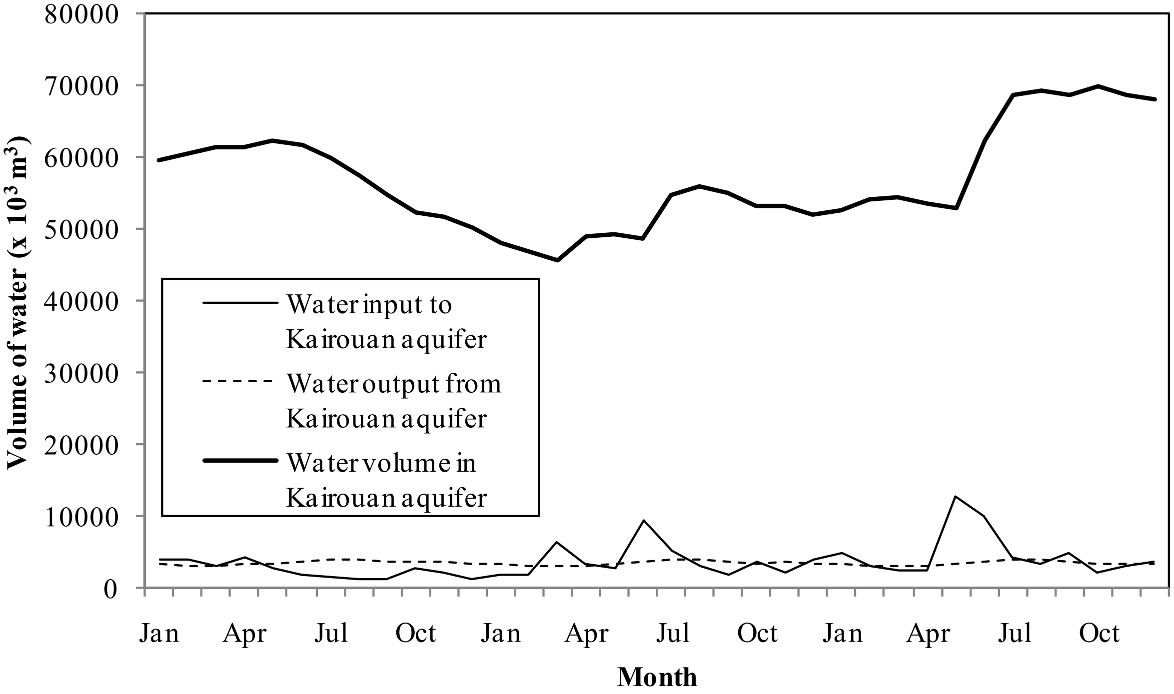


Figure 7: The 2050 Kairouan aquifer SDM results.

As with the baseline scenario, the input series is considerably more spiky than the output series, and again this is driven primarily by rapid infiltration down the fissure in the El Haouareb dam. The demand pattern is far more damped than the input, with peaks still being observed in the summer months. The total future demand volume is approximately 80% of the baseline situation. This result is largely due to the government target of reducing water transfers to the coast by 50%, resulting in a large net decrease in water demand. The volume of water in Kairouan aquifer is also presented in Figure 7, and shows a more optimistic picture than Figure 6. Although there is a period of net overexploitation early in the simulation, for the much of the time, there is net recharge to the aquifer. Unlike the baseline scenario, Figure 7 suggests that the volume of water in Kairouan will either stay roughly the same or increase slightly. The simulation suggests a net average annual recharge of c. 3 x 10^6 m^3 a^{-1}. It should be noted that the initial volume of water held in Kairouan aquifer at the start of the 2050 simulation was assumed to be equal to the present day volume. This will probably not be the case however the value of Figure 7 is more in the potential pattern of the water availability situation in 2050 rather than in the absolute numbers.

Sensitivity analysis was performed in order to ascertain which parameters have the largest influence on model output (i.e. local water availability) with focus on parameters with uncertain, assumed or estimated numerical values. During each test, only the parameter value being tested was adjusted, one at a time, with all other values held constant. All sensitivity tests were carried out on the baseline datasets for which there is less uncertainty. This was a strategic decision, so as to decide the impact of various parameters to the critical output, namely the evolution of the total volume of water stored in Kairouan aquifer over the simulation period. The full range of tests are outlined in Table 1.

Sensitivity test	Baseline value	Range of values tested	Increment	Result of testing: volume of water in Kairouan aquifer at the end of model simulations
1. Changing the catchment area receiving rainfall and contributing infiltration to the Kairouan aquifer	5%	2-10%	2%	17.9 - 80.6 $x10^6$ m^3.
2. Changing the volume of water transferred to coastal cities	Government target is a 50% reduction by 2050	25% reduction to 75% reduction	10%	61.5 - 101 $x10^6$ m^3.
3. Changing the proportion of waste water reuse	10%	0-20%	4%	36.4 - 46.4 $x10^6$ m^3.
4. Changing the estimate of private irrigation water use	10% of public water use	0-50% of public water use	10%	31.7 - 43.8 x 10^6 m^3.

Table 1: Outline of the sensitivity tests carried out for the Tunisia case study

Catchment area receiving rainfall and contributing to infiltration. Testing shows that water availability is highly sensitive to changes of this parameter (Figure 8). Only if the catchment receiving/contributing area is > 8% (of the total catchment area) is net recharge modelled. If the current overexploitation reported by Luc (2005) is accurate, then a catchment receiving/contributing area of only 2% replicates better this level of deficit, suggesting the assumption of 5% is too high. However, the recent opening of the fissure in the El Haouareb dam may also account for the difference between these studies (the fissure contributes more to groundwater, thus lowering the annual deficit).

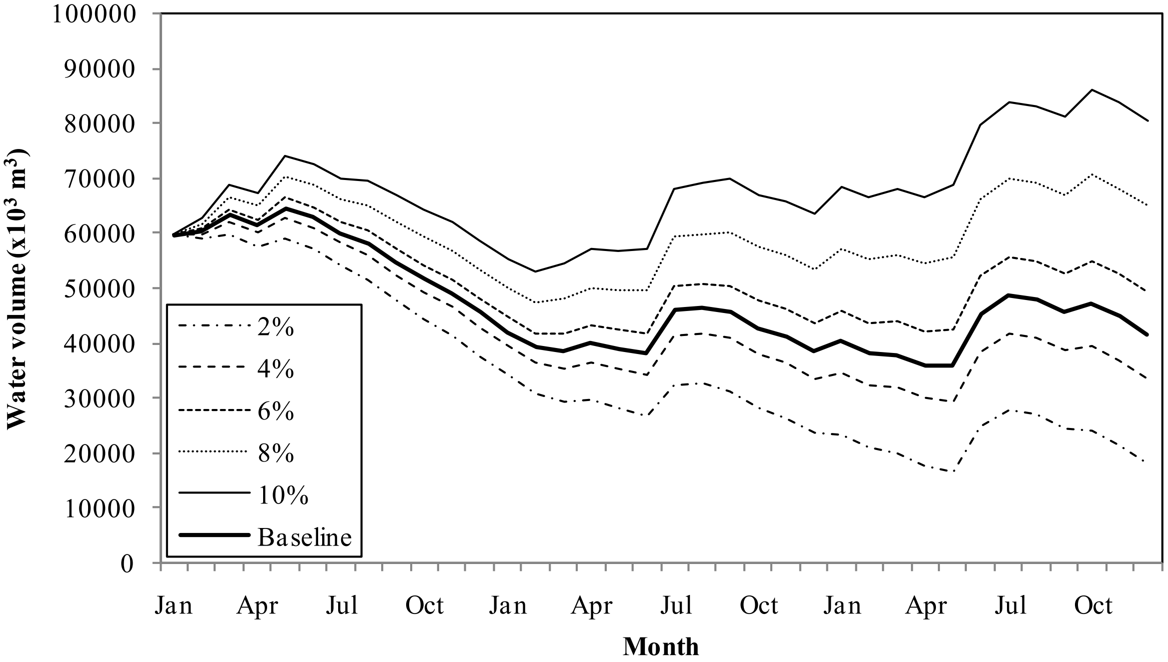


Figure 8: Sensitivity results for the catchment area receiving rainfall tests.

Volume of water transferred to coastal cities. As above, this parameter is sensitive to change (Figure 9). If the volume transferred to the coast is only cut by 25% (i.e. it is 75% of current levels) then the aquifer is no longer overdrawn. So long as water transfers to the coast are less than c.75 % of the current level, the model suggests sustainable aquifer recharge (all other values remaining the same), with potential recharge becoming significant if the government target is met or exceeded. It was necessary to investigate the impact of this parameter, because any future policy measure/guideline aim to include it, in one way or another.

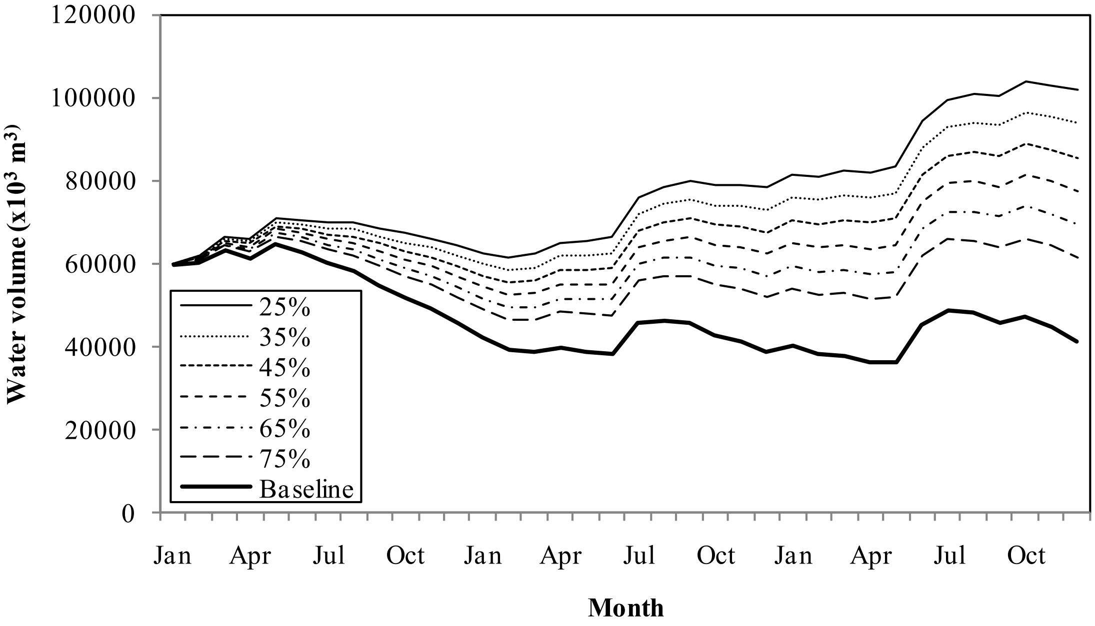


Figure 9: Sensitivity results for the volume of water pumped to coastal cities tests.

Waste water re-use rate. This parameter is less sensitive to alterations than the previous two described (Figure 10). Even a doubling in the current reported re-use rate to 20% still leads to an average deficit of 4.3 x 10^3 m^3 yr^{-1}, all other parameters remaining the same. This suggests that even significant improvements to the waste water re-use rate will have negligible impact of total water availability.

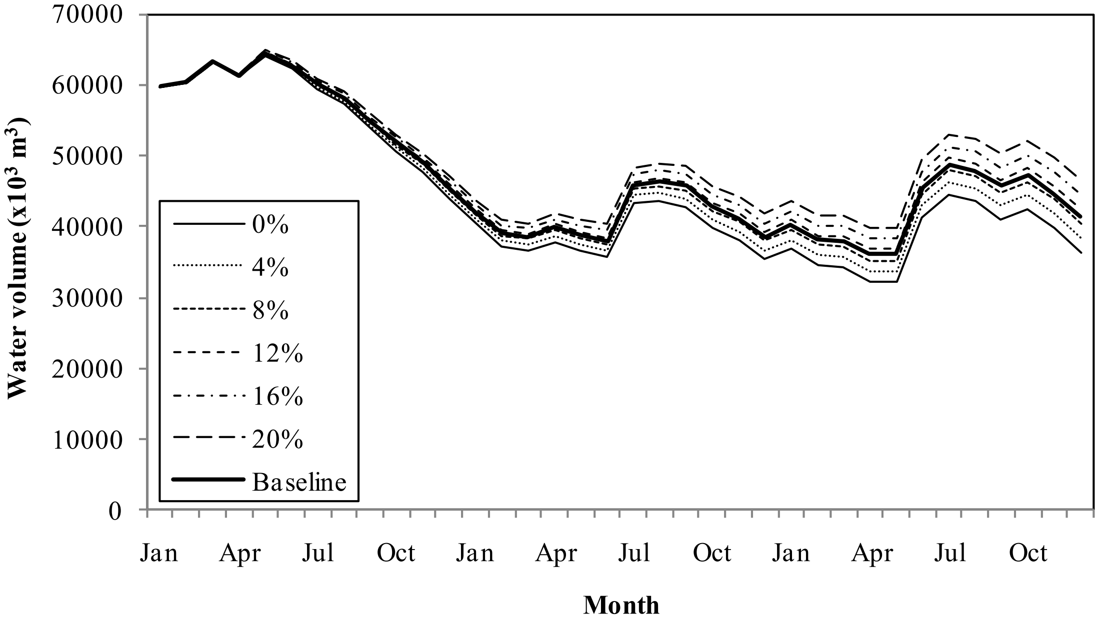


Figure 10: Sensitivity results for the waste water re-use tests.

Private irrigation fraction. Like with waste water re-use, model results are relatively insensitive to changes in this parameter (Figure 11), suggesting that only cutting back on unregulated use may have little impact on total water availability in the region. This is an important remark, regarding potential future policies and measures in the region.

