Desertification assessment

for the Guadalentín River Basin, Spain

using the Medaction® PSS

(Policy Support System) integrated model.

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MSc DISSERTATION

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ABSTRACT

The Guadalentín Basin (3,300 km²) in South-eastern Spain is an important EC MEDACTION case study of land and water degradation and desertification processes.

To contribute for a better understanding of the complex dynamics between biophysical and socio-economic drivers that can lead to resource degradation and ultimately to desertification it was implemented an important decision tool for policy-makers and analysts – the MedAction® Policy Support System (PSS).

The MedAction® PSS desertification-related outputs are extremely valuable for the understanding of possible impacts derived from imposed policy management or climatic events at a relevant regional scale and time span and therefore it is a resourceful tool to support efficient policy implementation and in the long-run sustainable development.

There are inumerous "what-if" scenarios that can be analysed using MedAction® PSS. For the present work there were tested four pertinent scenarios relative to extreme climatic events, water management and crop subsidy: severe drought, limitation of groundwater exploitation, increase of reservoir water cost and crop subsidy increase. The obtained outputs are relevant desertification indicators that are used to evaluate impacts on the biophysical and socio-economic spheres of the Guadalentín Basin.

The main conclusions derived from MedAction applied for the Guadalentín Basin is that the agricultural sector is clearly mismanaged; there is an strong culture for intensive irrigated farmlands with high-inputs associated to an arid climate and poor-quality soils; groundwater resources are critically over-exploited being most of the water transported by inter-regional transfer channels; farmer's decisions main driving forces is the availability of irrigation water and profit maximization attending to crop profitability and CAP subsidies, with little consideration to sustainable environmental development.

Key-words: MedAction® PSS, Guadalentín Basin, Desertification-indicators, Baseline and Scenario change (%), biophysical and socio-economic scenarios.

Desertification indicator assessment for the Guadalentín River Basin, Spain

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1 - Desertification definition and study importance

The best definition and concept for desertification is given by the United Nations Convention to Combat Desertification: "Desertification is the degradation of drylands in arid, semi-arid and dry sub-humid areas. It involves the loss of biological or economic productivity and complexity in croplands, pastures, and woodlands. It is mainly due to climate variability and unsustainable human activities (UNCCD, 1994).

Desertification is the consequence of a set of important degradation processes in the Mediterranean environments, especially in semi-arid and arid regions where water is the main limiting factor of land use performance on ecosystems (FAO, 2006) and (Kosmas *et al*, 1999). Climate change exacerbated with socio-economic pressures acting on the land may induce a reduction of resource potential and thus affect directly the livelihood of rural populations (Delden *et al*, 2005). Additionally, the long dry season and occasional droughts restrain the natural recovery of drylands ecosystems, intensifying land degradation caused by human activities (ESA, 2003) and (ICIS, 2000).

Land use change is increasingly related with desertification phenomena with the incidence biodiversity loss and disruption of hydrologic regimes, soil erosion, decreases in soil fertility, loss of extractive reserves and disruption of indigenous people (Kosmas and Valsamis, 2001).

Land use change as desertification processes are influenced by a range complex interactions among physical, environmental and socio-economic driving forces (Figure 1) (UNCCD, 1994). In resume:

*- **Physical factors** include mainly crop management practices such as irrigation, fertilization, tillage operations, level of mechanisation, or farm conditions such as farm size, farm fragmentation and so forth;*

*- **The environmental factors** provide the basic conditions for crop growth, such as air temperature, precipitation, sunshine, soil chemical and physical properties, and landscape characteristics;*

*- The **socio-economic factors** including among others subsidies, land tenure, product price are basic determinants in land use change* (Kosmas and Valsamis, 2001).
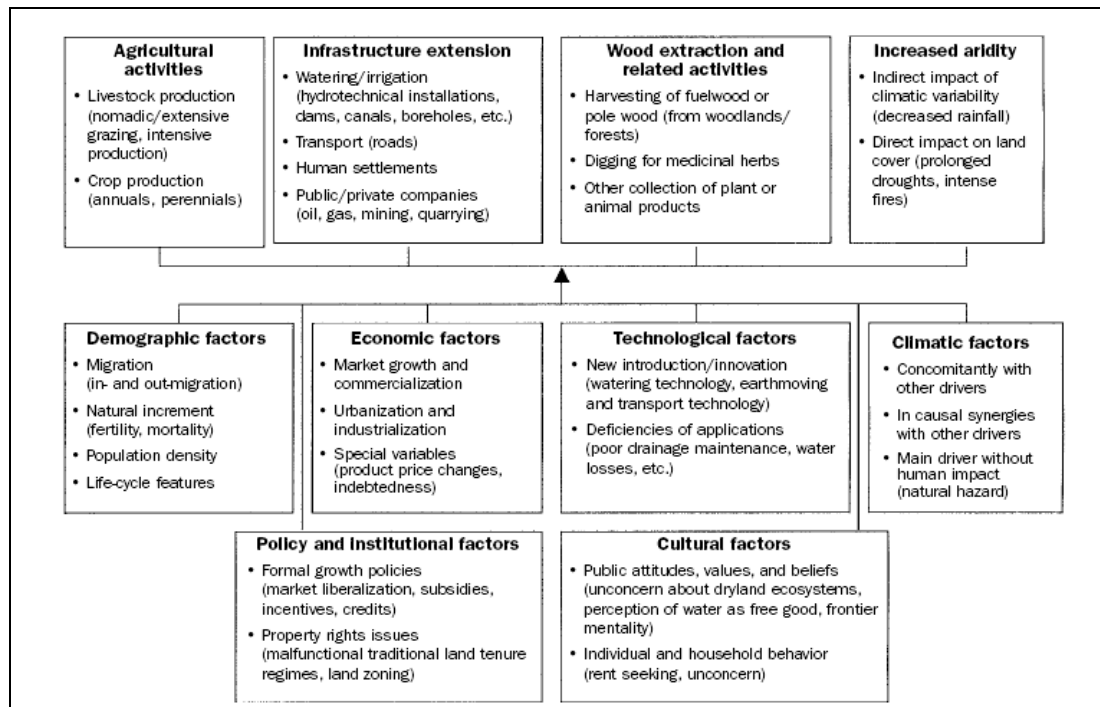
Figure 1 – Causes of desertification. Six broad clusters of driving forces (socio-economic and biophysical factors) with direct consequences on the Landscape system. Source: Helmut and Lambin (2004).

According to ESA (2003) and FAO (2006) the main manifestations and consequences of desertification processes in the Mediterranean are:

- Biophysical: As soils become more vulnerable to water (and wind) erosion, with consequent flash-flooding risk increase due to low vegetation cover. Irrigated lands may become salinized as water tables drop. In croplands, yields may diminish. Water resources for drinking and for agriculture may decrease.

- Socio-economic: People are abandoning desertified drylands in large numbers, joining the world's growing number of environmental migration, by massive exodus of rural individuals to cities.

- Global issues: The process of dryland degradation threatens elements of global biodiversity, particularly core agricultural species, forest biodiversity and the conservation of unique wetlands.

Desertification in Spain (Figure 2) is largely a society-driven problem, which can be effectively managed only through a thorough understanding of the principal ecological, socio-cultural, and economic driving forces (UNCCD, 1994) and (Kok and Delden, 2006). Recent land use changes are mainly due to physical and technological factors as well as socio-economic reasons (Kosmas and Valsamis, 2001).
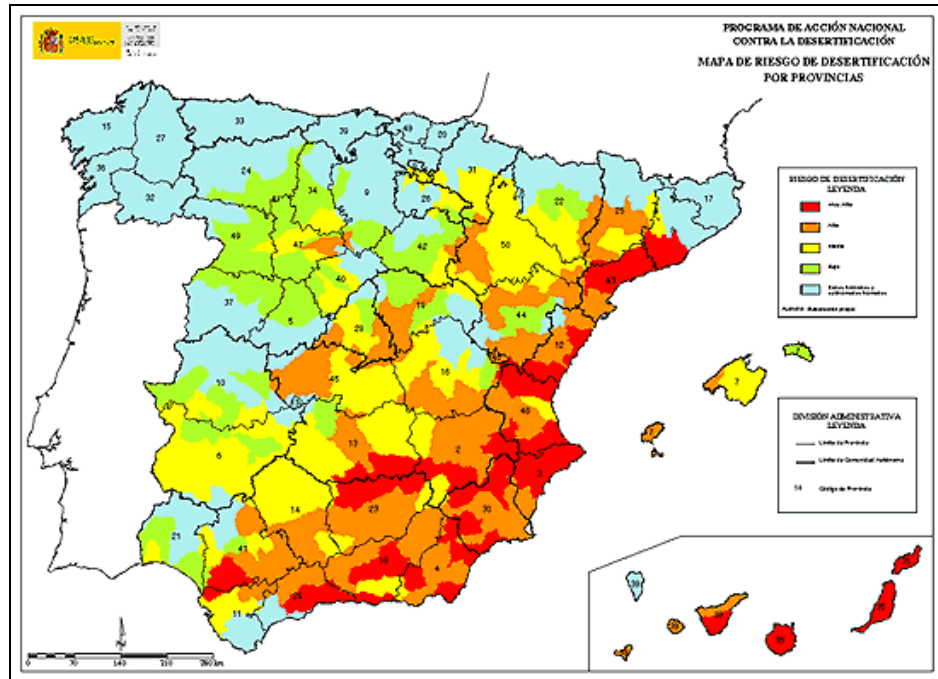
Figure 2 – Desertification Map of Spain. Source: MMA (2006).

2 – The Guadalentín River Basin importance

The Guadalentín Basin is a study model for desertification processes in the Northern Mediterranean region. The desertification problematic is rooted in certain physical circumstances—a semi-arid climate (decrease of precipitation and distribution change) which affects vegetation cover; the scarce availably of water resources (mainly groundwater) associated with highly erodable metamorphic and sedimentary rock; over which recent historical trends of land use, social and technological change have developed (such as intensive farming systems) (Onate and Peco, 2005) and (Laguna *et al.,* 2000). All these factors have resulted in one of the severest case in Europe (Lopez-Bermudez, 1998) *cit. in* (Cummings *et al*, 2001).

The Guadalentín Basin is located in south-eastern Spain (Fig. 3) covers 3,300 km². Administratively belongs to the Autonomous Region of Murcia.
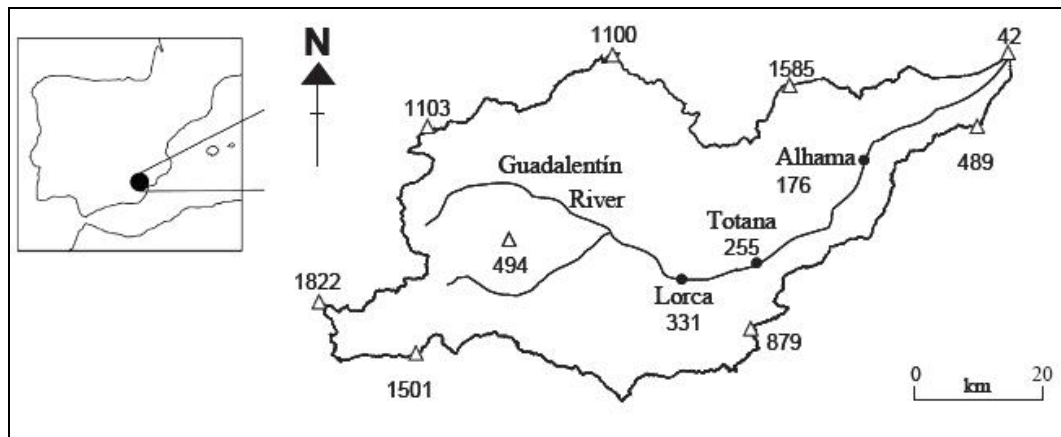
Figure 3 - Location of the Guadalentín river basin in Spain (left). Source: Delden *et al.* (2005). Main cities and altitudes, meters above sea level (right). Source: Onate and Peco (2005).

As described by Kok *et al.*, (2003), Guadalentín landscape main drivers are: Climate change, water availability, human migration, agricultural land use, tourism (golf courses), agricultural and regional policies.

2.1. Guadalentín Agricultural System

According to Onate and Peco (2005) the critical land use change considered as immediate causes of desertification are:

1- The **expansion of irrigated agriculture in the valley** is a main driver for aquifer over-exploitation and surface depletion in semi-arid climates, soil salinisation and water resources and pollution, drying off fluvial courses and springs, dying and destruction of wetlands and soil losses caused by erosion.

2- Tradition land use abandonment and the occurrence of intense and rapid land use changes in the **surrounding impoverished hilly dry land areas**, including both intensification and abandonment of agricultural practices as well as sudden changes in crop choices following the more rewarding EU subsidies. These changes act on a sensitive combination of semi-arid climate and vulnerable soils, which effects on erosion rates.
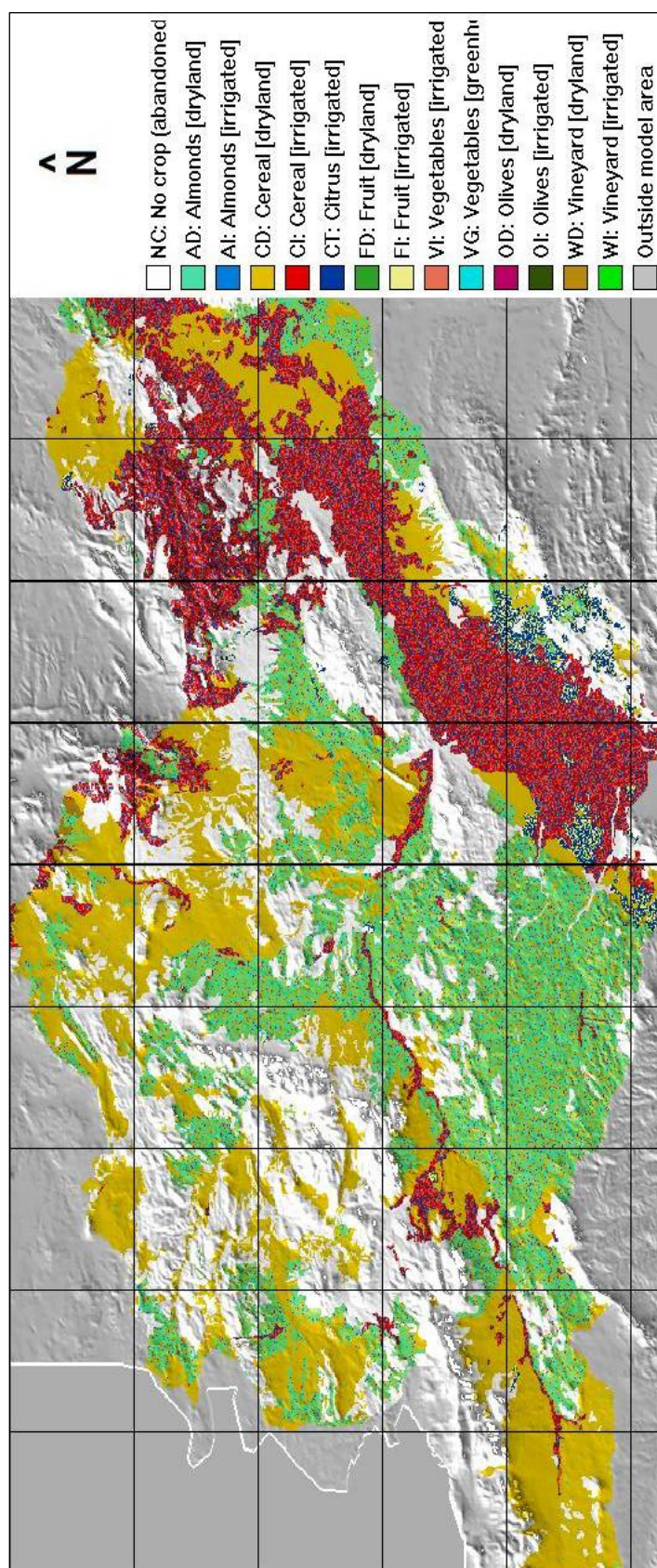
Figure 4 – MedAction® PSS initial crop type map. The reddish area represent the Guadalentín basin lowland with high concentration of irrigated cultures (vegetables, cereals, almonds, citrus and fruit), the greenish area represent hilly areas where the dryland cultures are distributed (almonds, cereal and olives), brown dryland cereals, white – no crops.

5

Agricultural production in Mediterranean climates is directly related to the availability of water as the most important limiting factor (Gomez-Limon and Berbel, 2000).

The Guadalentín has a long history of water shortage. Desertification is not a potential threat but a long-term reality - mini-deserts are developing. Water availability is influenced heavily by water policies. Because of a developed infrastructure, agriculture is partly more intensive and produces for the export market. Additionally, the vicinity of relatively large urban centres (Lorca and Murcia) and the accompanying problems of urbanisation and industrialization (Kok et al., 2003).

- Farmers Structure

According to Kosmas and Valsamis (2001) the Guadalentín farmer's structure is characterized by:
- Farming is a part time activity (parallel employment, 50%). The "weekend farmers" amount almost 40% of Guadalentín Basin farmers. Only 10% of them keep farming as secondary activity. On the other hand, exclusive dedication to farming affects farmers who are fully dependent on subsidies;
- For the Guadalentín Basin, the total used agricultural area is 113,500ha, from which 88,374 ha are private, 22,793 ha are rented, 1967 ha are freehold and 372 ha have other status;

- In Guadalentín 68.3% of total explorations are smaller than 5 hectares. Irrigated lands are small and there is a high percentage of rented land, while the drylands are bigger in size and mostly private;

- Most of the farmers are members of co-operatives and rely on them for almost all financial aspects of their farm, including the subsidies they apply for. The clear role of the co-operatives in influencing farmers' decision-making was also clear regarding the size of irrigation expansion by farmers, with members expanding to a greater extent than non-members.

- Irrigated Agriculture

The expansion of intensive farming in the Guadalentín lowlands (Figure 4) was also favoured by the excellent soil and climatic conditions and the availability of ground or surface water.

The region's remarkable growth is based on irrigated agriculture, which increased 60,000 ha during the 1975-1986 period; in 1997 the total irrigated land in Murcia was 190,000 ha (Onate and Peco, 2005).

The regional economic model is based on the development of irrigation agriculture that has been the driving force of Regional planning and management. The spread of irrigated land is part of a regional trend, now almost 31% of the regional Utilised Agricultural Area, more than two-fold the national level (Onate and Peco, 2005).

Guadalentín lowlands is also know as the ''Orchard of Europe'', with the fertile alluvial soils of the valley the been dedicated to growing the boost of available water (highly supplied by human infrastructures) provided an economic impulse for the region increasing of crop specialisation and technification with high derived yields (Perez-Sirvent *et al.*, 2003) and (Cummings *et al.*, 2001).

Guadalentín basin is characterized by the highest growth rates in Spain (CESRM, 1997) *cit. in* (Onate and Peco, 2005). Large share of production is located in the basin lowlands with the development of high input agriculture providing much higher net outputs than those obtained from hilly areas or terracing agriculture (Kosmas and Valsamis, 2001).

The basin lowland is characterized by an intensive agricultural use of highly profitable crops (e.g. fruits and vegetables)[1] with low canopy coverage, where over-exploitation of water resources is severe (not rechargeable under the present climatic conditions) (Albiac-Murillo *et al.*, 2002) and with increased water salinity and toxicity. Higher evaporation rates result as well as higher runoff generation, less soil moisture content and higher salinization risk (Post *et al.*, 2006).

Converting dry land into irrigated is three times economically more advantageous which causes framers to expand their irrigated land. The marginal value of water of dryland is 0.18 – 0.36 €/m³ and for irrigated 0.054 €/m³ (MIMAM, 2001) *cit. in* (Onate and Peco, 2005).

Even if high investment is required and the soil conditions are not so suitable for that use, farmers will choose irrigation farming. This preference is co-determined by the big difference in the benefits obtained between irrigation and dry farming (Kosmas and Valsamis, 2001).

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[1] *As an example, horticulture and fruit account for 62% of the Total Agricultural Production of Murcia, 28% Spanish average and also 16% for Community average (Ministerio de Economía y Hacienda, 1994; CES, 1997) cit. in (Cummings et al, 2001) and (Onate and Peco, 2005).*

Traditionally, irrigation has been the technique used to increase productivity and to enable people to settle in rural areas, since agriculture is the main source of employment. Irrigated agriculture employs a ratio of seven to eight times as high labour input per area – i.e. around 62,000 direct and indirect employees only in Murcia (Onate and Peco, 2005), than on unirrigated land. A decrease in irrigation regimes would seriously affect rural employment (Gomez-Limon and Berbel, 2000).

