Establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe

Deliverable 3.2 & 6.3

PILOT DESCRIPTION AND ASSESSMENT

Upper Guadiana Basin (Spain)

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LIST OF ABBREVIATIONS & ACRONYMS

CC	Climate Change
FAO	Food and Agriculture Organization of the United Nations
GSOs	Geological Survey Organisations
MS	Management scenario
SAC-SMA	Sacramento Soil Moisture Accounting
UGB	Upper Guadiana Basin

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1. EXECUTIVE SUMMARY

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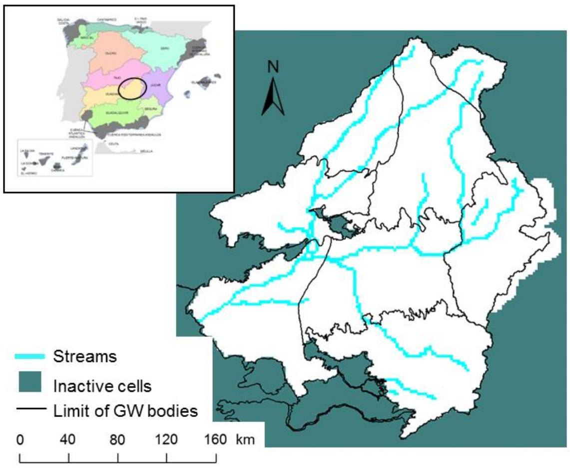
<tr><td>Pilot name</td><td>UPPER GUADIANA BASIN</td><td rowspan="6">
</td></tr>
<tr><td>Country</td><td>Spain</td></tr>
<tr><td>EU-region</td><td>Mediterranean region</td></tr>
<tr><td>Area (km^2)</td><td>14000 km^2</td></tr>
<tr><td>Aquifer geology and type classification</td><td>Detrital and carbonated. Sedimentary & karstic.</td></tr>
<tr><td>Primary water usage</td><td>Irrigation / Drinking water / Industry</td></tr>
<tr><td>Main climate change issues</td><td colspan="2">Decrease in piezometric levels and some negative environmental impacts upon groundwater-dependent wetlands, streams and rivers. Identify and assess climate change adaptation measures for a sustainable management of the Basin.</td></tr>
<tr><td>Models and methods used</td><td colspan="2">Generation of local future climate change scenarios and definition of adaptation scenarios (by applying top-down and bottom-up approaches). Propagation with a chain of auxiliary models (recharge, agricultural) to generate inputs for a distributed flow model defined with the MODFLOW code; Propagation of impacts on laggoons by using regression models that include climatic and hydrological explanatory variables.</td></tr>
<tr><td>Key stakeholders</td><td colspan="2">Guadiana River Basin Authority, farmers associations (farmers are a highly heterogeneous group, whose interests often cannot be generalised; this implies a wide range between those associations working at institutional level and those working at political scale representation), water supply companies, Environmental Conservation Groups.</td></tr>
<tr><td>Contact person</td><td colspan="2">L. Baena, D. Pulido, A. de la Hera, M. Mejias, JD Goméz, Aj Collados-Lara. IGME (Spain), l.baena@igme.es; d.pulido@igme.es; a.delahera@igme.es; m.mejias@igme.es; j.dedios@igme.es; Aj.collados@igme.es</td></tr>
</table>

Eight groundwater bodies compose the Upper Guadiana Basin (UGB), including detrital and carbonated aquifers with a complex geology. The intensive groundwater use mainly for irrigation has trigger abundant social and economic benefits; however, it has also produced a significant decrease in piezometric levels and some negative environmental impacts upon groundwater-dependent wetlands, streams and rivers. The Basin shows strong natural interaction between groundwater and surface water gives rise to over one hundred wetlands that make up UNESCO's Mancha Húmeda Biosphere Reserve; under semi-natural conditions wetlands totalled about 25000 ha. However, this area is now reduced to only 7000 ha. In addition, some rivers and streams that were naturally fed by the aquifers now have become net losing rivers. Some climate change (CC) predictions forecast an increase in temperature and a decrease in precipitation, which will cause a decrease in water contributions and an increase in the magnitude and frequency of extreme phenomena such as floods and droughts. In front of these scenarios it will be necessary to design adaptation strategies able to be impemented with the acceptation and support of all groundwater users.

The overall objective of this study is to assess and summarise impacts of potential future CC scenarios on the quantitative status of aquifers and groundwater depend lagoons. This assessment will require the generation of local future CC scenarios. Their impacts are assessed by propagating them with a chain of auxiliary models (recharge, agricultural) that generate inputs for a distributed flow model defined with the MODFLOW code. A regression model is also applied to estimate impacts on laggoons. Finally, we identify and analyse potential adaptation strategies by applying top-down and bottom-up approaches.

Results show that some CC scenarios would imply a reduction in the recharge due to higher temperature and lower precipitation. This entails an increase in pumping to maintain the irrigation area. These scenarios will produce a decrease of the water table regarding the reference year (2015), producing a reduction of the discharge and therefore, a smaller surface water in wetlands. Other scenarios estimate a slightly increase in both precipitation and temperature. It will imply an increase in groundwater recharge. For those scenarios, although the increase in pumping to maintain irrigated area (due to the higher temperature) will produce groundwater depletion in some areas, the groundwater discharge could increase regarding the mean historical discharge.