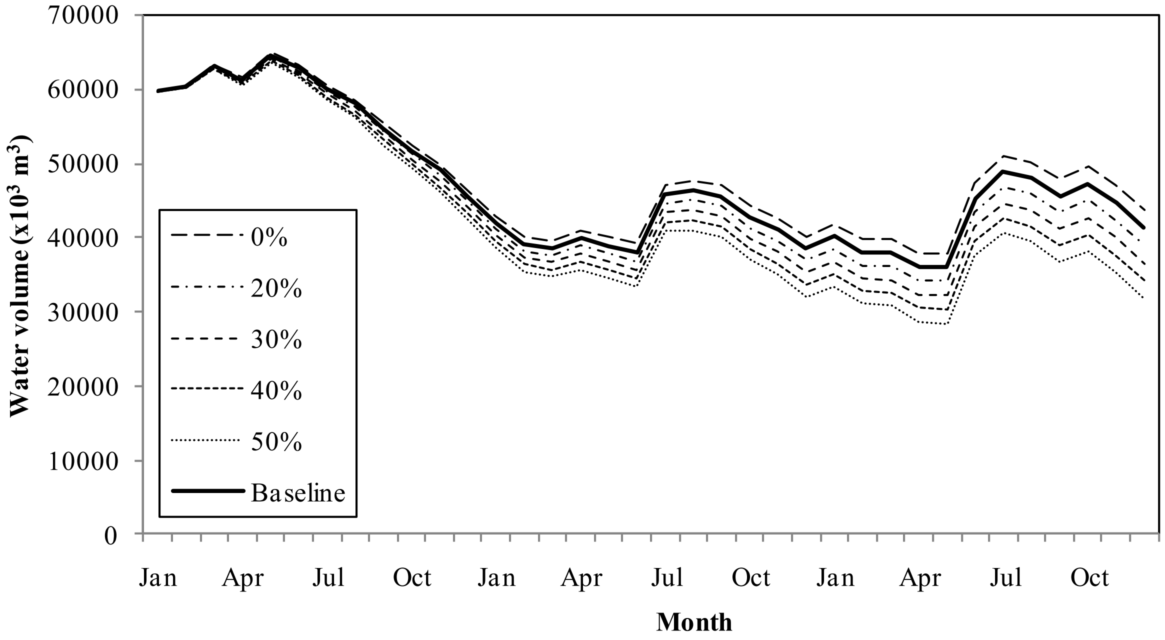


Figure 11: Sensitvity results for the private irrigation fraction tests.

3.1.3 Discussion

Baseline results indicate that at present, the Kairouan aquifer is undergoing net overexploitation (Figure 6). This is backed up by local observations of the water table level, piezometric readings and rudimentary mass balance calculations in the literature (Feuillette et al., 2003; Le Goulven et al., 2009; Leduc et al., 2007; Luc, 2005). The volume of overexploitation estimate here is slightly lower than other references in the literature. This behavior is unsustainable in the long term, and will ultimately result in significant depletion of the aquifer if it were to continue. This would have significant consequences for the local community. Local residents would suffer domestic water shortages, maybe facing usage restrictions or a lack of water in certain months of the year. Farmers would suffer from reduced yields as they would be unable to water crops sufficiently to maintain growth in the summer. Coastal cities would see a reduced pumped supply, and would have to look to other sources. The environmental quality would likely degrade, with reductions in water quality, and a potential threat to the sustainability of the sebkha regions.

For the ‘unmitigated’ 2050 scenario, the reduced rainfall totals and expected increases to agricultural and domestic demand result in a worse situation than the baseline, with even greater levels of overexploitation being estimated. If this situation were to gradually become reality, rapid and significant mitigation measures would have to be implemented in order to prevent serious water shortages and the onset of water stress.

Because the future is inherently uncertain, a suite of sensitivity tests were carried out that aim to represent a reasonable range of feasible future scenarios. Table 1 outlines all the tests that were carried out. The results are shown in Figures 8-11. The tests that changed the value of the catchment that receives and contributes rainfall to recharge and the value of volume reductions of water pumped to coastal cities showed the greatest sensitivity to change. Indeed, under extreme values (i.e. a large reduction to the volume of water pumped to the coast; a large increase to the area of the catchment contributing to recharge), net aquifer recharge conditions were suggested. This is promising, however, in reality there is little that can be done to significantly alter the area of a catchment that receives rainfall and contributes it to recharge. The tests that suggest recharge is possible by altering the volume of water pumped to coastal cities are more promising. Current government policy is to reduce the present volume by 50% by 2030, then maintain this level into the future. Results (Figure 9) indicate that implementing this policy alone will not be sufficient to achieve recharge, however significant improvements are made with respect to the current situation. By aiming for a more aggressive policy, recharge could be achieved through this measure alone. However, focusing on just one measure to reduce the current overexploitation and prevent aquifer depletion is too risky.

The two other tests adjusted the volume of permitted wastewater reuse (after treatment) and the volume of ‘private’ irrigation water use (as a fraction of the total irrigation use). Both these tests showed a relative lack of sensitivity to change, and neither indicated that recharge was possible through changes in these parameters alone. Despite their apparent lack of impact they may play a critical role in securing a more water secure future for the Kairouan region. As mentioned above, there is already a policy in place to reduce pumping to the coast. However, this alone will be insufficient to result in local aquifer recharge. However, if this were implemented in parallel with other policies such as allowing waste water treatment and reuse, mainly for agricultural use, and regulating the private irrigation sector, then together these policies may well result in net aquifer recharge. In addition, by spreading the mitigating efforts between many policy options, the risk is reduced if any one target were to be missed.

In summary, the current situation in Kairouan is one of net aquifer depletion, with this situation expected to become worse in the future unless mitigating measures are put in place. It is suggested that while some policy options will be more effective than others, a suite of options, implemented in parallel, should be considered in order to maximize the impact and minimize the risk should any one target be missed: that is, a multi-pronged policy landscape is deemed preferable here.

3.2 Rosetta, Egypt

3.2.1 The water balance model

Unlike the Tunisia SDM, the Rosetta model has been developed specifically for this project. The SDM model has been developed in cooperation with the local partner, ECRI who assisted in developing the model structure and providing key data as required. The final model is shown in Figure 12.

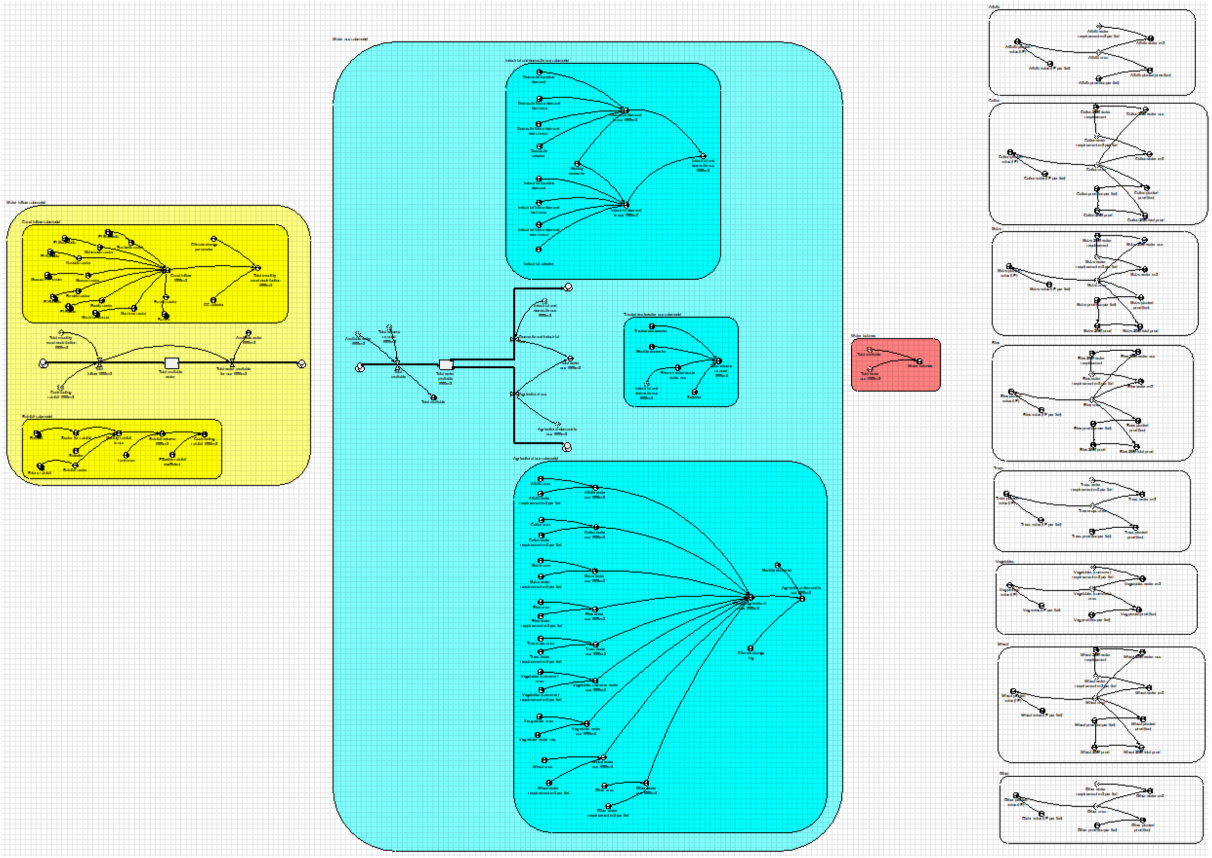


Figure 12: The Rosetta water balance SDM.

The model has four distinct sub-models: a water inflow/supply model (left in Figure 12), a water use sub-model (large box in centre of Figure 12), a sub-model that performs the final water balance calculation (smallest box, Figure 12) and a series of sub-models that calculate the future crop water requirements, crop productivity and economic output. Each of the sub-models will be discussed in turn.

The water input/supply sub-model deals with water supplying the study area from rainfall and from canals which receive water directly from the Nile. For the rainfall, either the baseline or the future rainfall data can be selected, depending on the scenario that is being modelled. Future rainfall data was provided by CMCC. The projection was modelling using the EHTZ regional climate model forced using Hadcm3Q0 and used the IPCC

A1B emissions scenario. The rainfall is scaled up by the total land area, then a reduction factor is applied in order to account for evaporation and the fact that rainfall does not fall evenly over the study area. For the canal water supply, the study area is fed by eight canals which take water directly from the Nile. Data are available for each canal. The monthly supply from each canal is summed to give a total monthly water supply from the canals. The rainfall and canal supply totals are added together to give the total water supply available in the study area.

For the Rosetta case study, industrial and domestic water demand are taken into account, as is agricultural water demand, which is by far the biggest water user in the study area. Also taken into account is waste water recycling and re-use. For domestic and industrial use, the modeller can choose to use as input either the baseline datasets or one of two future (2050) datasets. One of these represents the 'best' case, while the other represents the 'worst' future case in terms of climate and socio-economic development. These 'best' and 'worst' case scenarios were provided by ECRI.

For the agricultural water demand, seven different crop categories are accounted for separately: alfalfa, cotton, maize, rice, trees, vegetables and 'other'. For each crop classification, the water demand per unit area is given along with the area planted by that crop in the study area. The crop-specific demands are summed to give total agricultural water demand. The potential future impact of climate change can be investigated by changing just one parameter value that downscales planted area according to government projections. Alternatively, each crop could be adjusted individually to give a more detailed analysis. In addition, data were provided for the crop productivity (yield) per unit area for each crop and the economic output per unit area per crop. Therefore, analyses regarding yield and economic output can also be performed using this model.

The 'domestic + industrial' and agricultural water demand volumes are summed to give the total water demand in the study area.

For the waste-water re-use, the total annual treated waste water volume is used (data supplied by ECRI). In addition, the modeller can also choose to use the estimate for the future treated waste water volume. Treated waste water is modelled as an input.

The model includes crop-specific sub-models such that current and future per-crop water requirements, crop yield and economic output can all be simulated and analysed (boxes on right of Figure 12). This also allows for easy what-if scenarios to be examined. For example, one can change the per-crop planted area, reflecting changes in global market pressures for different crops or local-scale policy decisions that place emphasis on different crops. How changes to planted area of specific crops impacts on total water requirements, yield and economic output can also be assessed.

Finally, there is a sub-model that calculates the water balance. This simply calculates how much water remains once all the different supplies and demands have been taken into account.

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

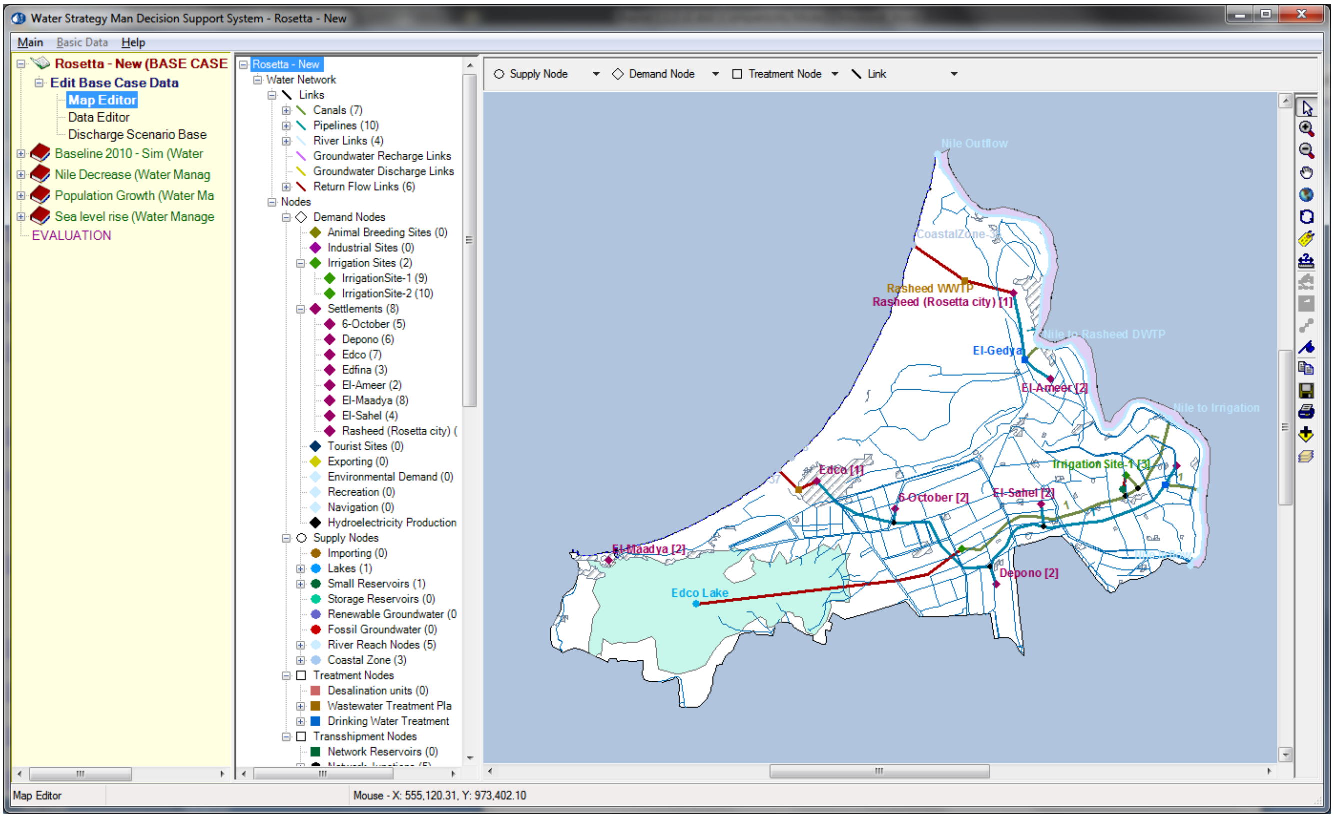


Figure 13: The baseline representation of the Rosetta water system, using the WSM DSS

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.

