An exploratory research to usability of WEAP and measures for potential water savings in Campo de Cartagena irrigation district, SE Spain

M.Sc. Minor Thesis by Edwin Haasjes

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An exploratory research to usability of WEAP and measures for potential water savings in Campo de Cartagena irrigation district , SE Spain

Minor thesis Irrigation and Water Engineering submitted in partial fulfillment of the degree of Master of Science in International Land and Water Management at Wageningen University, the Netherlands

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Abstract.

This research explores the effect of implementing regulated deficit irrigation and of covering agricultural water reservoirs in terms of absolute water savings in Campo de Cartagena, SE-Spain and the suitability of the Water Evaluation and Planning model to support this. This model appears to be useful in this research and shows potential for continuous research in this matter. With support of the model this research demonstrates that considerable potential water savings can be obtained. This is done by writing scenarios in which regulated deficit irrigation is applied thereby reducing demand, the agricultural water reservoirs are covered thereby reducing evaporation and a combination of both these scenarios.

Contents

Abbreviations and Acronyms

AWR	Agricultural Water Reservoir
CRCC	Comunidad de Regantes Cartagena
DIS	District Information System
DSM	Demand Site Management
RDI	Regulated Deficit Irrigation
SIRRIMED	Sustainable Use of Irrigation Water in the Mediterranean Region
WEAP	Water Evaluation and Planning

1. Introduction

In many watersheds of the Mediterranean Countries, water resources are presently fully or overcommitted. Demand for water is likely to continue increasing due to population growth as well as increased demand from in-stream users. Irrigated farms are the largest consumers of fresh water in Mediterranean Countries: either individually or as members of irrigation districts, using up to 80% of all allocated water in some regions. With the increasing water demand of other sectors and environmental constraints, water resources available for agriculture will decrease in the next decades. However maintaining or increasing the fraction of irrigated agriculture in the national food production is essential to reach or maintain food security and welfare in many countries of the World, and especially within the Mediterranean Basin. In this critical context, there is an urgent need to foster the adoption and implementation of alternative irrigation systems and management practices that will allow increased crop water productivity (Seventh Framework Programme, 2010).
The above mentioned is the incentive of the sustainable use of irrigation water in the Mediterranean region-project (from now on referred to as SIRRIMED). The SIRRIMED project will address issues related to sustainable use of water in Mediterranean irrigated agricultural systems, with the overall aim of optimizing irrigation water use. The approach proposed in SIRRIMED for reaching this goal will be based in an Integrated Water Irrigation Management (IWIM) where the improved water use efficiency will be considered at three scales: Farm, irrigation district and watershed scales (Ibid.). For more detailed information about the SIRRIMED-project see www.sirrimed.org.
This report will contribute to SIRRIMED in two ways, in a part of the irrigation district scale. First, this research aims to proof the usability of the Water Evaluation and Planning model (from now on referred to as WEAP) as a valuable and useful contribution to a district information system (from now on referred to as DIS). In the methodology chapter further elaboration on WEAP can be found. The DIS will be developed to assist in daily decisions on scheduling and on planning and strategic long-term decision making (SIRRIMED Grant agreement 245159, 2011). Second, in light of the aim of the SIRRIMED project and once WEAP has proven to be useful, possibilities to reduce water consumption by reducing evaporation from Agricultural Water Reservoirs (from now on referred to as: AWRs) and by applying regulated deficit irrigation (from now on referred to as RDI) are investigated.
As this research is done as partial fulfillment of a MSc degree, it cannot be considered as part of the SIRRIMED-project. It is better described as a symbiosis among a part of SIRRIMED and the author´s interest.

1.1 Regional background

From the Mediterranean areas involved in SIRRIMED, this research is done in the Segura river basin, Murcia region, South-East Spain. More specifically, in ´El Campo de Cartagena´ which is a part of the Segura basin. El Campo de Cartagena its primary land use is irrigated agriculture.
Cartagena is the city at the south border of el Campo de Cartagena and is home to the Comunidad de Regantes de Cartagena (from now on referred to as: CRCC) who controls the irrigation system in the area. Campo de Cartagena is a remarkable area as it is one of the driest regions in Europe and meanwhile holds title of being the most important area of Spain for vegetables, citrus and fruit trees production (Seventh Framework Programma, 2010).
There is a Mediterranean climate with an annual precipitation of 300 mm on average and a potential evaporation ranging from 800 to 1200 mm a year. The average annual temperature is 18° Celsius (Jiménez-Martínez et al., 2010). The high average temperature causes high potential evaporation, resulting in a structural deficit of water in this area. However, except for the evaporation, the climate makes the area very suitable for agriculture because of the mild winter temperature and high number of sunny days. To utilize these positive sides of the climate despite the high potential evaporation, a transfer canal is constructed. This canal, the ´Tajo-Segura trasvase´, brings water to Campo de Cartagena from almost 300 kilometers north of the area (Soria, 2003).

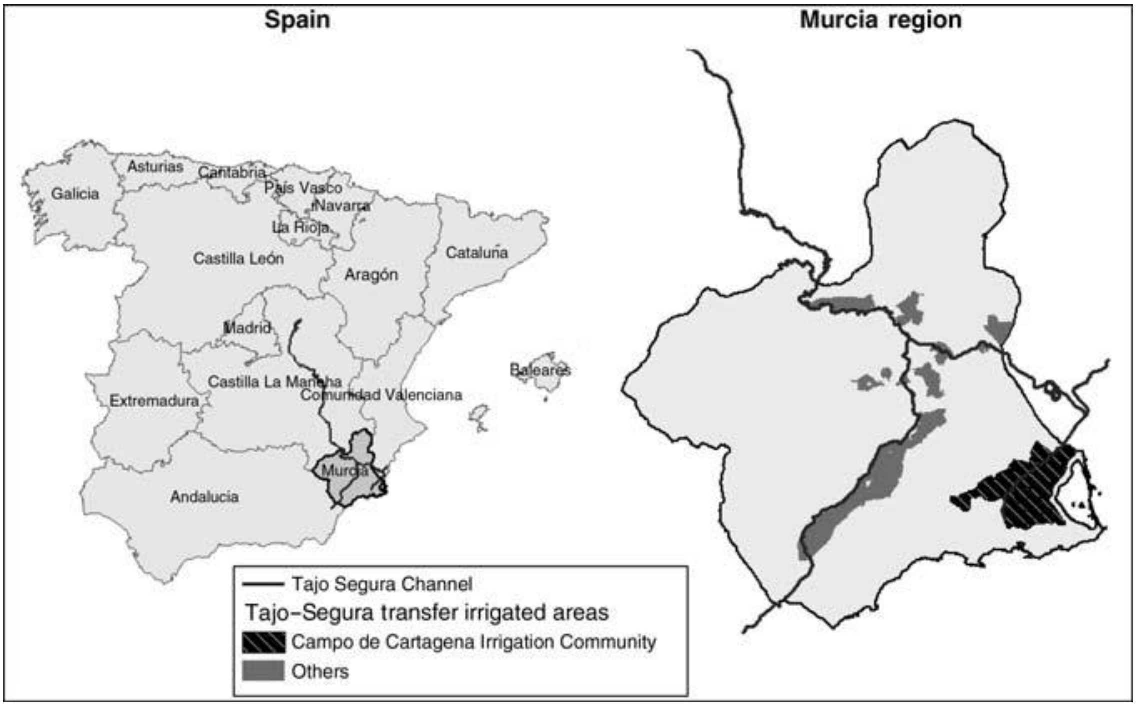


Figure 1: Location of the Tajo–Segura channel and the Campo de Cartagena (Rigby et al., 2009)

This canal feeds, among others, the ´La Pedrera´ reservoir from which the water flows into the area of this research, El Campo de Cartagena. This area is about 40.000 hectares and can be subdivided into four main hydraulic sectors which are again subdivided into 33 sectors (SIRRIMED Grant agreement 245159, 2011). Besides the supply from the ´La Pedrera´ reservoir, mainly groundwater is used to complement the demand. 95% of the area is using pressurized irrigation from which 90% is drip irrigation (Ibid.).

1.2 Rationale of the research

Despite the suitable climate for agricultural purposes, the high potential evaporation in combination with little rainfall makes the area depending on external supply of water. Most of the consumed water comes either from the Tajo-Segura transfer or from the groundwater. The transfer supply is not constant for which the irrigators have to rely on groundwater (and for a small part other supplies such as desalinisation plants) in some years more than the other. The groundwater supply however is of low quality. To pump the water and improve the quality is energy-demanding and costly.
With the increasing water demand of other sectors and due to environmental constraints, water resources available for agriculture will decrease in the next decades. In the area of research, tourism has been developed during the last decade which further increases domestic water demand (Jiménez-Martínez et al., 2010). However maintaining or increasing the fraction of irrigated agriculture in the national food production is essential to reach or maintain food security and welfare in many countries of the world, and especially within the Mediterranean Basin (Seventh Framework Programme, 2010). With decreasing water resources availability for agriculture, current irrigation strategies must change to maintain the same level of production and/or increase the sustainability of current water use.

1.3 Research objective

Following up on the rationale, there is a need to foster an increase in water productivity in Campo de Cartagena. A water resource model is considered to be useful to analyse and optimise the current water management as well as contribute to make a long-term strategic planning. WEAP21 is the model which is selected for this research as it fits within the concept of harmonisation (see next section). First, a ´proof of concept´ version of the representation of el Campo de Cartagena in WEAP will be created.

With this proof of concept version, an attempt is made to assess the potential for water saving by implementing of RDI and reducing evaporation from AWRs.

1.4 Research questions

To reach the objective of this research, the following main research question and subsequently the sub-questions are formulated:

To what extent can water savings be obtained by reducing surface water evaporation of agricultural water reservoirs and by applying regulated deficit irrigation in the Campo de Cartagena irrigation district, SE-Spain?

The following sub-questions follow from this objective:

- Is WEAP a suitable tool to assess water saving strategies at the district scale given the scope of SIRRIMED?
- What is the potential for water savings by implementing measures to reduce surface water evaporation from the AWRs in terms of water productivity?
- What is the water savings potential if regulated deficit irrigation is applied throughout the entire irrigation district?

1.5 Concepts

Proving the concept in this research is mainly to show to stakeholders and parallel SIRRIMED projects that WEAP is suitable for the project. That the model is working correctly and that it is able to represent Campo de Cartagena will be shown during the baseline scenario. Because that scenario consists of existing data, the outcome can also be calculated manually. If that output is the same and no strange output occurs with WEAP it is considered as suitable. Suitable for the project and especially for the DIS. Furthermore, WEAP fits good in the concept of harmonisation.
As the DIS will serve as supportive tool for the stakeholders involved with the irrigation and water management of the Campo de Cartagena, they are involved during the development of the DIS and their council will be used during meetings in which draft versions will be discussed. Although irrigation is the main fresh-water consumer, other demands sites also have interests in the water management. System harmonisation is therefore used as a concept to approach this research. It is defined by Khan et al. (2008, p. 494) as: "A strategy to improve cross-organisational communication and system-wide management to improve production and environmental outcomes in a whole of catchment context". The SIRRIMED-program defines it as "... consensus and collective decision making based on a process of optimisation of a production chain" (Seventh Framework Programme, 2010).

2. Methodology and data

This chapter introduces the data which was available. That data is subdivided into several sections. WEAP is partly used to present this data and is the software is explained in more detail after the available data. Before going to the actual representation of the area of research in WEAP, the scenarios are introduced. The chapter concludes with a subchapter of the assumptions which were made to be able to write and run the scenarios.

2.1 Study area

The Comunidad de Regantes del Campo de Cartagena, the irrigation association, controls the irrigation system from which the farmers receive their surface water. A farmer can request a certain amount of water at the irrigation association, depending on his/her area. They have a certain amount of water to supply which depends in its turn on the water availability upstream. The control of the irrigation system for the irrigation association starts from reservoir ´La Pedrera´. La Pedrera is one of more reservoirs which are supplied by the Tajo-Segura trasvase. The main canal, tapping water from La Pedrera, is also known as the trasvase and is identifiable in figure 2 as the blue line through the middle of the area. This picture presents Campo de Cartagena in three different zones. The distinction among these zones is the way of how the water is applied to each zone. Zona Oriental is irrigated under natural gravity. Zona Cota-120 is irrigated under artificial created pressure by means of reservoirs. The water is first transferred to higher located reservoirs and from their released to the farmers. Zona Occidental also requires additional energy as natural gravity does not provide sufficient pressure. Therefore, the pipes to this region are given extra pressure by means of direct impulsion. The water is then stored in a reservoir next to the main canal and from there the direct impulse is given to the pipes which transfers the water into higher located reservoirs (see also figure 3).