2. INTRODUCTION

CC already have widespread significant impacts in Europe, which are expected to increase in the future. Groundwater plays a vital role for the land phase of the freshwater cycle and have the capability of buffering or enhancing the impact from extreme climate events causing droughts or floods, depending on the subsurface properties and the status of the system (dry/wet) prior to the climate event. Understanding and taking the hydrogeology into account is therefore essential in the assessment of CC impacts. Providing harmonised results and products across Europe is further vital for supporting stakeholders, decision makers and EU policies makers.

The Geological Survey Organisations (GSOs) in Europe compile the necessary data and knowledge of the groundwater systems across Europe. In order to enhance the utilisation of these data and knowledge of the subsurface system in CC impact assessments the GSOs, in the framework of GeoERA, has established the project “Tools for Assessment of ClimaTe change ImpacT on Groundwater and Adaptation Strategies – TACTIC”. By collaboration among the involved partners, TACTIC aims to enhance and harmonise CC impact assessments, identification, and analyses of potential adaptation strategies.

TACTIC is centred on 40 pilot studies covering a variety of CC challenges as well as different hydrogeological settings and different management systems found in Europe. Knowledge and experiences from the pilots will be synthesised and provide a basis for the development of an infra structure on CC impact assessments and adaptation strategies. The final projects results will be made available through the common GeoERA Information Platform (http://www.europe-geology.eu).

The UGB pilot (Spain) represents one of the pilots in TACTIC where the impacts from CC on groundwater and dependent ecosystems will be adressed. The general challenge of the pilot is to assess future potential groundwater levels and changes in the surface of groundwater dependet lagoons. We will also study potential adaptation strategies by using a mixed top-down and bottom-up approach.

3. PILOT AREA

In the UGB strong natural interactions between groundwater and surface water are observed, which gives rise to over one hundred wetlands that make up UNESCO's Mancha Húmeda Biosphere Reserve. This pilot area also highlights the strong conflict between groundwater-dependent ecosystems and groundwater pumping to supply demands (mainly irrigation demands). This problem might be exacerbated in the future due to CC impacts. In this project we intend to assess potential future impacts, considering different potential CC scenarios and adaptation strategies.

3.1 Site description and data

3.1.1 Location and extension of the pilot area

The case study cover and area of near 14000 km^2 located in the Mediterranean region of EU (See Figure 3.1 and Table 3.1). It has traditionally been one of Spain's most intensively pumped groundwater systems, due to a predominantly dry climate and to the prevalence of irrigated agriculture, as well as to the fact that it stores large amounts of accessible groundwater (Martínez-Santos et al., 2018). It represents a unique example of a semiarid region where groundwater use has helped transform a largely poor rural region into a prosperous agricultural and industrial center (Hernández-Mora, 2002; Llamas, 2005).

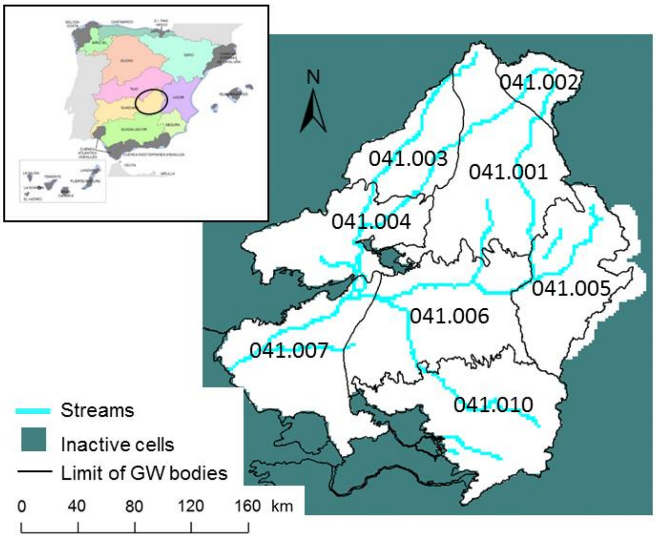


Fig. 3.1: Location of the pilot area.

Table 3.1: Groundwater bodies in the UGB according to UGB (2018, 77).

Name	Code	Extension (km^2)
Sierra de Altomira	041.001	2575
La Obispalía	041.002	490
Lillo-Quintanar	041.003	1102
Consuegra-Villacañas	041.004	1606

Rus-Valdelobos	041.005	1459
Mancha Occidental II	041.006	2536
Mancha Occidental I	041.007	2003
Campo de Montiel	041.010	2200

3.1.2 Geology/Aquifer type

The geology of the UGB is complex including detrital and carbonated aquifers (see Figure 3.2). One of the main groundwater bodies is the Mancha Occidental Aquifer, located in the central part of the UGB. Groundwater connectivity between the different aquifers in the UGB is structurally complex, however, the Mancha Occidental Aquifer is known to be on the receiving end of the system (IGME, 2004; Martínez-Cortina, 2003; Martínez-Santos et al., 2008) and it has been thoroughly described from the hydrogeological viewpoint in several works (IGME, 2004, 2005; ITGE, 1989; Martínez-Santos et al., 2008).