3.2.2 Model results

Before the results are presented, the scenarios modelled will be defined.

For the baseline scenario, the most up-to-date data are used that were available. Monthly recorded rainfall from within the study area for the years 1995-1997 was used, the latest years of data available. For canal inflows, data for eight local water supply canals at monthly resolution for the years 2008-2010 were used. For domestic and industrial use, and for treated wastewater reuse, only a single annual value for 2009 was available. In the absence of better data, it was assumed that these demands were evenly distributed through the year, and the annual cycle was repeated three times. For agriculture, data were available for nine crops in the study area: alfalfa, cotton, maize, rice, tree crops, summer vegetables, winter vegetables, wheat and 'other'. For each crop, the data available were: crop planted area, monthly crop water requirement per unit area, crop productivity (yield) per unit area and crop economic value per unit area.

Two 2050 scenarios were simulated: a best case and a worst case, both defined with ECRI. The best case scenario, on top of decreasing rainfall totals, assumes a 10% increase to canal inflows (a proxy for changes to Nile flows), significant increases in treated waste-water volumes, and mitigation measures put in place to prevent inundation due to sea-level rise. The worst case scenario assumes decreases to canal flows, that sea-level rise results in a 13% loss to agricultural land (assumption from ECRI), that water consumption increases generally and that treated waste-water volumes do not improve on the present day. Both scenarios assume increases in domestic and industrial demand, thereby accounting for population increase and improving living standards.

There are two main areas of considerable uncertainty with respect to the 2050 scenarios: a) the proportion of land that could be lost to sea-level rise. Because of the uncertainty in the actual level of sea-level rise predicted by global climate models, and because it is not known how much effort will be put into local mitigation efforts, values between 2-20% land loss were chosen to represent various levels of sea level rise and/or investment in mitigation measures. b) the direction and magnitude of changes in Nile flows. The results of numerous modelling studies have not converged to agree on either the direction or magnitude of change to Nile flows, with the current range of predictions from -50 to +60% (Conway, 2005). This full range was tested during sensitivity analysis.

In order to examine the potential impacts of changing cropping patterns (potentially due to policy instruments or market drivers) on local water availability, crop yield and economic output, a suite of 22 crop scenarios were simulated. All the scenarios were conducted on baseline data due to lower uncertainty in this dataset. The scenarios were developed with ECRI who provided data on potential changes to crop water requirements and crop productivity in 2050 for four crops (wheat, maize, rice and cotton). No estimates were available for future economic output so baseline values were used.

Initially, changes were implemented to crop water requirements and crop yield only, with no alterations to the area planted by each crop type. This formed Scenario 1. For all the other Scenarios (2 to 8), planted crop areas were altered according to one of three 'pathways': a) food security, b) economic security, and c) a balanced pathway. For scenarios 2 to 8, the crops that had their areas altered were: wheat, rice, cotton and vegetables (winter and summer). In each of the scenarios from 2 to 8, the area of rice (baseline = 7096 feddans) was decreased by 1000 feddans except in Scenario 8, when it was reduced to zero. As such, in Scenario 2, the area of rice was reduced by 1000 feddans, in Scenario 3 it was reduced by 2000 feddans and so on. This 'recovered' land was partitioned according to each of the three pathways as follows: a) food security: 50% new land to wheat, 25% to cotton and 25% to vegetables; b) economic security: 50% to vegetables, 25% to cotton and 25% to wheat; c) 'balanced': 33.3% to each. As an example, Scenario 2a denotes the food security pathway with a rice reduction of 1000 feddans, while 4c denotes the balanced pathway with a rice reduction of 3000 feddans. The 3000 feddans was then split equally between wheat, cotton and vegetables. It is noted that these scenarios are hypothetical, and do not reflect any current or proposed policy measured being implemented in the Rosetta region.

Under baseline conditions, the model simulation suggests an average local annual water deficit of c. 133 x 10^6 m^3 (Figure 14). At present, it is reported that water is being over-exploited in the area, although this is the first time that a figure has been put on the over-exploitation, giving local and regional policy-makers a handle on the size of the problem being faced. Because there are some assumptions in the baseline data set, and because it is unlikely that the simulation is comprehensive (i.e. some system aspects have probably been neglected), this number gives a first-order approximation of the deficit, rather than an accurate definition. Total current agricultural yield in the study area is c. 536 000 t yr^{-1}, and economic output is c. 567 x 10^{6} Egyptian Pounds (LE) yr^{-1}.

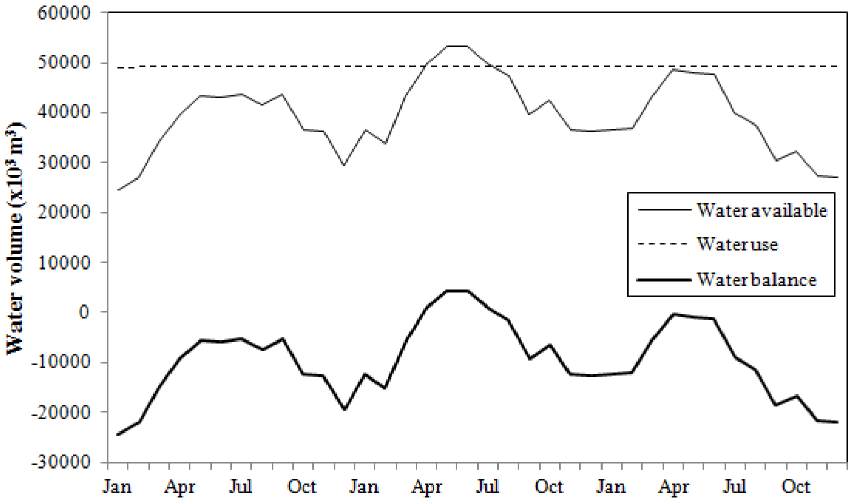


Figure 14: Baseline mode results for the Rosetta case study.

Under the best case 2050 scenario, the water balance situation is shown to improve by c. 35%. While still over-exploited, the average annual deficit is c. -74 x 10^{6} m^{3} yr^{-1}. Because no changes were made to cropping patterns and no land was lost to sea-level rise, there are no apparent changes to agricultural yield or economic output. This is of course is unlikely to be the case in reality.

Under the worst case scenario, the situation becomes worse than the present day, with a water deficit of -122 x 10^{6} m^{3} yr^{-1}. Because agricultural land is lost to sea level rise in this scenario, the economic output and crop productivity values also decrease by 13% with respect to the baseline (a linear relationship with land loss is assumed due to a lack of better data).

From the canal inflow sensitivity tests (Figure 15), it is shown that if canal inflows increase by more than 30% with respect to the present day flows, then the region will have surplus water, assuming all other parameters remain as today. If inflows increase by 60%, then this surplus is considerable (127 x 10^{6} m^{3} yr^{-1}). However, if inflows decrease by 30% with respect to today, then the average annual water deficit is over twice as much as the baseline, and if inflows reduce by 50%, then the situation is critical, with a deficit of over 340 x 10^{6} m3 yr^{-1}.

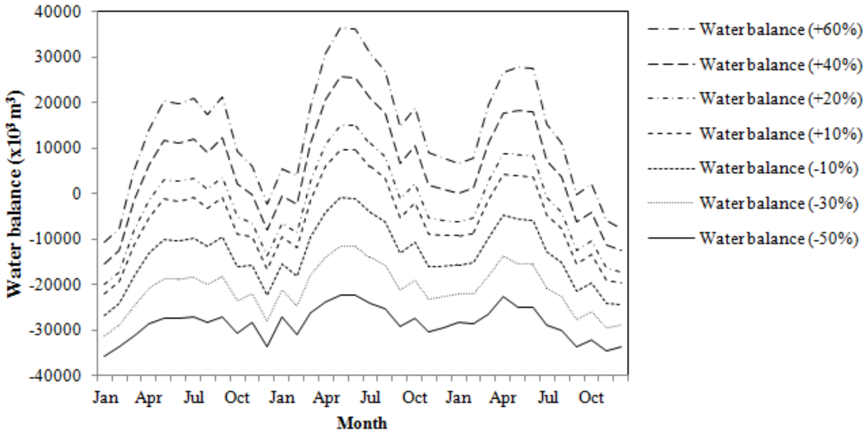


Figure 15: Results of the canal inflow sensitivity tests.

With regard to the land loss sensitivity tests (Figure 16), the results are somewhat counter-intuitive in that the water balance situation improves as more land is lost to inundation. This is because it is assumed that the total agricultural water requirement is linearly proportional to land loss. Therefore, if land loss is 10%, total crop water requirements decrease by 10% and so on. If 20% of the land in the study is lost, and if all other parameters remain unchanged, then the water deficit is only -2 x 10^6 m^3 yr^{-1}. However, increased land loss is viewed a negative impact because agriculture is the largest economy in the region. Thus, a slow-down in agricultural output could hinder local development, and mitigation efforts are being explored despite the fact that this will impact water saving efforts.

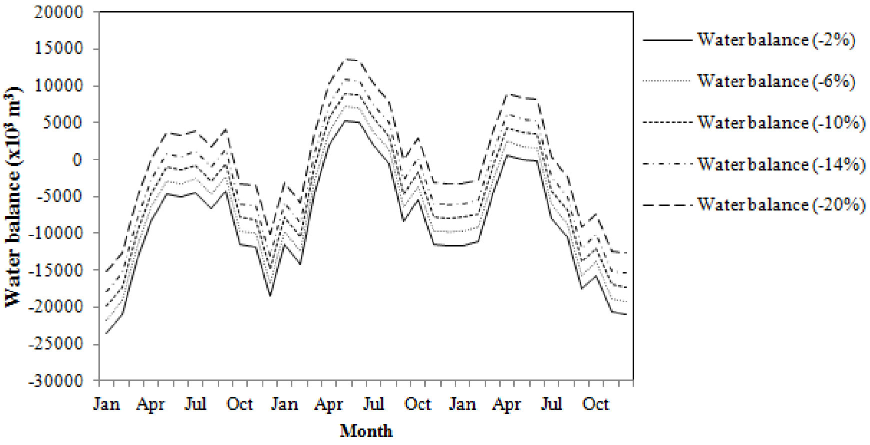


Figure 16: Results of the land loss sensitivity tests.

The 22 cropping scenarios tested examine the effects of changes to the crop water requirements, crop productivity and cropping patterns in the area. Figure 6 shows the absolute *change* in total annual agricultural water requirement, agricultural yield and economic output when compared with the baseline for all 22 scenarios.

Figure 17 indicates that improvements to economic output only can be made with relatively little change to the current cropping regime, however water consumption increases and yield decreases at these small changes. However, by the Scenario 4 suite of tests (in which the rice area is reduced by 3000 feddans), the total water requirement starts to decrease with respect to the baseline and total yield and economic output increase. As one moves through the scenarios, the improvements get more desirable, peaking at Scenario 8b, under which the total annual water requirement is 22 x 10^6 m^3 yr^{-1} less than at present, while the yield and economic output increase by 24 000 t yr^{-1} and 13 x 10^6 LE yr^{-1} respectively. Somewhat surprisingly, the 'economic security' pathways modelled in a Scenario produce a better improvement to agricultural yield than the corresponding 'food' security pathways, and are generally more favourable than the balanced pathways. Upon close inspection this was found to be due to the 9% estimated decrease to the yield of wheat (which is important for the food security pathway) by 2050 coupled with the 17% increase in the yield of cotton and a very high yield for vegetables (which are important in the economic security pathway) and the interaction of these changes with changes to the cropping regime. These factors were not taken into account when deriving the pathways with ECRI, but have proved to have subtle, unexpected but important implications on the final results.

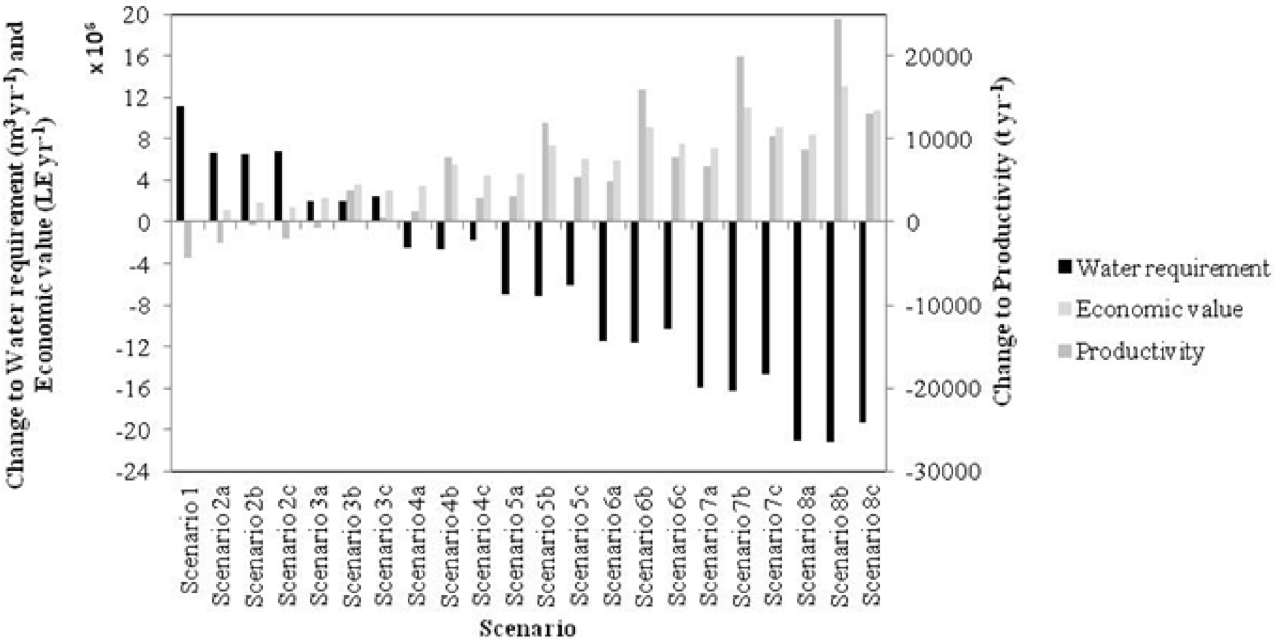


Figure 17: The absolute change in crop water requirements, crop productivity and economic output in all of the 22 cropping regime scenarios.

WSM DSS results

Figure 18 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, estimated on the basis of data described in Section 3.2.1 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 m³/yr.