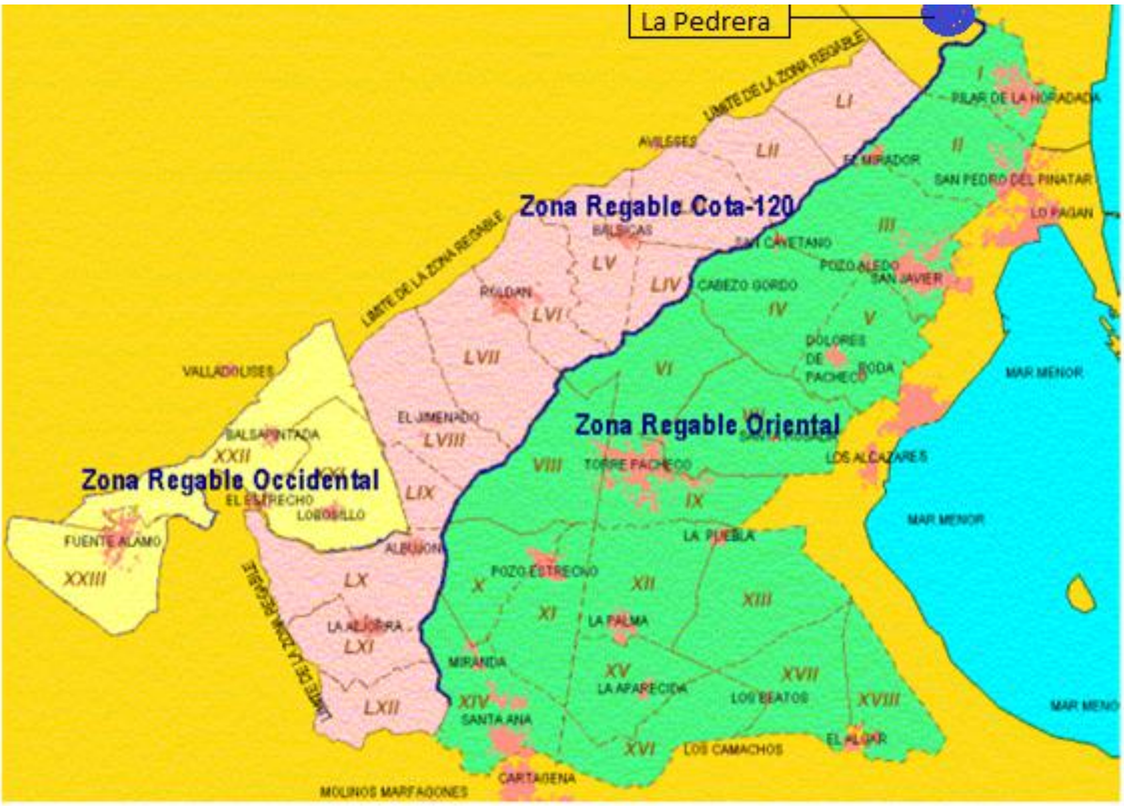


Figure 2: Hydraulic sectors of Campo de Cartagena

The network of the pipes and reservoirs of the irrigation system divide Campo de Cartagena different to the above mentioned picture. Below a picture is presented with only the reservoirs and the pipes which allows us to divide the area of research in four different hydraulic zones.

Figure 3: Reservoirs and tubes of Campo de Cartagena. Source: www.gis.CRCC.es[1]

This picture is the basis of the classification of the irrigation zones in Campo de Cartagena. This classification is shown in the following picture and shows the four separated hydraulic zones which are all involved in the research:

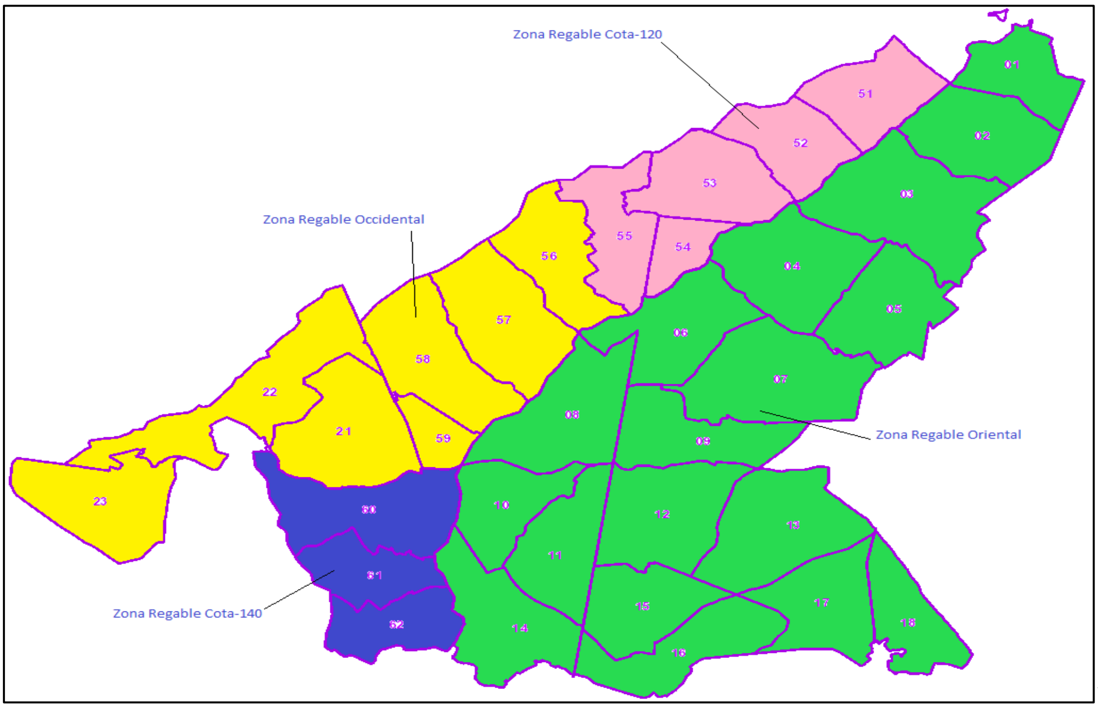


Figure 4: Classification of the irrigation zones. Source: ww.gis.CRCC.es

[1] Consulted on 20/06/2012

2.2 Available data

SUPPLY

The irrigation association records and stores the discharges through the pipes of the system. Therefore, a data set of the discharges was available. For this research it is decided to use the years 2002 up to and including 2010 as the period to be analysed. This term includes some extreme years in both, dry and wet conditions and is still fresh in memory for which it is easier recognised by the stakeholders. For those years, the available amount of surface water for the CRCC was as follows:

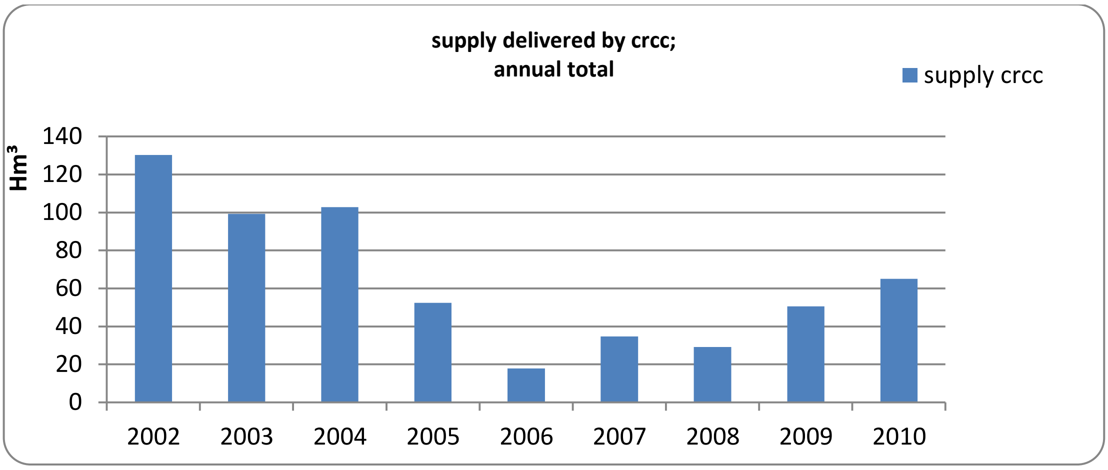


Figure 5: Annual total supply of surface water; data from the CRCC

DEMAND

The agricultural activities in Campo de Cartagena can be brought together into two groups. On the one hand there is horticulture, on average accounting for 66% of the area and on the other hand there is fruit production for the remaining area. Within Work Package 3 of SIRRIMED on benchmarking, the annual irrigation water demand per crop type is calculated to be 9676 M3/Ha for the fruit trees and 5097 M3/Ha for horticultural crops. This calculation is done according to the FAO Irrigation and drainage paper 56 (Allen et al., 1998). Hence, the crop evapotranspiration is resulting from the different crop factors (Kc) times the reference crop evapotranspiration (ETo). Effective rainfall and leaching requirements are added to this calculation resulting in the below presented graphs.

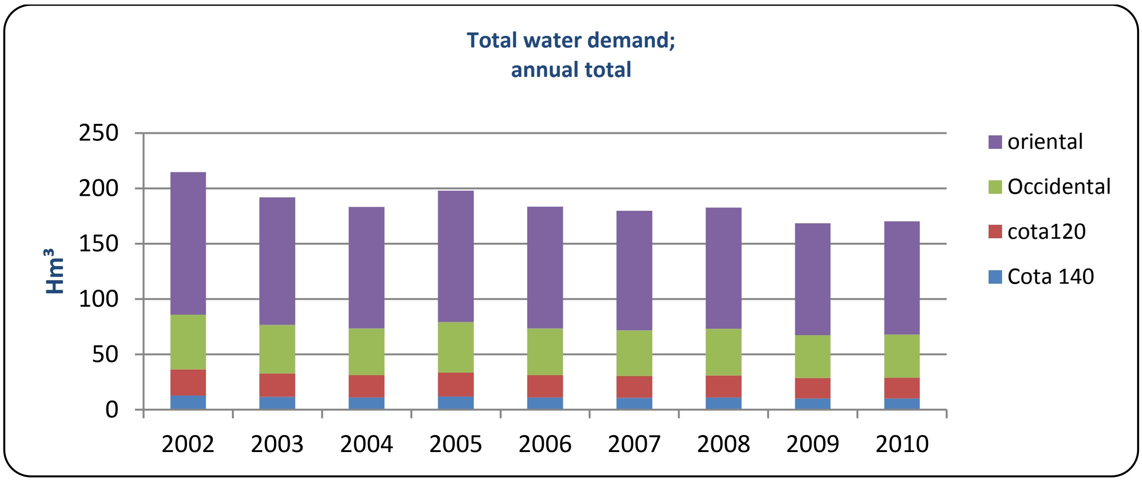


Figure 6: Annual total water demand; calculated within SIRRIMED-project

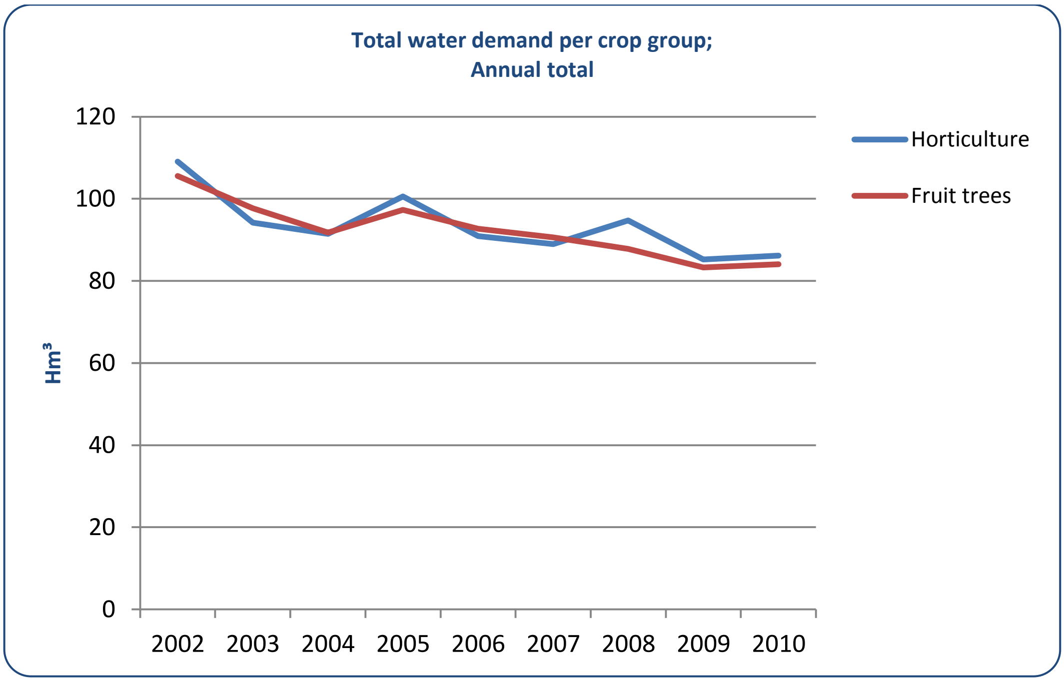


Figure 7: Annual water demand per crop group in hm³

The demand as presented above is the annual total demand. Within the years, the demand varies according to the climatic conditions and the growth stages of the crops.