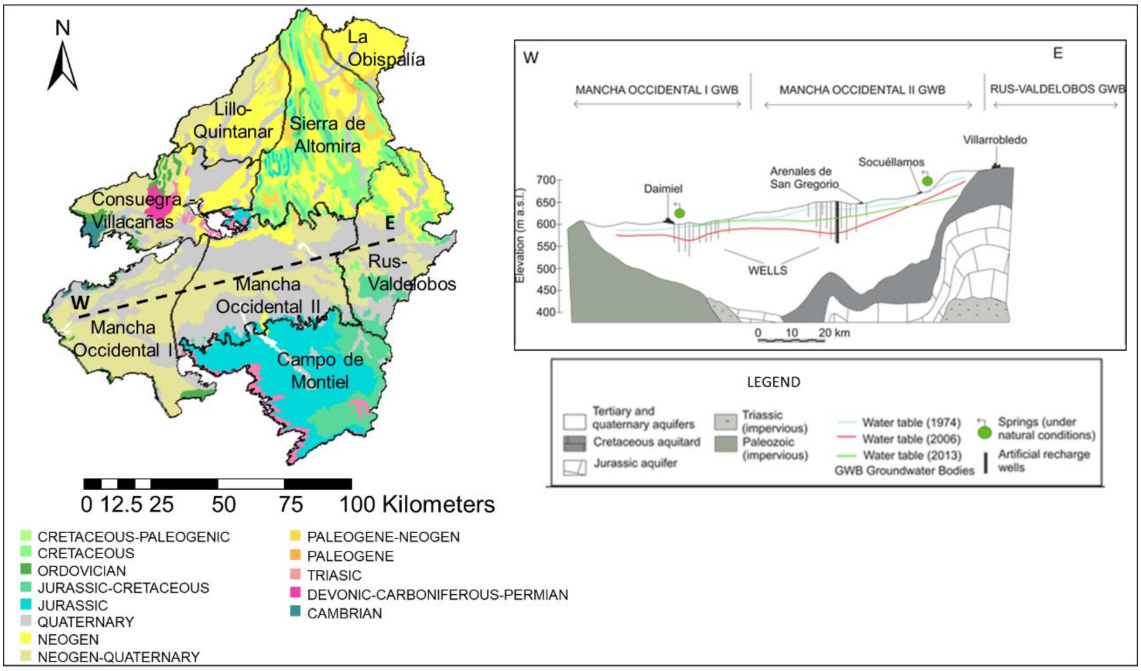


Fig. 3.2: Geological map and cross sections.

3.1.3 Topography and soil types

The area is predominantly flat, sloping gently over 150 km, from the northeast (elevation 730 m.a.s.l.) to the southwest (600 m.a.s.l.) (Figure 3.3, left). The soils (Figure 3.3, right) in the basin mainly belong to the calcisol group according to the FAO classification (1998). It also be found Regosol and others such as luvisol and podzol can be found in the southeast area (Conan et al. 2003).