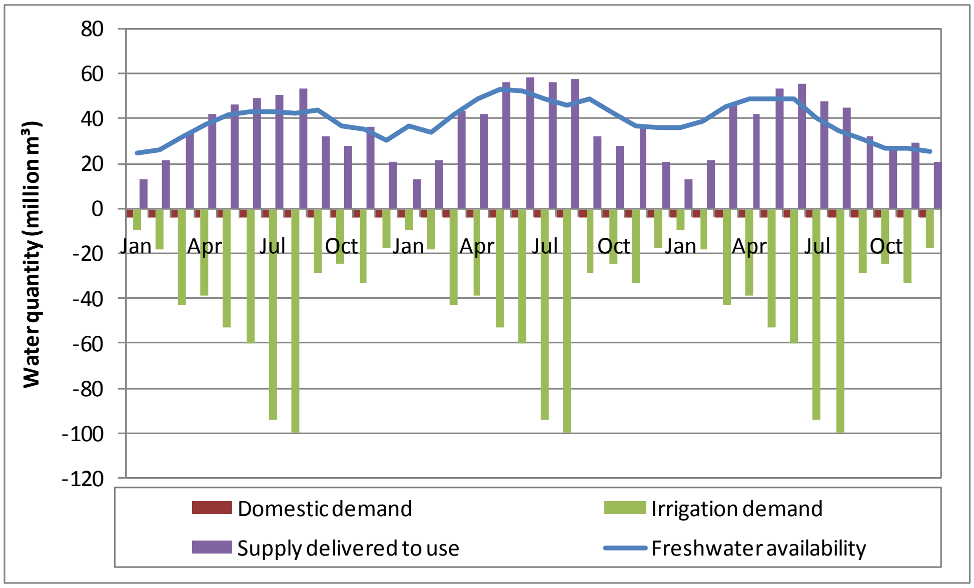


Figure 18: Water demand, freshwater availability and supply delivered to use in Rosetta, as estimated by the WSM DSS for the baseline conditions

Due to the priority setting, domestic deficits are equal to 0 throughout the simulated period. Figure 19 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.

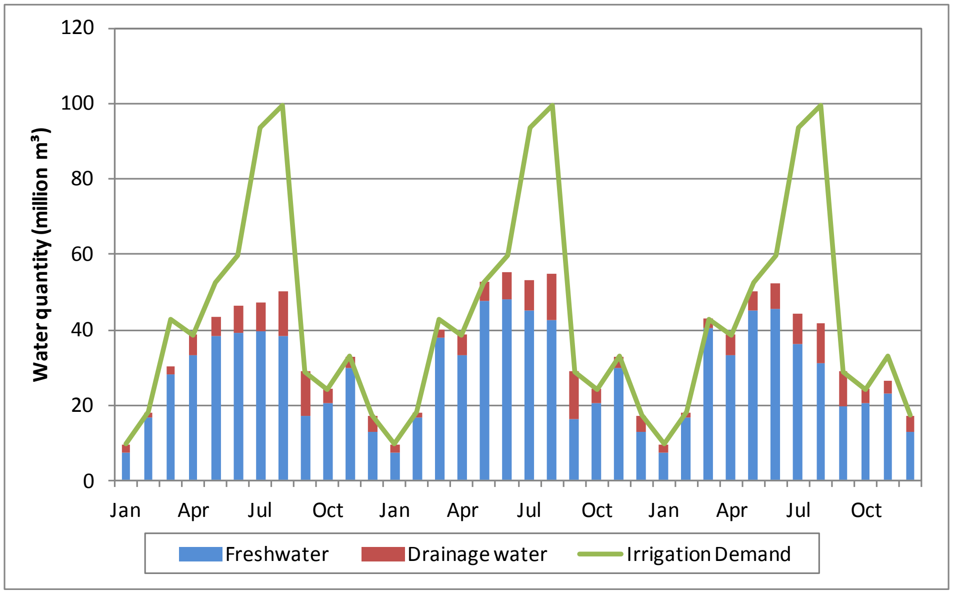


Figure 19: Water demand, supply sources and deficit in the agricultural sector of Rosetta, as estimated by the WSM DSS for the baseline conditions

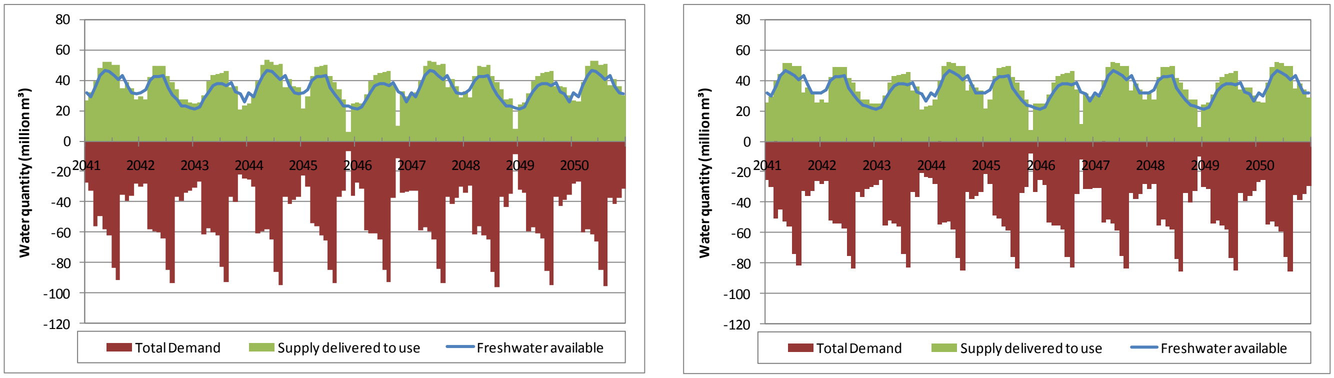
Future scenario simulations in the WSM DSS concerned the best and worst case scenarios, as described by ECRI for WASSERMed Deliverable 5.1.2 (Sušnik et al., 2011b). In summary:

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



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

Figure 20: 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 21 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 21), the economic output can be higher for the Worst Case scenario, offsetting the loss of agricultural land.

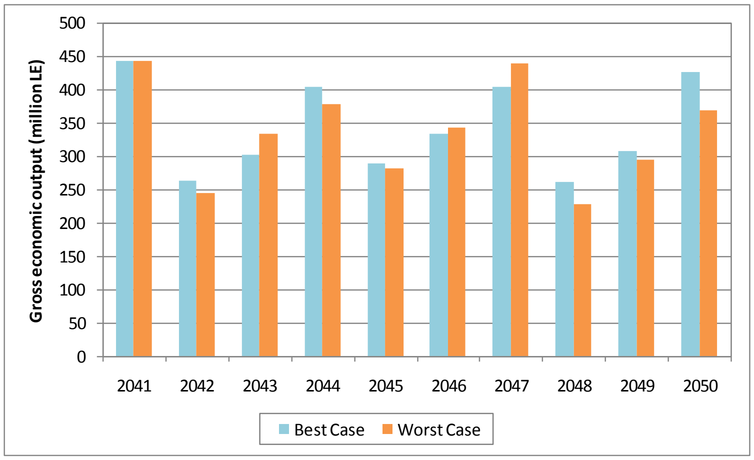


Figure 21: Gross economic output from agriculture for the Best and Worst Case scenarios, as estimated by the WSM DSS [2041-2050]

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.

3.2.3 Discussion

Baseline results from both the SDM and the WSM DSS modeling suggest that at present, the Rosetta region water demand is greater than the supply, something that is not sustainable for the long term (Figures 14, 18 and 19). For the future scenarios, the SDM results indicated continued overexploitation of the water resource, even under ‘best case’ conditions as defined by ECRI. A similar situation is also found from the WSM DSS results, with significant overexploitation still being predicted (Figure 20).

Based on a suite of cropping scenarios carried out in SDM, it was shown that, with suitable and sustained changes to the cropping regime to incorporate those crops with lower crop water requirements but with higher yield and economic value, agricultural water savings can be made while yield and economic output can both be increased. However, due to the volume of overexploitation, while encouraging, these savings represent only c. 3% of the deficit. Despite this, it is possible that with careful management, a new beneficial positive feedback loop could be setup that would further improve the situation into the future. With excess crop, some of the excess could be sold, generating even greater revenue. Some of this could be used to improve irrigation efficiency, while some could be used to import highly water demanding crops, thus utilizing the power of the virtual water trade to alleviate the current situation. More water is saved through this mechanism, and focus can start to shift to higher yielding, more economic crops. Greater yields will lead to more surplus, more can be sold and more revenue is generated, and so the cycle goes on. However, to develop such a feedback loop would take time, dedication and careful and appropriate management.

There are many uncertainties regarding this case study however. One pertains to the direction and magnitude of change in Nile flows. Another regards the rate and amount of sea-level rise, and how much protection will be given to the agricultural lands in the Rosetta region. Finally, there are social uncertainties, borne out recently by the shift to democratic leadership in Egypt as a result of the Arab Spring. All these factors make this case study and interesting, but difficult subject to study and may impact heavily on regional water resources. Finally, as with the Tunisia case study, it is likely that a range of mitigation measures will have to be implemented in parallel in order to form a coherent water saving strategy.

3.3 Jordan River, Jordan

3.3.1 The water balance model

The SDM for the Jordan Basin is shown in Figure 22.

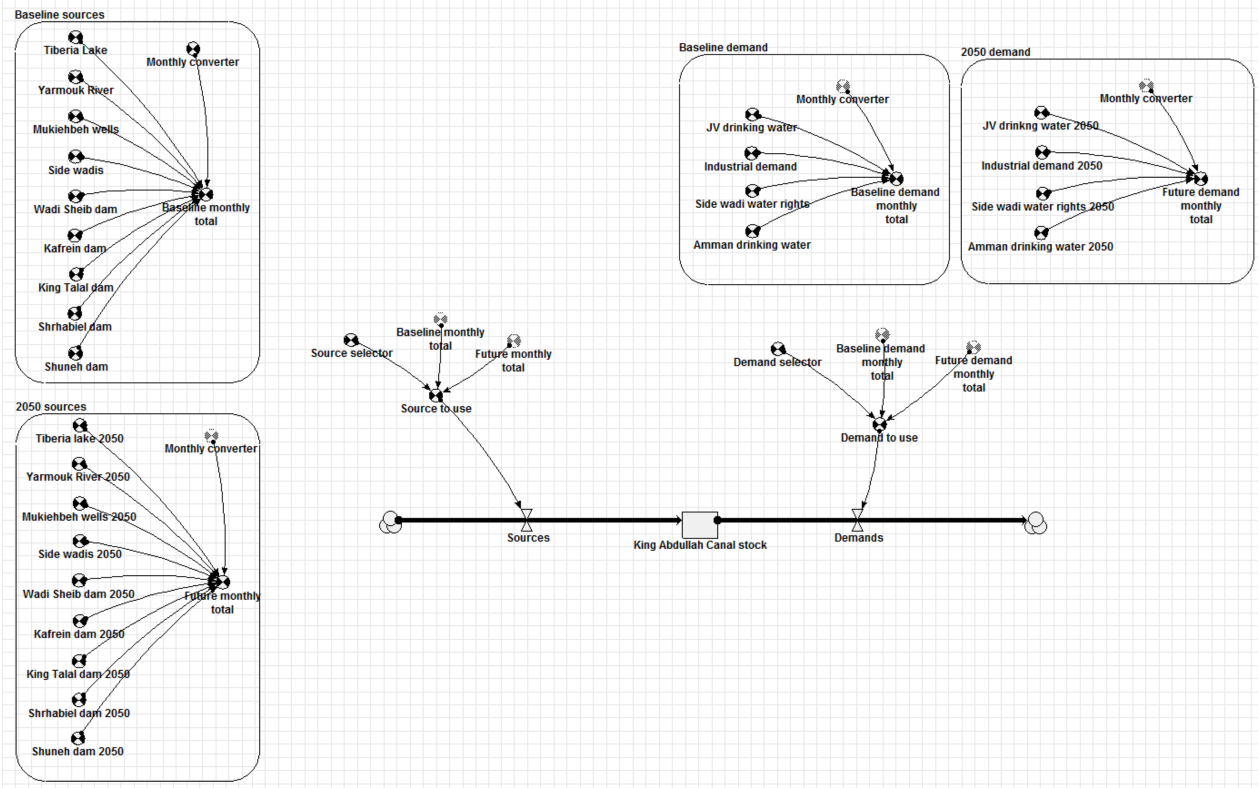


Figure 22: The Jordan River SDM.

The model (Figure 22) comprises of two main parts: sub-models for current and 2050 sources and models for current and 2050 demands. With respect to the supply sub-models, nine sources are accounted for: Tiberia Lake, the Yarmouk River, Mukiehbeh wells, side wadis, Wadi Sheib dam, Kafrein dam, King Talal dam, Shrhabiel dam and Shuneh dam. All timeseries' were provided by NCARE at annual resolution. Therefore, all are divided by 12, assuming even distribution throughout the year, which may not be the case. On the demand side, Jordan Valley drinking water, industrial demand, side wadi water rights and Amman drinking water are accounted for. For both the supply and the demand, baseline and 2050 conditions can be modelled by changing one value which acts as a data selector. The main water stock is the King Abdullah canal. This element in the model tracks the difference between the supply and demand. Because of the extreme water scarcity in this region, and according to the literature (e.g. (Hadadin et al., 2010; Hussein et al., 2004), it is expected for this number to be negative, implying over-abstraction and depletion of the resource (i.e. the volume of water available in the King Abdullah Canal). In fact, (Hadadin et al., 2010) report significant water resource overexploitation at present throughout the lower Jordan Valley, with this expected to get worse in the future.

3.3.2 Model results

Under baseline conditions, model results suggest significant water surplus in the King Abdullah Canal (Figure 23). Supply outstrips demand by over three times. This is not what was expected. It was expected that the water availability would be stable if not declining in this region. The most likely explanations are that a) too much water is being removed from one or more of the sources feeding the King Abdullah Canal or that b) the demands are being underestimated.

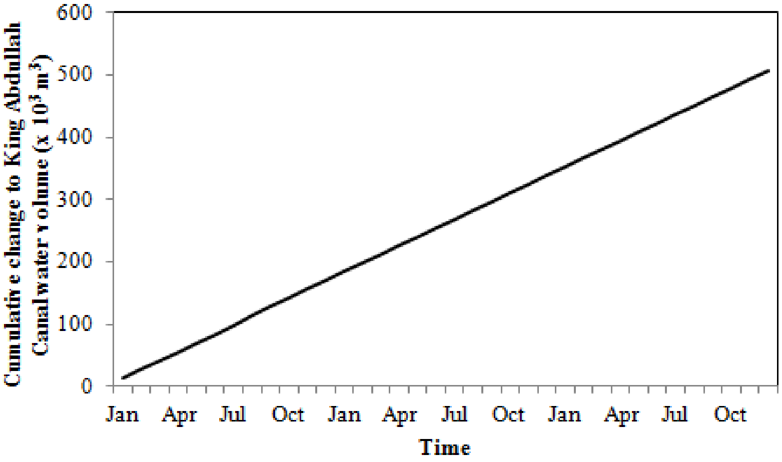


Figure 23: Baseline model simulation for the Jordan River case study.

Figure 23 shows an monthly water surplus of 14 000 m^3 according to the input data provided by NCARE, the Jordanian WASSERMed partner.