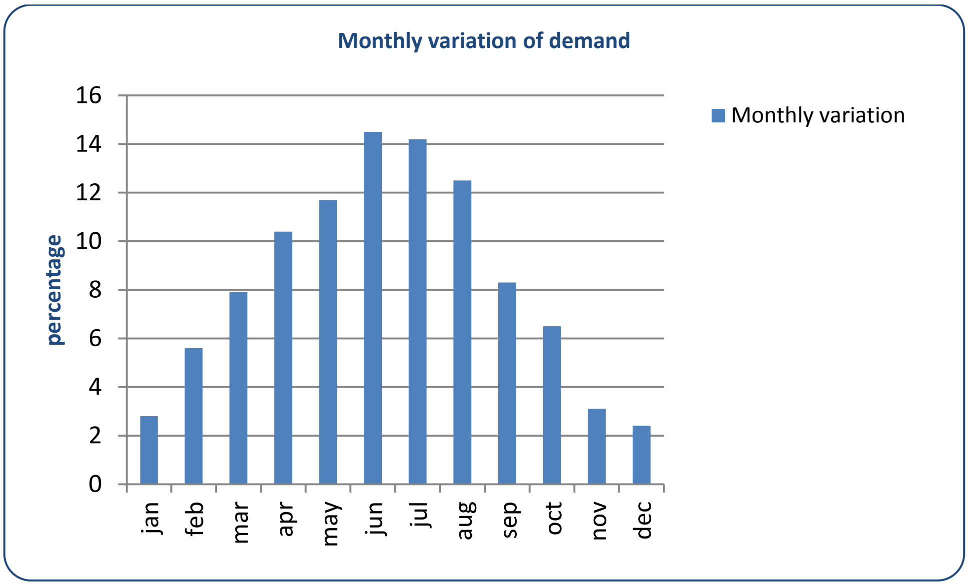


Figure 8: Monthly variation of demand; source: personal communication with Alvarez, V. M., researcher within SIRRIMED-project.

RESERVOIRS AND EVAPORATION

As mentioned, the irrigation authority manages reservoirs in the area, mainly to create sufficient head. However, driving around in el Campo de Cartagena loads of other, rather small reservoirs can be seen, not only in the higher located zones. These reservoirs are called ´agricultural water reservoirs´ and are not under control of the irrigation authority. These relatively small reservoirs are property of the farmers themselves and almost every farmer has one. They have different purposes of which the storage and thereby securing water for dry periods is the most important. Besides, they also function as a place to mix lower quality ground water with the surface water and to spread the allocated amount of water over a longer period.

Because the AWRs are owned by only one farmer, the size of an AWR is not big as it only has to serve one farm. However, taking in account that most of the farmers in the Campo de Cartagena have an AWR, evaporation losses are potentially large. This is mainly due to the large area/volume ratio (Alvarez et al., 2008). According to Alvarez et al. (2008) there are over 15.000 AWRs in the Segura river basin, with a surface area varying from 0.1 to 3 hectares and a depth of around 5 meters. From these 15.000 AWRs, 3643 are located in the Campo de Cartagena, covering a total of 1223 hectares (Paya Pina, 2011). The suitable climate for agriculture's other coin side is that the high temperature also results in high evaporation rates. The evaporation rate is presented in the following figure:

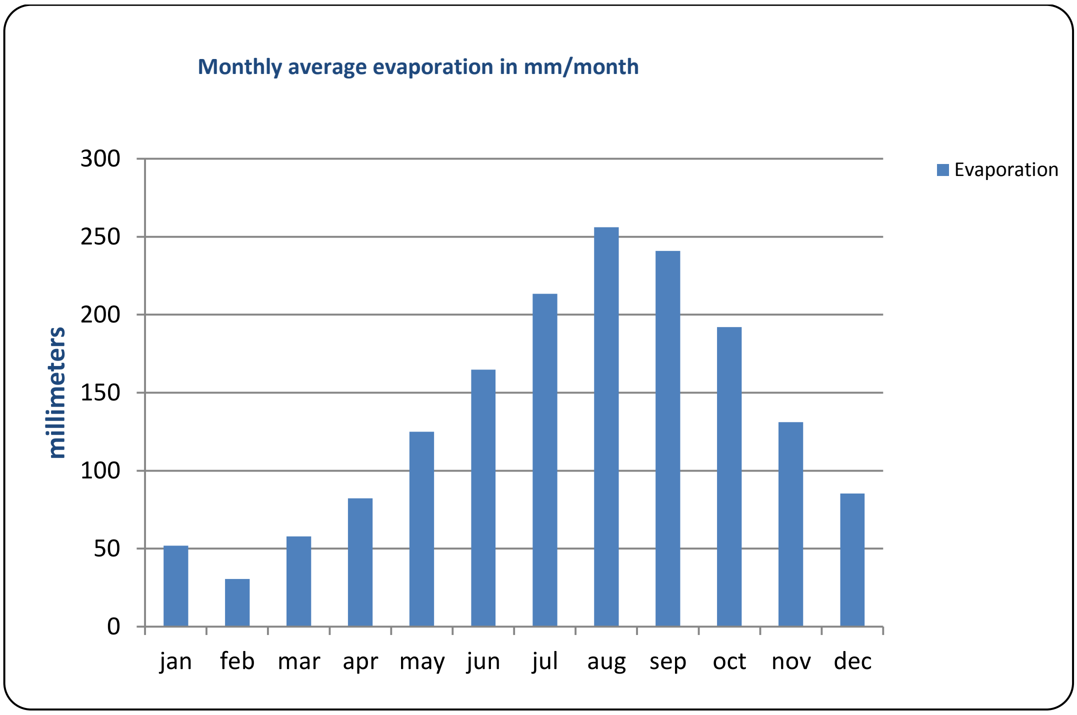


Figure 9: Monthly average evaporation. Source: Alvarez et al., 2008

2.3 WEAP21-model

For this research, the model WEAP is selected to support the project for several reasons.
First WEAP is a ¨user friendly software tool that takes an integrated approach to water resources planning¨ (SEI, 2012). Thanks to its transparent structure system, stakeholders can easily be involved in the modeling process. It´s focus is rather on policy making than on only hydrological data and is therefore suitable for this research. Different management decisions can be analysed on its long-term effects by writing scenarios with WEAP.
WEAP´s distinction by its integrated approach to simulating both the natural (e.g., evapotranspirative demands, runoff, baseflow) and engineered components (e.g., reservoirs, groundwater pumping) of water systems allows the user access to a more comprehensive view of the broad range of factors that must be considered in managing water resources for present and future use. The result is an effective tool for examining alternative water development and management options (SEI, 2012)
WEAP is based on water balance accounting principles, which can test alternative sets of conditions of both supply and demand. The user can project changes in water demand, supply, and costs over a long-term planning horizon to develop adaptive management strategies. WEAP21 is designed as a comparative analysis tool and has two main functions: First, it simulates the natural hydrological features/processes to be able to assess the availability of water in the catchment and second, it simulates anthropogenic influences into this natural system with regard to allocation of the water and influence on the availability of the water (Yates *et al.*, 2005).
The use for WEAP within the SIRRIMED project is to contribute to the DIS. Because of the above mentioned properties, WEAP lends itself as a useful model to integrate different data sets, i.e. a combination of natural and engineered components as well as different management strategies.

To produce scenarios to support decision making, a few basic steps are to be taken in WEAP, making use of five main views within the program. These steps are:

- **Study definition:** The time frame, spatial boundaries, system components, and configuration of the problem are established.
- **Current accounts:** A snapshot of actual water demand, pollution loads, resources and supplies for the system are developed.
- **Scenarios:** A set of alternative assumptions about future impacts of policies, costs, and climate, for example, on water demand, supply, hydrology, and pollution can be explored.
- **Evaluation:** The scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

These steps are to be taken within the different views WEAP provides. The views are:

- Schematic view
- Data view
- Results view
- Scenario explorer
- Notes

The study definition can be drawn in the the ´schematic view´. In this view, rivers, demand sites, reservoirs etc. can be dragged and dropped into the area. The demand sites and supply system can be connected with transmission links. GIS vector or raster files can easily be added as background layers. In the picture below an example of a schematic view is given. On the left side men could select one of the other views which are available. Next to that box, the different features which can be dragged and dropped into the schematic view are shown. Below this box the different layers vector layers are shown. As can be seen, in this schematic view only the country borders, the sectors and the reservoirs are activated.

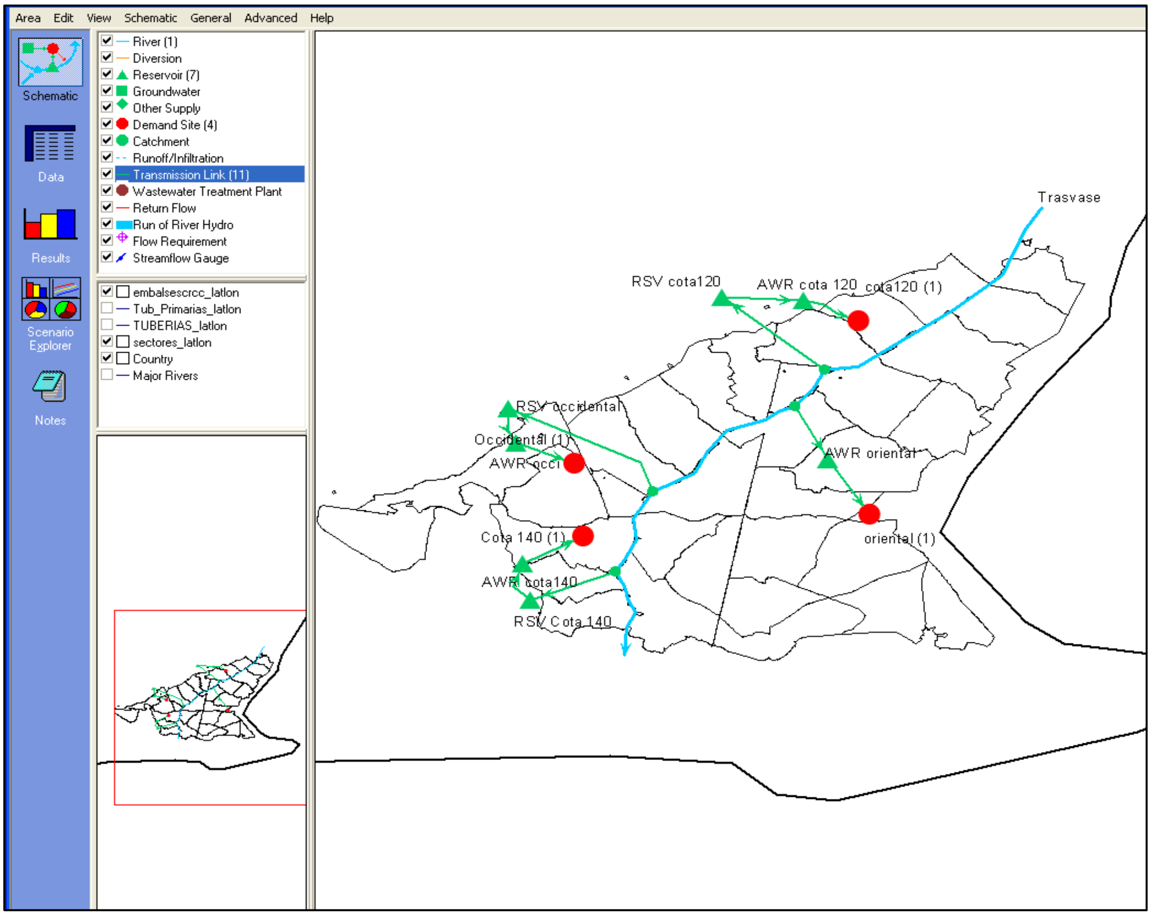


Figure 10: Example of schematic view

Once the schematic overview of the area is created the associated data can be added in the ´data view´. The data view also allows using mathematical expressions and can be linked to Excel.
In the data view, different branches can be selected to add data to the model. The main branches are:

- Key assumption
- Demand sites
- Hydrology
- Supply and resources
    - River
    - Reservoirs
    - Transmission Links

The hydrology branch is not used for this research. The demand and supply data are added to their branches. The data can be directly entered to these branches or via the ´key assumption´ branch. By adding data for supply and demand via a key assumption, a change of input can easily be made as it is passed through. This is especially useful if some basic information has to change for different scenario´s.
WEAP also provides different (mathematical) equations and functions which can be added to the data and opportunity of adding data with monthly variation. For example, if there is a large data set over a long time span, the function ¨read from file¨ can be used to add a large data set into WEAP. In the next picture an example of a data view is given.