In Spain, the average productivity of irrigated agriculture is 700% higher than non-irrigated land. Spain's average consumption of irrigation water is almost double the average level in Mediterranean agriculture, and still 40% of farms still suffer from water shortage (Gomez-Limon and Berbel, 2000).

- Dryland Agriculture

The low profitability of dryland farms, in hilly areas with shallow soils and semiarid climatic conditions, are clearly not economical sustainable without any financial support. In Guadalentín, subsidies have helped the preservation of declining dryland farms on sloped land (cereals, almonds, olive groves) preventing rural exodus. Furthermore, the expansion of irrigated areas, olive groves and vineyards appeared in the context of 1992' revision CAP. Although in several cases, subsidies have negatively affected land degradation and desertification of abandoned land (Kosmas and Valsamis, 2001).

In dryland areas, due to lack of labour and land management which are done by part-time farmer's soil protection techniques are neglected in yield plots, e.g. ploughing along contour line, terracing and gully correction (Kosmas and Valsamis, 2001).

In the Guadalentín area, dryland agriculture takes place in the upstream part of the basin (Figure 4) and it mainly consists on cereal crops and traditional almond groves (Cummings *et al.*, 2001).

2.2. Guadalentín Desertification Drivers

2.2.1 - Water and Agricultural policies

Guadalentín's agricultural production is directly related to the availability of water as the most important limiting factor (Gomez-Limon and Berbel, 2000) even more than soil properties which only acts as a physical basis and the use of fertilizers to compensate the lack of soil nutrients (Onate, pena, 2005).

The constantly rising demand for water in Spain is clearly confirmed by the growing relative shortage of this resource. The water usage by irrigated farms accounts for 80% of national water consumption (Ministry of the Environment, 1998) *cit. in* (Gómez-Limón and Riesgo, 2004). In the South-eastern watersheds, water scarcity is specially acute because of the large and increasing water irrigation demand, triggering the over-exploitation of aquifers (Albiac-Murillo *et al.,* 2002). In Mediterranean areas, water resources are scarce and some of them have low quality (Ortega et al., 2004).

Spanish Water policies is essentially translated into government support for infrastructure construction and structural aid for efficiency enhancements, as well water concessions, promoted irrigation expansion at the expense of neglected drylands (declining since the late 1970s drought) (Kosmas and Valsamis, 2001).

Spanish law defines water as a "public good" – meaning that the water itself is absolutely free and it cannot be sold on the market. Farmers only pay the costs of distribution, maintenance of infrastructure, control and administration (Gomez-Limon and Berbel, 2000).
"The current cost of water in irrigated public Spanish lands is about 0.12 m^3", including regulation, transport and distribution to the farmer's plot, with public subsidies of approximately 90% (Corominas, 1996) *cit. in* (Ortega *et al.*, 2004).

Spain's entry to the EEC in 1986 provided structural aid for farm modernization promoting productivity increase and indirectly irrigation expansion - worsening water deficit and forcing new water transfers (Onate and Peco, 2005). Since then, land use changed significantly from traditional dry-farming techniques associated with pasture (sheep and goats) towards a profit-oriented agriculture obtained through intensive irrigation farming (Post *et al.*, 2006) partly driven by subsidies and increased export opportunities provided by the EU (Kosmas and Valsamis, 2001).

The White Book on Water from the Spanish Ministry of Environment sustains that future administration will mainly support irrigation areas with high economic profits, but not the low profit irrigated areas, and the high-priced Ebro water-transfer project is a result of this policy (Albiac-Murillo *et al*, 2002).

Guadalentín's economic model is oriented to profit and productivity maximization, being regional and EU policies the most significant factor influencing the region agricultural strategy. CAP and subsidies allocated today in specific types of crops or land uses in conjunction with the market prices greatly affect the intensity of the land use, control farmers choices and land use patterns (Kosmas and Valsamis, 2001).

The Alto Guadalentín basin has been exploited for over 500 years. The severe droughts that occurred in the southern Iberian Peninsula during the 1980 – 1995 period contributed to the increase of water demand which is the main cause of its over-exploitation, with a consequent negative impact on existing drills and becoming infeasible the construction of new perforations (GSGTB, 2006).

The Segura Hydrographical confederation emitted in 1998 a declaration of over-exploitation. The phreatic level was located between 300 and 400 meters in depth and salinity has increased up to 3- 9 g/l, which is a severe risk to soil quality and agricultural production (GSGTB, 2006).

"The Spanish government has declared the Valle del Guadalentín as an overexploited hydro-geological unit" - mean annual recharge 29 x 10^6 m^3/yr, and mean annual exploitation 99 x 10^6 m^3/yr (EEA, 1996).

In Europe, the policies relating to water use (2000/60/EC) pay particular attention to the need of its protection and conservation. To ensure this, a large number of measures, including the establishment of prices which really correspond to their usage costs, have been set forth (Ortega *et al*., 2004). Charging water pricing has become one form of action due to the agricultural demand of water (Ortega *et al*., 2004).

2.2.2 – Technological Drivers

The most expressive technological events sustaining the region's high agricultural productivity are:

1. The Autonomous Region of Murcia has developed a good transport infrastructure with better access of production systems to regional and international markets (Kosmas and Valsamis, 2001) and (Kok *et al.*, 2003)

2. Construction of the Tagus-Segura transfer channel operational since 1980 contributed clearly to irrigation expansion with average transported water volume of 250 Hm^3/year (Cummings *et al.*, 2001). Furthermore, the implementation of the new National Hydrological Plan, foresees a huge investment (6 billion €) (Albiac-Murillo *et al.*, 2002) in infrastructure for water transfer from the Ebro River basin (Northeast Spain) to Murcia and neighbouring regions. Also, the 2008 scenario National Irrigation Plan foresees existing irrigation expansion enhancements (Juntti and Wilson, 2003) *cit. in* (Albiac-Murillo *et al.*, 2002) and (Kosmas and Valsamis, 2001)

3. Construction of dams: At the moment, the regulation capacity of the dams of the Segura River basin makes up nearly 1,100 Hm^3 (Cummings *et al*, 2001).

4. - The spreading of the use of submersible pumps in the region, that permitted the water extraction in unattainable depths with previous techniques led to, from the 60s, an unprecedented increase of extracted water volumes (Cummings *et al*, 2001).

5. Water management techniques introduction such as dripping irrigation technique substituting the previous Flooding irrigation technique. With irrigation efficiency improvements, expansion or intensification of irrigated area been reemployed by most farmers (Kosmas and Valsamis, 2001). It also contributed to the reduction of certain crops such as cereals and cotton and the introduction of horticulture as well the reinforcement of vineyards.

2.2.3 - Environmental factors

The Guadalentín environmental context is characterized by surface and groundwater overexploitation, soil and aquifer salinization and natural habitat destruction along with a massive increase of irrigation agriculture in the valley.

- Groundwater overexploitation

In the Guadalentín area, the lack of water has always been a structural problem, not necessarily linked to climate change acceleration (Kok and Patel, 2003) and (Kosmas and Valsamis, 2001). The main environmental impact of irrigated agriculture is water consumption itself (Gomez-Limon and Berbel, 2000).

In the semiarid Mediterranean region, the absence of high rainfall and the existence of ephemeral rivers increase the importance of groundwater resources. Within an agricultural high water demand context, overexploitation of water bodies and natural aquifers is an important setback (EEA, 1996). Water shortage intensifies every year in the agricultural sector with an increasing irrigated area and thus water demand (Kosmas and Valsamis, 2001).

The resulting increase in productivity and change in land use can establish a cycle of unsustainable socio-economic development within an irrigated region, accelerating the desertification processes (UNCCD, 1994) and (EEA, 1996).

Water scarcity is especially acute in the region due to the production expansion of non-traditional and irrigated crops (fruit and vegetable) that has a huge demand for water, triggering over-exploitation of aquifers with hydric systems degradation (Albiac-Murillo *et al.*, 2002). Basin's Water deficit is structural and keeps increasing, it is officially estimated to be 460 Hm^3, although considering illegal exploitation it may reach 800Hm^3. New expansions of the irrigated area are officially foreseen (Onate and Peco, 2005).

The Tajo-Segura water transfer canal and a new projected one to transport water from the Ebro River in the North East down to the Guadalentín (Kok *et al.*, 2003) is a consequence of the regions high water demand.

- Soil and aquifer salinization and pollution

Salinisation becomes more severe by anthropogenic activities such as irrigation, deforestation and overgrazing (Faulkner and Hill, 1997). Closely related to irrigation is soil salinity (Delden *et al.*, 2005). This way, soil salinisation is caused by the use of water with too much nutrients, as a consequence of the overexploitation of aquifers (Kok and Patel, 2003). Water consumption increased in the recent decades aggravating the progressive degradation of water and soil quality (Albiac-Murillo *et al.*, 2002).

Contamination problems affect the Guadalentín aquifers, either because of point-source pollution (urban and industrial) or as a result of a widespread pollution caused by agricultural (incorrect use of fertilisers and chemicals) and livestock activities. Fertilisers are often applied to crops in excessive amounts, coupled with inefficient irrigation activities, causes nitrates to be washed away into the aquifers (EEA, 1996). Additionally, using fertilisers beyond soil capacity when water is not available has a negative impact on both soil structure (salinization) and crop yields (Dominguez, 1997 *cit. in* Gomez-Limon and Berbel, 2000). Therefore, the excess use of fertilizers is also associated to the intensification of land degradation and desertification processes (Laguna *et al.*, 2000).

Recent droughts, the scarcity of water volume in certain sections of the river and the increase of water consumption have led to the use of badly treated or highly saline water with consequent soil chemical degradation widespread (Albiac-Murillo *et al.*, 2002). The reuse of poorly purified and industrial waters in semiarid areas may have a harmful effect and lead to progressive desertification (Perez-Sirvent *et al.*, 2003) since irrigation with extracted saline water lowers production due to soil salinization (Onate and Pena, 2005). Furthermore, the Region's high temperatures and subsequent high potential evapo-transpiration values result in a serious water deficit (Perez-Sirvent *et al.*, 2003) and (UNC, 2006) intensifying environmental degradation.

In Guadalentín the severest salinization case is located river valley, which is presently taken by highly irrigated agriculture (Delden *et al.*, 2005). Nowadays, the situation reaches the extreme limits in highly irrigated areas (orchards and horticulture). Lowering of river flow rates and the inability to dilute sewage from the growing populations (Onate and Pena, 2005).

3 – Integrated Modelling strategy: Medaction® PSS overview

To mitigate Land degradation and desertification, water management and sustainable farming problems in Mediterranean watersheds and regions, the EC funded the research project MedAction[2], in which a Policy Support System is developed with the aim of providing a support tool for policy makers (Delden *et al*, 2005) with regard to policy formulation for sustainable land management at the regional and local level (Kok and Delden, 2006).

In the context of the EC MEDALUS (Mediterranean Desertification and Land Use), the focus here is primarily on European Mediterranean environments where physical loss of soil by water erosion, and the associated loss of soil nutrient status is identified as the dominant problem. In more arid areas, there is greater concern with water erosion and salinisation problems (Kosmas *et al*, 1999).

The MedAction® PSS is a integrated assessment model developed with the fundamental aim to better understand the phenomena of land degradation and desertification and specifically to provide a valuable tool to support policy formulation to prevent, mitigate or adapt to the consequences of these processes (Mulligan, 2005).

The MedAction® PSS Integrated Assessment Modelling (implemented with the GEONAMICA® application framework) incorporates both socioeconomic and physical processes and drivers of land degradation in the northern Mediterranean -the driving forces in MedAction® PSS are demographic and economic growth as well as climate change This is accomplish with strong interactions and bi-directional feedback loops between them (Delden *et al*, 2005), (Oxley *et al.*, 2004) and (Mulligan, 2005).

The MedAction® PSS addresses three policy themes regarding regional development in Mediterranean watersheds: land degradation and desertification, sustainable farming and water resources. For each, the main problems, goals, policy options and policy indicators have been gathered and structured in a conceptual framework (Figure 5) used as the basis for the design and implementation of the PSS (Delden *et al*, 2005).

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[2]*MedAction® PSS: Policies to combat desertification in the Northern Mediterranean region. Research project supported by the European Commission under the Fifth Framework Programme and contributing to the implementation of the Key Action 2: "Global Change, Climate and Biodiversity"; Subaction 2.3.3 "Fighting Land Degradation and Desertification". The MedAction Policy Support System (PSS) was developed by Research Institute for Knowledge Systems (RIKS BV) and King's College London. Website: www.icis.unimaas.nl/medaction.*

Themes	Policy measures	Indicators
Sustainable farming Long term profits Sustainable land use	• Subsidies, taxes • Water price • Water availability	• Profit • Crop type • Number and location of abandoned cells • Dynamic suitability maps • Irrigation water used from different sources • Amount and cost of irrigation water
Water resources Availability and price of water	• Water availability and price • Amount of water from outside the region • Construction of desalinisation plants	• Change in aquifer and reservoir budget • Natural water input (runoff and recharge) • Costs and amount of water used
Land degradation & desertification		
Erosion	• Afforestation • Grazing regulations • Construction of check dams • Dredging	• Fertile soil depth • Erosion rates • Change in storage capacity of reservoir • Total cost of dredging
Preservation of nature and forests	• Afforestation • Zoning	• Forested area • Changes in natural vegetation type groups • Dynamic suitability maps
Salinisation	• Maximum amount of water available from aquifer and desalinised water • Maximum allowable percentage of salt in water from desalinised	• Soil salinity • Salt concentration in the aquifer • Restricted factor for plant growth (yes/no)
Sustainable land use in region	• Zoning • Construction of infrastructure (dams, roads, channels)	• Land use map • Dynamic suitability maps • ESA

Figure 5 - Linking themes, policy measures and indicators in the MedAction® PSS. Source: Delden *et al*, (2005).

3.1. MedAction® PSS – Dynamic Land Use Planning for the Guadalentín Basin

Currently the Guadalentín basin is one of the large research areas within the MEDALUS project. It was selected as a study area since it embodies much of the problems of Mediterranean land degradation (Barrio *et al*., 1996). The present version of The MedAction Policy Support System is applied to the Guadalentín river basin in Spain.

The user interface of the Guadalentín PSS features a system diagram (Figure 6, upper right) representing the different interacting sub-models and processes[3]. The system diagram contains six different integrated models: climate and weather, hydrology and soil, vegetation, water management, land use and farmer's decisions. Within each model a series of sub-modules exist, where each sub-model is made up of a series of processes (Mulligan, 2005).

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[3] *"The MedAction system couples external and internal biophysical processes with external and internal human processes. External biophysical processes include climate and weather. Internal biophysical processes include all of the hydrological processes (surface and subsurface), soil wash erosion and sedimentation, vegetation growth, development and succession for crops and natural vegetation and soil salinisation. The external socio-economic components include external markets for crops, agricultural incentives, water 'imports' and the various policy options (water pricing, terracing, crop planning and irrigation). The internal socio-economic components include water demands and usage, water resources allocation, land use (change), profit and crop choice and dynamic land suitability" (Mulligan, 2005).*
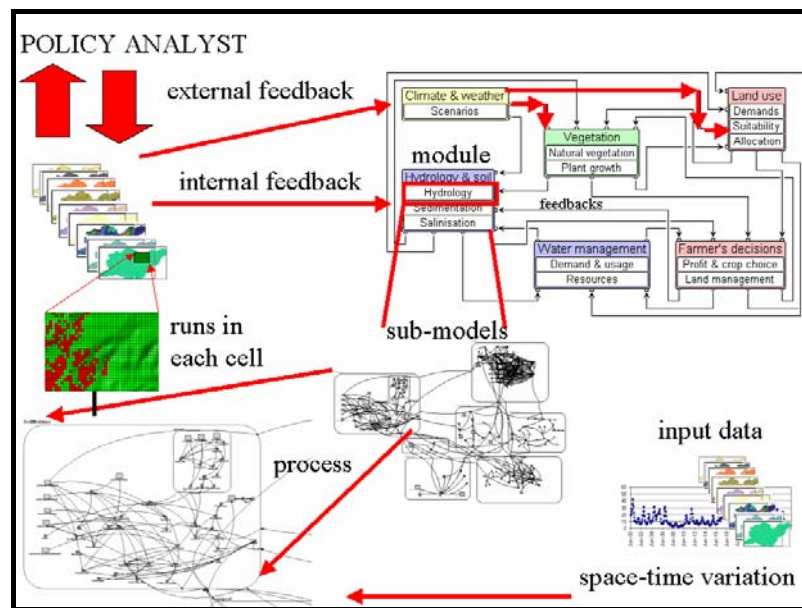
Figure 6 - A Basic outline of the structure of the MedAction® PSS. Source: Mulligan (2005)

The main advantages of this framework is its user-friendly interface that enables the user to give input to a specific module (policy options, scenarios, parameter changes) and also provide access to the alphanumeric and graphical of the simulation outputs (Engelen *et al.*, 2003) and (Delden *et al*, 2005).

This integrated model has the regional extent of the Guadalentín River Basin (3,300 km²), and runs with timescales from sub-minute to annual (each integrated model runs on a temporal resolution appropriate for the process modelled); The spatial resolution of the models is essentially the 1 ha (100m) grid with some minor processes modelled at the level of the whole region; the temporal scale of each run is 30 year (maximum), from 2000 to 2030 (Mulligan, 2005) and (Delden *et al*, 2005).

The integrated model provides a series of environmental sensitivity indicators with policy relevance (Mulligan, 2005) that can be used as desertification indicators. During a simulation exercise the all biophysical and socio-economic indicators are recalculated yearly through complex feedback loops.

3.2. MedAction® PSS - Policy Relevance

Policy-makers and policy analysts have to address human-natural system as a complex integral whole, where it is insufficient only to focus on individual processes. In the given circumstances, integrated models as part of Policy Support Systems (PSS) can provide valuable support.

The Medaction Policy model[4] is foremost oriented towards addressing practical policy issues at the appropriate temporal and the spatial resolution at which processes are represented. Models are interesting in a policy context because they deliver practically useful output, and to help explore the possible effects of policies (Winder, 2003 cit. in Oxley *et al*, 2004).

The MedAction® PSS Integrated model will enable the end-user, a policy maker or policy analyst, to understand how different processes in the target area interact in space and time. It enables the end-user to explore the impacts of different climate (e.g. climate change) and socio-economic scenarios (e.g. economic and demographic growth) in the region as well as the impacts of different policy options through what-if analyses (Engelen *et al.*, 2003) and (Kok and Delden, 2005).

Since the PSS integrates different disciplines in a dynamic and interacting way, is a resourceful tool to "explore the behaviour of the system associated to its autonomous dynamics largely determined by the human agents active in the system, subsidies and other policy measures imposed on the agents, and the exogenous drivers, climate change, technological change, demographic growth, and market forces" (Delden *et al*, 2005). This grants immediate access to very rich and operational knowledge in a broad context (Engelen *et al.*, 2004).

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[4] *Models are a "simplified representation of a system (or process or theory) intended to enhance the ability to understand, predict, and possibly control the behaviour of the system" (Neelamkavil, 1988 cit. in Oxley et al, 2004). The model may be complex, but generally is kept as simple as possible (Oxley et al, 2004)*

4. Methodology

This section presents some case studies which explore the dynamics of desertification in response to the change of external and internal processes either biophysical or human components impacts that can be measured by means of a number of policy relevant indicators which change dynamically during the MedAction® PSS simulation run.

4.1. Data Derivation

To explore the dynamics of desertification the MedAction® PSS model is run twice, once a baseline scenario where all parameters are left as default – this 30-yr simulation will be used as the equilibrium experiment or control; then again with one isolated "perturbation" (only one parameter is changed) to the system dynamics. The two simulation outputs are compared and statistically analyzed (using Equation 1) to identify changes over the selected policy relevant desertification-indicators (Table 1).

Each individual scenario (Table 4) is applied for all Guadalentín basin area (3,300 km²), it runs for a 30-year period simulation (between the years 2000 and 2030). It is fully applied at t=0 (1 of January 2000), except when mentioned. The spatial resolution is 1ha grid and the temporal resolution varies between one day and one year (depending on the model's process).