Under future conditions, it is expected that the baseline situation will deteriorate. Lower rainfall totals, reduced streamflow volumes, increasing population, improving lifestyles and increased evapotranspiration from crops suggest that while the supply is set to decrease, the demand will rise. Therefore, the 2050 simulation is expected to show a more pessimistic scenario than the baseline. Figure 24 shows the results for the 2050 simulation. Contrary to expectations, the situation improves. While the demand does indeed increase, the supply increases by a greater amount. This suggests that either the input data are over optimistic, or that the various supply sources are set to be even more overexploited than at present (Hadadin et al., 2010). Thus, this picture can be thought of as a 'false positive', as will be discussed in Section 3.3.3.

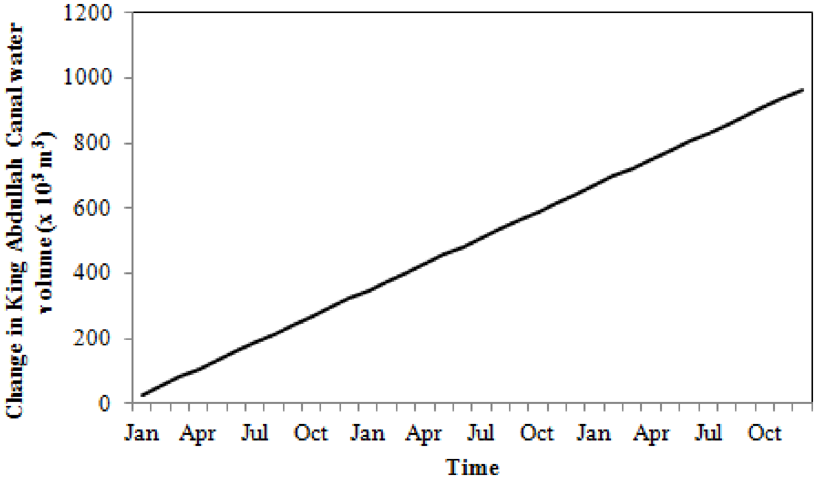


Figure 24: 2050 model results for the Jordan River case study.

3.3.3 Discussion

There is much literature regarding the current extreme water scarcity situation being experienced in Jordan (e.g. Hadadin et al., 2010; Hussein et al., 2004; Raddad, 2005). Despite this, the modelling results for the baseline (Figure 23) indicate that the current system behaviour is one of net water accumulation in the King Abdullah Canal (KAC). This is surprising and counter to what is written in the literature. The two main expected reasons for this model behaviour are: a) that too much water is being extracted from one (or more) of the sources that feed the KAC or; b) the water demand is being seriously underestimated.

Point (a) means that essentially the result in Figure 23 is showing a 'false positive'. While on initial inspection, the water balance situation in the study area appears to be optimistic, with excess water supply being suggested, the reality is very different. In essence, this result is merely 'moving' the problem elsewhere (e.g. to another river reach, catchment, etc.), and is not addressing the real issue that in Jordan, there is a severe water crisis looming (Hadadin et al., 2010). There is much evidence that the water use in Jordan (and the riparian Jordan River countries) in exceeding water supply. For example, Jordan River flows are now a fraction of their historic values (1550 x 106 m^3 yr^{-1} historical value vs <200 x 106 m^3 yr^{-1}, NCARE, *Pers. Comm.*), and the surface area of the Dead Sea, into which the Jordan River discharges, has reduced significantly recently (from c. 1000 km^2 in 1965 to c. 600 km^2 in 2006, NCARE, *Pers. Comm.*). Thus, there can be little doubt that in reality, demand is seriously exceeding supply. Therefore, the result in Figure 23 is believed to be misleading.

Point (b) suggests that the demands are being underestimated. This may be case, especially considering that there is a large local farming community, and some of these farmers may extract water 'off the grid'. However, the magnitude of the underestimation appears to be very large in order to give the result displayed in Figure 23, and it is believed that either the supply is being vastly overestimated (or that an alternative supply source such as fossil groundwater is being exploited but not declared in the modelling data) or that the problem is being 'moved' elsewhere, as discussed above.

Figure 24, showing the results from the 2050 model simulation, is also surprising. Various studies suggest that the regional rainfall totals will decrease (Samuels et al., 2009) leading to concomitant decreases in streamflows (Samuels et al., 2009). In addition, potential changes to the socio-economic situation could lead to increasing demand. The overall impact would suggest a worsening of the already serious situation. Despite this, the modelling results indicate a significant improvement of the situation. While at first it appears optimistic, in reality, this is likely being driven by widespread massive overexploitation of the water resources in other parts of the Jordan Basin, and may therefore be detrimental in the long term. Other possible explanations for the increase are: a) a fossil aquifer is being tapped for resources, but again, this is unsustainable use of a non-renewable resource; b) that new dams have been built in the Jordan Valley. However, damming rivers simply prevents water from reaching the Jordan River itself, and does not address the longer term issue of regional overexploitation of the water resource in the Jordan Basin.

3.4 Syros Island, Greece

3.4.1 The water balance model

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 25.

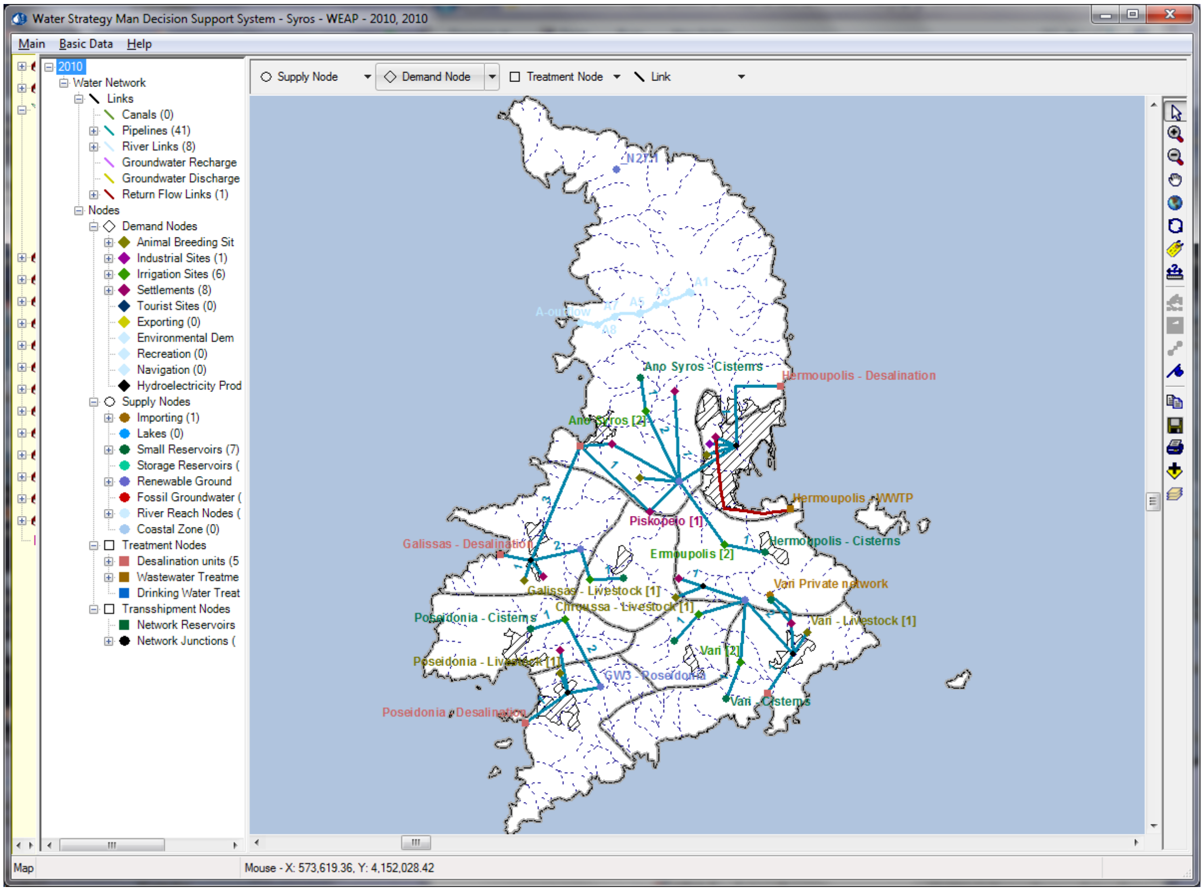


Figure 25: The schematization of the Syros water system in the WSM DSS

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[1], 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 2.

Table 2: 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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[1] 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

3.4.2 Model results

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).

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 in the Syros water system. 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 26 presents the 2010 deficit in the urban and agricultural sectors. As evident, urban water demand is fully met throughout the year (desalination capacity is adequate to meet water demands in all major agglomerations). A very 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. The monthly profile of water deficits presented in Figure 26 reveals that these are 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. Similarly, the small amount of water replenishment in September and October does not allow the coverage of water demands in November, thus resulting in deficit also during that month.

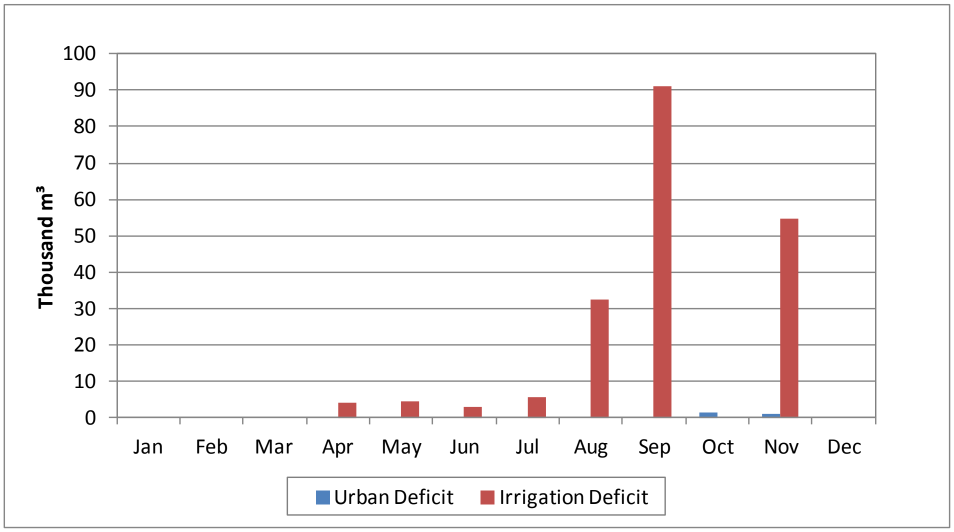


Figure 26: Water deficit in the urban and agricultural sectors for the 2010 baseline

Figure 27 presents results on 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 (the difference between actual and simulated annual production is about 1%). Actual desalinated water production data from the other units were not available.

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).

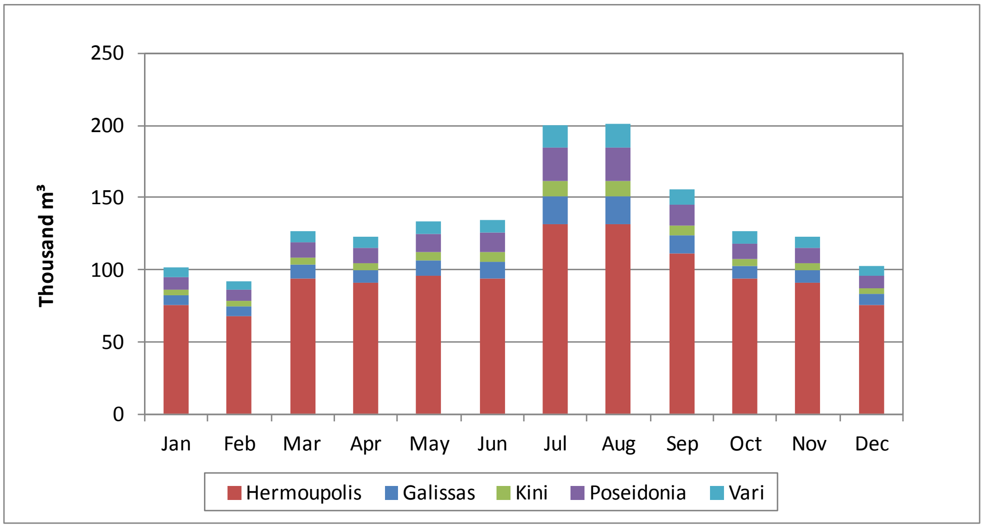
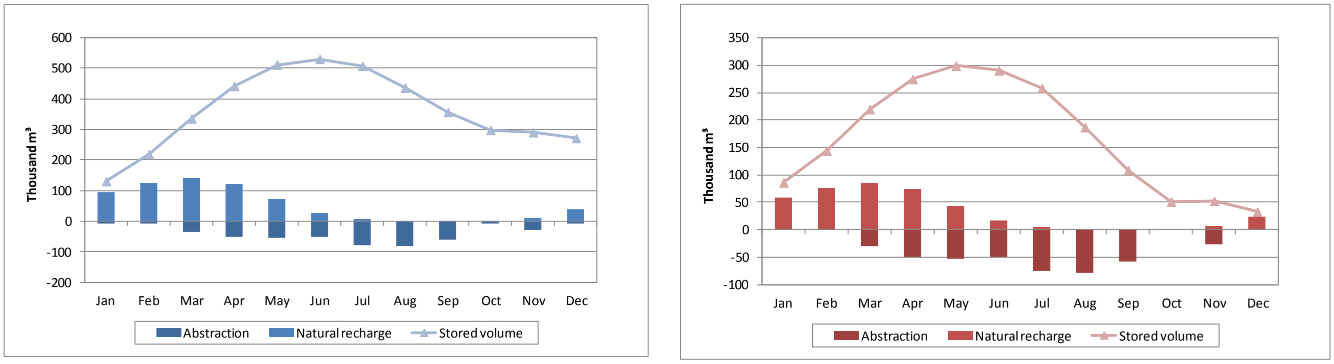


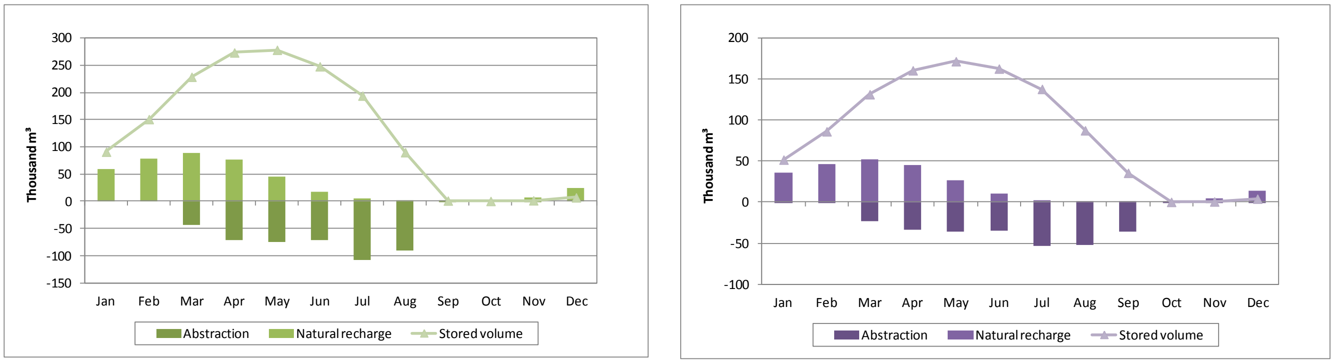
Figure 27: Desalinated water production for the 2010 baseline

Figure 28 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 28: Water balance in the hydro-geological units of Syros for the 2010 baseline

Table 3 summarizes the results from the sensitivity analysis for the baseline conditions.