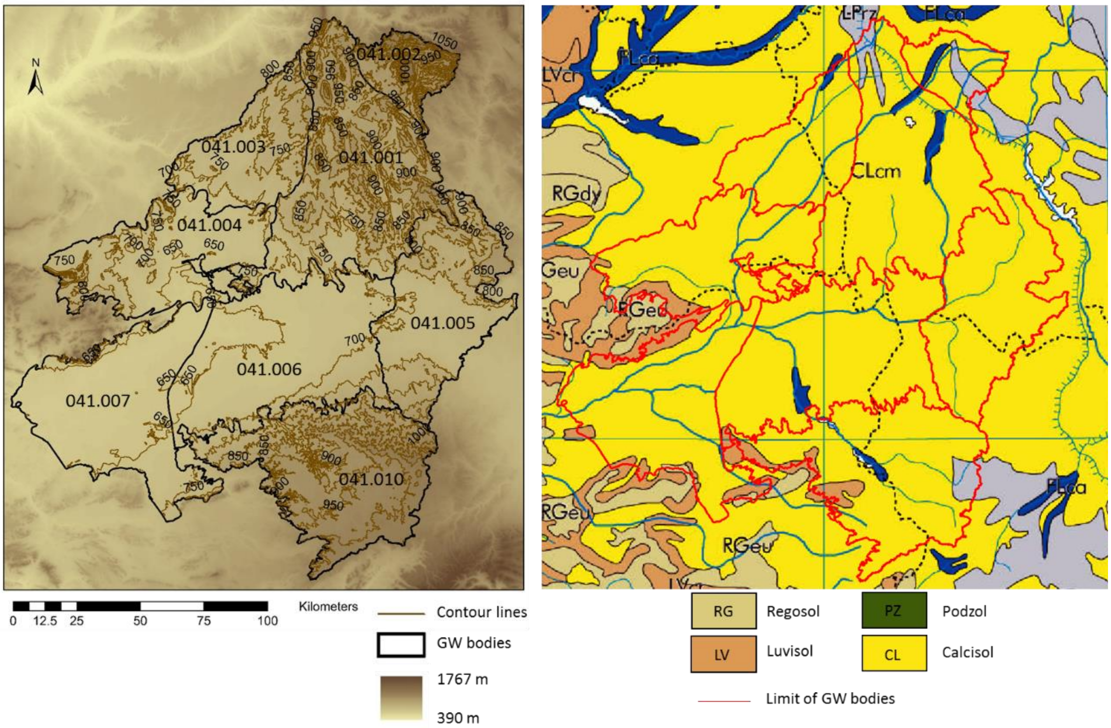


Fig. 3.3: Left: Topography (Digital Elevation Model map with a resolution of 100m); right: soil map from IGN (E 1:3000000).

3.1.4 Surface water bodies

The Basin shows strong natural interaction between groundwater and surface water which gives rise to over one hundred wetlands that make up UNESCO's Mancha Húmeda Biosphere Reserve (see Figure 3.4); under semi-natural conditions wetlands totalled about 25000 ha. However, this area is now reduced to only 7000 ha (De la Hera, 2003) due to intensive groundwater pumping. The most part of them are groundwater-dependent wetlands. The current groundwater management implies that a good number of them are at risk to survive. Intensive groundwater withdrawal depleted the water table by more than 20 m between the mid-1970s and the first decade of the new century (IGME, 2004). Although an important and unexpected recovery of the Mancha Occidental aquifer has occurred recently, there are still uncertainties with regard to ecosystems functionality and provision of ecosystem services.

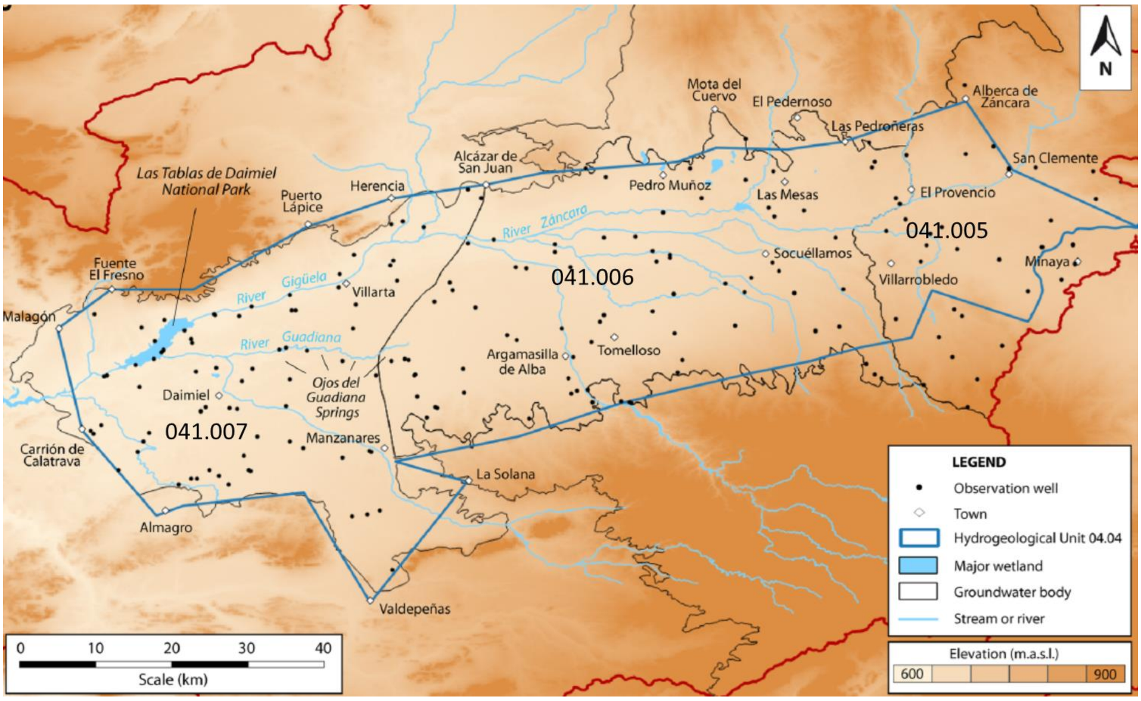


Fig. 3.4: Wetlands that make up UNESCO's Mancha Húmeda Biosphere Reserve.

There are some flow gauges in which the streamflows of some sub-basins are measured even in nearly natural conditions. The location, resolution and period covered by them are represented in Table 3.2 and Figure 3.5.

Table 3.2: Statistics of the flow gauges.