4.2. Statistical Analysis of Results

- The statistical analysis is based on the selection of relevant policy desertification indicators provided by the Medaction SPP simulation outputs;
- The year average is calculated for each indicator, from which is calculated the yearly change (equation 1, n=30 years) between baseline scenario and study-scenario – calculating the time series of the indicator change;
- The 30-year average of change (%) is calculated for each indicator and is used to globally quantify the perturbation impact on the biophysical and socio-economic conditionings of the Guadalentín basin area.

With the baseline scenario values used as reference, the perturbation-scenario run output is compared and the change (%) between simulations is calculated using the equation:

$$change \ (\%) = \frac{baseline - scenario}{baseline} \ x \ 100 \qquad \text{(Equation 1)}$$

Result interpretation: Positive change (%): indicator's values are higher for baseline than for study-scenario – the study-scenario assumes change (%) value decrease; and vice-versa.

There were selected and analysed a total of 131 indicators (Annex 2, Tables 1 to 8), upon which a narrative story was developed using the indicators that changed more than ± 5% between the simulations. The selection of this high number of parameter-indicators allows us to examine the model outcomes in a more holistic way than would be possible by analyzing specific processes or variables in isolation (Mulligan, 2005).

Table 1 - MedAction® PSS policy relevant desertification indicators used to test the impact of introduced "perturbation".

MedAction® PSS policy relevant desertification indicators
- Hydrology and Soil – evaporation, soil budget, discharge, erosion budget and salinity budget general indicators (total 13 indicators);
- Land Use Suitability – generally for natural vegetation and agriculture; and in more detail for dryland and irrigated crops and greenhouse vegetables (13+2 parameters); *[Indicator based on soil salinity, fertile soil depth and slope, mean values for temperature and soil moisture]*
- Vegetation cover – of dryland and irrigated crops, natural vegetation: woodland, shrubland and grassland (total 20 indicators);
- Harvested Area – of dryland crops, irrigated crops and greenhouse vegetables (total 13 indicators);
- Farmer's average crop profit and choice: dryland and irrigated crops and greenhouse vegetables (13 parameters); *[Indicator based on Crop price; Subsidies; Yield; Water availability; Water price; Growth suitability of the land; and farmer's decision-making process]*
- Water Management: Water demand – water demand from aquifer, reservoirs, desalinated sea water by social sector; and water shortage by social sector (total 24 indicators); Water resources – water extraction and replacement by aquifer, reservoirs and desalinated sea water; and water volume by water resource (total 9 indicators);
- Cumulative average Irrigation – from each water resource - aquifer, reservoir, desalinated sea water - by crop type (24 parameters); *[Indicator based on Crop type and Available amount of water]*

4.3. MedAction® PSS developed scenarios

4.3.1. Baseline Scenario characterization (MedAction® PSS default values)

Note: (Annex 1.2 – MedAction® PSS Baseline Data for the Guadalentín Basin)

The baseline scenario simulates actual biophysical and socio-economic conditions of the Guadalentín watershed (3,300 km²):

- Global climate scenario based on the ECHAM model characterised by a decreasing precipitation in the Guadalentín watershed (change between 2000-2030 at Alhama de Murcia: rainfall decrease by -0.560 mm/month and +0.170˚ C. temperature increase);

- A land use claim increase over time (2000-2030) from all socio-economic sectors, expect for agriculture that remains constant (228,260 ha): rural residential (293 to 300ha), dense residential (1,404 to 2,000ha), industry and commerce (548 to 750ha), tourism (7 to 100ha) and ex-patriots (0 to 50 ha);

- Subsidy and Crop prices are those observed in the past years and remain constant for the full duration of the simulation (Table 2);

- It is assumed that there is enough water available from outside the region to meet most demands (Ebro transfer channel), the monthly input from Tajo is 2.0 x 10⁶m³ (Adapted from Delden *et al*, 2005);

- Details on original values of water resources – water price, initial volume and resource salt content can be found in Table 3.

The Original values of crop properties (same as Baseline run) are represented in Table 2.

Table 2 - Initial model conditionings – from Farmer's Decisions module – Profit and crop choices, crop properties parameter. Source: MedAction® PSS.

| profit and crop choice | price | init cost | yearly cost | subsidy | tax | max yr harvest | soil moisture for max growth | irrigation soil moisture level | plant growth soil moisture | Initial area |
	€/kg	€	€/yr	€/year	€/yr	kg/ha yr	[-]	[-]	[-]	(ha)
dryland almonds	0.79	5,000	0	2,500	0	484	not irrigated	not irrigated	0.70	44,924
irrigated almonds	**0.79**	**5,000**	**0**	**2,700**	**0**	**2,218**	**0.40**	**0.15**	**0.20**	**7,486**
dryland cereal	0.17	5,000	0	2,300	0	4,686	not irrigated	not irrigated	0.40	101,668
irrigated cereal	0.20	5,000	0	3,500	0	5,240	0.45	0.20	0.10	27,979
irrigated citrus	0.20	5,000	0	1,200	0	19,379	0.55	0.35	0.10	12,769
dryland fruit	0.51	5,000	0	1,200	0	1,362	not irrigated	not irrigated	0.90	48,601
irrigated fruit	0.41	5,000	1,650	0	0	15,814	0.55	0.35	0.10	22,024
irrigated vegetables	0.36	5,000	6,200	0	0	34,064	0.45	0.25	0.40	15,841
greenhouse vegetables	0.45	5,000	13,300	0	10,000	101,479	irrigated	irrigated	1.00	362
dryland olive	0.52	5,000	0	1,950	0	1,398	not irrigated	not irrigated	0.80	2,340
irrigated olive	0.53	5,000	0	1,750	0	3,626	0.40	0.15	0.20	842
dryland vineyard	0.32	5,000	0	1,950	0	2,400	not irrigated	not irrigated	1.00	2,249
irrigated vineyard	0.32	5,000	250	0	0	5,940	0.55	0.35	0.10	494

The default water resources values of the Guadalentín Basin area represented in Table 3.

Table 3 –Water Resources original values; from water management module → resources sub-module; Hydrology and soil module → Salinisation. Source: MedAction® PSS

	Original water price €/m³	Initial Volume (m³)	Original resource salinity (g/m³)
Aquifer	0.20	6.5×10^8	17.5
Reservoir	0.25	8.9×10^7	15.0
Desalinated sea water	0.30	5.0×10^6	80.0

4.3.2. The Biophysical and Socio-economic scenarios developed:

Table 4 - Scenarios development in MedAction® PSS

Biophysical scenario:

S1 – "Severe drought or precipitation absence"
Description: simulation of extreme climatic event where there is no rainfall during the 2000-2030 period.
MedAction Model: "climate and weather model" → "weather generators" parameter → "precipitation offset" map
Operation: binary map editing: all values are set to zero; precipitation values decrease 100%

Socio-economic scenarios:

S2 - "Aquifer resource for agriculture usage limited to zero" – water-use restriction policy
Description: Prohibition of Aquifer Water extraction for irrigation practices (to avoid resource over-exploitation).
MedAction Model: "Farmers decision's" → "Land management" → "Irrigation" Sub-module
Operation: "aquifer irrigation" binary map editing

S3 –"Reservoir water resource cost increase (0.18 €/m³)" - water management policy
Description: simulation of the impact of water price increase of one of the main water resources in the region.
MedAction Model: "water management" → "water resources"
Operation: aquifer price change, from 0.25 to 0.43 €/m³; Cost increase of 0.18 €/m³.
 [uplifting from 2000 to 2005 and continuous onwards];

- Agricultural subsidies:
S4 – "Irrigated almonds subsidy increase of 50%"
Description: simulation of the impact of agricultural policy on biophysical and socio-economic systems.
MedAction Model: "Farmers decision" → "profit and crop choice" → crop properties table
Operation: substitute irrigated almonds subsidy of 2700 by 4050 €/year.

5. Simulation Results and Discussion

Note: Detailed scenario results can be found in Annex 2, Tables A to H.

5.1. Biophysical scenario: "Severe drought or absence of precipitation".

Drought is defined as a "naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels", (…) "causing serious hydrological imbalances that adversely affect land resource production systems" (ESA, 2003).

Table 5 - MedAction® PSS Rain offset initial values for the Guadalentín Basin (Baseline scenario).

Rain offset Initial values:
(mm/m^2·mo)
0 - 0.55 mm = 11,814 ha
0.56 - 0.65 = 161,340 ha
0-66- 0.75 mm = 134,919 ha
0.76 - 0.85 mm = 16,485 ha
0.86- 0.95 = 4,418 ha
Total = 328,976 ha
Average = 0.71 mm
Total = 232,562 mm
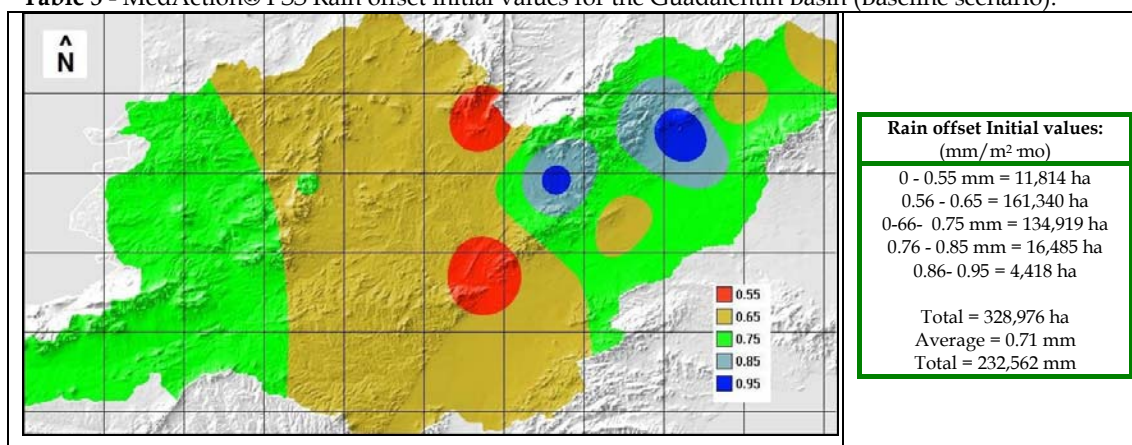
Figure 7 - MedAction® PSS Rainfall baseline map and values. Grid size 100 km^2; Area 3,300 km^2.

Table 6 - MedAction® PSS Rain offset final values for the Guadalentín Basin (scenario simulation run).

Rain offset final values:
(mm/m^2·mo)
0.00 mm = 328,968 ha
(total)
Average = 1.7 x 10^{-5} mm
Total = 5.60 mm
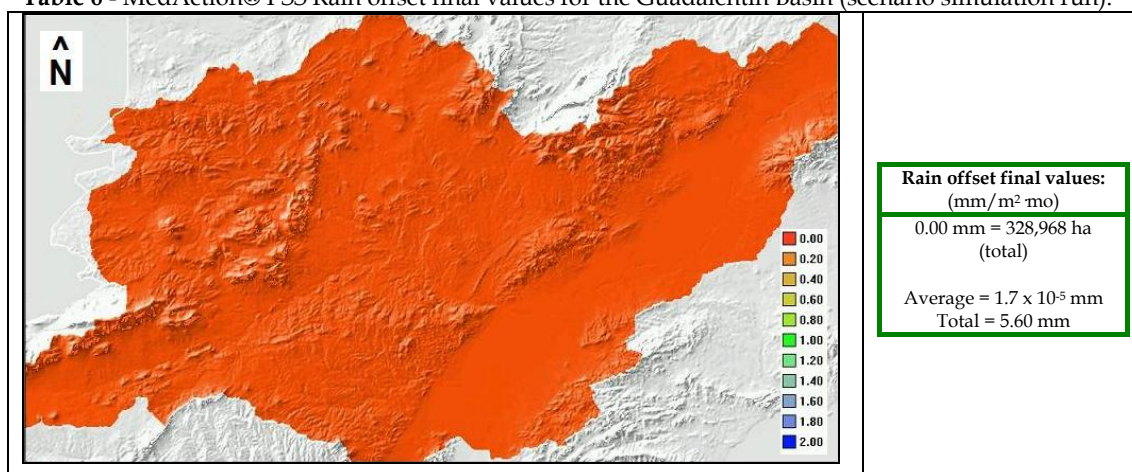
Figure 8 - MedAction® PSS Rainfall final map and values (all values set to zero (mm/m^2·mo), Area 3,300 km^2.

The total rainfall in the Guadalentín area decreases 100% during the 2000-2030 period – there is literally no rain (Figure 7 and 8) and therefore rain water cesses to be a water source supplier.

5.1.1. "Severe drought or absence of precipitation" Scenario – Results

Table 7 – Change analysis (%) of the Desertification indicators comparing Baseline and "Severe drought or precipitation absence" scenarios.

Indicators:	S1 - Severe drought or precipitation absence – Results:
Hydrology and Soil	- Decrease of erosion budget (≈ - 100% for all sediment indicators); - Evaporation budget decrease: soil evaporation (- 75%), interception, evaporations and transpiration (- 42%); - Water-soil budget decrease – average soil water (- 71%), Infiltration (- 64%); - Increase of salinity budget - aquifer salinity (544%), irrigation salt (124%) and average soil salinity (30%); - No change in average water discharge.
Land Use Suitability	- Decrease of global land use suitability - Natural vegetation suitability decrease (21%) and agriculture suitability decrease (5%); - Total Irrigated crops suitability decreases (- 335%) – mainly citrus fruit and vineyard (-57% each), cereal (-54%), olives and almonds (-46%) and vegetables (-18%); - Total dryland crops suitability decrease (-48%) – mainly for cereal (-27%).
Vegetation cover and Harvested Area	**Vegetation cover:** - Total dryland crops cover decrease (-467%) – all crops decrease between - 97% and - 82%; - Total irrigated crops cover increase (222%) – mainly olives cover (132%) and almonds (73%); - Natural vegetation cover decrease – woodland (-297%), shrubland (-202%) and grassland (-196%).
	Harvested area: - Total dryland crops have a harvest increase (329%) – mainly vineyard (235%), olives (147%) and almonds (55%); - harvest decrease for dryland fruit (-77%) and dryland cereal (-31%); - Total irrigated crops have a decrease of harvested area (-150%) – mainly fruit (-51%), olives (-47%), vegetables (-38%), citrus (-33%); - And increase of irrigated cereal (52%).
Farmer's average profit and crop choice	- It is recorded a global decrease of farmers profit. - Total Irrigated crops profit decrease by 199% - mainly vegetables (-98%), fruit (- 43%), olives and citrus (-25% each); - Increase of irrigated almonds (12%); - Total dryland crops decrease (- 182%) – mainly fruit (-80%), vineyard (-41%), olives (-36%), cereals (-13%), almonds (-12%); - Greenhouse vegetables profit decrease (-68%).
Water Management	**Water demand:** – Increase of water demand of reservoir resource (1.7×10^{22} %) – mainly from agriculture (1.7×10^{22} %); - Increase of desalinated sea water demand (5.3×10^{20} %) – mainly from urban residential (3.1×10^{20} %) and agriculture (2.2×10^{20} %) and industry and commerce (230%);

	- Decrease of aquifer total water demand (-423%) – all sectors (-76 to -88%), except ex-patriots (-7%); - Water shortage increase *(1.1 x 10^{21} %)* – mainly urban residential (1.1 x 10^{21} %) and industry and commerce (290%); and decrease for agricultural sector (-64%).
	Water resources: – Total water extraction increases (1,289%) – mainly from reservoirs (946%) and desalinated sea water (418%); - Decrease of water extraction from aquifer (-76%). - Total water replacement increase (1,237%) – mainly of reservoir resources (1321%). - Decrease of Total volume of water resource (-107%) – mainly of aquifer (-89%).
Cumulative average Irrigation	- Increase of total cumulative average irrigation from reservoirs (1.3 x 10^{20} %) – balanced use in all sectors (expect greenhouse vegetables); - Increase of total cumulative average irrigation from desalinated sea water resource (3.4 x 10^{18} %) – balanced use in all sectors (1.3 x 10^{15} ; 1.8 x 10^{18}), expect greenhouse vegetables (0%); - Decrease of total cumulative average irrigation from aquifer (- 543%) – mainly for greenhouse vegetables (- 86%), vineyard, citrus, fruit, vegetables (range between – 77% and - 79%).
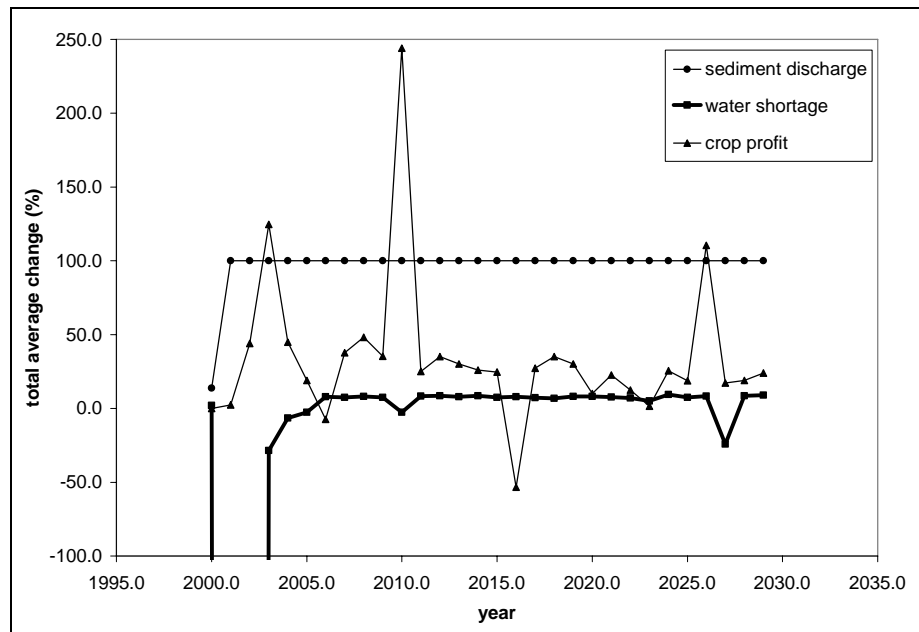
Figure 9 – "Severe drought or precipitation absence" scenario – change (%) analysis of sediment discharge as an erosion indicator, regional total water shortage and global farmer's profit.

Comparing baseline with drought scenario (Figure 9) and using regression analysis, it is shown that: Total crop profit decrease 0.7%/year; total water shortage increase 3×10^{19} %/year (with a strong water shortage in 2002-2003); and total sediment discharge decrease 1.8 %/year (strong decrease during 2000-2001, stabilizing at 100% change).

5.1.2. "Severe drought or precipitation absence" scenario - Discussion

- Within a more arid environment natural vegetation cover suffered a severe decrease [woodland (-297%), shrubland (-202%) and grassland (-196%)], and as well dryland farming area (-467%); the average soil moisture decreases (-71%) with consequent plant's water-stress increase, which has a negative influence on natural growth dynamics. "Inevitably the vegetation structures and soil and water balances would be affected". The lower rates of organic matter production could cause a general deterioration in the structure of many soil types and alter their ability to partition rainfall between infiltration and runoff (Faulkner and Hill, 1997).

The aridity increase has a influence on the decrease of global land use suitability due to soil salinity increase (+30%) and soil moisture decrease (-71%): natural vegetation suitability decreases (21%); total Irrigated crops decreases (- 335%) and total dryland crops also decrease (-48%). The Increase of irrigation to compensate the lack of precipitation shows that the suitability for agriculture decreases the most.

- "Severe droughts have a larger impact on dryland than irrigated farmland as the loss of rainfall water cannot be compensated by irrigation. This conditioning will be the driving force on farmer's choice to change land use" - change to irrigated or eventually cause dryland farmers to abandon their land (Delden *et al*, 2005).
- This assumption is clearly explicit in the simulation run results. With the 100% decrease of rainfall (for the 30-yr period), the **vegetation cover** changes considerably with the total dry farmland cover area decrease (-467%) and total **irrigated** farmland cover area increase (222%), especially high-value crops such as olives (132%) and almonds (73%) located at the valley, substituting all other crops.

- The highest productivity (harvested area) increase recorded is for dry crops: vineyard (235%), olives (147%), almonds (55%) and irrigated cereal (52%). This selection corresponds to crops that are more adapted to climate adversity, being less water dependent (less soil moisture to max growth); and as well the most profitable crops – with high market value, higher subsidies and higher yield (Table 2), and additionally, the farmlands haveh less water expenses.