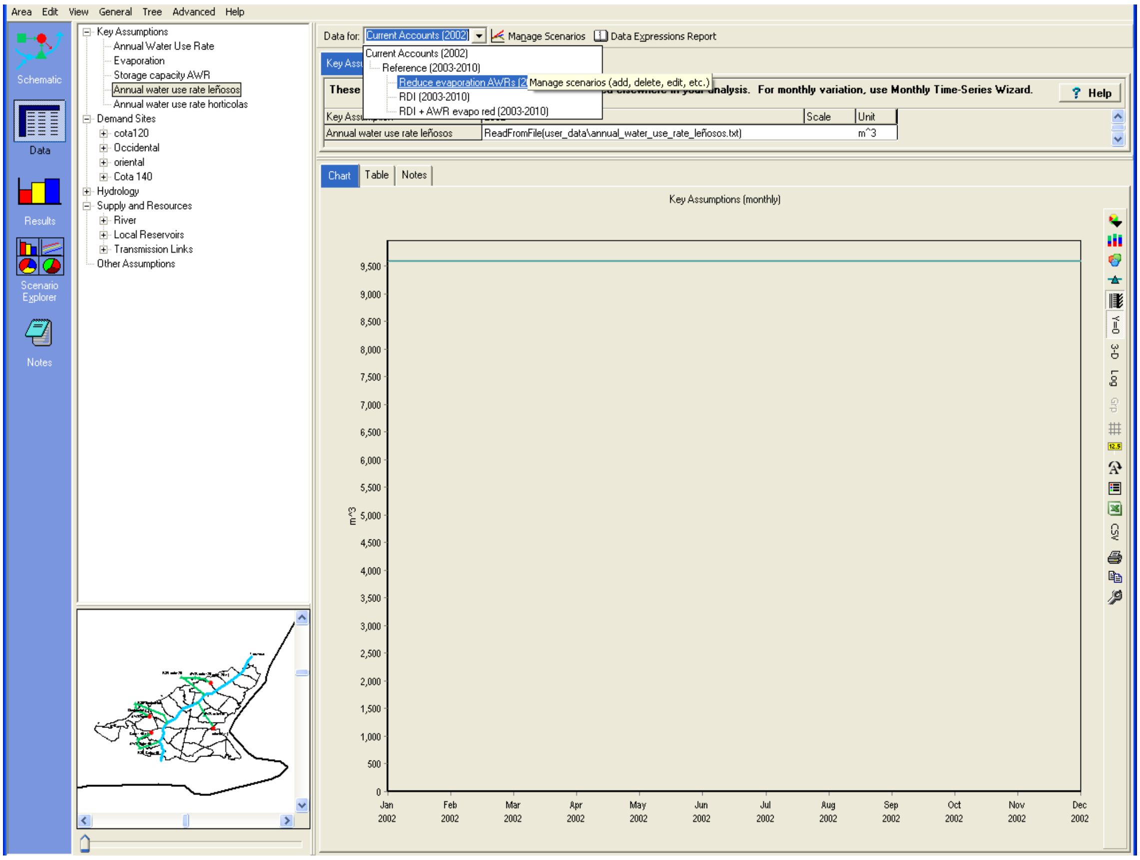


Figure 11: example of data view

All the features added in the schematic view appear on the left side from where they can be selected. Selecting one of the features makes this feature be highlighted in the small schematic view in the down-left corner. In this picture, there is a drop down menu shown on top of the picture in which different defined scenarios can be selected to adjust the added data per scenario.

If the data is added to the model, the ´results view´ will command WEAP to calculate the outcome of the given input in the data view. In this result view, different variables can be selected to be shown in graphs, tables and on the map and can also be exported to Excel. (SEI, 2012). The results are organised into four groups from which the two following are used for this research:

- Demand results
    - Water demand
    - Supply requirement
    - Supply delivered
    - Unmet demand
    - Coverage
    - Demand-site inflow and outflow
    - Instream flow requirement
    - Instream flow requirement delivered
    - Unmet Instream Flow Requirement
    - Instream flow requirement coverage

- Supply and Resources Results
    - Inflows to area
    - Outflows to area
    - River
        - Streamflow
        - Streamflow relative to gauge (absolute)
        - Streamflow relative to gauge (%)
        - Stage
        - Velocity
        - Reach length
    - Groundwater
        - Storage
        - Inflow and outflow
        - Overflow
        - Height above river
        - Outflow to river
    - Reservoir
        - Storage volume
        - Storage elevation
        - Inflows and outflows
        - Hydropower
    - Transmission Link
        - Flow
        - Inflows and outflows
    - Other supply
        - Inflows and outflows
    - Return link
        - Flow
        - Inflows and outflows

The two other groups which are not used for this research are about water quality and financial aspect.

From the supply and resources tree, inflows to area and outflow to area can be selected. WEAP defines inflow and outflow as follows (help function WEAP21):
¨Inflow: Water entering the system (river headflows, surface water inflows to reaches, groundwater recharge, local reservoir inflows, other local supply inflows, catchment precipitation).
Outflow: Water leaving the system (consumption at demand sites, catchment evapotranspiration (ET Actual), evaporation on river reaches and reservoirs, losses in transmission and return flow links, groundwater and local reservoir overflow, losses in wastewater treatment, and outflows from the end of rivers and diversions that do not flow into other rivers or groundwater nodes)¨.
For this research, the outflow is used to see whether there is a matter of water savings by comparing the outflow of different scenarios. The outflow captures all the consumption and is therefore more useful than the inflow, which for example does not include the evaporation.

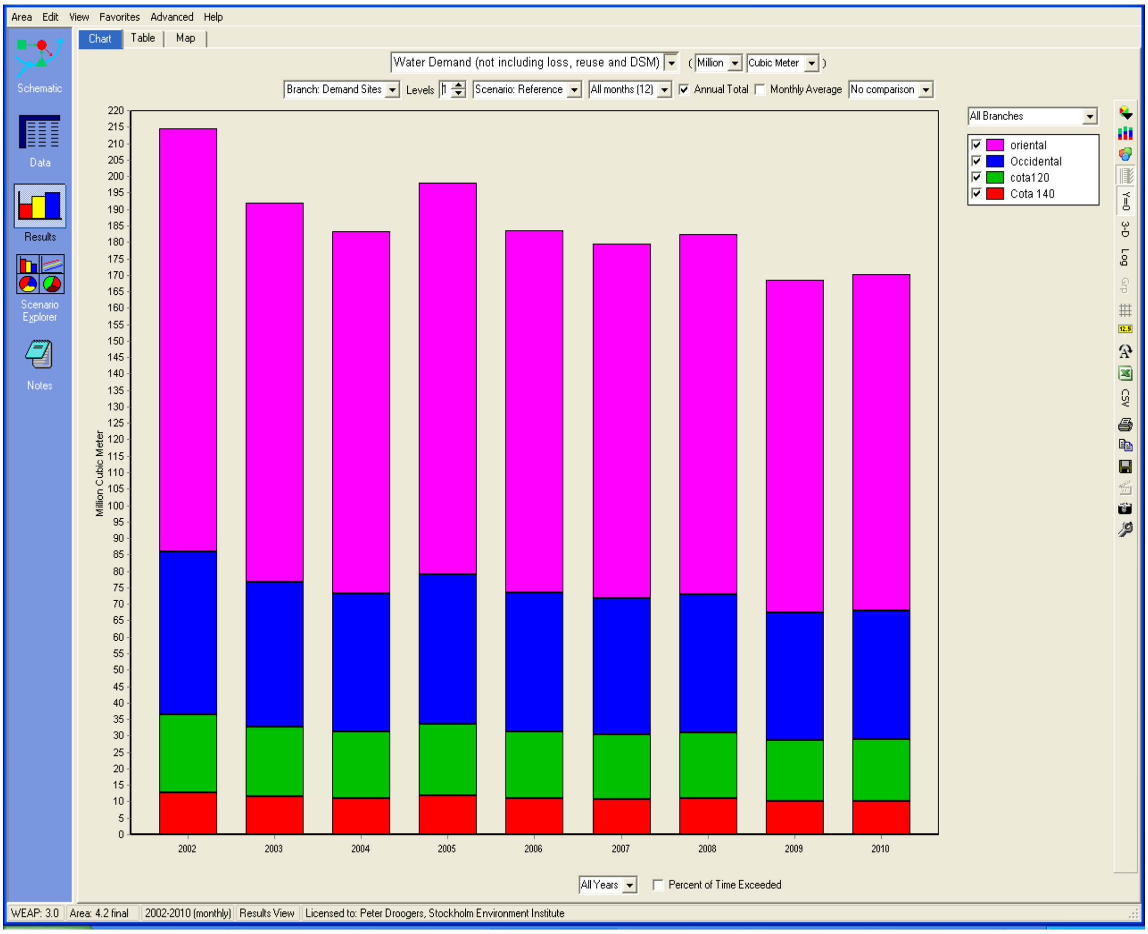


Figure 12: example of results view

Besides from the above mentioned outcomes which can be selected, the results view also provides the option to display different scenarios independently in the same figure or as relative to one another. Also different levels can be activated. Figure 12 shows level one. One level higher, WEAP will make a distinction among the different crops per area if added accordingly to the data view. Besides, years, areas of interest and monthly total can be selected. In short, the results view has a broad spectrum of showing the outcome of the added data.

The scenario explorer view gives opportunity to compare different result views in one screenshot. The last view, notes, can be used to make comments for each (sub)branch and, if desired, it can be exported to a Word document. This can make the input more transparent and understandable for any other user.

2.4 Scenarios

Three scenarios are analysed with the WEAP model. First, the baseline scenario had to be created in order to be able to compare and see the impact of other scenarios and to check WEAP capabilities to give a good representation. The scenarios are briefly introduced. Each scenario is partly based on an assumption which will be explained in their section.

2.4.1 Baseline scenario

For the baseline scenario, the area had to be created and represented as the current situation. The symbols were dragged into the schematic view and the associated data was added. As presented in chapter 2.1, most of this data was already available except for the additional inflow. No accurate data is available on how much water the farmers use additional to the surface water supply of the CRCC. The additional flow is assumed to be maximal 4 m³/s for the whole area of Campo de Cartagena and to divided amongst the zones. It is established by assuming that in the year 2006, the driest year of the period of research, no considerable yield loss has been suffered by the farmers. With an additional 4 m³/s with no yield loss, 50% of the demand in 2006 is satisfied and was just sufficient, additional to the little surface water supply. This discharge will only replenish the AWRs in case the surface water flow is insufficient. Despite some criticism during a stakeholder meeting, no better or other method to represent this additional flow was suggested. Hence, this assumption is also added to the baseline scenario. From the dragging and dropping, the following figure results. For the scenarios, no more symbols were added to the schematic view and thus, this figure remaines the same during this research.

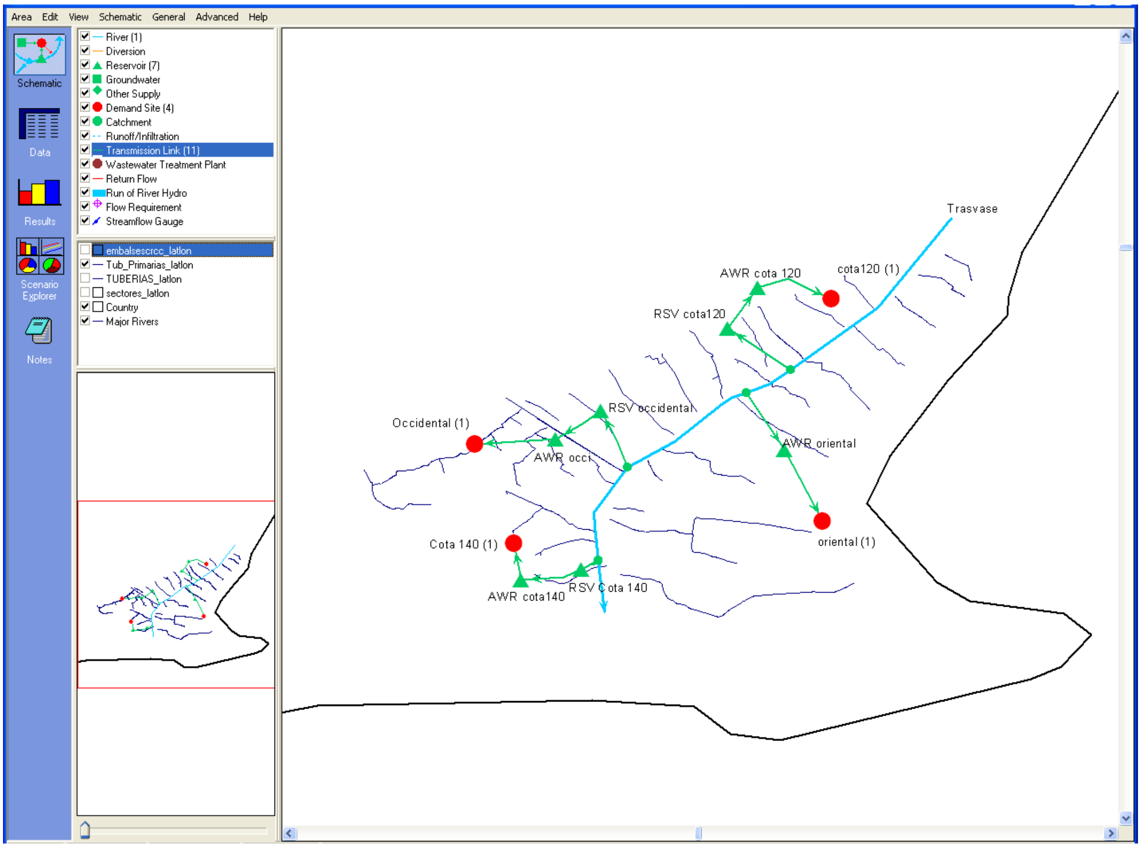
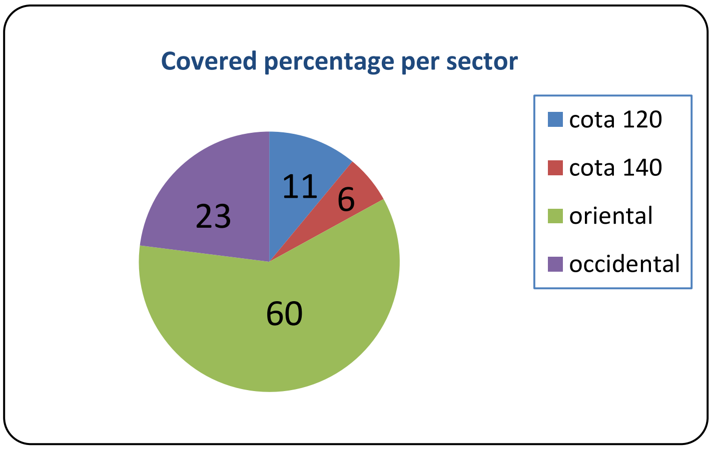


Figure 13: schematic representation of Campo de Cartagena

The area is divided into the four hydraulic sectors which are represented as demand sites, the red dots in figure 13. The four sectors cover a different percentage of the Campo de Cartagena. The division is presented alongside



For each of these sectors the following characteristics are drawn in the schematic overview:

- Demand node: Yearly irrigation water demand with monthly variation (2002-2010) as calculated by other researchers within SIRRIMED-project
- Transmission links: Yearly water supply with monthly variation (2002-2010), data available at the irrigation association
- Reservoirs (RSV and AWR)

In short, the baseline scenario consists of the available data plus the assumption of the 4 m³/s additional supply and, as the name indicates, servers as basis for the following scenarios.