Flow gauges	Average Q(m^3/s)	Period	Temporal resolution	Surface (km^2)
4004	2.17	1973-2015	Daily	847
4101	0.44	1973-1996	Daily	674
4201	1.22	1973-2012	Daily	1080
4202	1.01	1973-2015	Daily	3120
4224	0.67	1975-2015	Daily	2090

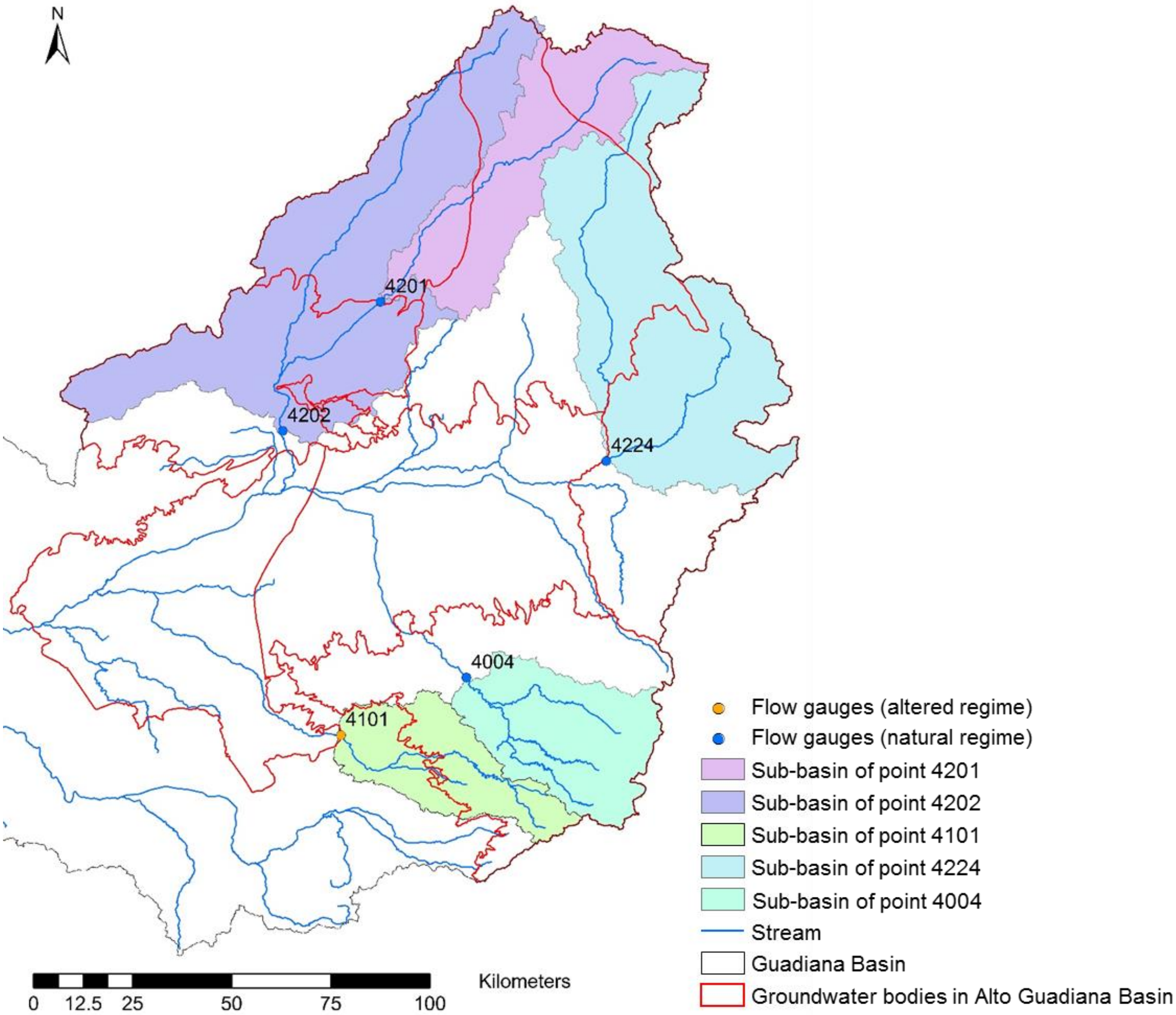


Fig. 3.5: Flow gauges distribution.

3.1.5 Hydraulic head evolution

The intensive groundwater withdrawal depleted the water table by more than 20 m between the mid-1970s and the first decade of the new century (IGME, 2004). In Figure 3.6 we represent the location of the observation points, the maximun observed drawdowns and the temporal evolution in some relevant observation wells.

Aquifers located in the central part of th UGB (Mancha Occidental I and Mancha Occidental II) have experienced a spectacular recovery of its piezometric levels in recent times; in fact, it is currently close to full storage, to the point that its wetlands, artificially maintained for decades, have experienced natural groundwater discharge again for the first time since the early 1980s (Martínez-Santos et al., 2018).