NOTE: greenhouse vegetables (199%) harvested area increase (located in the small "allowable" patches in the lowlands). Greenhouse farmland is characterized by high technological input (highly efficient irrigation techniques, e.g. dripping), sophisticated water

extraction (e.g. deeper drill) and the poor soil and water quality is compensated by high fertilization input. However, its total profit decreases (-68%).

It is recorded a wide-ranging decrease of farmers profit; the Irrigated crops total profit decrease (-199%), and the dryland crops total profit also decrease (- 182%) – except for irrigated almonds being the most (and only) profitable crop of the set (+12%).

- The profitability of the irrigated agriculture depends largely on the market prices of the crops and attributed crop subsidies; if they are high enough, profits can still be made even if more is spent on irrigation water" (Delden *et al*, 2005). If farmer's profits suffer a severe decrease, there will be consequences in local / regional economy with labour cuts and possibly rural exodus and crop change.

Farmers' Drought Adaptation capacity is based on the adoption of more complex cropping patterns that include permanent crops and appropriate crop rotations, that operates under a flexible water demand, and on its flexibility to allocate their permanent labour resources (Iglesias *et al*, 2003).

- Furthermore, the farmers selection on dry perennial crops – generally associated with natural understorey vegetation and located in the Guadalentín hilly areas, contribute significantly to a general decrease of all erosion indicators (≈ - 100%). Additionally it is recorded a decrease of infiltration (-64%) with consequences of soil moisture availability decrease for plant growth having a deterius effect on crop yield and soil stability (Faulkner and Hill, 1997), and the reduction of to aquifer natural recharge. in addition, there is a clear indication of its exploitation – a increase of aquifer salinity (544%).

- As dryland crops harvest increases (+329%) and irrigated cropland decrease (-150%) total water shortage for the agricultural sector (-64%) also decrease. The agriculture sector water demand increases from reservoirs (+1.7 x 10^{22} %) - at lower price than desalinated; and from desalinated sea water (+2.2 x 10^{20} %). As a consequence of the higher irrigation input generally with high salt content (Table 3), the average soil salinity increases (30%) in all regional extent.

These values show a high dependency on inter-regional water import – the Tajo-Segura water transfer channel, being a cheaper and with higher quality water resource than desalinated.

- A decrease in precipitation increases salt concentration in soils. The structural intrinsic water deficit is aggravated and water extraction increases. Most of the times this water used for irrigation, has poor quality (e.g brackish), mobilizing otherwise immobile salt within the

soil profile which move up the profile and are deposited at or near the surface. (Faulkner and Hill, 1997)

- Relatively to Basin's groundwater resources, it is recorded a decrease of extracted water (-76%), total decrease of irrigation (- 543%) and as well a total volume decreases (-107%). Aquifer resource gets severely over-exploited during the 2000 to 2002 period with a total 30-yr average volume decrease of 100%. Furthermore, it has (originally) higher salt content (Table 3), thus lower quality than reservoir.

- The occurrence of pluriannual periods of drought can also aggravate water quality conditions; the reduction in water volume causes further ecological degradation with a more aggressive penetration of saline water into the soil (Prat and Ibañez, 2001) *cit in* (Albiac-Murillo *et al.*, 2002).

 In summary:

Guadalentín's environment becomes more arid, with overexploited groundwater and loss of semi-natural vegetation and total dryland farming area due to water stress increase. As total irrigated land use area increases (222%) the water demand increases exponentially being dependent on the water supplied from outside the region and provided at higher costs. Soil becomes degraded due to salinization and total farmers profit decrease.

5.2. "Aquifer resource for agriculture usage limited to zero" Scenario

The Segura Hydrographical confederation emitted in 1998 a declaration of the Guadalentín aquifer over-exploitation. A Management Plan for the Aquifer should legally be implemented, in which the water usage should be restricted until its recovery (Cummings *et al*., 2001).

The MedAction® PSS irrigation sub-model simulates irrigation by farmers. For the current scenario, the ability to extract water from the aquifer resource at defined location is changed to zero in almost all basin area (figures 10 and 11). The policy restriction proposed for this scenario assumes that groundwater availability for farming usage decrease 94%.
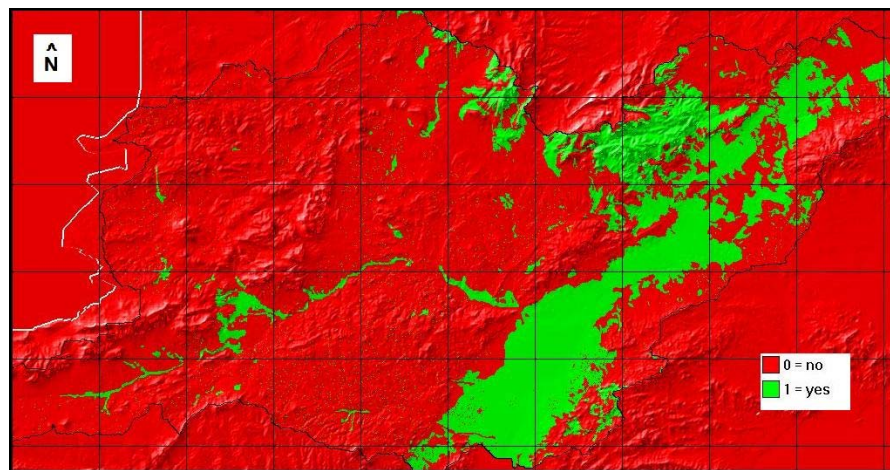
Figure 10 - MedAction® PSS Aquifer availability Initial map and values for the Guadalentín Basin. Aquifer extraction limited (No): 256,764 ha; Aquifer extraction allowed (Yes): 70,759 ha (total = 327,523 ha). Baseline scenario. Grid size 100 km²; Area 3,300 km².
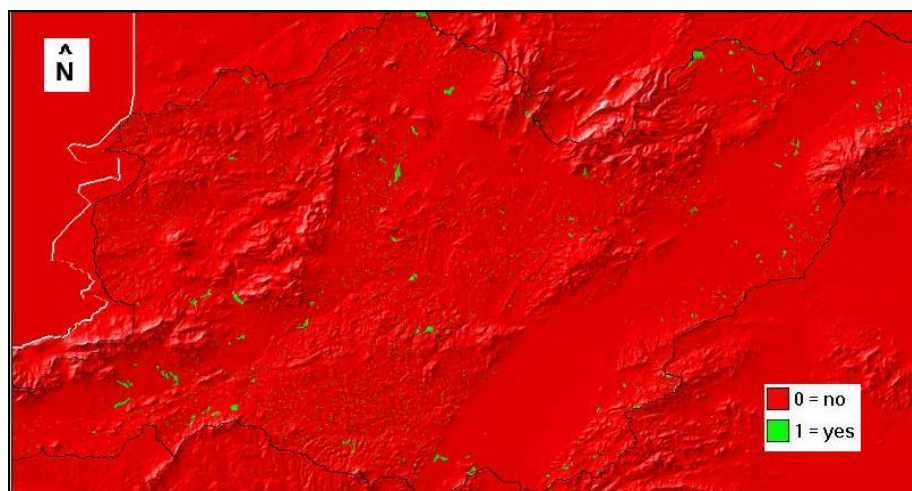
Figure 11 - MedAction® PSS Aquifer availability Final map for the Guadalentín Basin. Final– No: 323,310 ha, Yes: 4,213 ha (total = 327,523 ha). Perturbation-scenario run.

5.2.1. "Aquifer resource for agriculture usage limited to zero" – Results

Table 8 - Change analysis (%) of the Desertification indicators comparing Baseline and "Aquifer resource for agriculture usage limited to zero" scenarios.

Indicators:	S2 - "Aquifer resource for agriculture usage limited to zero" scenario – Results
Hydrology and Soil	Scenario assumes a increase of Reservoirs sediment (38%), sediment discharge (11%), and Aquifer salinity (8%).
Land Use Suitability	Compared with baseline, the scenario change remains almost unaltered.
Vegetation cover and Harvested Area	**Vegetation Cover:** - The total vegetation cover of irrigated crops increases by 23%; and for dryland crops the total increase is 19%; - The crops with highest cover increase are: irrigated olives (13%), dryland vineyard (9%), irrigated almonds (9%) and dryland fruit (7%); - The natural vegetation total cover area change is almost zero.
	Harvested area: - Scenario assumes a general decrease of harvested area for total irrigated crops (-73%) and also for total dryland crops (-15%); - The crops with highest decrease are: irrigated vineyard (63%), greenhouse vegetables (26%), irrigated citrus (15%), irrigated olives and dryland fruit (9% each); - It is recorded a increase of irrigated almonds (6%) and irrigated cereal (5%).
Farmer's average profit and crop choice	**-** The scenario assume a decrease of total average profit for irrigated crops (-113%) and a slight increase for dryland crops (14%); - It is recorded a increase of average profit for dryland fruit (8%); - Scenario also assume a average profit decrease for irrigated fruit (-95%), irrigated citrus (-12%), irrigated olives (-8%), irrigated vineyard (-6%) and greenhouse vegetables (-6%).
Water Management	**Water demands:** - The scenario assumes higher Aquifer water demand mainly from: Industry and commerce (4,496%), Urban residential (1,857%); - Higher Reservoir water demand from agriculture sector (-9.9 x 10^{22} %); and higher desalinated sea water from agriculture sector (-6.3 x 10^{20} %). - Total water shortage for agriculture sector increase (15%).
	Water resources: -The scenario assume a increase of water extraction from Reservoirs (1480%) and Desalinated sea water (955%) and a decrease of aquifer water extraction (-46%); - Increase of water replenishment to Reservoirs (611%); and a strong increase of aquifer volume (8,269%).
Cumulative average Irrigation	- Scenario assumes higher irrigation volumes supplied by reservoirs (1.9 x 10^{20} %), and desalinated water (1.7 x 10^{18}), while aquifer supply decreases (-267 %); - Reservoir supply increases for all crops (between 1.8 x 10^{18} % and 5.1 x 10^{19} %); - Desalinated water also increases also for all crops (between 5.6 x 10^{16} % and 8.0 x 10^{17} %) except for greenhouse vegetables (0%); - Aquifer water supply only increases for greenhouse vegetables (224%), for all other crops the aquifer supply decrease (between -82% and -30%).
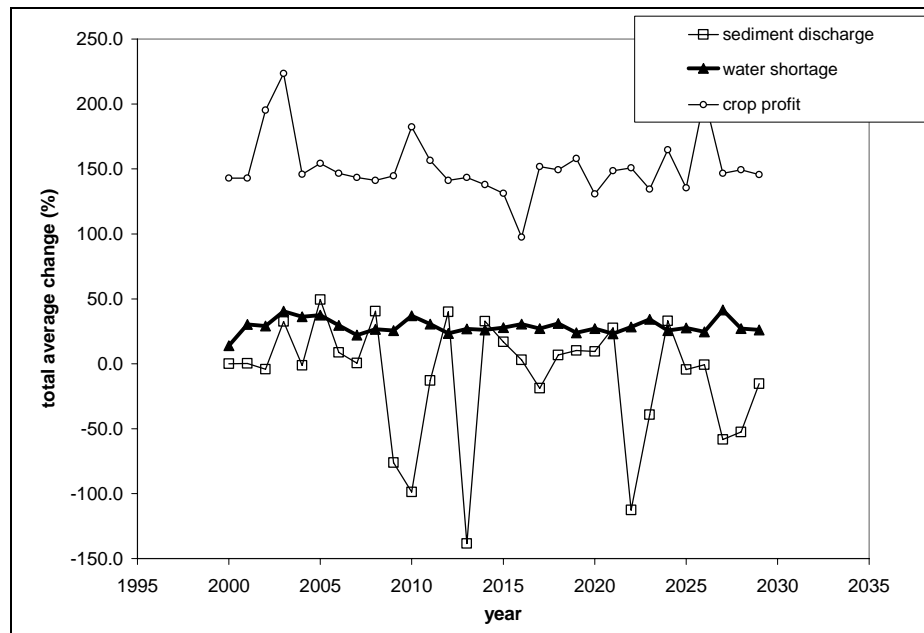
Figure 12 - Comparing baseline with "aquifer resource for agriculture usage limited to zero" scenario. Graphic shows that: total crop profit decrease -0.4%/year change; total water shortage remains constant (0.0%/year); and total sediment discharge decrease -1.1 %/year (regression analysis).

5.2.2. "Aquifer resource for agriculture usage limited to zero" Scenario – Discussion

- The scenario assume a general productivity decrease (harvested area) for both irrigated crops (-73%) and dryland crops (-15%). Associated to low agricultural productivity, the scenario assumes a decrease of total average profit for irrigated crops (-113%) and a slight increase for dryland crops (14%) [mainly dryland fruit (8%)].

- The limitation of a cheaper water resource available (aquifer) presupposes a decrease of irrigated farmland harvest, possibly due to the influence of water price on farmer's net profit, including crop market value and subsidies.

Because irrigation supported by aquifer resource is limited by policy restriction, the remaining two water resources (reservoirs and desalinated) that supply water at higher cost, having a direct effect on farmers profit and therefore harvested area.

The profit increase of certain irrigated crops is only possible if the final profit compensates water price.

- The agricultural sector water demand increases substantially from reservoirs (9.9×10^{22} %) and desalinated sea water (6.3×10^{20} %) resources; while from aquifer the demand decreases (-74%).

The extraction restriction is only applicable to farmland irrigation. Being this resource more demanded by urban areas, industry and tourism.

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The aquifer restriction scenario has a positive effect on groundwater recharge (Figure 13). Aquifer is recharged due low extraction intensity and infiltration increment; it is recorded a strong change (%) increase of total aquifer volume of 8,269%.

- Both reservoir and desalinated water are highly demanded from the agricultural sector, being the only sector that demands water from these resources. The scenario assumes higher irrigation volumes supplied by reservoirs (1.9×10^{20} %), and desalinated water (1.7×10^{18}), while aquifer supply decreases (-267 %). Even since, it is recorded a increased water shortage (15%) for the agricultural sector.

Reservoir water resource is provided at lower cost than desalinated water and has higher quality – lower salt content (table 3).
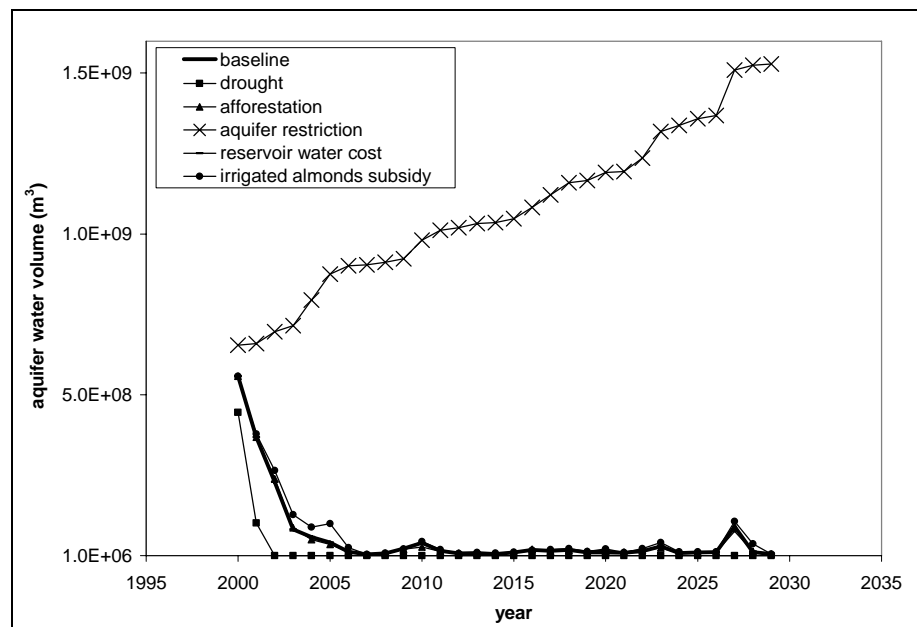
Figure 13 - Aquifer water resource volume indicator for the baseline scenario and the selected five scenarios. For all scenarios the aquifer resource suffers a rapid over-exploitation, with a rapid decrease from 2000 and 2006 ≈ 1×10^6 m³. For the "aquifer restriction scenario" there is an increase of aquifer volume of from 6.6×10^8 (2000) to 1.5×10^9 (2030).

In summary:

The main advantage of this restrictive policy implementation is the saving and accumulation of groundwater resources. The imposed water saving water across relevant periods results in a lower consumption rates when stocks are already at critical capacity. Furthermore, the indication of likely future supply cuts would create a response from the farmers that would decide to decrease farming water dependency and this way save water (Iglesias *et al.*, 2003).

Saving groundwater has positive environmental effects, with less pressure in the phreatic sheets and consequently on river flow and wetland quality enhancement. Furthermore, less irrigation involves less fertilizers usage.

5.3. "Reservoir water resource cost increase" Scenario

The "reservoir water cost increase" scenario was chosen due to the desertification related phenomena occurring in the Guadalentín area: (1) existence of over-increasing water demand and (2) soil degradation by increasing irrigation with poor water quality. Being urgent the improvement of water management it is tested a scenario involving water policy restrictions such as water pricing increase from reservoir resource.

Furthermore, large investments are proposed by the National Hydrologic Plan to transfer water resources from the Ebro basin to the Segura basin, an investment above 6 billion € to be financed with national and European Union funds. Therefore, it has been proposed augmenting water prices to recover full costs (Albiac-Murillo *et al.*, 2002).

5.3.1. "Reservoir water resource cost increase" Scenario - Results

Table 9 - Change analysis (%) of the Desertification indicators comparing Baseline and "Reservoir water resource cost increase (+ 0.18 €/m³)" scenarios.

Indicators:	S3 -"Reservoir water resource cost increase" - Results
Hydrology and Soil	Scenario assumes higher change increase of erosion budget indicators: check dams sediment (6%) and sediment discharge (5%).
Land Use Suitability	Scenario assumes land use suitability change decrease for the total irrigated crops (-8%).
Land Cover and Use	**Vegetation cover** - Scenario assumes a agricultural cover change increase for total dryland crops (6%); - Irrigated area and natural vegetation components remains unchangeable.
	Harvested Area - Scenario assume a harvested area change decrease for greenhouse vegetables (-17%), also for total dryland crops (-9%); total irrigated crops harvested area remains unchangeable; - For dryland crops the most expressive decrease change is for fruit (-8%); - For irrigated crops it is recorded a change increase of olives (12%), almonds (6%) and cereal (3%); and a decrease of citrus (-8%) and fruit (-5%).
Farmer's average profit	- Scenario assume a average profit change decrease for total irrigated crops (-131%) and greenhouse vegetables (-9%); and total dryland crops profit remains

and crop choice	unchangeable; - It is recorded a profit change decrease for the irrigated crops fruit (-38%), vegetables (-38%) citrus (-29%), vineyard (-11%) and cereal (-7%); - It is also recorded a increase for the fruit dryland crop (5%).
Water Management	**Water demand** - Scenario assume a increase of total reservoir water resource demand (3.0 x 10^{17}%) – manly from ex-patriots - followed by aquifer water demand (10%), and desalinated sea water demand remains unchangeable; - Total water shortage remains unchangeable.
	Water resources - Scenario assume a decrease of total water extraction (-8%) and total water replacement remains unchangeable; - All other indicators remain unchangeable (Water extraction from desalinated sea water and reservoirs, total water volume of aquifer resource, Water replacement for reservoir and aquifer).
Cumulative average Irrigation	- Scenario assumes a increase of average cumulative irrigation from: total desalinated sea water (682%), total reservoir (45%) and total aquifer (15%); - It is recorded a cumulative irrigation change increase of <u>desalinated sea water</u> for: vegetables (256%), almonds (285%), olives (78%), citrus (28%), vineyard (16%) and remaining crops (≤ 10%); - From <u>reservoir</u> resource it is recorded a cumulative irrigation change increase for: cereal (33%), almonds and olives (11% each); - For the Cumulative irrigation from <u>aquifer</u> indicator, it is recorded a cumulative irrigation increase for cereal (6%).

5.3.2. "Reservoir water resource cost increase" - Discussion

- The total harvested area of irrigated cropland remains unchangeable (and total dryland crops decrease (-9%) independently to the fact that the water cost from reservoir resource increases.

- For the present scenario, the Guadalentín farmers select the most profitable crops – with higher market value and higher subsidies, which is the case for irrigated olives (12%) and almonds (6%) crops (table 2), which the increase of water cost has less impact.
Although the total profits for irrigated crops drop, there is no consequent abandonment of this type of farmland.