2.4.2 RDI scenario

RDI reduces the demand for a specific period in which the crops, in this case the citrus trees, receive less water than ETc without having a negative impact on the yield. The phenology of the plant should be well understood in order to avoid damage to harvest and know when the plant can cope with water stress (García-Tejero et al., 2010). RDI is only applicable to the fruit trees because the vegetables cannot cope with water stress.
From interviews conducted for the SIRRIMED-project it appears that farmers apply 50% less water than ETc requires. This is done in years of little water availability but indicates that a reduction of 50% is, although extreme, a realistic number. Especially as the 50% reduction is born out of necessity. It is therefore not *regulated* deficit irrigation. If by some reason the 50% needs to change to another value, it can easily be changed in WEAP and it will calculate the results for the new value. For this scenario a 50% reduction is assumed as possible, based upon interviews. As this 50% reduction is for the whole year, there is not (yet) a matter of *regulated* deficit irrigation but rather deficit irrigation.

2.4.3 AWR cover scenario

To calculate the evaporation from the AWRs, WEAP needs data about the AWRs (surface, depth, storage) and the evaporation itself. For the AWR-scenario, the evaporation rate is the only data which has been changed. The input data as given for the reference scenario is multiplied by 0.1 thereby reducing the evaporation with 90%. In reality this can be done by covering the AWRs (Alvarez et al., 2008). Preferably, WEAP calculates the evaporation for this scenario with climate data over a smaller area to see the results according to a percentage of farmers who do cover their AWR. Unfortunately this is not possible in with WEAP, hence the assumed reduction of 90%. Again, this input can easily be changed to other preferred numbers.

2.5 Assumptions

For this research some assumptions where there was data lacking. These assumptions are taken well in consideration. In research following up on this, more detailed data might be available to replace the assumptions with scientific data.

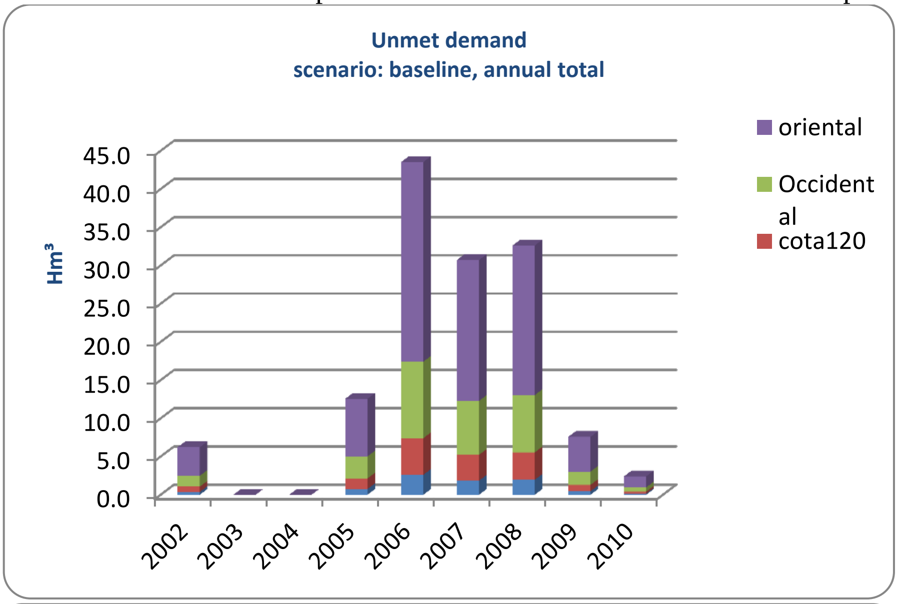
- Additional supply for Campo de Cartagena is 4 m³/s
- RDI scenario reduces demand for fruit trees with 50%
- AWR_cover scenario reduces evaporation from the AWRs with 90%

3. Results and discussion

The results of the analysis of the area with WEAP are presented below in three sections regarding the research question. First, the results of the baseline scenario are presented. This also shows the suitability of WEAP. Thereafter, three subsections follow to demonstrate the results of the scenarios: RDI, AWR_cover and a combination of the two. The chapter concludes with a discussion section.

3.1 Baseline: Proof of concept

In order to answer the research question using WEAP and considering future use in the SIRRIMED-project, the program needs to valuable, useful and able to represent dynamics as a consequence of measures of the Campo de Cartagena.
The baseline scenario will serve as example of the proof of concept. For this scenario, the input is from ´reality´. Comparing the results with calculation in excel show that the outcome is the same. The full use of a model such as WEAP becomes clearer once more complex input is given, in this case during the scenario projections. Therefore, the usefulness and validity will become clearer during the following sections whereas the actual representation will become clear in this subchapter.



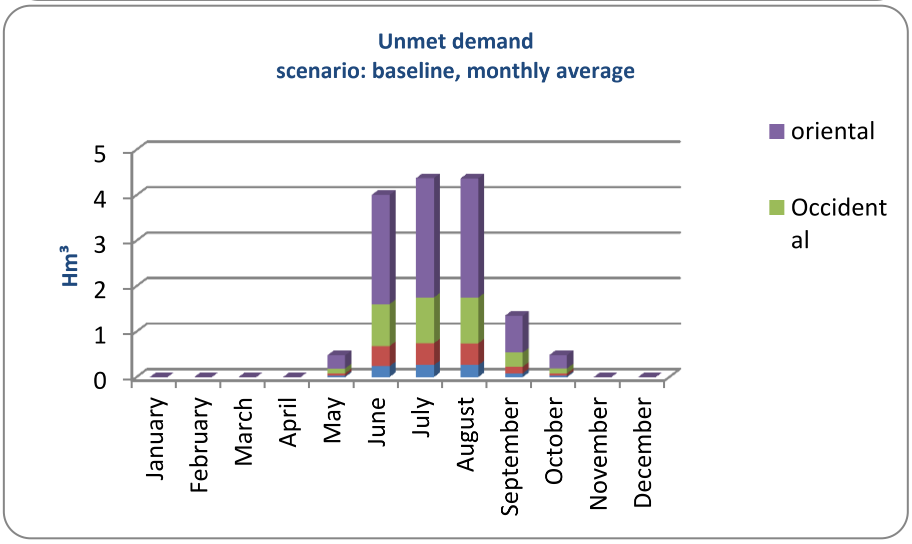


Figure 14: Unmet demand as annual total and monthly average in hm³

The baseline has one input which is not based upon measured, empirical data. The additional supply (in total 4 M^3/S) is based upon an assumption as explained before. In the following figures some graphs of the results of the baseline scenario are presented. These figures show the unmet demand, AWR storage volume and the AWR evaporation.

As shown in the graph of the description of the baseline scenario, 2006 was a dry year or at least a year with little surface water availability for the CRCC. This results in a high unmet demand for that year. From the monthly average unmet demand it is shown that during the summer months the unmet demand is highest as a result of high evapotranspiration.

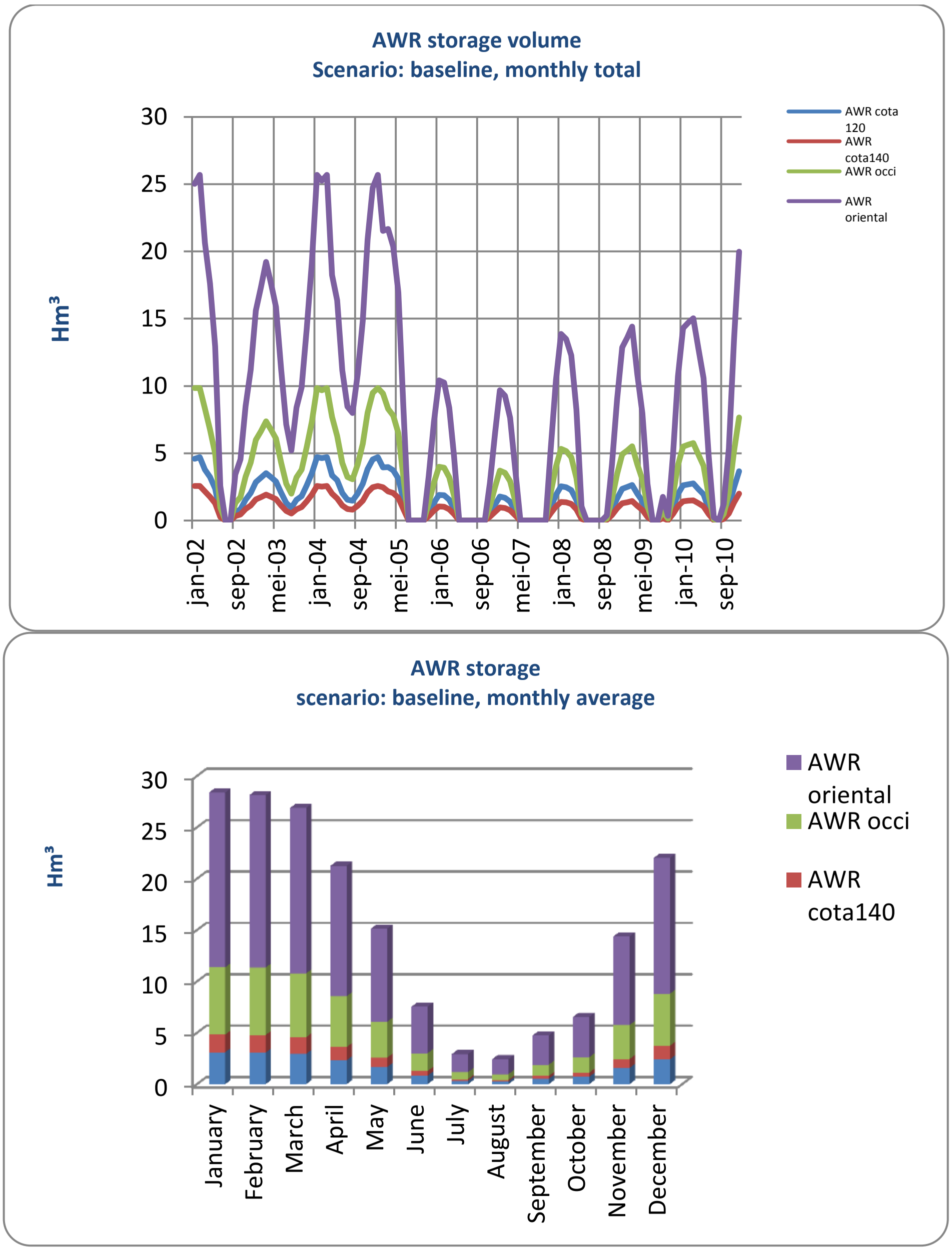


Figure 15: AWR storage as monthly total and monthly average in hm³

In the total monthly storage graph, the driest years result in a low storage volume in the AWRs as the water is requested by the farmers. The additional supply of 4 M³/S (subdivided per area) is not sufficient to keep the reservoir filled.
In the monthly average storage graph, the coincide of the monthly average demand is shown. In the summer months, when demand is highest, the storage volume is lowest.