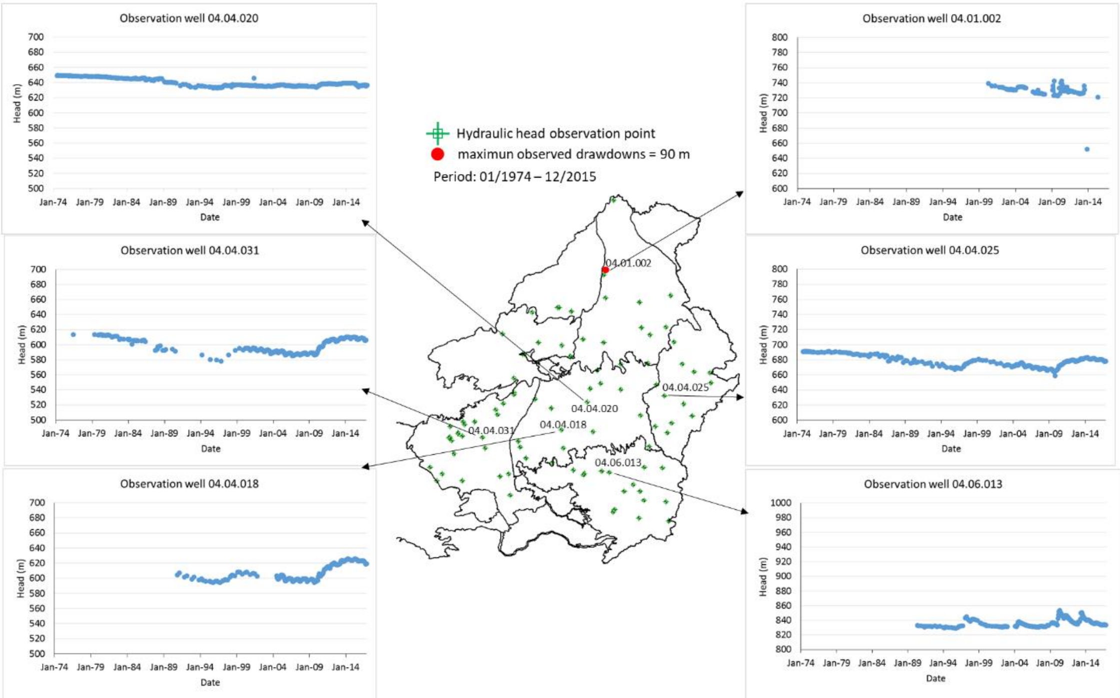


Fig. 3.6: Location of hydraulic head observation points.

3.1.6 Climate

Although this pilot is located in the Mediterranean Region in accordance with the EEA maps, the climate conditions are typically continental and semiarid. Summers are hot and dry, and winters are short and generally mild (Martinez-Santos et al., 2018).

The precipitation is irregularly distributed in the time (see Figure 3.7). The annual average value in the period 1904-2014 is 405 mm (Martinez-Santos et al., 2018). The mean annual temperature is 14.7 °C, oscillating between a maximum mean value of 25.5 °C in July and a minimum of 5.4°C in January. The mean potential evapotranspiration is 700 mm/year. Rainfall is the main source of aquifer recharge.

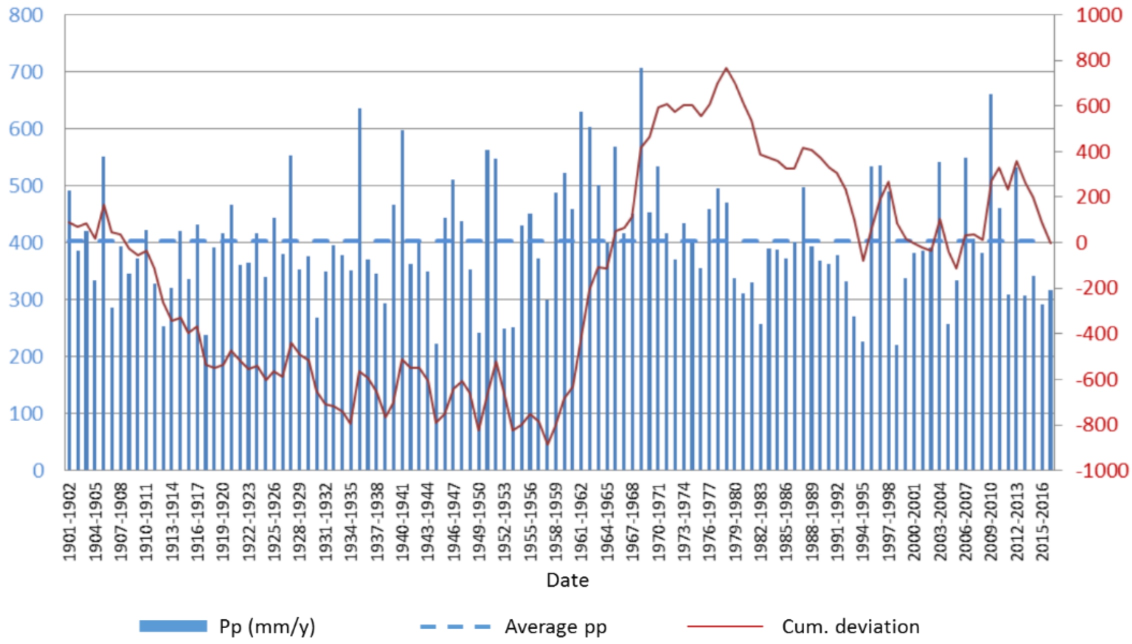


Fig. 3.7: Temporal evolution of the Precipitation (mm/year).