- With a global lower harvested area, the **s**cenario assumes an average profit change decrease for total irrigated crops (-131%) while total dryland crops profit remains unchangeable and greenhouse vegetables also decrease (-9%).

- The total farmer's profit decreases for total irrigated crops (-131%) due to the higher expense of reservoir water (0.38 €/m³) and desalinated sea water (0.30 €/m³). It would be expected a increase of aquifer resource extraction (0.20 €/m³) but it gets critically overexploited in the

beginning of the simulation run (2000-2002 period, Figure 12) therefore its extraction is limited, remaining unchanged.

- Consequently, it is recorded a major increase of desalinated sea water for irrigation use, being the cheapest water resource available. For irrigation purposes the total usage of desalinated sea water increases (682%) as well reservoir (45%) and aquifer (15%).
The desalinated sea water is used to irrigate the most profitable crops: as vegetables (256%), almonds (285%), olives (78%), citrus (28%), vineyard (16%) that can compensate the higher water expense; while reservoir water usage is suppressed and only used for a small range of crops [cereal (+33%), almonds and olives (+11% each). The irrigation efficiency has to maximized to sustain farmers positive income.

- The consumption of water is the variable that policy makers wish to control as a consequence of changes in water management policy. An increase of 0.18 €/m^3 in the price of reservoir water (0.38 €/m^3) reduces total water extraction (-8%) while the total water shortage and total water volume of aquifer resource remaining unchangeable.

- Farmers in irrigated areas, according to economic theory, would respond to the increase of water prices by reducing their consumption, in accordance with a negatively sloped demand curve. However, water price increase by itself will not contribute to a reduction of water consumption in agriculture. The desired changes in water use (reduced consumption and environmental re-allocation of the water saved), does not occur "due to the low elasticity of demand for irrigation water". This means that consumption will not be reduced significantly until prices reach such a level that farm income and agricultural employment are negatively affected (Gomez-Limon and Berbel, 2000).

In summary:
Guadalentín farmers respond to price increases by changing to the next available and cheapest water resource, without any significant water consumption or major crop management change.
The agricultural sector water demand decreases within the scenario – water becomes an expensive resource that only highly profitable crops can afford its usage.

In the Guadalentín basin the reservoir water cost increase (up to 0.48 €/m^3), reduces the irrigated agriculture profitability. The decrease of total profit for irrigated crops (-131%) is mainly due to the higher water cost of the cheapest water resource available (desalinated sea water, 0.30 €/m^3). The less profitable crops are specially affected by the reduction of available water with consequent decrease of cultivated land area.

Some farmers will not be able to support this extra expense, the situation is aggravated by overexploitation and unavailability of aquifers. This change has a direct impact on farmers' incomes. Again, farmers profit decrease has major negative implications in the socio-economic structure the basin's rural sector.
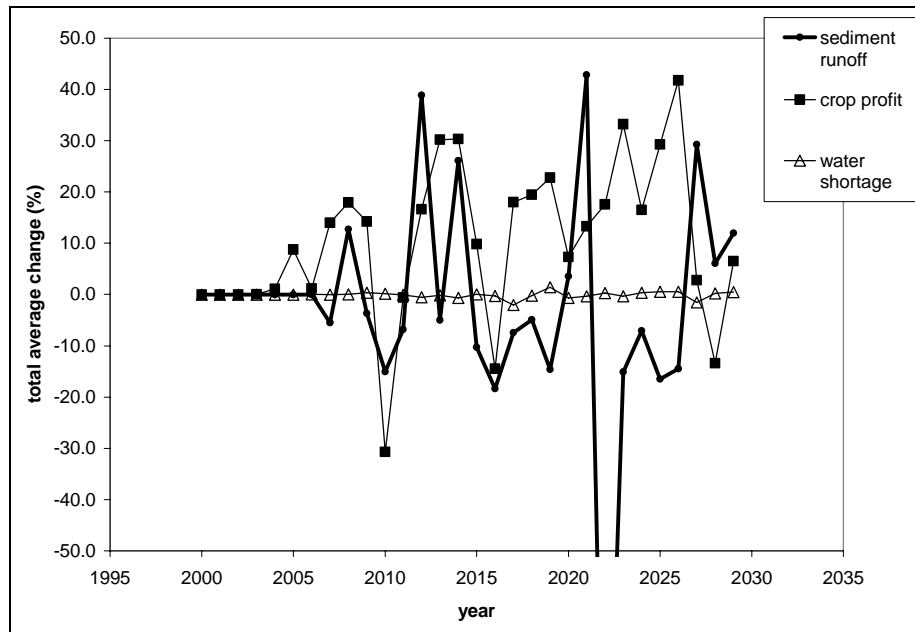
Figure 14 – "Reservoir water resource cost increase (0.18 €/m³) scenario. The graphic show that total crop profit increase 0.6%/year; total water shortage remains unchangeable (0%/year); and total sediment discharge decrease 0.3 %/year (regression analysis).

5.4. "Irrigated almonds subsidy increase of 50%" Scenario

5.4.1. "Irrigated almonds subsidy increase of 50%" Scenario - Results

Table 10 - Change analysis (%) of the Desertification indicators comparing Baseline and "Irrigated almonds subsidy increase of 50%" scenarios.

Indicators:	S4 – "Irrigated almonds subsidy increase of 50%" – Results
Hydrology and Soil	- Decrease of salinity budget indicators: aquifer salinity (-44%), irrigation salt (-42%) and average soil salinity (-8%); - Increase of reservoir sediment (36%); - decrease of infiltration (-5%).
Land Use Suitability	- Total land use suitability for agricultural practices decreases: total irrigated crops decrease (-16%) and dryland crops unchangeable.
Vegetation cover and Harvested Area	**-Vegetation cover** **–** Increase of total dryland crops cover (13%), and decrease of irrigated cover (-22%); -It is recorded a increase of irrigated olives (13%), dryland vineyard (5%) and fruit (5%); - Decrease of irrigated almonds (-25%) and irrigated fruit (-5%); - Increase of the total natural vegetation cover area (7%).
	-Harvested Area **-** Increase of total irrigated area (146%), decrease of total dryland area (-28%), and decrease of greenhouse vegetables area (-8%); - It is recorded only one crop which harvested area increased – irrigated almonds (416%).; - All other crops decreased – especially the irrigated crops: cereal (-63%), citrus (-59%), fruit (-47%), olives (-41%), vegetables (-36%), vineyard (-24%); and dryland fruit (-15%), dryland olives (-8%) and vineyard (-6%).
Farmer's average profit and crop choice	- The total crop profit for irrigated crops decreases (-134%); the total crop profit for dryland crops increase by 8%; -the irrigated crops with highest change decrease are: irrigated vegetables (- 71%), fruit (-50%), olives (-44%), greenhouse vegetables (-22%) and citrus (-14%); - The highest profitable crop from all is irrigated almonds with a change increase of 46%.
Water Management	**Water demand**: - There is total a increase of water demand from reservoir (3.1×10^{17} %), followed by aquifer (101%), and a decrease of desalinated water (-51%); - Reservoirs: increase of water demand from ex-patriots (3.1×10^{17} %); - Water demand from agriculture decreases for the reservoir resource (-42%), desalinated water (-45%), aquifer resource remains almost unchanged; - Total water shortage increases (34%); agricultural shortage alone increase (51%).
	Water resources - Total water extraction decrease (-65%): reservoir (-46%), desalinated sea water (-17%) and aquifer resource remains almost unchanged; - Total water replacement decrease (-52%): reservoirs (-46%) and aquifer (-6%); - The total water volume increases by 37%, with larger gain for aquifer resources (35%).
Cumulative average Irrigation	- The total cumulative irrigation change from the three main water sources of irrigation are: reservoirs decrease (-200%), aquifer increase (364%) and desalinated water increase (697%);

	- For the almond crop, the cumulative irrigation change is provided by: desalinated sea water increase (284%), aquifer increase (71%) and reservoir decrease (-27%); - It is recorded a change increase of the aquifer water usage for general crop irrigation; – Including olives (83%), almonds (71%) and cereal (51%), remaining crops with change value between 27% and 45%. - For the reservoir water resource used for crop irrigation it is recorded a decrease for all crops (change between -31% and -19%); - Desalinated sea water use for irrigation increases for the selected crops: almonds (284%), olives (333%), vineyard (27%) and cereals (14%).

Figure 15 - The graphic shows that Comparing baseline with drought scenario: Total crop profit increase (0.4%/year); total water shortage decrease (-0.4 %/year); and total sediment discharge decrease 0.1 %/year.

5.4.2. "Irrigated almonds subsidy increase of 50%" Scenario - Discussion

An increase of irrigated almonds subsidy (one of the most profitable crops of the Guadalentín basin) has the major effects:

- The total dryland crops cover increases (13%), the total irrigated cover decreases (-22%); and increase of the total natural vegetation cover area (7%).

The only crop with increased production (harvested area) is irrigated almonds (416%), all other crops irrigated and dryland have a production decrease.

- It is recorded a accentuated total profit decrease of irrigated crops (-134%) – except almonds (+46%); and a slight increase for dryland crops (8%), which has a negative impact on the basin's rural social and economic structure.

With the increased production area destined for irrigated almonds crop (+416%), all other perennial and annual crops production area decrease.

- Being the highest (and almost the only) profitable crop from all others, the irrigated almonds with a profit change increase of 46% is a clear signal of the importance of agricultural policies has on farmer's decisions. Even already having highly profitable crops, the farmers chose is to reduce existing developed croplands and substitute them by the most profitable one.

- The decrease of total irrigated cover area (-22%) associated with the decrease of almost all irrigated farmland production areas, it is reported a decrease of water demand by the agricultural sector from: reservoir (-42%), desalinated (-45%), and aquifer unchanged; contributing to the increase of water and soil quality this is, a general decrease of salinity budget indicators: aquifer salinity (-44%), irrigation salt (-42%).

- In addition to the total aquifer water volume increases (35%), although groundwater resource usage increases for general crop irrigation (+365%, second main source after desalinated sea water with +698% change increase). Consequently, agricultural water shortage increases (51%).

For the "crop subsidy" scenario water resource change in the following way:
- The total cumulative irrigation change from the three main water sources of irrigation are: reservoirs decrease (-200%), aquifer increase (364%) and desalinated water increase (697%);
- For the almond crop, the cumulative irrigation change is: desalinated sea water increase (284%), aquifer increase (71%) and reservoir decrease (-27%);
- Desalinated sea water use for irrigation increases for all perennial crops: almonds (284%), olives (333%), vineyard (27%) and cereals (14%);
- For the reservoir water resource used for crop irrigation it is recorded a decrease for all crops.

A large proportion of agricultural income depends upon CAP subsidies, and farmers cannot afford to ignore CAP regulations that affect most of the crops available for cultivation (Gomez-Limon and Berbel, 2000). CAP subsidies and crop profit are the main influence of farmer's decisions: CAP subsidies allocated to specific types of crops or land uses in conjunction with the market prices greatly affect the intensity of the land use, control farmers choices and land use patterns (Kosmas and Valsamis, 2001).

6. Main Conclusions

All the features that characterize land degradation and desertification in the Mediterranean Region – described on Annex IV of the United Nations Convention to Combat Desertification (UNCCD) - are present and active in the Guadalentín Basin area, for this reason it is considered an important European case-study due to the intensity of environmental exploitation and consequent irreversible degradation, being recorded the occurrence of an ongoing mini-deserts development (ICIS, 2000). In the Guadalentín Basin there is the strong evidence of land and water mismanagement with significant negative consequences on environmental quality and sustainability.

The two main conclusions derived from the implementation of the proposed scenarios in the Guadalentín Basin system using MedAction® PSS is that:

- Water is an important issue; groundwater is severely over-exploited and most of the irrigation water is transported from other regions, these circumstances are aggravated by the fact that in the Basin, irrigation is a top priority and that water deficit has always been an intrinsic structural problem.

- Farmer's decisions are acutely influenced by external drivers such as Regional and European subsidies with direct influence on farmer's profit; also known as the "subsidy culture" syndrome.

This type of unsustained water management and land misuse can lead to rapid land degradation and probably desertification. Therefore, there is the extreme urgency on a profound analysis and comprehension of land degradation and desertification driving forces to implement accurate land and water management policies.

Water management

One of the main conclusions derived from the study-scenarios analysis is that regional groundwater resources are out of balance, there is more extraction than replenishment.
Running only a few simulation-runs it is recorded that from 2000 to 2006 there is the occurrence of a severe aquifer overexploitation.

With groundwater dried out, the most important water resource is the imported water from other regions through sophisticated water transfer channels – the Tajo-Segura channel and probably in the future also by the Ebro water transfer channel.

Even with more expensive water provided by reservoirs and desalinated sea water, the regional irrigation intensity is unaffected due to the existence of several socio-economic conditionings that potencies the regional agricultural high productivity and revenue, mainly in the Guadalentín river lowlands. Only a considerable increase of water prices would influence a change of farmer's management choices (Gomez-Limón and Berbel, 2000).

The high intensity agriculture-type practiced on Guadalentín lowlands is highly dependent on inter-regional imported water, especially in the eminence of groundwater overexploitation and on the development of desalinisation technologies – which acts as back-support during pluriannual droughts or when water demand is much higher than supply.

Therefore, public and private-sector efforts should be put into reducing the heavy dependence of irrigated agriculture (and hence the economy of rural areas) on a very small number of crops (Gomez-Limon and Berbel, 2000). The efficient use of water resources is a fundamental target for farmers and water management (Ortega et al., 2004).

In areas and interludes where water demand is higher than supply, two ways to manage water resources are: increase the price of water and to limit water extraction for irrigation purposes. Raising the water price has a large impact on the profits of irrigated farmland and greenhouses and thus influencing the decrease of these production areas. Although, this effect can be undone if market prices for irrigated crops compensate the total farmer's expense.

Restricting water accessibility – either by price increase or usage limitation, would produce collateral effects, such as a decrease in agricultural income and a reduction in the demand for agricultural labour". Since irrigated agriculture is the main source of employment in many rural areas of Spain, any change in policy (and the occurrence of climatic extremes) will significantly affect the social structure of rural areas (Gómez-Limón and Riesgo, 2004).

If the influx of irrigation water comes to a halt, crops can no longer be irrigated and if switch back to dryland crops is too expensive, especially where investments have been made recently, can lead to the abandonment of crops cultivation with a high water demand and eventually the land could be abandoned (Delden *et al*, 2005) and (Albiac-Murillo *et al*, 2002),

with serious consequences on rural employment and consequent massive rural exodus. Since irrigated farmlands employ a ration of seven to eight times as high labour input per area (Onate and Peco, 2005).

Irrigation management is also a fundamental key to reduce environmental problems created by the excessive use of water resources, but also to control pollution from irrigation (Albiac-Murillo *et al.*, 2002). As farmers substitute crops in order to save water, fertiliser use also decreases having a positive impact in the reduction of non-point chemical pollution by agriculture (Gomez-Limon and Berbel, 2000). Less irrigation is also associated to less salt input on cultivated soils, since most of the times the water used for irrigation has poor quality. The raise of water price is also an incentive to use less water and to make farmers switch from irrigated to dryland agriculture (Delden *et al*, 2005).

The scenarios "limited extraction of aquifer water" and "reservoir water cost increase" show that even with less water available and extra water cost, irrigated farmlands production area is practically unaffected. For both scenarios farmers profit and total irrigated crops harvest and water shortage have similar values.

Comparing the management efficiency of these two water policies, it is noticed that for the limitation of aquifer exploitation, there is over time a significant natural recharge (a total 30-year average recharge change of 8,270% increase, when compared with baseline scenario).

Crop Subsidies

Other important conclusion, derived from the "subsidy increase" scenario is the evident high influence of subsidies (therefore on total farmer's profit) which is one of the most important driving forces of farmers management choices: If a particular crop subsidy increases substantially, all other crops including the already profitable ones are rapidly substituted by the most profitable one, with evident impact on landscape homogeneity and environmental impoverishment.

In the Guadalentín Basin, socio-economic factors such as Regional and European market characteristics are more influential than local biophysical character and natural limitations, e.g. water availability for irrigation or poor soil quality. The foreseen and expected end of CAP subsidy regime by 2006-8 could lead to soil abandonment conservation practices done

by farmers customized to subsidies (Onate, pena, 2005) and seriously affect farmers profit leading ultimately to land abandonment.

Policy support with the MedAction® PSS

Within MedAction® PSS integrated model system, a series of study-scenarios related to desertification issues – soil and water resources degradation, where applied to simulated environmental policy-relevant issues.

The great advantage of using a integrated model related to desertification and land degradation issues applied to an regional area – the Guadalentín Basin, is its usefulness in understanding and analysing the complex environmental system with its relevant components, their interactions and dynamics when subjected to an external or internal driving force (e.g. climate or land use change) and reaction intensity through absorption and buffering processes of either biophysical and socio-economic spheres.

Medaction links science with policy making allowing the integration of policy themes, options and indicators, the desertification issue can be analysed through a comparative what-if scenario for a regional scale. The better understanding of desertification drivers acting over complex environmental and social systems is a strong contribute for a more sustainable development, thus combating land degradation and desertification.

The implementation of inumerous possible future scenarios, using MedAction® PSS integrated model outputs, is a valuable policy resource to evaluate the impact of biophysical and socio-economic drivers at a regional and local scale. The MedAction® PSS relevant policy indicators (e.g. soil salinity, sediment runoff, farmer's profit, available water resources) can be used to support policy decisions, contribute to a better communication transfer within the policy-making chain, and therefore support a more sustainable development either at Local, Regional or European level.

Annexes

Guadalentín River Basin Characterization

Location:

Administratively belongs to the Autonomous Region of Murcia (45 municipalities) and is comprised by two districts, Bajo Guadalentín (Aledo, Totana, Librilla, Alhama de Murcia, Mazarron) and Alto Guadalentín (Lorca, Puerto Lumbreras, Aguilas) (Anuario Estadistico De La Region De Murcia 2004) (Figure 1) (Kosmas and Valsamis, 2001).
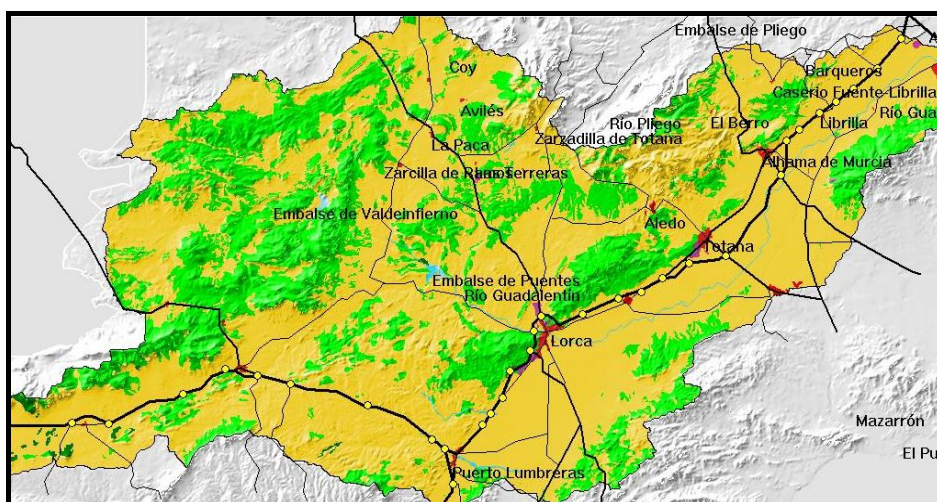
Figure 1 - Modelling area – Guadalentín watershed. With transport network infrastructure detail, village names, river Guadalentín, main Reservoirs - *Embalse de Puentes* and *Valdeinfierno*, and morphology.

Climate:

The Guadalentín area has the typical Mediterranean semi-arid subtropical climate and belongs to the most arid parts of the Mediterranean basin (Figure 2) it is also verified the high inter-annual variability of average rainfall and temperature (Figure 3).

The average annual air temperature reaches 18°C, with hot summers (absolute maximum temperature of 40°C) and mild winters (average temperature of 11°C in the winter months of December and January) (Post *et al.*, 2006). The evapotranspiration rate is high (900 mm/y) and the hydric deficit is around 600 mm/yr (Sánchez Toribio *et al.*, 1996) *cit. in* (Laguna *et al.*, 2000).