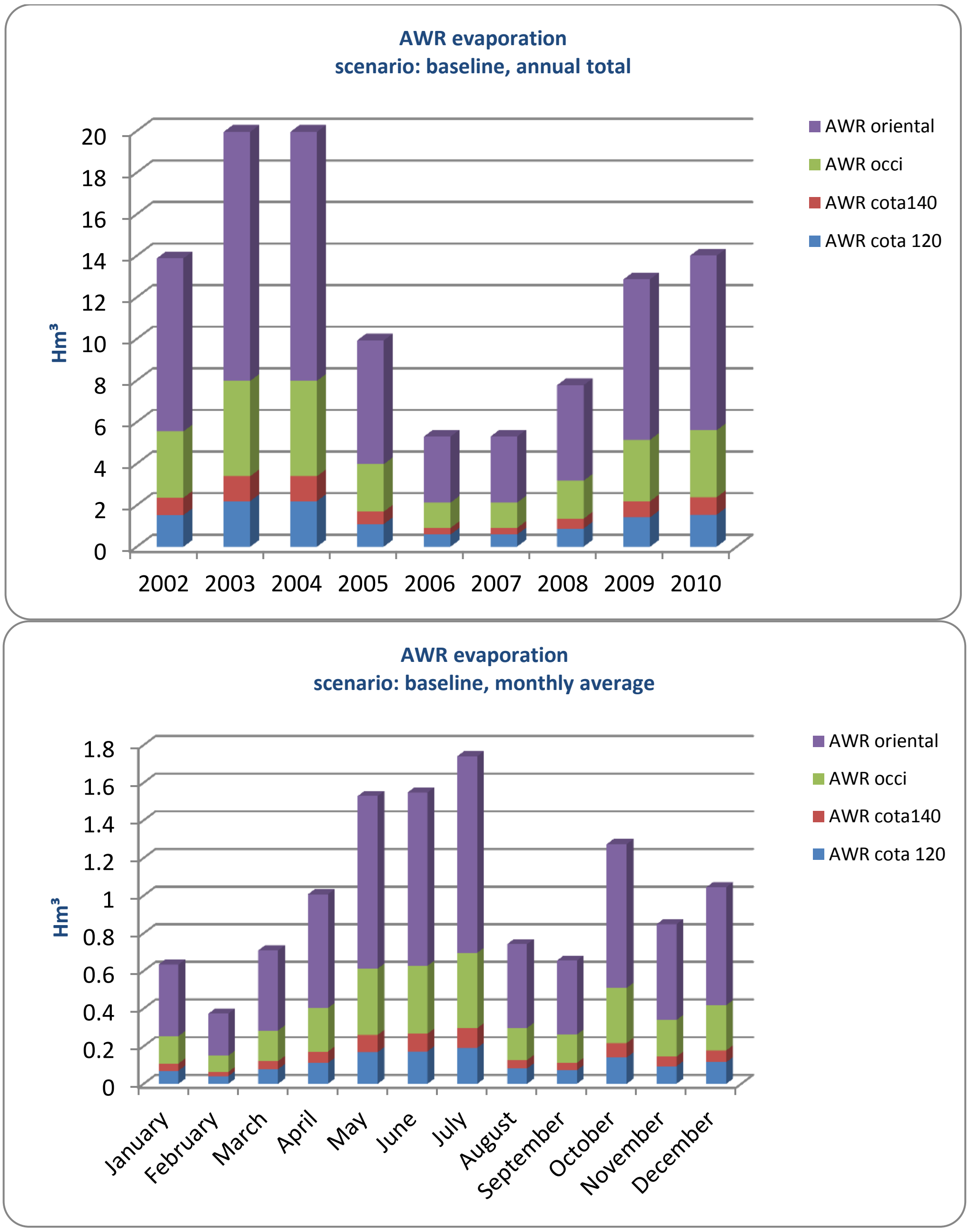


Figure 16: AWR evaporation as annual total and monthly average in hm³

In the above figure again the driest years emerge as having a low evaporation due to low water availability because the reservoirs are fully exploited in the summer months (see also figure 15). The summer months have the highest evaporation rate as expected due to high temperature. However, a decrease in August and September is not expected but can be attributed to the same effect as the dry years i.e. again looking at figure 15, little to no storage can be seen in these months. The water which was available was already used in the previous month, July.

The graphs as they are presented are the outcome of WEAP. The calculations of WEAP do not show any strange or inexplicable outcomes. Besides, these outcomes are also calculated with excel and no differences emerged. This, and the all the potential data which can be added to the model is considered as a good and sufficient basis to continue the research with WEAP and start with the scenarios.

3.2 Scenarios

3.2.1 RDI

The contribution of RDI towards more sustainable use of irrigation water and an water savings lies especially in reducing demand. The difference of this scenario in relation to the baseline scenario is that the demand for fruit trees is reduced with 50%. As this number is determined to bring unmet demand to zero for the driest year, the unmet demand after this input is zero for all years. Therefore, less water will be needed from the additional supply and the function of AWRs as a buffer is more emphasized in the results of WEAP.

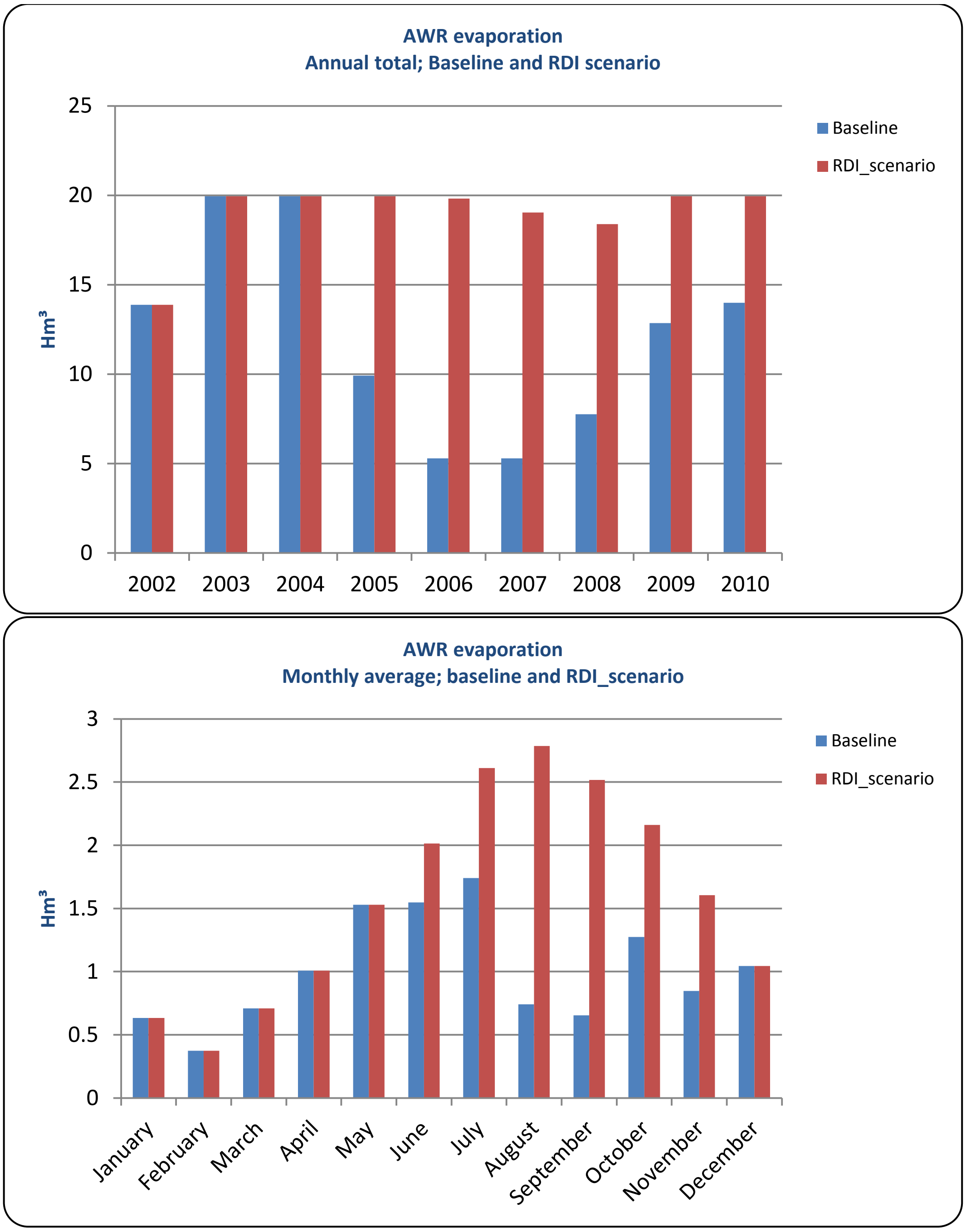


Figure 17: evaporation as annual total and monthly average

The higher evaporation as a result of more storage in the AWRs can be recognized in the following figure:

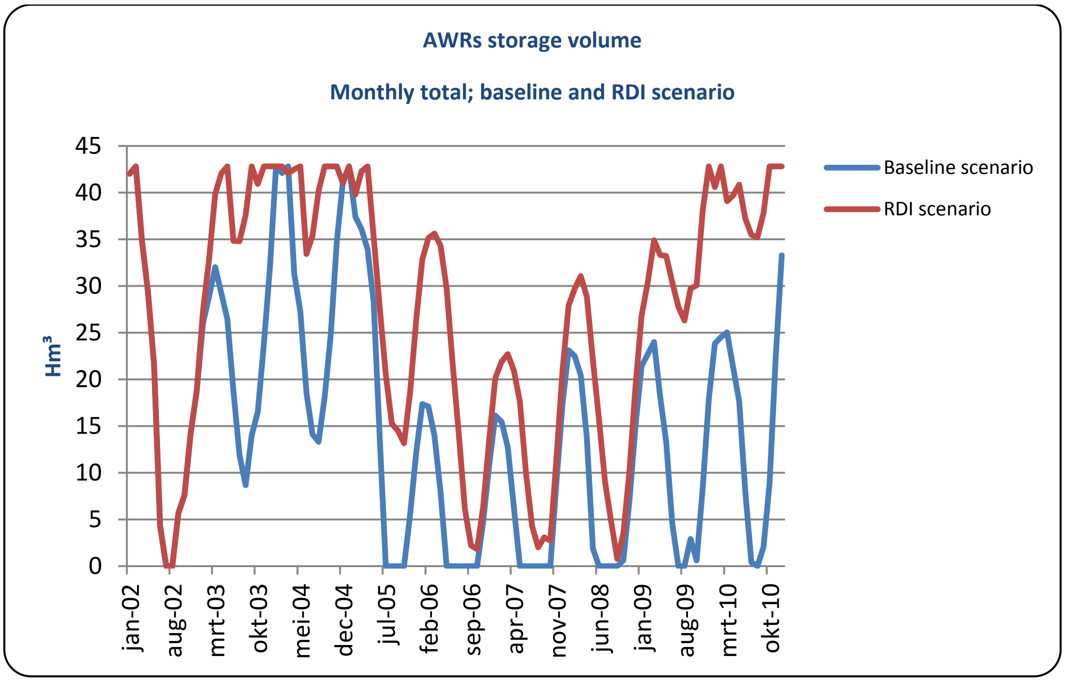


Figure 18: AWR storage volumen for both scenarios

Summarizing, the RDI scenario results in total fulfillment of the demand by decreasing the demand for citrus trees with annual average of 50%. However, evaporation losses from AWRs increase as the storage amount increases. This amount does not offset the reduced demand.
WEAP calculates a total reduction, comparing the baseline results and RDI results, of inflow to the area of 98 hm³ and of the outflow a reduction of 108 hm³. There is a slight difference between inflow and outflow due to changes in storage of the AWRs. As explained in sub-chapter 2.3, the comparison of outflow is considered as water savings.
Applying RDI thereby reducing demand for fruit trees with 50% year round will yield 108 hm³ despite the increase of evaporation. This amount is for the period 2003-2010. The outflow per year of the RDI scenario relative to the baseline is presented in the graph below.

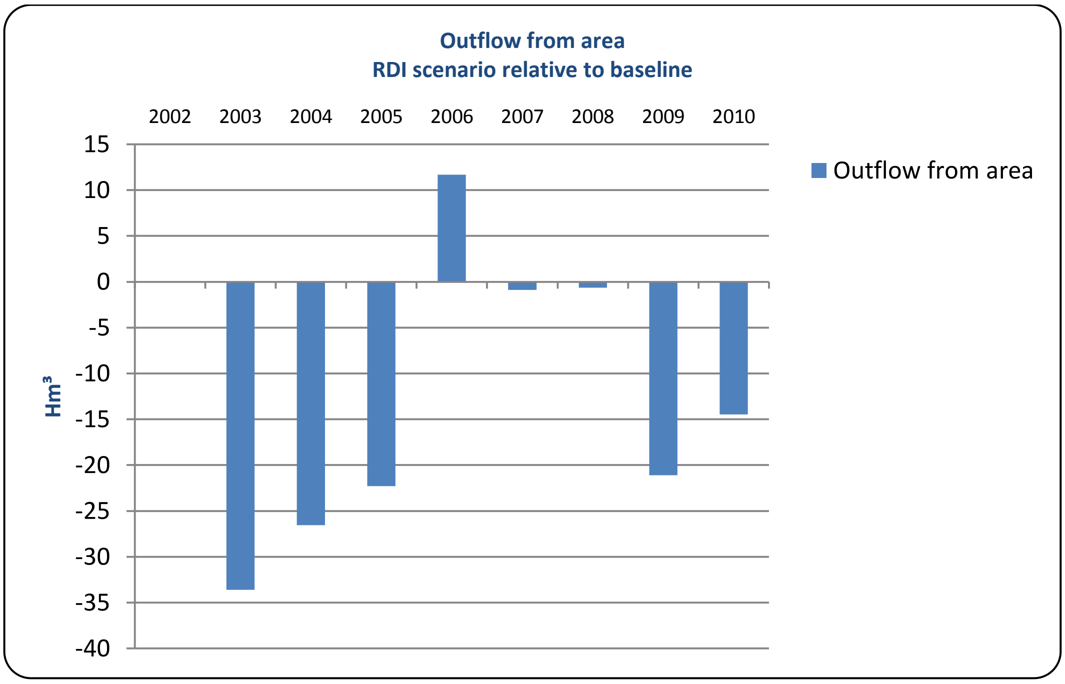
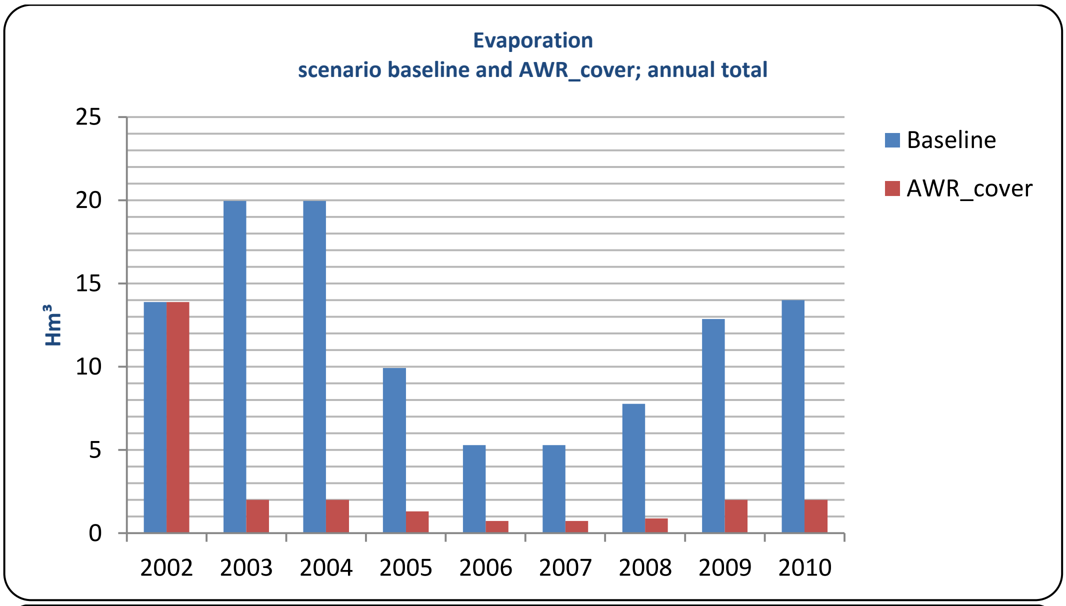