3.1.7 Land use

The main land use is agriculture (see Figure 3.8), which has been expanded in this area since early seventies. The main crops are winter cereals, vineyards and olives (Conan et al. 2003). Although non-irrigated agriculture is the most extensive, there are important irrigation areas mainly located in the central part of the basin.

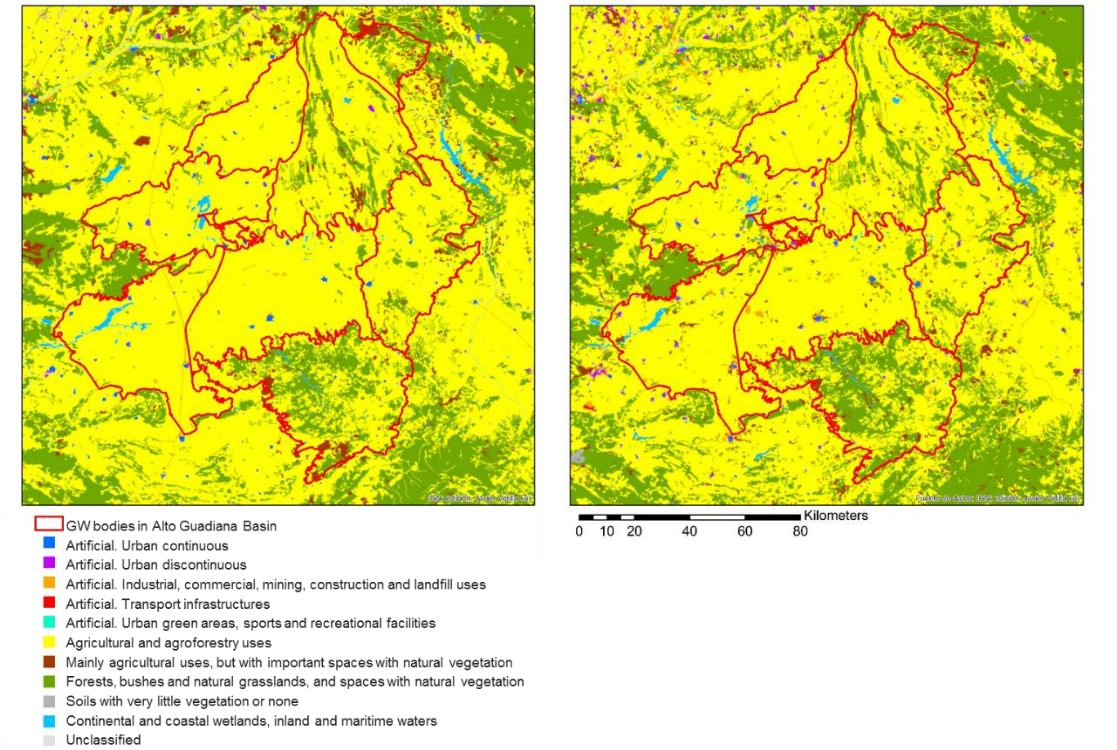


Fig. 3.8: Land use maps from CORINE (1990 and 2012).

3.1.8 Abstractions/irrigation

Currently, pumping-based irrigation accounts for over 90 % of the total water uses. The intensive groundwater pumping in turn led to the desiccation of most groundwater-dependent ecosystems, including Ramsar-listed Las Tablas de Daimiel National Park (Castaño-Castaño et al., 2008), and triggered a series of measures to constrain irrigation. This intensive groundwater pumping is partly due to inadequate management and partly to the presence of thousands of illegal wells. Figure 3.9 and Figure 3.10 show the annual historical temporal evolution of the pumping applied in the MODFLOW model and the spatial distribution in the UGB.