Annual rainfall in the lowlands of the Guadalentín drainage basin is scarce (approx. 300-350 mm/year) while in the high mountain areas these values locally exceed 1000 mm per year; falling mainly between spring and autumn (April and October), being the summer an extremely dry season. Furthermore, most of the rainfall events provide very small quantities (75 % of all rainfalls are below 4 mm), which hardly exceed soil's infiltration capacity (Post *et al.*, 2006) and (Kosmas and Valsamis, 2001). With such dry climate, the water table is very deep - 400 meters or even more (Kosmas and Valsamis, 2001).
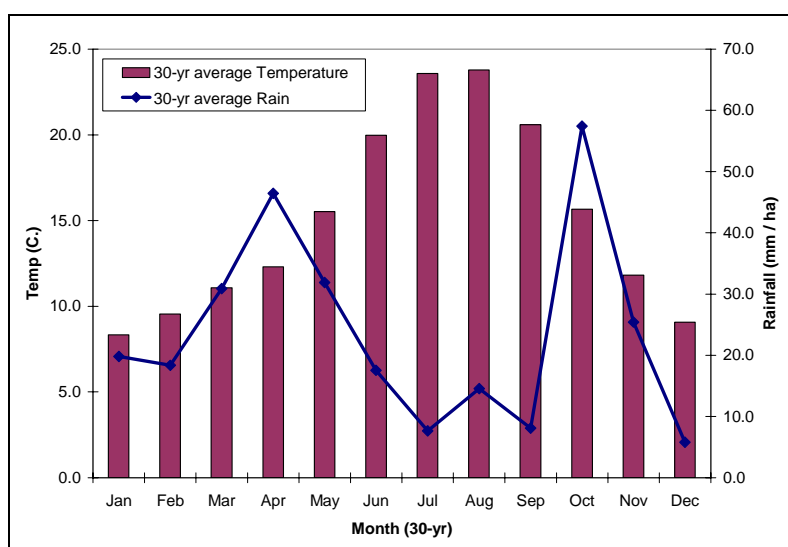
Figure 2- Precipitation and rainfall values for the Guadalentin basin using ECHAM climate change scenario. Baseline simulation run from the year 2000 to 2030. Source: MedAction® PSS data
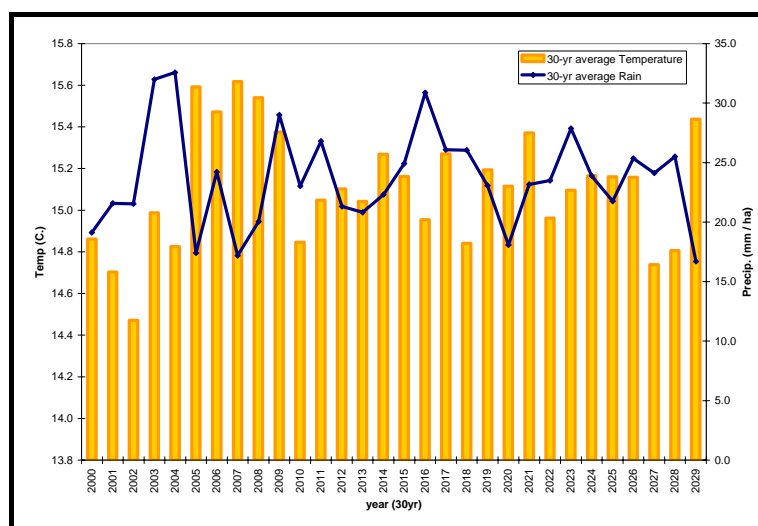
Figure 3 - Temperature and rain intra-year climatic variability of Guadalentín basin, using 30-year averages (2000-2030 years). Source: MedAction® PSS data

Geomorphology:

- Relief of the Guadalentín drainage basin ranges from high mountainous character in the headwater area to a steep undulating relief along its middle course (Figure 4) into a coastal plain in its lower reach (Post *et al.*, 2006).

- Drainage network: The catchment of the upper Guadalentín River is one of the major tributaries of the *Segura* River. Most tributaries of the Guadalentín River are ephemeral streams, whereas only the main course is periodic to perennial (Post *et al.*, 2006).

- Lithology of the drainage is dominated by limestone and marls of Jurassic to Tertiary age, locally in its most southeastern part Paleozoic phyllites are outcropping (Post *et al.*, 2006).

- Pedology: Cambisoles, Regosoles and Xerosoles dominate the overall conditions, with medium to high water permeability (Post *et al.*, 2006).
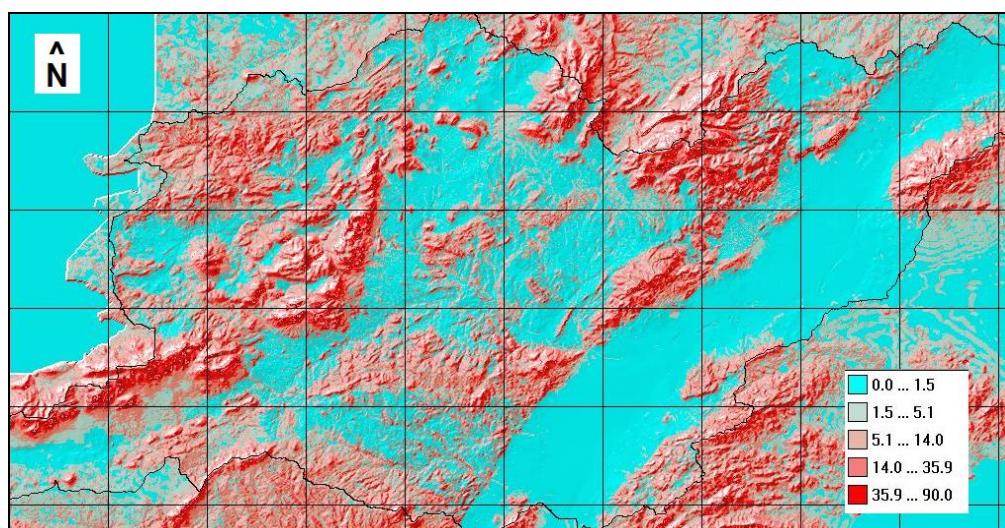
Figure 4 - MedAction® PSS slope map (degrees).

Vegetation Cover:

Guadalentin's Natural vegetation (Fifures 5 and 6) cover is completely disturbed, the area contains Mediterranean deciduous forests or Maquis (with oaks, wild pistachio, cistus, etc.), few areas with *Pinus halepensis* reforestation, degraded shrubland (Matorral and Espartal vegetation communities) and tussock grassland mainly of alfa grass (*Stipa tenacissima*) (Post *et al.*, 2006) and (Kosmas and Valsamis, 2001).
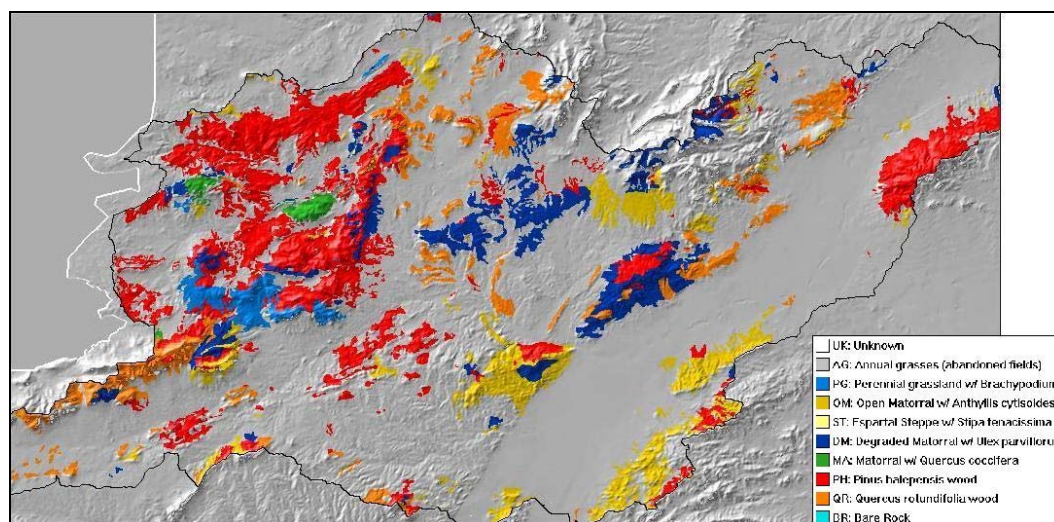
Figure 5 - Guadalentín Basin Natural vegetation types. Source: MedAction® PSS data.
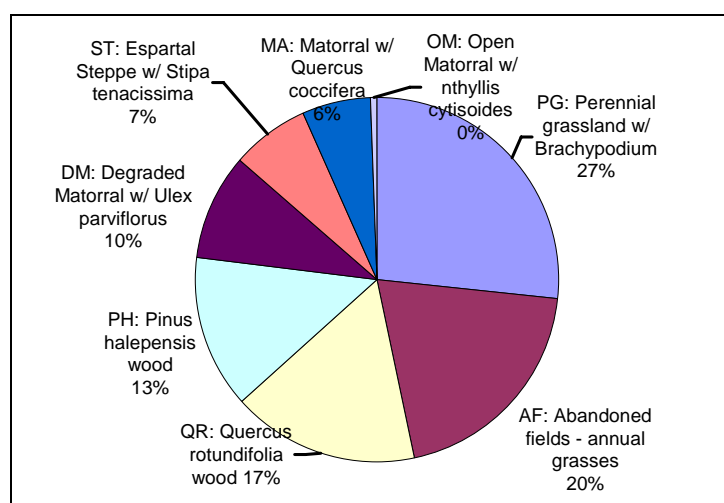
Figure 6 – Natural vegetation main species and percentage of the Guadalentín basin area. Source: MedAction® PSS data.
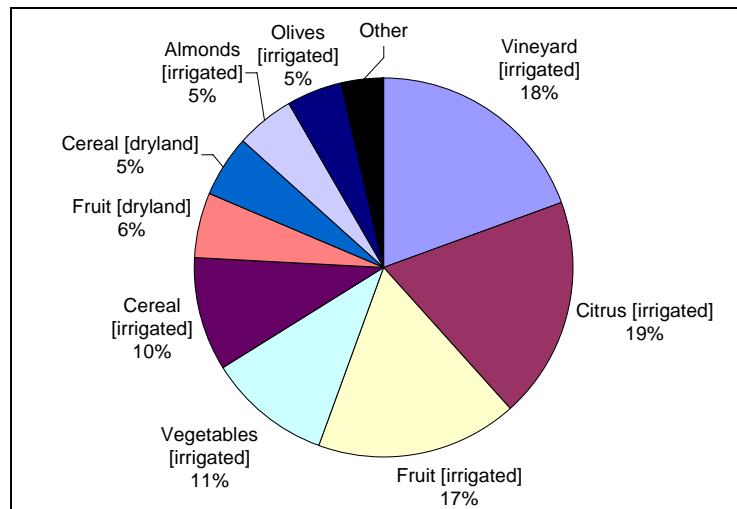
Figure 7 - Crop type and percentage in the Guadalentín basin. Source: MedAction® PSS data.
The agricultural land is dominated by rainfed arable land, with either cereals such as barley and oat, or perennial crops such as fruit trees, almonds and olives.

Agriculture:

In the Guadalentín basin area the agriculture has Mediterranean characteristics, which is based on the dry-irrigated duality (Figure 7). The regional dryland production is centred in the Mediterranean trilogy – cereals, vineyards and olives, which recently was added almonds (Laguna *et al.,* 2000). This agricultural system is directly affected by climatic variability and drought tendency.

And the irrigated production (in smaller extension) is characterized by high production and profitability favoured by the good regional climatic conditions. The structural hydric deficit did not limit the expansion of irrigated area. In the contrary, the construction of several dams, the overexploitation of groundwater and water transference from other basins (the Tajo-Segura channel) has contributed to its expansion (Laguna *et al.,* 2000).

MedAction PSS Baseline scenario
of the Guadalentín watershed (3,300 km²)

- **Climate and Weather**

Table A – Baseline values of Climate and Weather. Source: MedAction® PSS

	Baseline		
	Average temperature [°C]	Average rain [mm/ha/month]	Average net radiation on flat surface [mm/ha/month]
30-yr average	15.1	23.7	0.9
SD	0.28	4.15	0.01

- **Hydrology and Soil**

Table B - Baseline values of Hydrology and Soil. Source: MedAction® PSS

	Indicators:	
Evaporation	Soil evaporation (mm/ha)	17.4
	Interception, evaporation, transpiration (mm/ha)	8.9
Soil budget	Soil water (average) * (mm/ha)	45.6
	Infiltration (mm/ha)	26.0
	Runoff (mm/ha)	2.3×10^7
Discharge	Water discharge (m3)	1.1×10^{11}
Erosion budget	Sediment runoff (mm/ha)	23.1
	Sediment Discharge (m3)	7.7×10^4
	Check dams sediment (m3)	7.9×10^4
	Reservoir sediment (m3)	8.7×10^5
Salinity budget	Average soil salinity (gr/m3)	139.4
	Aquifer salinity (gr/m3)	15.6
	Irrigation salt (gr/ha)	737.4

- **Land Use Suitability and Allocation**

Table C – Baseline values of Land Use Suitability. Source: MedAction® PSS

Land Use Suitability	[-]
Total Average of Natural vegetation suitability	9.60
Total Average of Agriculture total suitability	9.48
Total Average of Fruit [dryland]	9.47
Total Average of Olives [dryland]	8.60
Total Average of Vineyard [dryland]	8.12
Total Average of Almonds [dryland]	8.01
Total Average of Cereal [dryland]	6.15
Total Average of Vegetables [greenhouse]	5.84
Total Average of Almonds [irrigated]	4.92
Total Average of Olives [irrigated]	4.92
Total Average of Vegetables [irrigated]	4.91
Total Average of Citrus [irrigated]	3.93
Total Average of Fruit [irrigated]	3.93
Total Average of Vineyard [irrigated]	3.93
Total Average of Cereal [irrigated]	3.32

Table D - Baseline values of **Land Use Allocation.** Source: MedAction® PSS

Land Use Allocated Areas	Area (ha)
Total Average of Agriculture	221,757.9
Total Average of Natural vegetation	100,604.4
Total Average of Urban residential	1,691.6
Total Average of Water courses	1,254.0
Total Average of Forest reserves	902.0
Total Average of Industry and commerce	696.9
Total Average of Rural residential	295.9
Total Average of Water bodies	245.0
Total Average of Tourism	51.5
Total Average of Ex-patriots	23.8

- **Vegetation Cover**

Table E - Baseline values of Natural Vegetation Cover. Source: MedAction® PSS

Initial vegetation types	Area (ha)
Annual grasses (abandoned field)	231,385
Perennial grassland w/ *Brachypolium*	4,070
Open Matorral w/ *Anthyllis cytisoides*	16,970
Espartal Steppe w/ *Stipa tenacissima*	6
Degraded Matorral w/ *Ulex parviflorus*	16,057
Matorral w/ *Quercus coccifera*	1,508
Pinus halepensis wood	41,042
Quercus rotundifolia wood	16,482
Bare rock	3
Total	327,523

Table F - Baseline values of Initial crop type. Source: MedAction® PSS

Initial crop type summary	Area (ha)
No crop (abandoned fields)	99,264
Almonds - dryland	46,630
Almonds irrigated	7,778
Cereal dryland	105,661
Cereal irrigated	29,195
Citrus irrigated	13,304
Fruit dryland	430
Fruit irrigated	2,180
Vegetables irrigated	16,536
Vegetable greenhouse	373
Olives dryland	2,432
Olives irrigated	874
Vineyard dryland	2,347
Vineyard irrigated	519
total	*327,523*

- ## **Harvested area**

Table G - Baseline values of Harvested area. Source: MedAction® PSS

Harvest	area (ha)
Average of Cereal [irrigated]	**25,391.0**
Average of Vegetables [irrigated]	**16,475.9**
Average of Citrus [irrigated]	11,848.0
Average of Almonds [irrigated]	7,820.7
Average of Fruit [irrigated]	2,375.0
Average of Olives [irrigated]	855.0
Average of Vineyard [irrigated]	467.8
Sum	65,233.3
Average of Vegetables [greenhouse]	296.9
Average of Cereal [dryland]	**98,970.9**
Average of Almonds [dryland]	**46,465.5**
Average of Olives [dryland]	1,521.9
Average of Vineyard [dryland]	1,304.8
Average of Fruit [dryland]	209.5
Sum	148,472.7

- ## **Water management Module– demand and resources**

Table H - Baseline values of Water Demand. Source: MedAction® PSS

Water Demand [m³]	Aquifer		Reservoirs		Desalinated water		Shortage	
	avrg	%	avrg	%	avrg	%	avrg	%
Agriculture	6,404,619.18	97.4	9,756,905.73	97.5	97,018.14	23.8	(73,870,990.03)	100.6
Rural residential	7,353.30	0.1	2,554.17	0.0	-	0.0	-	0.0
Urban residential	88,349.75	1.3	109,114.98	1.1	146,505.73	36.0	165,588.57	-0.2
Industry and commerce	59,854.83	0.9	118,280.18	1.2	163,374.18	40.2	257,934.24	-0.4
Tourism	11,866.12	0.2	19,163.88	0.2	-	0.0	-	0.0
Ex-patriots	578.79	0.0	1.69	0.0	-	0.0	-	0.0
sum	*6,572,621.98*	*100.0*	*10,006,020.64*	*100.0*	*406,898.05*	*100.0*	*(73,447,467.22)*	*100.0*