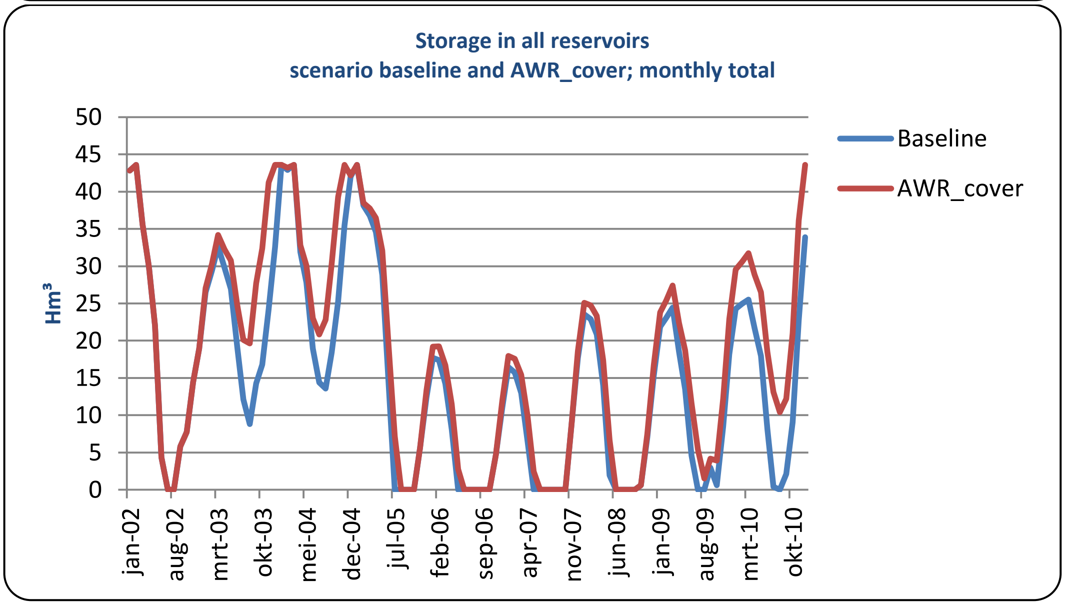
Figure 19: outflow from area in hm³

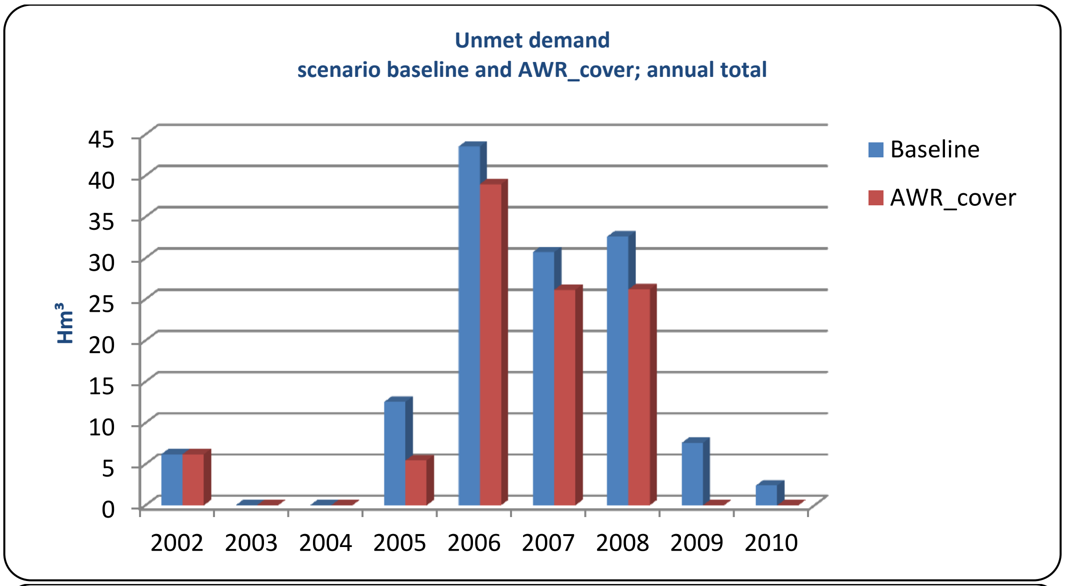
Remarkably the year 2006 has a higher outflow for the RDI scenario, i.e. the scenario results in a higher quantity of water use. Although remarkably at first sight, it is not inexplicable or unrealistic. As with regulated deficit irrigation unmet demand for 2006 is just about zero, the decrease of additional supply for 2006 amounts only 2.8 hm³, i.e. only 2.8 hm³ of the 4 m³/s (year round) is not used. On the other hand, the 4 m³/s discharge gives opportunity to evaporation because more days during the year, water is stored in the AWRs. According to WEAP, the amount of evaporation increases with 14.5 hm³. This results in a netto increase of water use of (14.5-2.8) 11.7 hm³. For all the other years, the decrease in additional supply outweighs the increase of evaporation.

3.2.2 AWR_cover

The gain of this scenario is focussed on evaporation and is therefore presented by comparing the AWR storage and evaporation differences. These changes in storage and evaporation are also reflected in the unmet demand. The evaporation is reduced with 90% for this scenario and results in the graphs presented in figure 20 below.







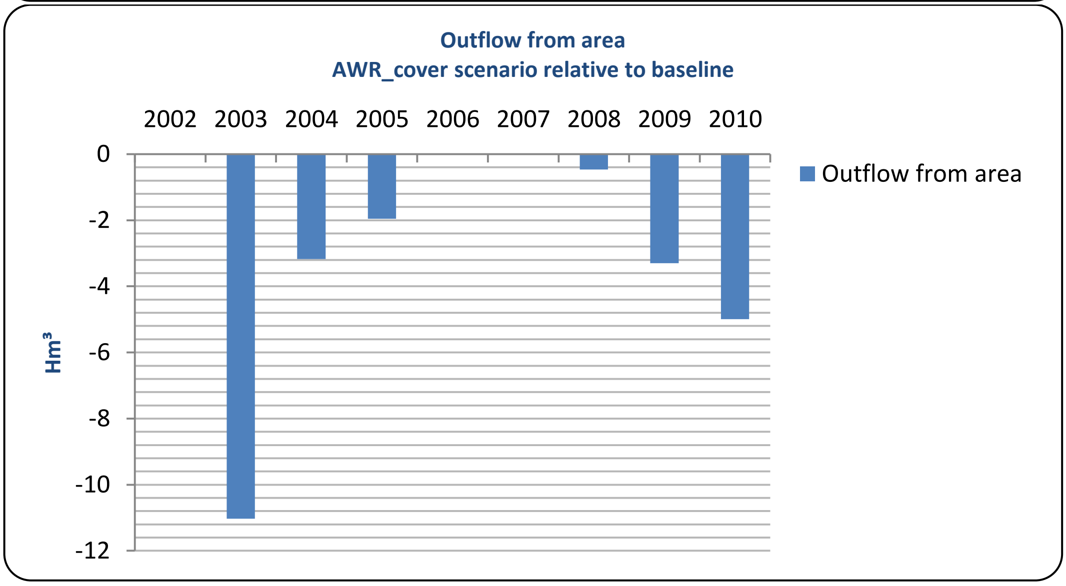
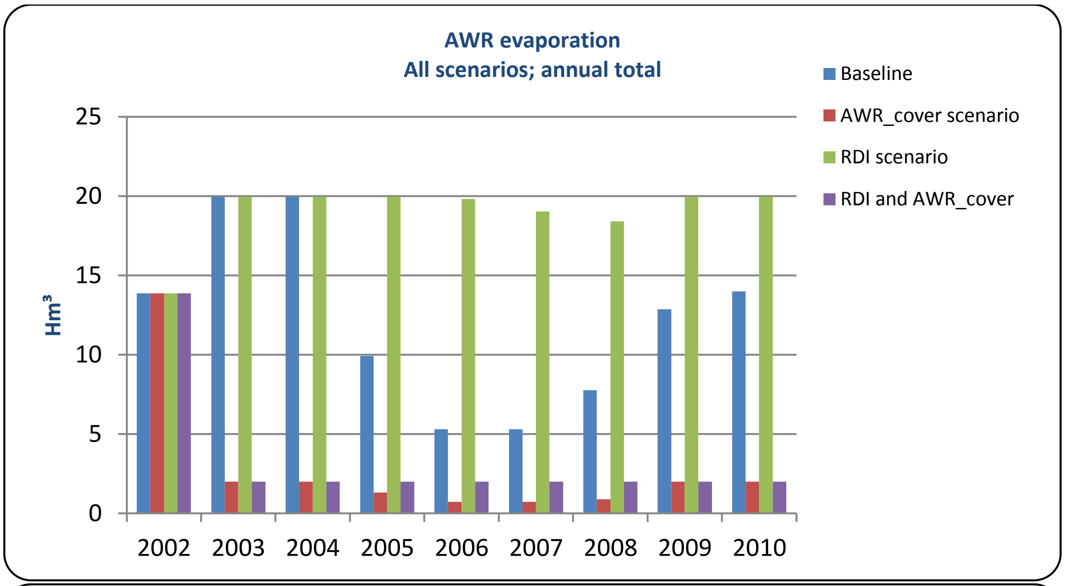


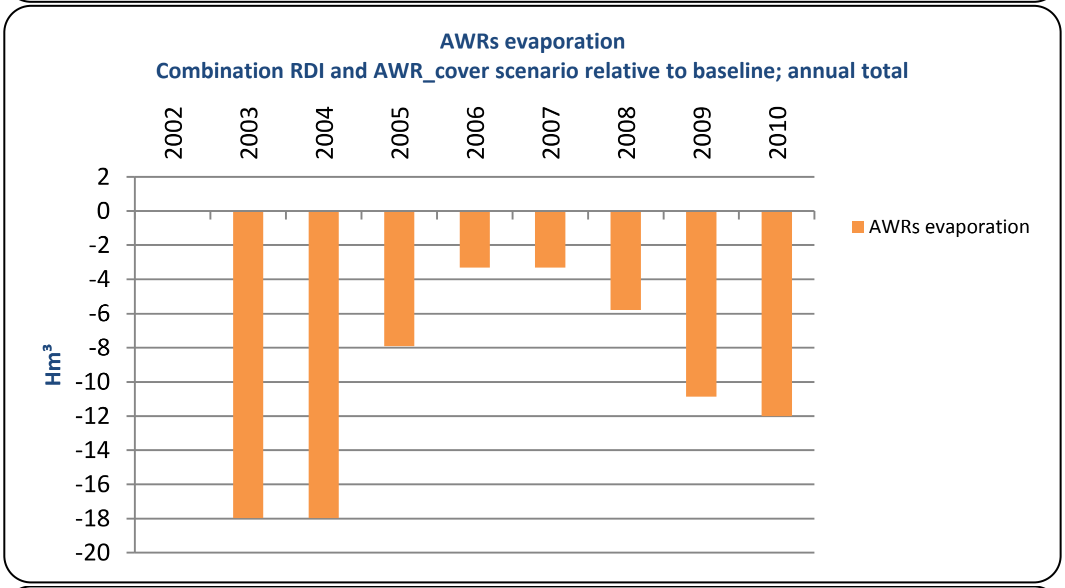
Figure 20: results of AWR cover scenario