Table 3. 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 m³/yr Groundwater exploitation index [2]: 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 m³/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 m³/yr Groundwater exploitation index: 97% (No change)

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

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).

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. The formulation of scenarios is detailed in WASSERMed Deliverable 5.1.2. Table 4 summarizes the main scenario parameters.

From the scenarios described in Table 4, 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. Additional simulations for these two scenarios concern the potential impacts of climate change on tourism. The relevant analysis is detailed in WASSERMed Deliverable 4.3.2 (Kampragou et al., 2012), and includes the forecast of the potential direct impacts of climate change on the tourism sector of Syros. 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.

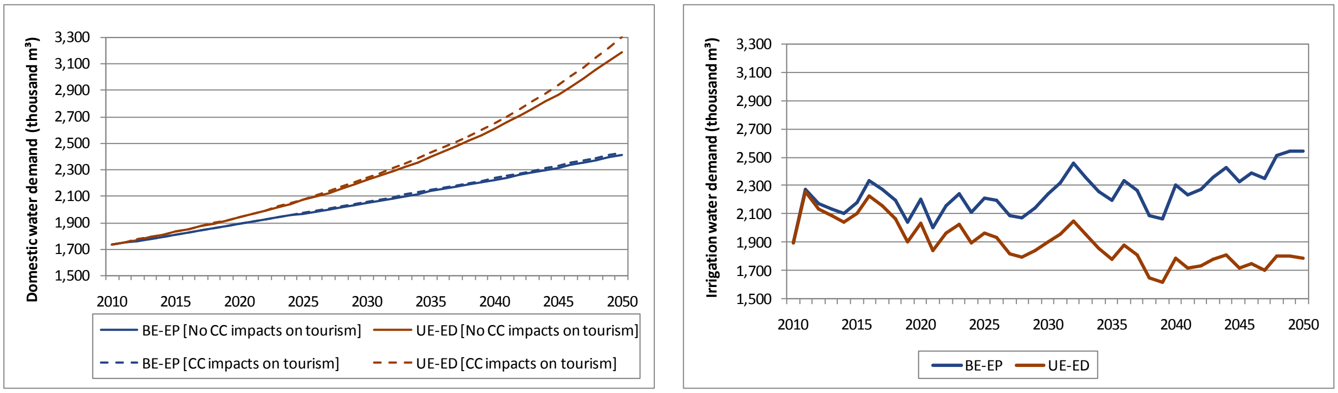
Table 4: Parameters of socio-economic scenarios for Syros

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

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 29 to 32.

Results are further summarized through a basic set of **indicators** concerning water security, environmental security and economic security (Table 5). Selected indicators include: (a) average values, reliability and resilience in the coverage of domestic and irrigation water demands (water security indicators), (b) levels of groundwater exploitation (environmental security indicator), and (c) gross economic output from tourism and agricultural activities (economic security indicators). 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].

Figure 29 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 (Figure 29a). This is particularly true in the case of the BE-EP scenario, which describes a pattern of light tourist development. Overall, irrigation demand (Figure 29b) 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.

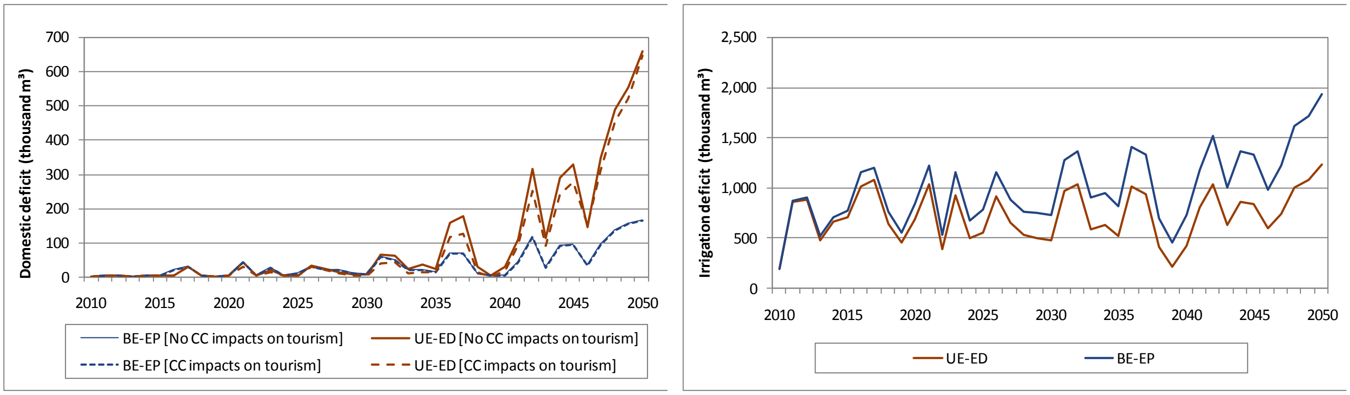


(a) (b)

Figure 29: Domestic and irrigation water requirements for the BE-EP and UE-ED scenarios for 2010-2050

Figure 30 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 (Figure 30a). Initially, and up to 2030, the deficit mainly concerns inland agglomerations (Ano Syros, Piskopeio and Chroussa) which depend on groundwater, and is a result of the reduction in groundwater availability in these years, due to reduced precipitation. From 2030 and onwards, the domestic deficit is significantly more pronounced and gradually affects all agglomerations, since: (i) the existing desalination capacity is not adequate to meet water needs, initially during the peak summer season and gradually throughout the rest of the year, and (ii) groundwater is increasingly used to meet domestic demand. 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. The "flattening" of the water demand pattern alleviates the summer peak and water demand is shifted towards spring and autumn, when the existing desalination capacity is adequate to meet requirements, at least up to 2035.

On the other hand, deficits in the agricultural sector are significantly more pronounced (Figure 30b). 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, which contribute to higher crop water requirements, (ii) reduced groundwater availability, and (iii) increased groundwater abstractions for domestic use, which has a higher priority than irrigated agriculture.



(a) (b)

Figure 30: Domestic and irrigation deficits for the BE-EP and UE-ED scenarios for 2010-2050

Figure 31 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.

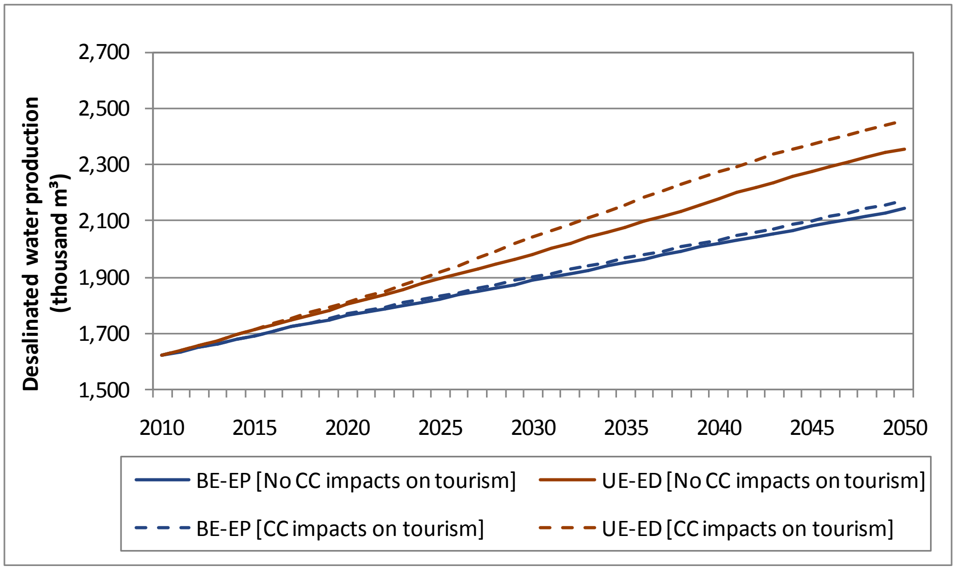


Figure 31: Desalinated water production for the BE-EP and UE-ED scenarios

Finally, Figure 32 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.

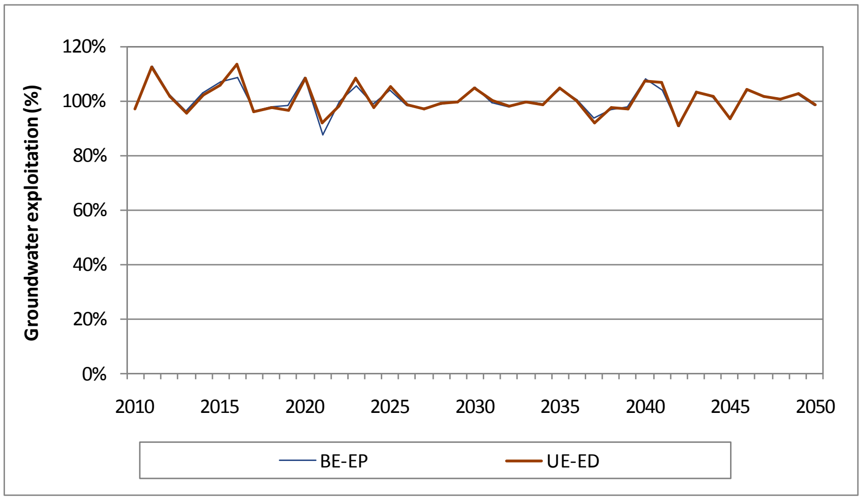


Figure 32: Groundwater exploitation index for the Syros water system in the BE-EP and UE-ED scenarios

Table 5 provides a summary of the range of results obtained from the simulation of the scenarios for the selected indicators on water-related security threats.

Table 5: 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%**
Economic security	Yearly average of total economic value from domestic water use, incl. tourism (M€/yr, current values)[3]	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 5 the following can be summarized:

- Water security gradually deteriorates in the simulation time horizon, 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.

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[3] 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].

- 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 in the area. 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 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.

As with the case of the WSM DSS application in Rosetta, the above concern results for scenarios without adaptation measures. Potential interventions, as discussed with local stakeholders, concern rainwater harvesting in the domestic sector, further enhancement of desalination in order to minimize the dependence of domestic usage from groundwater resources, wastewater reclamation through the use of treated wastewater for aquifer recharge, and limitations in groundwater abstractions. These measures will be assessed by determining the improvement of the indicators described in Table 5, and in terms of costs, during the last phase of WASSERMed, in order to derive policy recommendations.

3.4.3 Discussion

Baseline results (Figure 26) indicate that urban water demand is fully met all year, while agricultural demand suffers a small deficit. However, while this initially appears encouraging, Figure 28 shows that aquifers are exploited to a high degree, that may be unsustainable in the long term, and also that there is a high contribution from energy-intensive desalinated seawater (Figure 27).

Most of the parameters used for the Syros water balance model have been validated in close collaboration with local authorities and stakeholders. Of the range of data inputs, the main sources of uncertainty concern:

- Water losses in the distribution networks of the main agglomerations: Currently, the Municipal Enterprise of Hermoupolis-Syros estimates that physical losses (leakage) are as low as 15% in Hermoupolis, and about 20% in all other areas. For the purposes of sensitivity analysis, losses are set to vary between 15 and 25% in all agglomerations of the island.
- Capacity and level of coverage of irrigation demand by rainwater harvesting: Local farmer associations estimate that about 15% of crop water requirements are met through rainwater stored during the October-April period, but this likely represents an upper threshold of the demand that can be covered

through cisterns. Depending on the sub-system, it is assumed that this percentage may vary between 5 and 15%.

- Overnight stays: Despite the fact that overnight stays have been estimated based on official data, they can very well vary about 20%, considering that a large number of beds are unregistered and operate unofficially.

With respect to future scenario modelling (Table 4), potential increases in tourism may impact on domestic water deficits, although agricultural water supply would suffer to a greater degree, and this is shown in Figure 30. It is also predicted that beyond 2030, water deficits in both sectors become much more pronounced due to an ever-increasing reliance on the unstable groundwater supply. The obvious mitigating option here would be to increases dramatically the desalination capacity. The significant increase in the agricultural water deficit is due to three main factors: i) reduced rainfall totals; ii) reduced groundwater availability and; iii) increasing groundwater abstractions for domestic use, which has priority over agriculture. This could have significant impacts on the local economy.

Although the current situation is not as serious as some of the other case studies, it has the potential to become worse in the future. The current heavy reliance on unstable groundwater supply is risky, especially considering projected reductions in recharge due to lower rainfall totals. The current desalination capacity is adequate, however a potential mitigating option may be to increase significantly the future desalination capacity. This will have three main impacts: i) it will secure the domestic water supply into the future; ii) it will reduce the pressure on groundwater sources, maintaining their quantity and quality and; iii) it may prove crucial in preserving the local agricultural economy. The main downsides of such a strategy are the large energy cost associated with desalinated water, and the more expensive cost of supplying desalinated water to consumers who may be likely to see their costs rise.

3.5 Sardinia, Italy

3.5.1 The water balance model

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 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 demandsof each reservoir. Figure 33 shows the areas in Sardinia served by the four selected reservoirs.

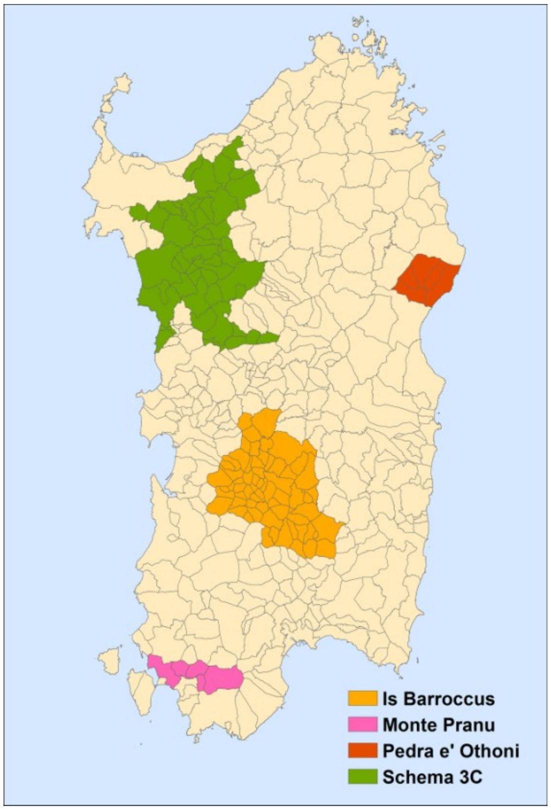

Figure 33: Townships served by each modeled aquifer. Touristic flows are highest in coastal townships.