Table I– Baseline Water Resources. Baseline values of Source: MedAction® PSS

Water Resources [m³]	Volume [m³]	%
Total Average of Aquifer – Replenishment	4.8E+06	24.0
Total Average of Reservoirs - Replenishment	1.0E+07	50.9
Total Average of Desalinated sea water - Replenishment	5.0E+06	25.1
Sum	*2.0E+07*	*100.0*
Total Average of Aquifer – Extraction	6.6E+06	38.7
Total Average of Reservoirs – Extraction	1.0E+07	58.9
Total Average of Desalinated sea water - Extraction	4.1E+05	2.4
Sum	*1.7E+07*	*100.0*
Total Average of Aquifer – Volume	5.8E+07	5.6
Total Average of Reservoirs – Volume	1.4E+08	13.9
Total Average of Desalinated sea water - Volume	8.4E+08	80.5
Sum	*1.0E+09*	*100.0*
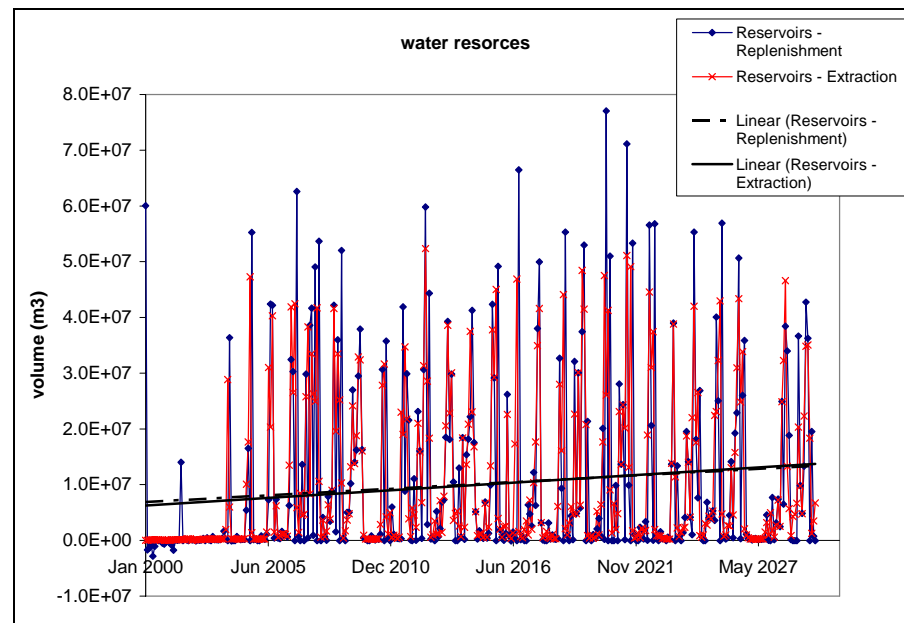
Figure 1 - Baseline Reservoir water resources. Source: MedAction® PSS
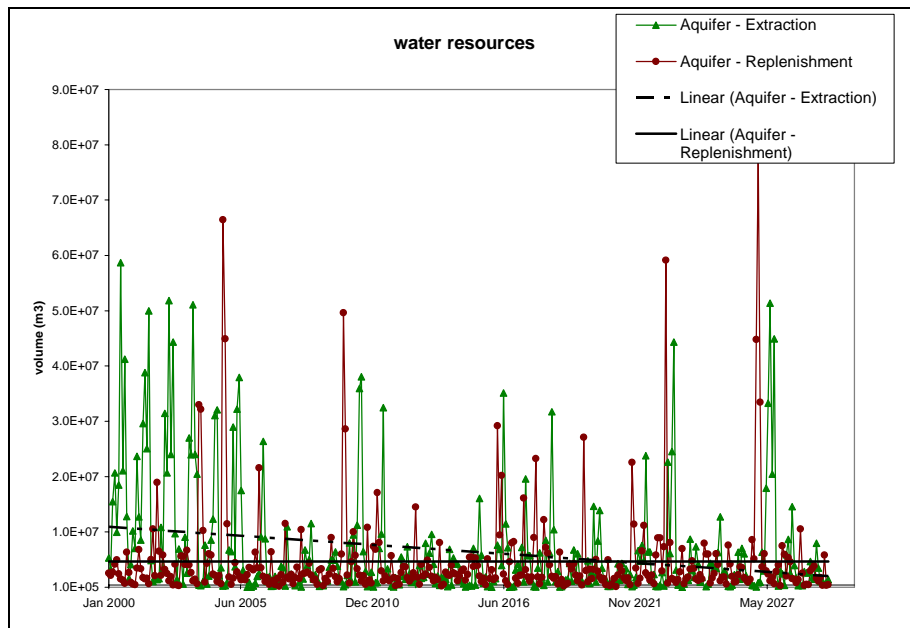
Figure 2 – Baseline Aquifer water resources. Source: MedAction® PSS
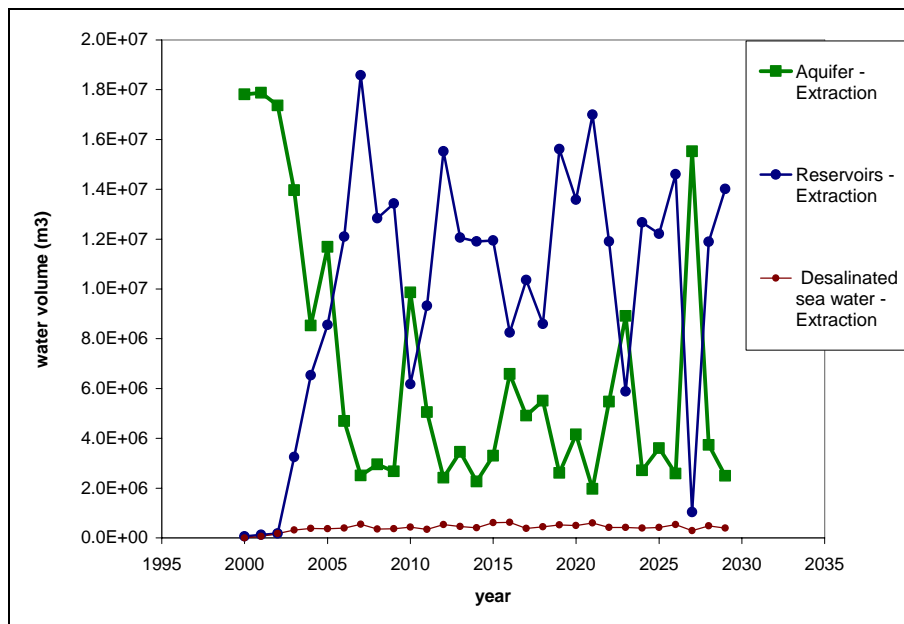
Figure 3 - Reservoir and aquifer extraction are indirectly related. Aquifer over-exploitation indicator with a rapid decrease of volume in the first years. **Source: MedAction® PSS**

- ## **Farmers Decisions Module – Crop Profit and Irrigation**

Table J - Baseline values of Crop Profit. Source: MedAction® PSS

	crop profit	**[€/ha]**
	Vineyard	4,431.5
	Cereal	3,059.2
	Almonds	2,623.6
Irrigated	Citrus	1,699.5
	Olives	1,544.8
	Vegetables	942.9
	Fruit [irrigated]	656.4
	sum	*14,957.9*
	Vegetables [greenhouse]	11,593.5
	Fruit [dryland]	3,738.0
	Cereal [dryland]	2,502.6
Dryland	Almonds [dryland]	2,499.4
	Vineyard [dryland]	2,197.1
	Olives [dryland]	2,007.0
	sum	*12,944.1*
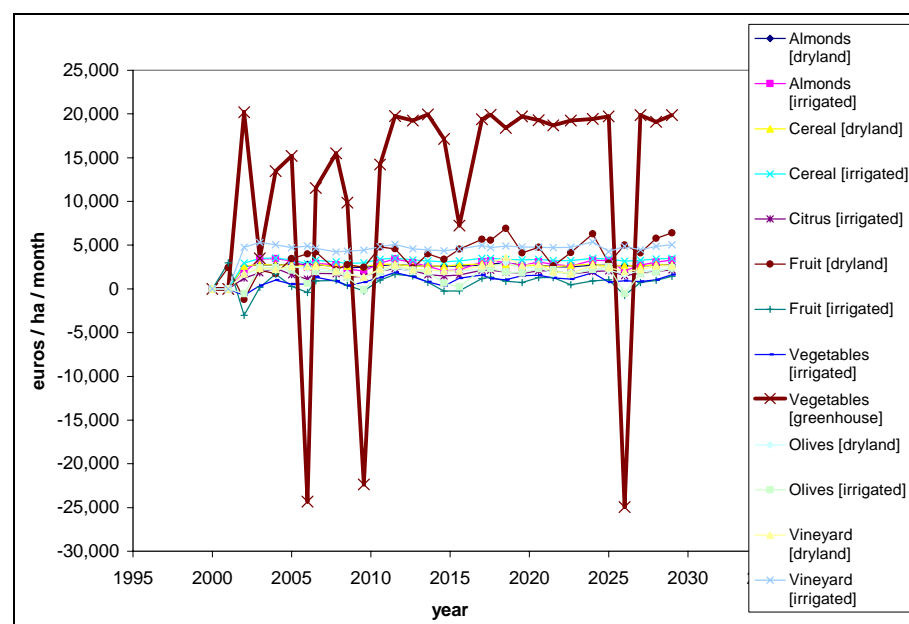
Figure 4 – Baseline crop profit. Source: MedAction® PSS

Table K - Baseline values of Cumulative Average Irrigation. Source: MedAction® PSS

	irrigation baseline	[m³/ha]	%
Aquifer	Vegetables [greenhouse]	3398.4	26.7
	Vineyard [irrigated]	2158.0	17.0
	Citrus [irrigated]	2151.5	16.9
	Fruit [irrigated]	2027.5	15.9
	Vegetables [irrigated]	1119.1	8.8
	Cereal [irrigated]	859.5	6.8
	Almonds [irrigated]	504.2	4.0
	Olives [irrigated]	502.2	3.9
		12720.4	**100%**
Reservoir	Vegetables [greenhouse]	5101.6	27.0
	Citrus [irrigated]	3017.4	16.0
	Vineyard [irrigated]	3002.2	15.9
	Fruit [irrigated]	2841.4	15.1
	Vegetables [irrigated]	1739.8	9.2
	Cereal [irrigated]	1392.9	7.4
	Almonds [irrigated]	891.7	4.7
	Olives [irrigated]	879.8	4.7
		18866.8	**100%**
Desalinated water	Citrus [irrigated]	50.5	30.3
	Fruit [irrigated]	47.8	28.7
	Vineyard [irrigated]	47.1	28.3
	Cereal [irrigated]	12.0	7.2
	Vegetables [irrigated]	6.5	3.9
	Olives [irrigated]	1.4	0.8
	Almonds [irrigated]	1.3	0.8
	Vegetables [greenhouse]	0.0	0.0
		166.6	**100%**

"The output of the Standard run in 2030 shows a land use quite similar to the current situation. The built-up area (industry, tourism, residential, greenhouses) has slightly increased at the expense of agriculture. The latter experiences a slight additional decline because of the decrease in precipitation causing dryland crops to produce lower yields and irrigated crops to use more irrigation water, both leading to a decline in profits and land abandonment" (Delden *et al*, 2005).

Results: Desertification indicator Change (%) between Baseline and Perturbation-scenario.

For all tables: the values represent the 30-yr total average of change (%) between baseline scenario and perturbation- scenario.
The indicator Change (%) is calculated using equation 1, for the total area of the Guadalentín river basin (3,330 km²).

The respective Standard Deviation is also provided (as measure of values dispersion from the mean).

Note: the extra scenarios here presented – forest reserve implementation, terracing implementation, agricultural land use demand increase of 20%, dry cereal subsidy increase of 50% - were not furtherly described and interpreted due to the word-limit and timing of this work. Nevertheless, they are here presented as an indication of the MedAction® PSS potential to analyse a various amount and diversity of scenarios that can be used as a policy-support tool.

- **Hydrology and Soil Indicators**

| | | S1 | | S2 | | | | | | | | S3 | | | | S4 | |
| | | Severe Drought | | Aquifer Over-exploited | | Forest Reserve implementation | | Terracing implementation | | Agricultural LU demand increase 20% | | Reservoir Water Cost +50% | | Dry cereal Subsidy +50% | | Irrigated Almonds Subsidy +50% | |
	Indicators:	avrg	SD	avrg	SD	avrg	SD	avrg	SD	avrg	SD	avrg	SD	avrg	SD	avrg	SD
Evaporation	Soil evaporation	75.4	4.7	-0.2	1.8	-14.4	4.6	-0.2	2.4	-0.4	2.4	-0.2	2.1	3.4	2.6	-3.5	3.0
	Interception, evaporation + transpiration	41.7	10.7	1.7	5.4	29.3	6.0	0.1	5.4	0.3	5.3	1.6	3.8	-1.7	5.7	22.4	9.2
Soil budget	Average Soil water*	70.9	5.9	-0.1	1.9	-3.2	2.0	-0.3	2.9	-0.9	2.4	-0.3	2.3	-1,076.9	30.4	2.4	2.5
	Infiltration	63.8	4.5	0.5	2.0	-1.7	2.1	-0.4	2.4	-0.3	2.0	0.7	1.9	1.8	1.9	5.0	2.2
	Runoff	3.8	17.9	-0.3	19.3	0.3	14.8	1.5	18.1	-4.2	17.7	0.6	14.5	1.7	22.9	1.9	14.2
Discharge	Average Water discharge	3.8	17.9	-0.3	19.3	0.3	14.8	1.5	18.1	-4.2	17.7	0.6	14.5	1.7	22.9	1.9	14.2
Erosion budget	Sediment runoff	98.3	9.1	-3.1	20.0	-17.3	23.4	0.3	22.2	0.1	22.8	-3.1	26.9	-3.5	25.0	1.2	18.9
	Sediment Discharge	97.1	15.8	-10.7	46.5	-13.3	48.8	0.5	47.9	1.4	49.0	-4.8	52.1	-6.1E+06	1.5E+07	-2.8	46.4
	Check dams sediment	100.0	0.0	-0.9	22.9	-41.0	32.4	-3.8	29.5	2.2	25.9	-5.8	29.9	-5.0	32.5	1.2	22.3
	Reservoir sediment	100.0	0.0	-38.1	149.8	-0.6	47.1	-15.1	58.5	-41.7	148.1	-2.4	20.5	99.0	5.6	-35.6	133.1
Salinity budget	Average soil salinity	-30.1	15.7	1.5	0.4	-0.3	0.4	0.3	0.3	0.6	0.3	0.6	0.5	3.4	2.0	8.3	5.7
	Aquifer salinity	-544.2	199.2	-8.2	13.5	-6.0	10.1	-1.9	12.5	1.2	13.8	-1.4	9.4	16.6	12.9	44.3	24.2
	Irrigation salt	-124.1	35.3	1.2	13.2	-2.9	12.4	-0.6	10.8	2.0	12.1	3.7	8.1	14.9	11.6	42.0	19.8

Table A - Hydrology and Soil Indicators; 30-year total average change (%) analysis

- **Land Use suitability indicators**

		S1		S2										S3				S4	
		Severe Drought		**Aquifer Over-exploited**		**Forest Reserve implementation**		**Terracing implementation**		**Agric. LU demand increase 20%**		**Reservoir Water Cost increase +50%**		**Dry cereal Subsidy +50%**		**Irrigated Almonds Subsidy +50%**	
LU suitability Indicators:		average	SD	average	SD	average	SD	average	SD	**average**	**SD**	average	SD	average	SD	average	SD
	Natural vegetation suitability	21.4	6.1	0.0	0.9	0.0	0.6	0.2	0.8	-0.1	0.6	0.0	0.5	0.0	0.9	-0.4	0.8
	Agriculture total suitability	5.3	3.0	-0.1	0.8	0.1	0.9	0.2	1.0	0.1	0.9	0.2	0.9	-0.1	1.4	0.1	1.0
Dryland	Almonds	9.5	4.4	0.0	1.4	-0.2	1.9	0.1	1.5	0.1	1.3	0.1	1.5	-0.1	2.2	0.3	1.5
	Cereal	26.9	10.2	0.2	3.8	0.2	3.5	0.7	4.1	0.9	3.8	0.7	4.0	-0.4	6.6	1.4	4.1
	Fruit	5.5	3.0	-0.1	0.8	0.2	0.8	0.2	1.1	0.1	0.9	0.2	0.9	-0.1	1.4	0.0	1.0
	Olives	6.2	3.5	0.0	0.9	0.0	1.7	0.3	1.1	0.2	1.3	0.3	1.2	-0.1	1.8	0.2	1.3
	Vineyard	-0.3	0.7	0.0	0.0	0.1	0.0	0.0	0.2	0.0	0.0	0.0	0.0	-0.1	0.1	-0.1	0.1
	Sum	*47.9*		*-0.1*		*0.3*		*1.4*		*1.2*		*1.2*		*-0.7*		*1.8*	
greenhouse	Vegetables	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Irrigated	Almonds	45.5	15.3	0.2	6.7	-0.3	7.4	1.0	7.0	1.2	6.5	1.1	6.7	-0.7	12.1	2.1	6.9
	Cereal	53.6	17.0	0.4	8.2	-0.4	9.5	1.3	8.5	1.5	7.8	1.5	7.8	-1.0	16.2	2.7	8.2
	Citrus	57.4	17.9	0.2	8.6	-0.5	9.4	1.2	8.7	1.5	8.1	1.4	8.3	-1.1	16.6	2.6	8.6
	Fruit	57.4	17.9	0.2	8.6	-0.5	9.4	1.2	8.7	1.5	8.1	1.4	8.3	-1.1	16.6	2.6	8.6
	Vegetables	17.6	6.7	0.2	2.3	0.2	2.8	0.6	2.4	0.6	2.5	0.6	2.5	-0.2	3.7	1.0	2.5
	Olives	45.5	15.3	0.2	6.7	-0.3	7.4	1.0	7.0	1.2	6.5	1.1	6.7	-0.7	12.1	2.1	6.9
	Vineyard	57.4	17.9	0.2	8.6	-0.2	8.3	1.2	8.7	1.5	8.1	1.4	8.3	-1.1	16.5	2.6	8.6
	sum	*334.6*		*1.6*		*-2.0*		*7.3*		*9.0*		*8.3*		*-5.8*		*15.5*	

Table B - Hydrology and Soil Indicators; 30-year total average change (%) analysis

- ## **Vegetation cover Indicators**

		S1		S2								S3				S4	
		Severe Drought		**Aquifer Over-exploited**		**Forest Reserve implementation**		**Terracing implementation**		**Agricultural LU demand increase 20%**		**Reservoir Water Cost increase +50%**		**Dry cereal Subsidy +50%**		**Irrigated Almonds Subsidy +50%**	
		average	SD	average	SD	average	SD	average	SD	average	SD	average	SD	average	SD	average	SD
Dryland crops	Almonds	94.9	5.8	0.2	6.3	-5.1	6.3	0.8	9.6	-3.5	8.8	2.1	5.3	-400.7	282.6	1.6	6.8
	Cereal	81.6	5.7	-0.6	5.0	-0.2	5.1	-0.5	5.9	-0.6	4.9	-1.0	3.7	1.3	4.3	0.0	4.3
	Fruit	97.3	6.5	-7.3	12.5	-5.9	14.3	2.6	14.5	-4.5	10.4	-4.0	9.4	-14.9	16.0	-5.0	20.4
	Olives	96.4	5.6	-2.1	6.0	-6.7	6.2	-2.9	10.1	-7.0	10.8	-2.1	8.7	-198.3	112.1	-4.2	8.8
	Vineyard	96.6	5.5	-9.2	7.7	-16.6	9.5	-3.9	9.8	-12.0	12.1	-1.2	10.5	-162.1	77.0	-5.2	8.3
	sum	*466.8*		*-19.2*		*-34.4*		*-3.9*		*-27.6*		*-6.2*		*-774.6*		*-12.8*	
Irrigated Crops	Almonds	-72.9	46.6	-9.2	17.3	-9.1	15.8	-0.6	13.5	-5.5	15.0	-0.2	8.8	-11.4	14.7	25.3	10.7
	Cereal	-6.1	5.7	-0.2	4.9	-1.3	5.1	-0.4	5.8	-0.3	6.1	-0.5	4.5	-1.3	4.8	0.4	4.5
	Citrus	-3.7	2.3	1.1	3.5	-0.2	2.2	-0.2	1.9	0.2	2.2	0.5	2.1	-0.2	2.0	3.3	3.4
	Fruit	-5.2	6.8	-2.3	7.9	-0.3	5.2	-0.4	4.5	-0.3	4.9	0.6	4.0	0.0	4.0	4.6	6.4
	Vegetables	0.4	2.0	0.0	1.9	0.0	2.2	0.3	1.8	0.1	2.3	0.4	1.6	-0.3	1.9	1.6	2.3
	Olives	-132.1	75.1	-13.4	24.6	-13.8	24.9	-0.1	21.7	-7.0	21.3	0.1	16.9	-34.9	25.4	-13.2	28.8
	Vineyard	-2.2	1.5	1.3	1.4	-0.2	0.9	0.4	1.2	0.7	1.5	0.3	1.5	0.2	1.3	-0.1	1.7
	sum	*-221.7*		*-22.6*		*-24.9*		*-1.0*		*-12.2*		*1.1*		*-48.0*		*22.0*	
NV - woodland	PH: Pinus halepensis wood	99.1	3.5	-2.1	2.8	-27.3	9.9	-0.5	6.1	-3.3	5.0	-0.6	4.1	-2.5	4.4	-1.1	4.4
	QR: Quercus rotundifolia wood	99.1	4.1	0.4	3.4	0.7	4.8	-2.0	5.1	-0.8	3.6	1.3	3.3	-0.3	3.2	-1.4	4.2
	MA: Matorral w/ Quercus coccifera	98.8	2.9	0.2	4.9	-7.2	20.7	6.0	19.0	-1.1	4.7	3.1	4.7	0.5	4.3	-0.4	4.4
	sum	*297.0*		*-1.5*		*-33.8*		*3.4*		*-5.1*		*3.8*		*-2.3*		*-2.9*	
NV - shrub	OM: Open Matorral w/ Anthyllis cytisoides	4.4	16.5	0.1	0.2	97.3	14.7	-1375.5	2255.3	0.3	1.6	0.0	0.2	0.0	0.1	0.0	0.1
	DM: Degraded Matorral w/ Ulex parviflorus	99.0	3.5	-0.5	3.7	-5.2	6.2	-5.6	7.5	-1.5	4.7	0.9	3.8	-1.0	4.1	-1.0	4.3
	ST: Espartal Steppe w/ Stipa tenacissima	98.1	7.1	-0.5	8.0	-25.3	19.0	-0.6	15.3	-4.4	13.7	2.7	11.3	-0.4	13.5	-2.2	10.0
	sum	*201.6*		*-1.0*		*66.8*		*-1381.7*		*-5.6*		*3.6*		*-1.4*		*-3.1*	
NV - grassland	AF: Abandoned fields - annual grasses	97.9	9.2	-0.2	5.4	-6.3	9.2	0.7	6.1	-6.9	9.0	0.4	3.1	-2.9	5.7	-0.2	7.1
	PG: Perennial grassland w/ Brachypodium	97.7	11.8	0.0	1.0	3.4	3.5	-0.3	1.3	-0.1	1.0	0.1	0.9	-0.2	1.1	-0.5	1.0
	sum	*195.6*		*-0.2*		*-2.9*		*0.3*		*-7.0*		*0.5*		*-3.1*		*-0.8*	