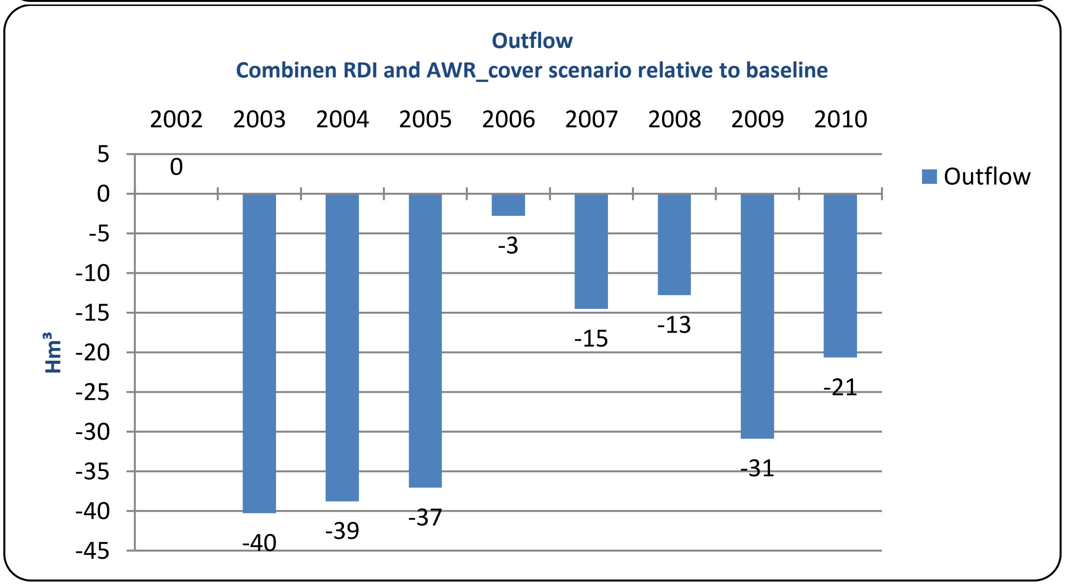
The WEAP output shows the decrease in evaporation to the maximum amount of evaporation except for the drier years, 2005-2008. In these years the storage drops for some periods to zero so that no evaporation can occur. The reduction in evaporation results in a lower unmet demand.
Ultimately, the outflow of the AWR cover scenario compared to the baseline yields 25 hm³ over the period 2003-2010. Again it is remarkable that the dry years do not contribute to this amount. The amount saved by covering the AWRs is used for consumption to reach demand. For the other years the gains of the reduction in evaporation outweigh the amount of water needed to reach the demand. Therefore, only in those years there is a matter of saving water.

3.2.3 Combining RDI and AWR_cover scenario

In this section, a scenario including RDI as well as AWR_cover scenario is ran. The resulting graphs are presented as comparison among the different scenarios. Unmet demand remains zero. The results are limited to the output where the yields can be observed. For this research the outflow is most important as it shows the amount of water saved by these measures. Evaporation is also compared for the different scenarios as this yield ultimately reduces pumping/energy costs.


AWR evaporation
All scenarios; annual total
Baseline
AWR_cover scenario
RDI scenario
RDI and AWR_cover
Hm³
25
20
15
10
5
0
2002
2003
2004
2005
2006
2007
2008
2009
2010


AWRs evaporation
Combination RDI and AWR_cover scenario relative to baseline; annual total
2002
2003
2004
2005
2006
2007
2008
2009
2010
AWRs evaporation
Hm³
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20


Outflow
Combinen RDI and AWR_cover scenario relative to baseline
2002
2003
2004
2005
2006
2007
2008
2009
2010
Outflow
Hm³
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
0
-40
-39
-37
-3
-15
-13
-31
-21

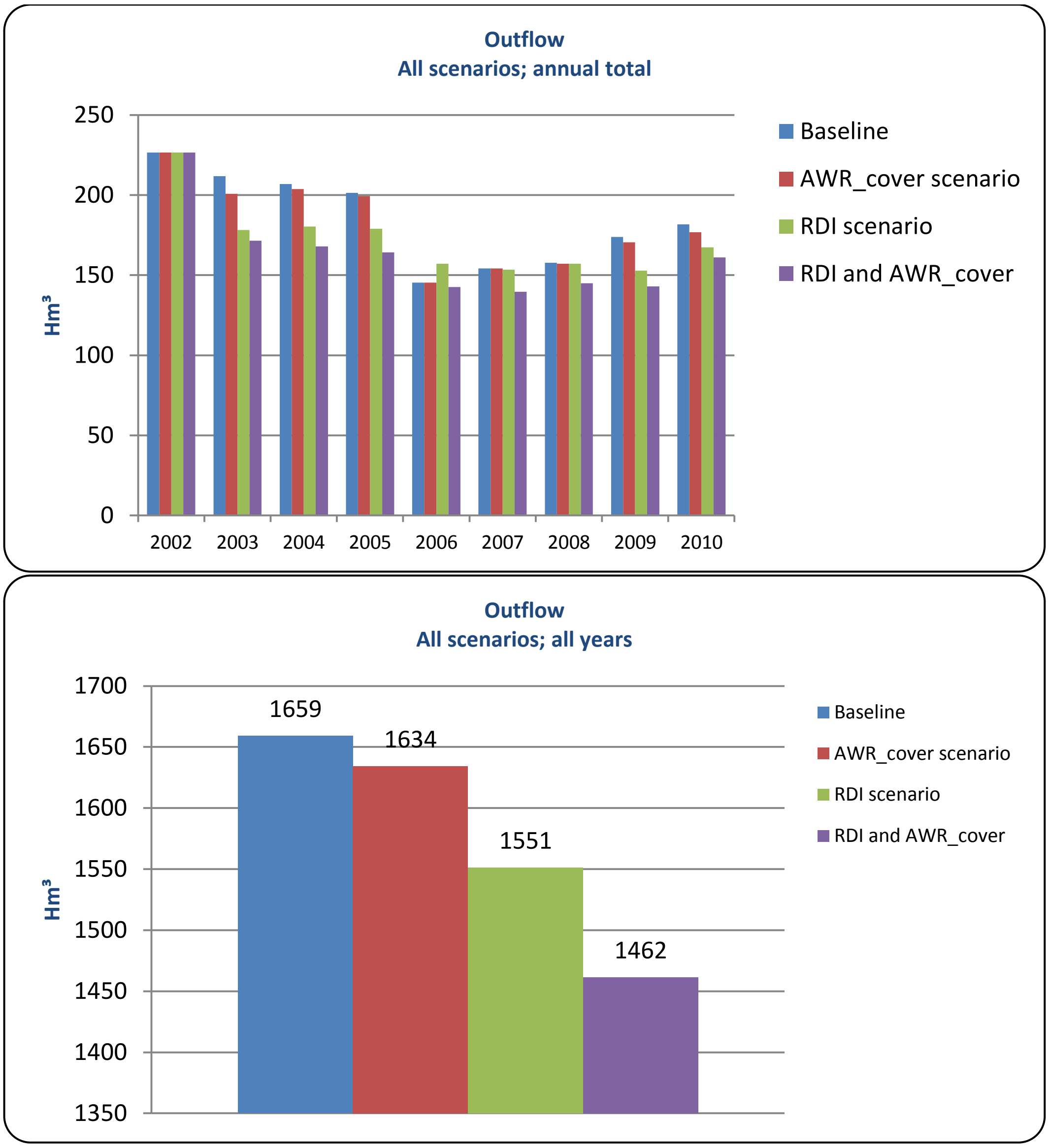


Figure 21: Results from WEAP comparing all scenarios

The graphs show a maximum amount of evaporation. This implicates that there is always water in the reservoir in contrast to the AWR_cover scenario. The year 2006 is remarkable as the results for only the RDI scenario show an increase in outflow with respect to the baseline and for only the AWR_cover scenario it remains the same. However, combining the scenarios results in a decrease of outflow. Comparing the total outflow per scenario, the potentiating effect also emerges. Adding the separate gains of total outflow gives a value of (108+25) 133 hm³ whereas in the combined scenario the total yield in outflow is (1659-1462) 197 hm³.
Considering a 50% reduction in fruit tree demand, the remaining average ETc is 4788M3/ha. For horticulture it remains 5097 M3/ha.

3.3 Water savings?

Both scenarios are subject to research on how to implement the measures which are at the base of these scenarios. According to the results of this research, a considerable amount of water can be saved with these measures. This research does not go into further detail about the saved water like expressing it terms of water productivity or who will benefit from these gains.
In the SIRRIMED-proposal it is mentioned that an aim of the project is to increase water productivity. Water productivity is mostly recognised as yield/actual evapotranspiration (ETa). SIRRIMED expresses water productivity in economic terms: yield/costs to produce the yield. Taking the

economical expression of water productivity gives opportunity to also involve the covering of the AWRs into the calculation. For the yield/ETa this is not possible because evaporation does not have influence on neither the yield nor on the ETa.
At this stage of the research and with the available data, it is not yet possible to include costs into the model. Hence, water savings in absolute amounts is presented here as final outcome.

3.4 Discussion

Although the assumptions made for this research are well taken in consideration, they might bias the outcome or give a non realistic outcome. During a stakeholder meeting in which some researchers of the SIRRIMED-project and a representative of the irrigation association were present, some critics were given on these assumptions.
First, the $4m^3/s$ discharge gave reason to discussion, not in the first place because it seemed unreal but rather the way how it was established. Because no data is available on this matter and no better or other ways to represent the additional supply was given, it was agreed to continue with the $4m^3/s$.
Second, the 50% reduction by applying RDI was considered too much. However, the only data available on this matter comes from the interview in which farmers responded that the do reduce the supply with 50% in case of severe drought. For this reason the 50% is added to the model. But more detailed information is needed about how much farmers normally apply. If they, for example, apply more than the ETc and reduce *that* amount with 50% the outcome will be different as it is added to the model now because the ETc is reduced by half in the current model.
Thirdly, also the 90% reduction of evaporation was considered as a (too) high value. This amount can and should easily be changed once more realistic values can be determined. Although this criticism, the scenario demonstrates the potential gains of covering the AWRs despite the fact that the outcome might be lower.
Besides the assumptions, it is known that the farmers do not use their allocated water to their area on which the quantity of water is based. They receive water according to their area but that does not necessarily mean that they grow crops or fruit trees in all that area. This can also bias the results in terms of unmet demand.
If looked critically to the RDI scenario, there is not really a matter of *regulated* deficit irrigation. The scenario includes the R of regulated because this is the basis of the real RDI scenario. The way it is presented in this report might be better called ‘emergency scenario’ or ‘severe drought scenario’. It is not realistic to cut the supply to fruit trees with 50% but more detailed data is needed to adjust this input. Furthermore, as mentioned, this 50% is result of interviews and is therefore assumed to be a relevant input.
Question marks can be placed at the graphs presenting the storage volume in the AWRs. For some considerable periods they stand dry. In reality, the farmers might pump more water in such cases in order to be less vulnerable to continuous drought and keep more control over their water availability.
During this research, the term water productivity seems to be useless although it is part of the SIRRIMED-project. This is partly because it is not known who will benefit from the saved water. Also, in the light of SIRRIMED aim of improving sustainability of irrigation water, it is questionable whether using of the saved water at all contributes to this aim considering the severe lack of water in the region. Once more information about what will happen with the saved water, WEAP is useful tool to analyse and support decision making in this matter.

4. Conclusion

WEAP proves itself as a suitable and useful tool for this research. It gives a good representation of the area as result of the added data. Furthermore, different management options can be added as scenarios to see what impact they have if executed. The results from WEAP are reliable and according to the added data and do not show a deviation or inexplicable events. Furthermore, there are still a lot of options to add more detailed data which fit perfectly in the SIRRIMED-project.

The model as it is established for this research, demonstrates the potential water savings if the demand of the fruit trees is cut by half except for the year 2006 (see also figure 19). Because of the reduced demand, the periods that the AWRs stand dry decreases. This results in a longer period in which water can evaporate from the reservoirs. Therefore, besides the gains because of the reduced demand, more water is consumed by evaporation. Except for 2006, the savings as result of the reduced demand outweigh the increase of consumption by evaporation.

WEAP also shows that potential water savings can be obtained if the AWRs are covered. For the dry years however, the saved water is used to reach demand. In the years where more surface water is available and hence, unmet demand is lower of even zero, less water is needed with this scenario.

5. Recommendations

To conclude this report, some recommendations which occurred during and after the research process are presented below.
During continuing studies with WEAP in Campo de Cartagena more details, if available, should be added:

- Replace the 4 m^3/s with a better underpinned value
- Include energy costs with regard to groundwater use. As for now the results are in cubic meters, it is more interesting to look at energy savings as derivative of this. That will be the true gains and will give more incentive to farmers to apply water saving techniques. It will also give opportunity to calculate economic water productivity thereby making it easier to compare and evaluate with the parallel projects of SIRRIMED elsewhere.
- Reconsider the 50% reduction under RDI and add more detailed data on when how much the demand can be reduced.
- More water users can be added to WEAP. The software is exceptionally suited to include different water users. It will also give more depth into the SIRRIMED's concept of harmonisation and future vulnerability regarding water security.

For continuing work with the same model, I also recommend to split the transmission link. In reality the farmers can also use the water directly from the irrigation system. By using and comparing both transmission links to the demand site (one via the AWR and one direct link) the effect and potential more sustainable use of energy can be explored.

Where agriculture faces water shortage and is thereby forced to use water of lower quality and along with it high energy (pumping and/or desalinization) costs, also domestic water demand is increasing. The research indicates that water can be saved if these scenarios are applied. However, it is at this moment not clear which sector will benefit from these water savings. WEAP is very suitable to include different water users to its set-up and analysis and can give more insight in this debate if included in the future.

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