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

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 modified version of the Penman-Monteith approach (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.

Water outflows

ENAS is responsible for the water management of the reservoirs and 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. Water for industries is directly bought by the single industries. ENAS also keeps track of the water discharges that occur to i) keep the dam inside legal security levels (some of the dams have not being tested for their full potential) ii) to deliver enough water to sustain the downstream ecosystems.

Each model accounts for water demands for each sector using the data from ENAS. Not all reservoirs have the same sectoral demands and one of them (Pedra e' Othoni) also has hydropower demand. ENAS water management policy is included in the model and limits water supply to each sector based on the available volumes in March.

Domestic use was calibrated on the standing population served by the reservoir and the touristic flows. Historical touristic flows were available for the four main areas of the island but not for each township. The touristic flows for the townships served by the reservoirs were estimated based on the distribution of the available beds in accommodation structure. Calibration suggests about 650 liters per day per person, while usually 400 liters per day per person are estimated. The difference includes water losses by the water distribution network. In the 2048-2050, domestic use accounts for the population growth and touristic flows estimated using the Touristic Climate Index (TCI). Note that population growth rate is low in Sardinia (1.04 per year) and that TCI suggest an overall increase in tourist presences and an extension of the tourist flows in both spring and autumn.

Irrigation use was calibrated against crop water requirements modeled with SIMETAW. The model was run for the irrigated crops served by the reservoir. Modeled crops were: olive, vineyard, and aggregation of vegetables. SIMETAW can also account for the water use efficiency of different irrigation system. Irrigation requirements over 2048-2050 are modeled assuming the same irrigated area as present. The effect of CO2 fertilization were considered and estimated in SIMETAW, but on average the overall field irrigation remain similar to present, since increase in water use efficiency for higher CO2 fertilization is compensated by lower predicted precipitation in 2048-2050.

The industrial and Hydropower use were not calibrated and assumed to remain equal to present.

Scenarios for 2048-2050 assume that all dams have been tested structurally and can work on their full potentials. 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 34.

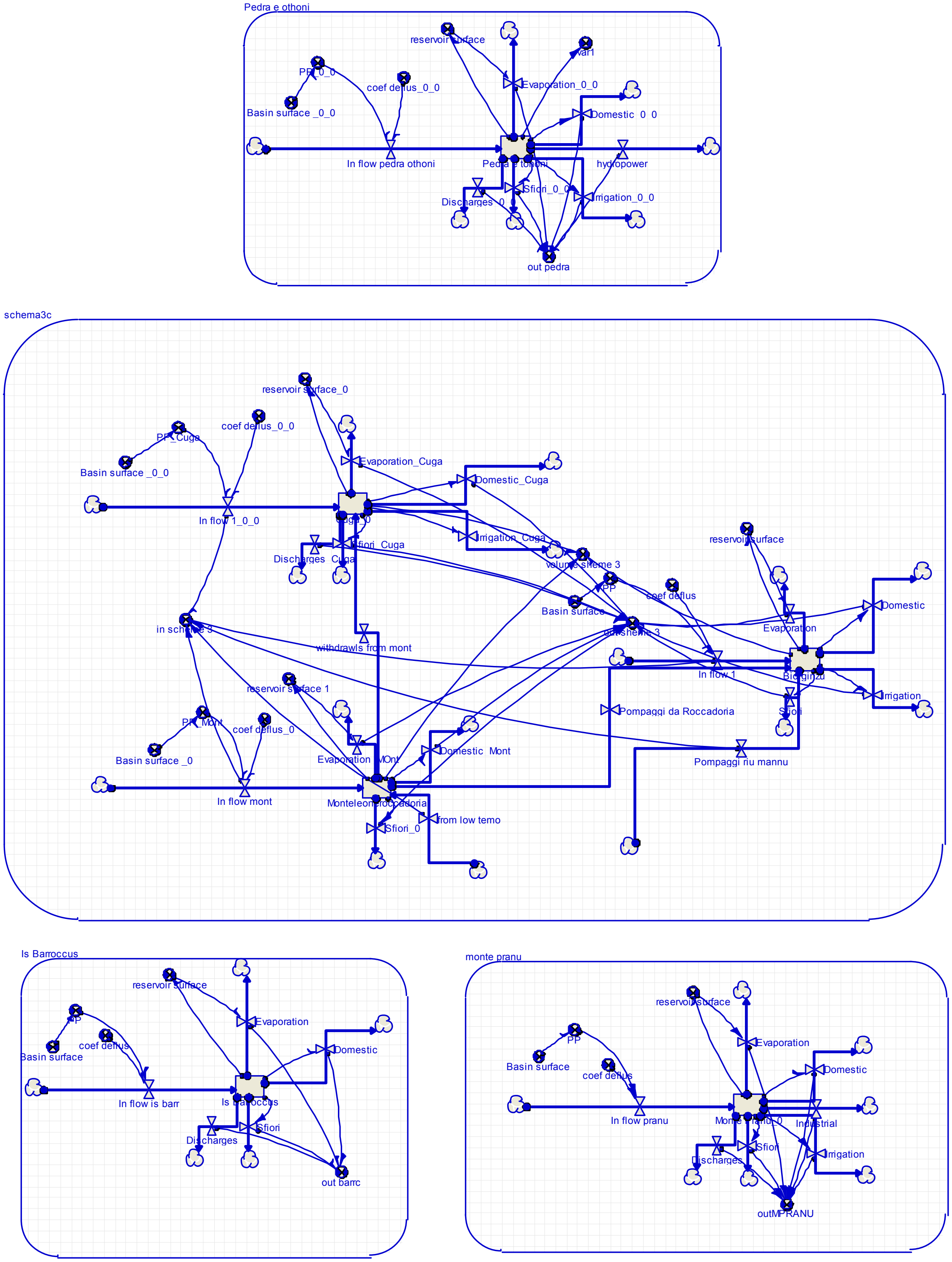

Figure 34: The developed SDM for the Sardinia case study.

In addition, ENAS is currently working on a water balance for the south of Sardinia and was specifically interested to develop the SDM model for the North of the Island. In view of D5.2.4 (“Final water balancing models”) the SDM model will be implemented for the North of Sardinia especially accounting for the Coghinas aquifer, which is perhaps the most important for the north of the island. The final scenarios will account also for the South of the Island by using the results of the model developed by ENAS.

3.5.2 Model results

The results for the baseline scenario (i.e. 2008-201 period) are shown separately for each of the four submodels: SCHEME 3C, Barroccus, Monte Pranu and Pedra e’ Othoni. (Figure 35).

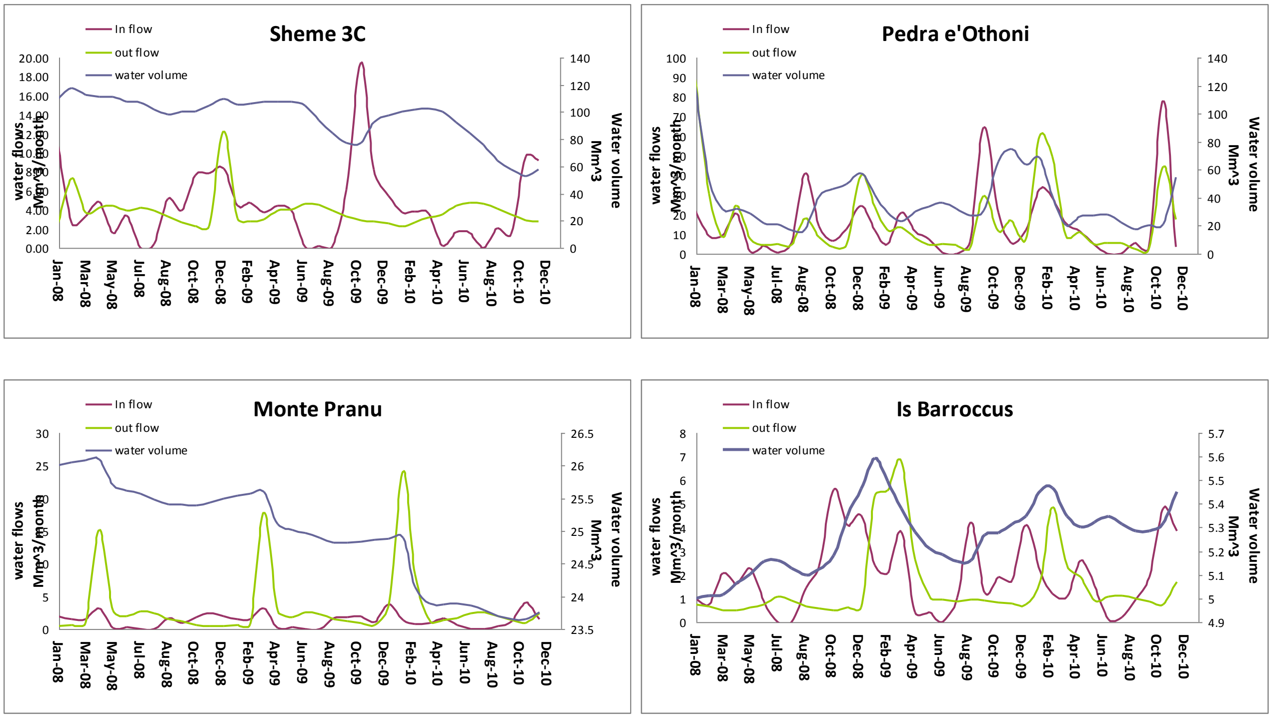

Figure 35: Baseline model results for the four modeled areas in the Sardinia case study

Scheme 3C, composed of three interconnected reservoirs, remains fairly stable in relation to water flows 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. These uses explain 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 36 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 3Cand 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.

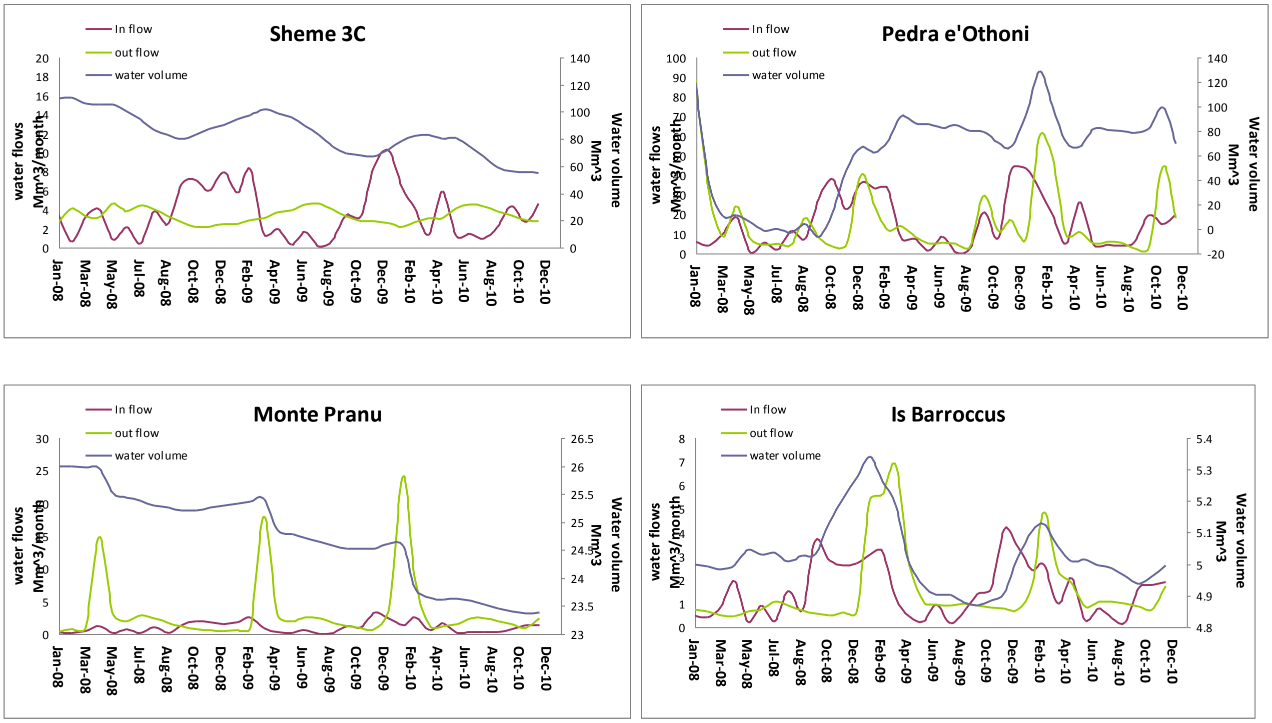

Figure 36: 2050 model results for the four modeled areas in the Sardinia case study

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 37). 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. Sensitivity for irrigation was not performed for Is Barroccus because this reservoir is not used for irrigation.