Table C - Vegetation cover Indicators; 30-year total average change (%) analysis.
Note: greenhouse vegetables (no data) and Bare rock where not included (value constant = zero)

- ## **Harvested Area Indicator**

Harvest crop indicators		S1 Severe Drought		S2 Aquifer Over-exploited		Forest Reserve implementation		Terracing implementation		Agricultural LU demand increase 20%		S3 Reservoir Water Cost increase +50%		Dry cereal Subsidy +50%		S4 Irrigated Almonds Subsidy +50%	
		average	SD	average	SD	Average	SD	average	SD	average	SD	Average	SD	average	SD	average	SD
Dryland	Almonds	-54.9	30.7	-0.4	0.6	-1.9	0.8	-0.5	0.7	-1.0	0.5	-0.7	0.7	74.3	26.3	-1.0	0.9
	Cereal	30.9	15.7	0.0	0.2	-1.5	0.3	0.3	0.2	-1.1	0.4	0.1	0.2	**-44.1**	15.4	0.6	0.4
	Fruit	76.6	32.1	8.7	10.9	-17.4	22.9	-2.4	20.0	-8.4	17.1	7.7	12.4	-2.8	12.4	14.5	18.4
	Olives	-146.6	62.0	3.4	4.3	4.4	4.4	2.1	4.0	4.1	4.8	3.0	7.8	71.9	22.7	7.7	6.3
	Vineyard	-234.9	112.1	3.5	4.9	2.4	4.6	-0.3	6.3	1.7	6.2	-1.0	8.5	66.5	20.8	5.8	6.1
	Sum	*-328.9*		*15.3*		*-14.0*		*-0.9*		*-4.6*		*9.2*		*165.7*		*27.6*	
Greenhouse	Vegetables	-199.4	96.4	25.7	10.7	16.2	12.8	-42.6	21.5	-4.9	10.1	17.1	12.4	23.5	12.1	8.3	7.7
Irrigated	Almonds	19.9	17.1	-6.1	7.1	-5.5	7.9	-1.9	5.0	-3.3	7.4	-6.1	8.2	15.4	6.0	-416.1	183.2
	Cereal	-51.6	15.5	-4.8	6.1	-0.1	2.1	0.0	1.7	1.3	1.6	-2.5	2.2	14.2	6.2	62.7	22.8
	Citrus	33.3	9.8	15.1	12.7	0.8	2.1	0.4	2.8	1.6	2.3	8.3	5.8	16.2	5.0	58.8	17.9
	Fruit	50.5	13.2	0.8	13.0	8.5	10.9	0.7	14.5	2.2	9.7	5.3	9.7	25.2	10.2	47.1	17.9
	Vegetables	37.7	18.5	-3.2	9.1	-3.8	10.2	0.6	9.8	-3.6	10.3	0.9	9.5	-4.2	7.0	35.6	15.4
	Olives	46.7	18.3	8.9	28.2	8.5	29.2	-5.3	31.1	-6.7	32.8	-12.2	29.8	36.3	15.6	40.6	24.5
	Vineyard	13.7	2.6	62.6	11.9	2.0	1.1	2.6	1.7	-0.3	1.1	3.2	3.2	-3.1	2.3	24.9	11.3
	Sum	*150.1*		*73.2*		*10.5*		*-2.8*		*-8.8*		*-3.1*		*100.0*		*-146.4*	

Table D - Harvested Area Indicator; 30-year total average change (%) analysis

- **Farmers Profit and Crop Choice Indicators**

		S1		S2										S3				S4	
		Severe Drought		**Aquifer Over-exploited**		**Forest Reserve implementation**		**Terracing implementation**		**Agric. LU demand increase 20%**		**Reservoir Water Cost increase +50%**		**Dry cereal Subsidy +50%**		**Irrigated Almonds Subsidy +50%**			
Profit and crop choice Indicators:		average	sd	average	sd	average	sd	average	SD	average	SD	average	sd	average	sd	average	sd
Dryland crops	Almonds	11.5	5.5	0.1	0.9	-0.4	0.8	0.2	1.2	-0.3	1.2	0.2	0.6	-36.6	29.6	0.4	1.0
	Cereal	13.1	4.9	0.0	0.7	-0.1	0.8	0.0	0.9	-0.1	1.1	-0.1	0.8	-37.5	10.9	0.2	0.8
	Fruit	79.5	58.6	-7.6	20.5	-3.4	20.5	4.1	22.8	-3.3	22.8	-5.1	12.9	-14.8	19.3	-4.3	25.2
	Olives	36.4	17.0	-1.9	8.0	-3.3	9.9	-1.4	9.8	-2.6	9.3	0.1	6.9	-63.5	45.8	-1.7	9.3
	Vineyard	41.0	17.9	-4.3	7.3	-7.3	8.9	-1.7	8.5	-4.4	9.2	0.4	8.8	-60.9	39.5	-2.2	8.9
	Sum	*181.6*		*-13.9*		*-14.5*		*1.2*		*-10.8*		*-4.4*		*-213.2*		*-7.6*	
Greenhouse	Vegetables	67.6	182.7	5.5	75.6	15.6	68.4	42.4	144.6	26.5	73.1	9.2	57.1	7.9	85.4	22.3	54.4
Irrigated crops	Almonds	-12.1	22.4	-4.4	14.6	-4.4	14.3	-1.9	14.1	-2.7	13.1	5.3	10.3	-5.6	11.0	-45.6	26.1
	Cereal	13.3	5.5	0.3	3.5	-0.1	4.2	-0.3	3.5	-0.7	4.0	6.8	5.9	-1.1	3.1	3.8	5.7
	Citrus	24.6	17.9	12.3	33.2	-1.6	15.1	-1.6	13.8	-1.8	16.3	28.9	20.6	-2.4	14.7	13.5	17.1
	Fruit	42.9	132.0	95.4	250.0	68.0	141.5	67.4	138.1	27.1	151.9	38.4	118.7	52.3	158.3	49.8	126.0
	Vegetables	98.3	81.1	-4.4	100.6	-25.5	82.4	3.8	64.9	-9.1	88.3	37.8	40.8	-41.5	65.1	70.9	63.5
	Olives	25.0	528.6	7.6	243.5	44.7	345.1	65.5	209.4	76.9	346.1	2.5	110.9	-12.4	269.0	44.0	306.4
	Vineyard	7.2	6.9	5.8	5.3	-0.5	5.4	0.7	5.4	0.7	5.6	11.1	8.2	-1.2	5.2	-2.4	6.6
	sum	*199.2*		*112.6*		*80.7*		*133.5*		*90.4*		*130.9*		*-11.9*		*134.1*	

Table E - Farmers Profit and Crop Choice Indicators; 30-year total average change (%) analysis.

- ## **Water Management - Water Demand Indicators**

		S1		S2										S3				S4	
		Severe Drought		Aquifer	Over-exploited	Forest Reserve implementation		Terracing implementation		Agric. LU demand increase 20%		Reservoir Water Cost increase +50%		Dry cereal Subsidy +50%		Irrigated Almonds Subsidy +50%	
	water demand indicators	average	SD	average	SD	average	SD	average	SD	average	SD	average	SD	average	SD	average	SD
Aquifer	Agriculture	75.5	38.0	73.6	16.4	-0.6	11.2	-1.9	12.9	-0.9	14.5	0.8	11.3	1.7	14.0	2.5	25.5
	Rural residential	80.4	19.1	- 40.3	30.6	0.6	5.3	0.2	4.1	-0.7	5.8	-0.3	3.8	-5.1	6.3	-8.6	9.6
	Urban residential	87.4	18.7	- 1,857.2	1,429.6	-2.2	14.1	-1.7	13.6	-3.7	17.0	-3.4	13.8	-9.8	18.7	-35.2	52.7
	Industry and commerce	88.1	16.2	- 4,496.4	3,375.4	-2.2	14.1	-1.5	13.7	-3.5	17.0	-3.4	13.8	-9.9	18.7	-36.1	52.3
	Tourism	84.4	20.8	- 202.6	193.3	-3.1	11.5	-0.6	10.6	-3.7	9.7	-4.4	13.0	-7.4	12.7	-24.2	40.8
	Ex-patriots	7.1	9.9	- 0.2	0.5	0.1	0.7	0.2	1.1	0.1	0.7	0.4	0.9	-0.1	0.5	0.5	1.3
	Sum	*422.9*		*- 6,523.1*		*-7.3*		*-5.4*		*-12.3*		*-10.3*		*-30.6*		*-101.1*	
Reservoirs	Agriculture -	-1.7E+22	9.3E+22	-9.9E+22	3.8E+23	-2.4	19.2	-2.1	14.4	-0.3	29.9	3.1	9.0	17.8	20.5	41.9	39.8
	Rural residential	-6.7E+19	2.3E+20	86.7	34.6	-5.5	16.9	-7.1E+17	3.9E+18	-3.0E+18	1.7E+19	-0.1	14.9	13.5	23.1	23.3	29.7
	Urban residential	-2.9E+20	1.6E+21	93.3	25.4	0.4	2.4	0.0	0.1	0.3	1.5	0.0	0.0	0.4	2.4	1.1	6.0
	Industry and commerce	-1.3	8.8	100.0	-	0.0	0.0	-0.1	0.3	-0.1	0.6	0.0	0.0	0.1	0.2	2.0	8.0
	Tourism	-3.2E+19	1.5E+20	90.0	30.5	-1.1	10.2	-0.6	8.9	3.9	17.5	2.0	6.9	8.3	20.9	21.2	30.7
	Ex-patriots	-4.4E+18	9.5E+18	16.7	37.9	-2.1E+17	6.8E+17	-2.9E+17	1.0E+18	-1.1E+17	3.9E+17	-3.0E+17	9.6E+17	-1.1E+16	5.8E+16	-3.1E+17	1.1E+18
	Sum	*-1.7E+22*		*-9.9E+22*		*-2.1E+17*		*-1.0E+18*		*-3.2E+18*		*-3.0E+17*		*-1.1E+16*		*-3.1E+17*	
Desalinated	Agriculture	-2.2E+20	1.2E+21	-6.3E+20	2.8E+21	-91.0	397.2	-71.7	224.8	-31.8	230.9	2.8	71.9	4.5	120.3	44.9	79.3
	Rural residential	0.0E+00	0.0	-	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Urban residential	-3.1E+20	1.7E+21	93.3	25.4	1.2	5.4	-0.1	3.2	2.3	9.3	-0.5	2.9	2.4	9.3	5.5	19.0
	Industry and commerce	-230.4	1230.5	100.0	-	-0.1	0.5	-6.4	32.3	-0.4	2.0	0.0	0.0	0.2	0.8	0.4	1.6
	Tourism	0.0	0.0	-	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Ex-patriots	0.0	0.0	-	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Sum	*-5.3E+20*		*-6.3E+20*		*-89.9*		*-78.3*		*-29.9*		*2.3*		*7.1*		*50.8*	
Shortage	Agriculture	64.3	13.9	- 14.6	44.1	0.6	7.1	-0.4	5.1	-1.2	8.7	-0.4	4.9	9.8	10.3	-50.9	25.8
	Rural residential	0.0	0.0	-	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Urban residential	-1.1E+21	4.4E+21	90.0	30.5	-1.2	5.3	0.3	3.9	1.3	9.6	0.0	2.8	3.6	9.9	10.0	16.9
	Industry and commerce	-291.1	1481.0	96.7	18.3	0.1	2.6	-1.8	10.1	-1.9	15.9	-0.1	1.4	2.9	7.4	6.5	13.0
	Tourism	0.0	0.0	-	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Ex-patriots	0.0	0.0	-	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	sum	*-1.1E+21*		*172.1*		*-0.5*		*-1.9*		*-1.8*		*-0.5*		*16.3*		*-34.4*	

Table F - Water Management - Water demand Indicators; 30-year total average change (%) analysis.

- **Water Management - Water Resources Indicators**

| | | S1 | | S2 | | | | | | | | S3 | | | | S4 | |
| | | Severe Drought | | Aquifer Over-exploited | | Forest Reserve implementation | | Terracing implementation | | Agricultural LU demand increase 20% | | Reservoir Water Cost increase +50% | | Dry cereal Subsidy +50% | | Irrigated Almonds Subsidy +50% | |
	water resource indicators:	average	SD	average	SD	average	SD	average	SD	average	SD	average	SD	average	SD	average	SD
Replenishment	Aquifer	84.3	6.8	0.6	11.4	-1.0	11.6	-4.9	14.0	-2.3	14.6	0.7	11.7	1.7	12.7	5.5	14.0
	Reservoirs	-1320.8	5331.7	-610.7	2416.6	-3.6	20.4	-3.2	24.0	-4.5	42.6	1.2	16.6	15.1	18.1	46.4	23.4
	Desalinated sea water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Sum	*-1236.5*		*-610.1*		*-4.6*		*-8.0*		*-6.7*		*1.8*		*16.8*		*51.8*	
Extraction	Aquifer	75.9	36.7	46.1	32.0	-0.6	11.1	-1.9	12.8	-1.0	14.4	0.8	11.3	1.5	14.0	1.9	25.6
	Reservoirs	-946.4	3098.3	-1480.8	4804.4	-2.2	18.4	-0.9	12.6	0.3	26.0	3.1	8.6	16.0	18.7	46.0	21.9
	Desalinated sea water	-418.8	1198.2	-954.8	5609.7	-1.2	17.0	-7.6	37.4	2.5	22.4	3.9	15.2	7.7	15.9	17.0	13.9
	Sum	*-1289.3*		*-2389.4*		*-4.0*		*-10.4*		*1.8*		*7.8*		*25.2*		*64.9*	
Volume	Aquifer	89.0	14.4	-8268.6	6359.6	-2.0	14.3	-2.3	13.8	-3.5	17.3	-4.1	12.5	-10.3	18.6	-35.2	48.4
	Reservoirs	5.5	3.8	1.5	2.4	0.7	2.1	0.3	1.8	0.3	2.4	0.2	1.8	-0.7	1.8	-1.0	1.9
	Desalinated sea water	12.6	4.2	-4.2	2.6	0.0	0.1	0.0	0.2	-0.1	0.4	-0.4	0.3	-0.6	0.4	-1.2	0.6
	sum	*107.1*		*-8271.3*		*-1.3*		*-1.9*		*-3.4*		*-4.3*		*-11.6*		*-37.4*	

Table G - Water Management - Water resources Indicators; 30-year total average change (%) analysis.

- **Cumulative average Irrigation – from aquifer, reservoir, desalinated sea water by crop**

		S1		S2								S3				S4	
		Severe Drought		**Aquifer Over-exploited**		**Forest Reserve implementation**		**Terracing implementation**		**Agricultural LU demand increase 20%**		**Reservoir Water Cost increase +50%**		**Dry cereal Subsidy +50%**		**Irrigated Almonds Subsidy +50%**	
Cumulative average Irrigation indicators:		average	SD	average	SD	average	SD	average	SD	average	SD	average	SD	average	SD	average	SD
aquifer	Almonds	36.8	56.5	29.6	41.2	-6.7	21.6	-0.2	28.2	-3.0	27.5	-0.4	19.0	-30.1	44.9	-71.2	88.9
	Cereal	70.7	43.8	81.7	12.6	-4.0	24.4	-3.8	27.2	-4.0	26.0	-5.9	20.8	-12.8	18.9	-50.7	55.4
	Citrus	79.3	31.2	73.9	15.9	0.1	12.2	-1.8	11.1	-0.6	14.0	-1.1	13.0	-8.7	16.1	-26.9	28.5
	Fruit	78.2	32.0	72.4	17.7	-0.1	12.0	-2.1	10.5	-1.4	14.4	-0.9	12.6	-9.7	16.1	-28.4	29.0
	Vegetables	77.2	38.7	78.6	14.9	-0.6	13.6	-1.4	11.4	-0.2	15.1	-1.7	14.4	-11.5	17.4	-45.2	46.1
	Vegetables greenhouse	86.3	20.0	-223.8	207.7	-3.3	11.8	-1.2	12.7	-2.3	10.7	-4.1	13.3	-8.0	13.8	-27.7	38.4
	Olives	34.7	57.8	79.6	12.8	-9.8	24.4	1.1	28.7	-2.3	26.5	0.2	19.4	-40.7	52.3	-82.7	99.7
	Vineyard	79.4	31.0	74.9	15.8	-0.2	12.1	-1.3	11.0	-0.2	13.6	-0.6	12.9	-7.5	16.1	-31.7	30.1
	Sum	*542.7*		*266.7*		*-24.6*		*-10.7*		*-14.0*		*-14.6*		*-129.0*		*-364.4*	
reservoir	Almonds	-2.4E+18	1.3E+19	-8.2E+18	3.1E+19	-6.0	33.4	-5.1	24.3	-8.0	38.2	-10.7	35.3	3.7	28.5	27.1	34.2
	Cereal	-1.9E+19	9.1E+19	-2.3E+19	6.9E+19	-25.4	113.6	-3.5	30.4	-155.3	874.6	-33.1	183.2	4.4	29.0	27.5	33.0
	Citrus	-7.2E+18	4.0E+19	-3.4E+19	1.3E+20	1.4	16.8	0.2	11.6	2.2	16.9	1.9	10.4	6.6	23.0	26.3	32.5
	Fruit	-3.4E+19	1.5E+20	-5.1E+19	1.5E+20	-0.7	15.1	-6.3E+13	3.4E+14	1.5	17.6	2.3	10.3	4.6	22.7	24.7	32.5
	Vegetables	-2.0E+19	9.4E+19	-2.7E+19	8.2E+19	-2.3	19.1	-3.5	20.4	4.6	26.5	1.9	10.0	10.4	26.1	31.6	33.0
	Vegetables greenhouse	-3.7E+19	1.6E+20	-1.5E+18	5.7E+18	-0.1	7.9	-0.6	6.9	1.7	12.6	1.2	5.0	6.5	14.7	19.3	29.2
	Olives	-2.5E+18	1.3E+19	-1.0E+19	3.9E+19	-11.3	34.4	-7.8	34.4	-10.9	42.0	-10.7	34.4	-1.6	30.2	22.1	33.6
	Vineyard	-7.3E+18	4.0E+19	-3.5E+19	1.3E+20	-1.6	15.8	-5.1	31.5	1.2	19.1	2.5	10.6	5.8	22.3	21.2	33.1
	Sum	*-1.3E+20*		*-1.9E+20*		*-46.0*		*-6.3E+13*		*-163.0*		*-44.7*		*40.4*		*199.8*	
Desalinated sea water	Almonds	-1.3E+15	7.3E+15	-4.2E+16	1.7E+17	-1103.2	2816.0	-686.5	1544.2	-175.3	448.6	-284.8	777.6	-489.9	1427.7	-284.1	743.7
	Cereal	-5.3E+17	2.6E+18	-2.0E+17	7.4E+17	-298.1	717.1	-193.4	393.2	-102.9	256.7	-10.4	82.0	-4.3E+12	2.3E+13	-13.6	163.7
	Citrus	-2.3E+17	1.3E+18	-1.8E+17	6.7E+17	-176.7	754.4	-141.8	507.7	-172.6	908.2	-28.6	127.5	-47.7	311.7	-4.9	226.3
	Fruit	-1.8E+18	8.7E+18	-8.0E+17	3.3E+18	-76.1	267.5	-108.0	332.8	-96.2	511.1	-8.2	74.2	-22.7	191.5	7.9	139.0
	Vegetables	-6.3E+17	2.8E+18	-1.7E+17	5.0E+17	-1.2E+13	6.7E+13	-2.7E+13	1.5E+14	-4.4E+11	2.4E+12	-255.8	937.9	-3.7E+13	2.0E+14	-42.6	244.8
	Vegetables greenhouse	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Olives	-2.8E+15	1.6E+16	-5.6E+16	2.2E+17	-420.6	811.5	-231.1	498.7	-143.1	329.8	-78.1	334.4	-272.9	514.6	-332.8	477.9
	Vineyard	-2.5E+17	1.4E+18	-2.9E+17	1.2E+18	-150.0	548.8	-154.5	457.2	-163.3	883.1	-15.6	98.7	-33.8	248.4	-27.2	246.6
	Sum	*-3.4E+18*		*-1.7E+18*		*-1.2E+13*		*-2.7E+13*		*-4.4E+11*		*-681.5*		*-4.1E+13*		*-697.4*	

Table H - Cumulative average Irrigation – from aquifer, reservoir, desalinated sea water by crop; 30-year total average change (%) analysis.

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