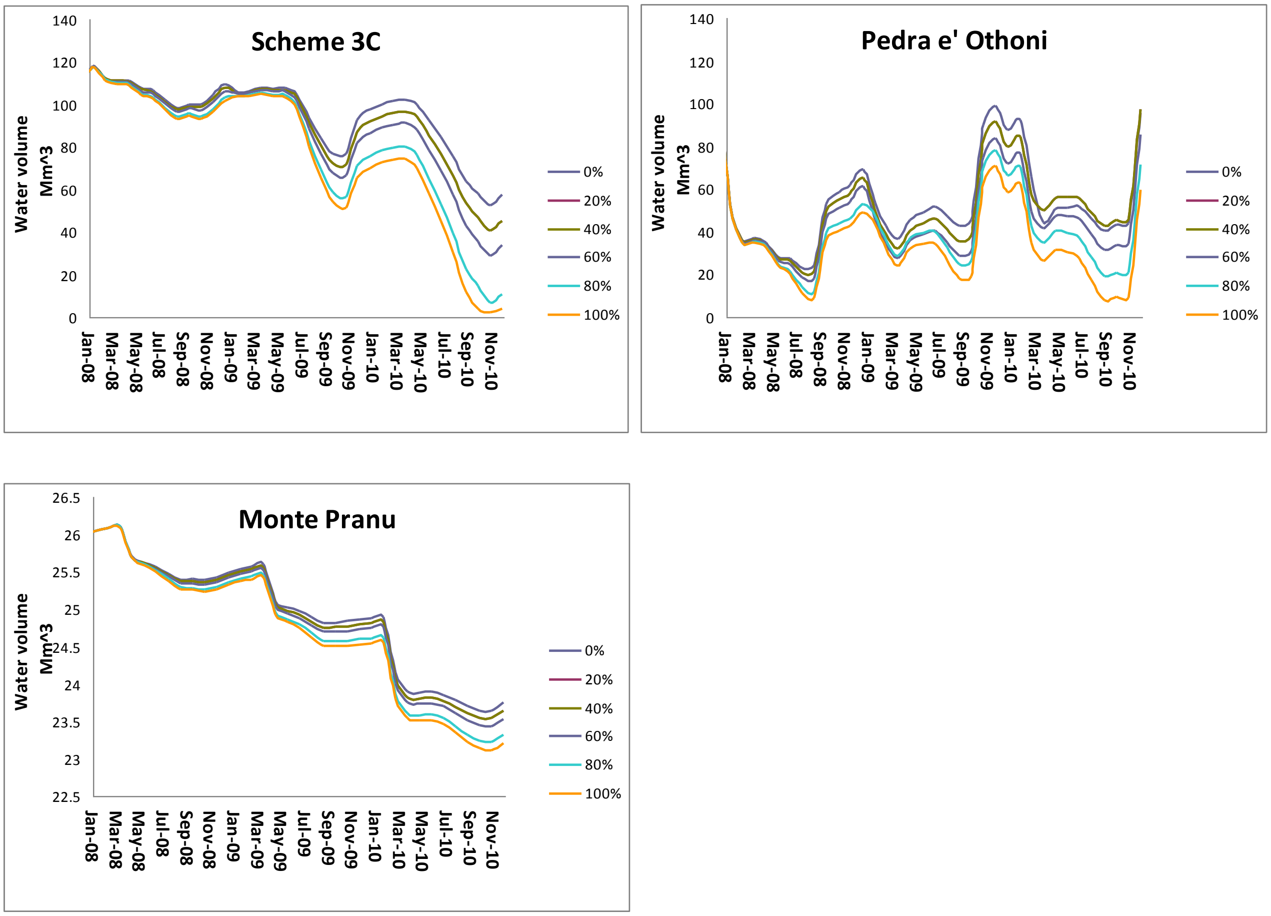

Figure 37: Sensitivity test for irrigation

Sensitivity for domestic use

Figure 38 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.

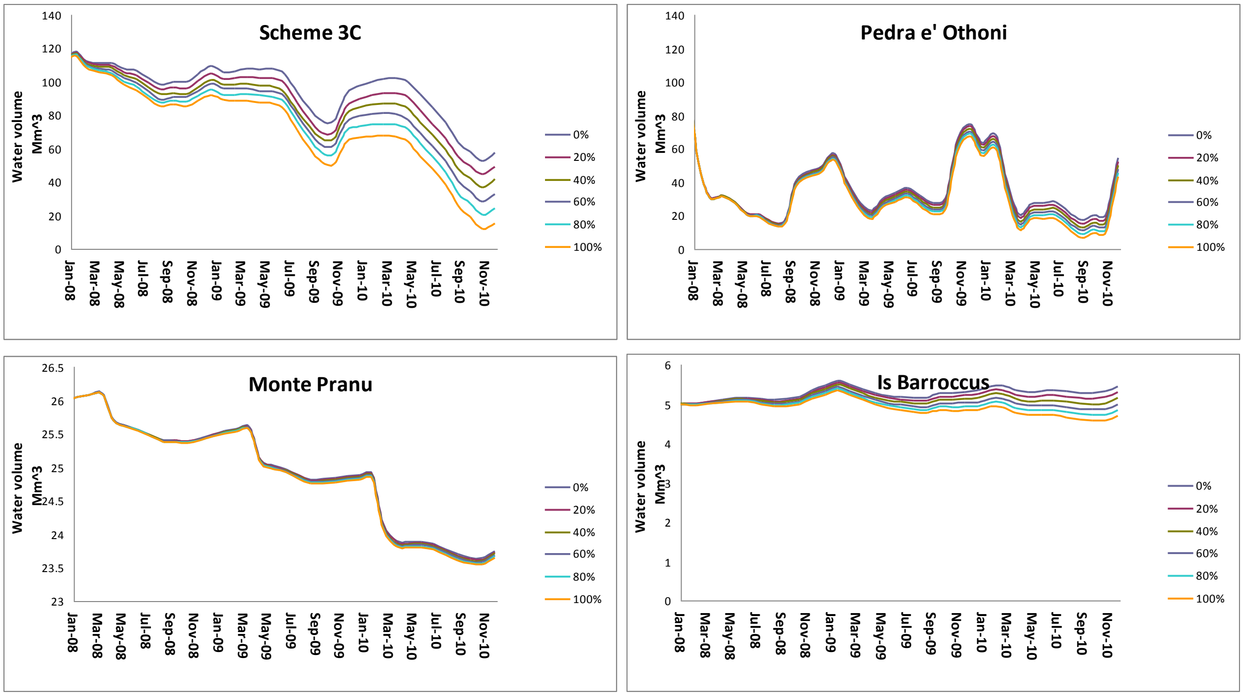

Figure 38: Sensitivity test for domestic demand

3.5.3 Discussion

At present, the situation in Sardinia is not as critical as in the other WASSERMed case studies. Three of the test basins show relatively stable trends, with only Monte Pranu indicating water overexploitation. Also encouraging is the fact that Scheme3 also serves as an emergency water source to nearby towns in case of emergency, and the fact that Pedra e' Othoni is also used for hydropower generation. Is Barroccus is the most sensitive to sporadic rainfall input, but is also the least exploited in terms of irrigation water use, so is at present at relatively low risk.

Simulations for the future scenarios, which incorporate a predicted 15% decrease in streamflow volumes entering reservoirs, indicate that the current overexploitation trend in mote Pranu becomes amplified, while Scheme3 is predicted to become overexploited. Is Barroccus remains stable while Pedra e' Othoni shows an increasing trend of water volume, an improvement over the present situation. This is due to policy that is aimed at allowing Pedra e' Othoni basin reservoir to fill to its full capacity - a water stress mitigation measure. This will ensure the water supply to the multiple conurbations that it currently serves, and will allow for the continuation of hydropower production. The results indicate that, while not predicted to be extremely critical, the situations in Monte Pranu and Scheme3 should be closely monitored, and measured implemented as soon as possible in an attempt to prevent the more significant overexploitation, particularly in Monte Pranu.

The sensitivity tests, related to changing the percentage of irrigated land and an increase in domestic demand, will prove useful when deciding which factors are key with respect to being the greatest threats to the Sardinian water supply, and will help to direct mitigating policy measures. Increasing domestic demand had relatively little impact in all basins except Scheme3 where slightly more variability is observed. For this basin, domestic demand needs to be closely monitored, with policy put in place at increasing domestic use efficiency and reducing per-capita use. It is noted in the results section, that significant increases in domestic demand in Scheme3 could lead to increased water shortages in the city of Alghero, with emergency supply being relied upon more frequently.

Increases to the irrigated land area showed a much greater impact to the water resources (except in Is Barroccus where there is no irrigated agriculture). This could prove a cause for concern in Sardinia, with irrigation and tourist water use perhaps coming more into conflict than at present. It could also have implications for the local agricultural economy as well as the viability of the water supply both in terms in quantity and quality (especially when considering the projections for lower rainfall totals in the region). From the results presented here, it is suggested that agricultural expansion should be closely monitored, and where possible, more efficient irrigation techniques should be implemented. This is especially true in the Scheme3 and Monte Pranu basins.

As with the other WASSERMed case studies, a single mitigating policy option is unlikely to be successful. Rather, a suite of options and measures aimed at reducing the overall water demand across sectors will be required if success is to be ensured. Despite the fact that the situation on Sardinia is not as immediately pressing as in some of the other case studies, this is no excuse for complacency or a lack of action. Comprehensive, early-implemented policies will ensure that the current situation does not unnecessarily become any worse than it needs to.

4. Conclusions

Water availability the world over is currently a major cause for concern, in some regions more than others, and is a major topic of international, interdisciplinary study. About 1 billion people lack access to safe, clean drinking water. Up to 2.4 billion people do not have basic water sanitation. Many regions of the globe are currently experiencing water shortages or water stress of sort or another. In western nations apparently rich in water, the resources is being overexploited in many cases, and is being used very inefficiently. In the Mediterranean, the situation is bought into sharp focus. Many countries are already water stressed (e.g. when defined by indicators such as the Falkenmark Index), particularly the north African and eastern Mediterranean regions. This is due to generally low rainfall totals, high evaporation rates, a population strongly concentrated along the coasts and a high dependency on agriculture focusing on water-demanding crops, particularly in the poorer countries.

Current projections of global climate change suggest that in general, Earth surface temperatures will rise to variable degrees. Predictions of changes to rainfall are more uncertain. Northern latitudes may experience slight increases in rainfall totals, particularly in winter months. Those areas that area already water stressed (the Indian subcontinent, the Mediterranean basin), area predicted to receive less rainfall than at present. This will have the impact of reducing streamflows and aquifer recharge, and will only be exacerbated by increasing evaporation. The Mediterranean region has been identified as a hotspot of global climate change, where the effects will be manifest most clearly.

In addition to the climate aspect of global change is the far more uncertain socio-economic aspect. The global population by 2050 is expected to rise to 9-11.5 billion depending on the scenario used for the estimate. Population growth is expected throughout the Mediterranean. It is also unclear as to how social behaviour changes will impact on per-capita water consumption. On the one hand, increasing wealth generally leads to greater per-capita water use, but on the other hand, it also leads to the development and implementation of more water efficient technologies which can offset some of the per-capita increases. How socio-economic developments will play out is almost unpredictable, as exemplified by the Arab Spring movement and the current global economic crisis.

It is clear that the current water shortage situation globally, and particularly in the Mediterranean, where WASSERMed is focused, is likely to get worse into the future with lower streamflows, aquifer depletion and reservoir drawdown. This will impact on domestic supply and health (as quality and quantity decreases) and on agricultural supply which in turn could negatively impact the dominant economy in many Mediterranean countries. In addition, environmental damage could be caused by reductions in water quantity and quality.

The case studies that are the focus of WASSERMed all have current water availability issues which will probably intensify in coming decades. These issues are unique to all each case study. By using a diverse set of five case studies, not only can we develop an intimate picture of the local issues being faced across the Mediterranean basin, but a higher level integrated assessment of the issues common over the entire Mediterranean can be undertaken. Thus, we aim to produce results which are ultimately useful at both the local/regional level and which are targeted specifically to each case study, but which may also be integrated to form wider policy suggestions at the European level.

To summarise the main results, all case studies show some degree of water overexploitation at present (except for Jordan, but these results are believed to be unrepresentative of the real situation, see Section 3.3). This overexploitation refers to surface water resources (streamflows, canal abstractions, reservoirs) and to groundwater sources (aquifers). Some case studies show greater levels of overexploitation than others. In some study areas, the overexploitation is due to a very large agricultural water demand, in others it is due to pumping of water outside of the hydrological system, while in others it is due to high domestic and tourist use.

Simulations of potential futures were carried out by using the latest climate forecast data and information provided by local stakeholders with regard to expected changes to population, per-capita water use, agricultural water use, the implementation of more water efficient practices to kerb demand increases and so on. In all cases (again except in Jordan, see Section 3.3) when the climate and socio-economic changes were simulated, the situation become worse relative to that of today. Either the supply volume was observed to become lower or more sporadic, or the demand was predicted to vastly increase either due to large increases in agricultural demand (due to either expansion of the irrigated area or increases in crop water requirements) or increases in the domestic/tourist demand.

Some case studies also provided data regarding sensitivity analysis of the most critical aspects of each system. For example, in Tunisia, sensitivity tests were carried out for four parameters, while for Rosetta numerous scenarios were tested that included altering the level of sea level rise and changes to the current cropping regime. Across all the case studies were sensitivity tests were carried out, some parameters had a much greater impact on model results than others. Some even suggested that water-surplus situations could occur provided that the parameter changed in the right direction and by the right magnitude. It is these most sensitive parameters that would be most closely looked at when developing potential mitigating policy measures. The idea would be to attempt to change the real-world version of this parameter in a way that would favour a more water-secure situation for the region. However, this may not always be practicable (e.g. in the Tunisia case study, there is little that can realistically be done to significantly alter the area of a catchment that receives rainfall).

It is suggested here that the results of the Jordan case study should be very closely scrutinised, as they do not reflect with the fact that the country, and the Jordan Valley is seriously overexploiting its resource. The current situation is widely reported in the literature, and the results presented here do not reflect the known situation. It is suggested that the data should be reviewed, and if necessary, the models should be re-run with more representative, more up to date information.

A major outcome from these modelling efforts is that in many cases, a multi-pronged policy strategy is likely to produce the best results in terms of decreasing the water deficit while also being to least risky by covering many bases. It also has the advantage of dealing with the great uncertainty when trying to predict how events will unfold 40 years into the future. As an example, in Tunisia, it could, in theory, be possible to achieve aquifer recharge simply through severe reductions to the volume of water that is pumped to the coast. However, just relying on this option is very risky. If coupled with other measures such as promoting more efficient irrigation techniques (through subsidies), limiting irrigation water volume per year per farmer, reducing domestic demand though publicity campaigns and financial incentives (e.g. tariff rises) and/or allowing the reuse of treated wastewater for irrigation (this list is indicative, and not exhaustive), then the risk is spread, and the chances of succeeding in achieving aquifer recharge are increased. It also puts less pressure on the success of just one policy measure.

Similar situations are apparent in all the WASSERMed case studies, although the specific measures are obviously unique for each one. Even in Sardinia, where the situation is not as severe as the other study areas, the rapid development of a robust policy landscape that can be implemented rapidly is recommended. This would aim to prevent the unnecessary onset of severe water stress. In other study areas such as Rosetta, the aim is to reverse the current trend of overexploitation against the backdrop of adverse climate (and potentially socio-economic) change. The idea is that through the development and nurturing of a new beneficial positive feedback loop created by slight alterations to current cropping practices, water can be saved on a regional level and the economic viability of the agricultural way of life can be maintained. However, if such a program were to be implemented, it would probably take years to be truly beneficial, would require the commitment of locals and government alike and would require careful management.

The water balance modelling of the WASSERMed case study has demonstrated the diverse nature of the threats being posed across the Mediterranean basin, but has also shown that there are many overlapping and common issues. The ultimate aims of these results are:

- to feed into the broader integrated water availability and security situation being studied in the WASSERMed project;
- to have useful input into other areas of related research, not just in WASSERMed, but in other EC FP7 and other academic/government studies;
- to reduce some of the uncertainty being faced across the Mediterranean when future forecasts of water availability are to be made;
- to advance the use of SDM and WSM DSS in water balance assessments, and to show their usefulness when undertaking wider, integrated analyses;
- to be useful on the ground in the study areas themselves, and to hopefully be beneficial to policy makers when deciding on appropriate courses of action for the future with regard to the water availability of their region;
- to help achieve a more water secure future for all sectors in all the case study regions and to encourage environmental rehabilitation.

5. References

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