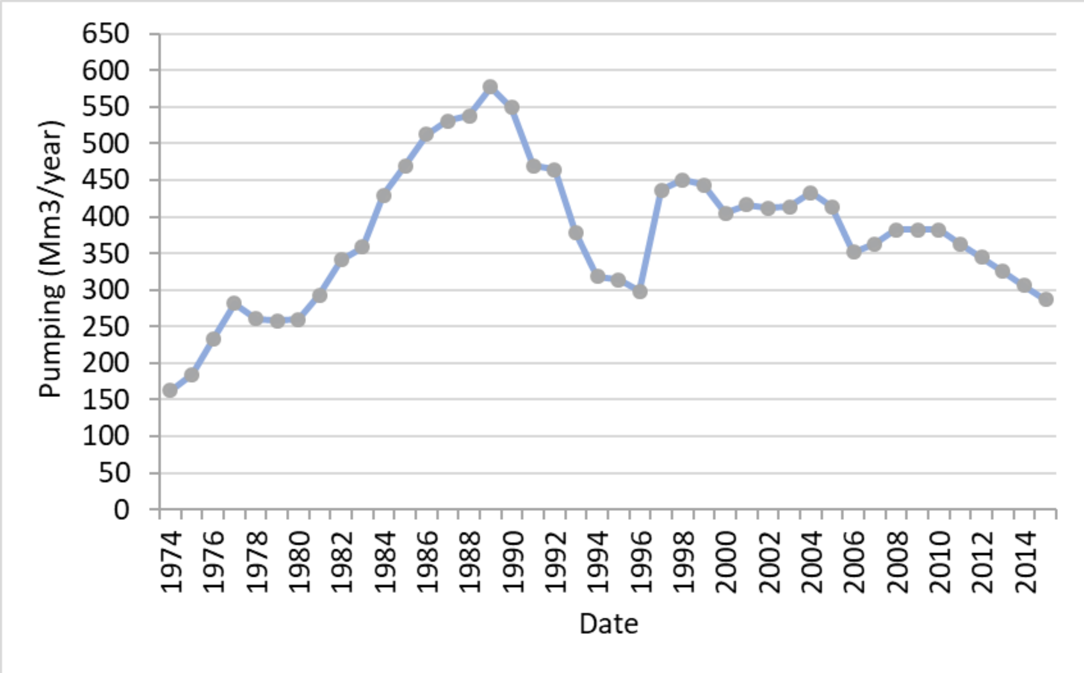


Fig. 3.9: Historical temporal evolution of pumping (Mm^3/y).

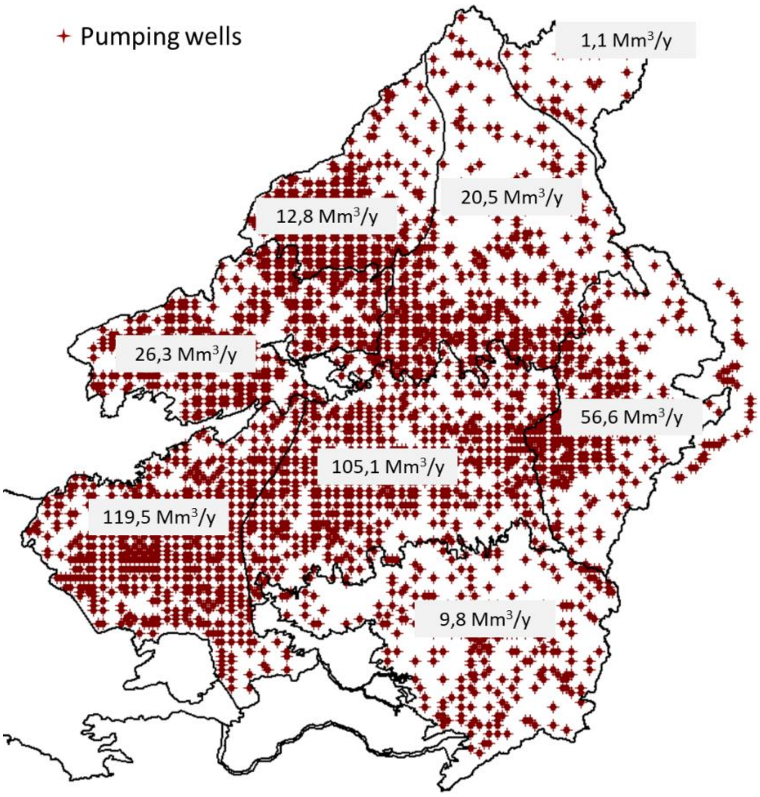


Fig. 3.10: Spatial distribution of the pumpings and mean pumping rates in each GW body in the period (2006-2015).

3.1.9 Flow balance components

The evolution of the main components of the flow balance in the UGB is sumarized in (Table 3.3).

Table 3.3. Approximate water balance in the Upper Guadiana Basin.

Inflow/outflow	Inflows (Mm^3/y)		Outflows (Mm^3/y)			
Date	Rainfall recharge	Recharge from streams	Groundwater pumping	Evapotranspiration from the water table	Discharge to rivers	Lateral transfer to Júcar
1976-1980	771.8	29.3	244.6	985.2	411.8	-19.5
1981-1985	481.2	31.6	347.9	279.5	148.0	18.9
1986-1990	628.5	32.7	489.1	177.4	123.4	47.2
1991-1995	237.4	22.6	328.7	80.2	79.9	52.4
1996-2000	742.6	31.6	336.2	180.5	127.5	68.5
2001-2005	484.0	27.8	340.9	116.1	100.2	72.9
2006-2010	620.6	29.7	375.5	93.5	87.8	0.9
2010-2015	591.1	31.4	327.8	163.1	126.3	0.3
1976-2015	**569.7**	**29.6**	**348.8**	**259.4**	**150.6**	**30.2**

3.2 Climate change challenge

In accordance with the EEA map the main expeted issues due to CC in this case study are those described in the Figure 3.11 for the Mediterranean regions. Existing national estimates show also a significant reduction (around a 20% for the RCP8.5 emission scenario in the horizon 2071-2100) of the aquifer recharge in the area (see Pulido-Velazquez et al., 2017).

The main challenge is to find adaptation measures to maintain a sustainable use of the groundwater bodies with a balance between supply water demands (different uses) under future CC conditions and maintaining a good status in the related ecosystem.

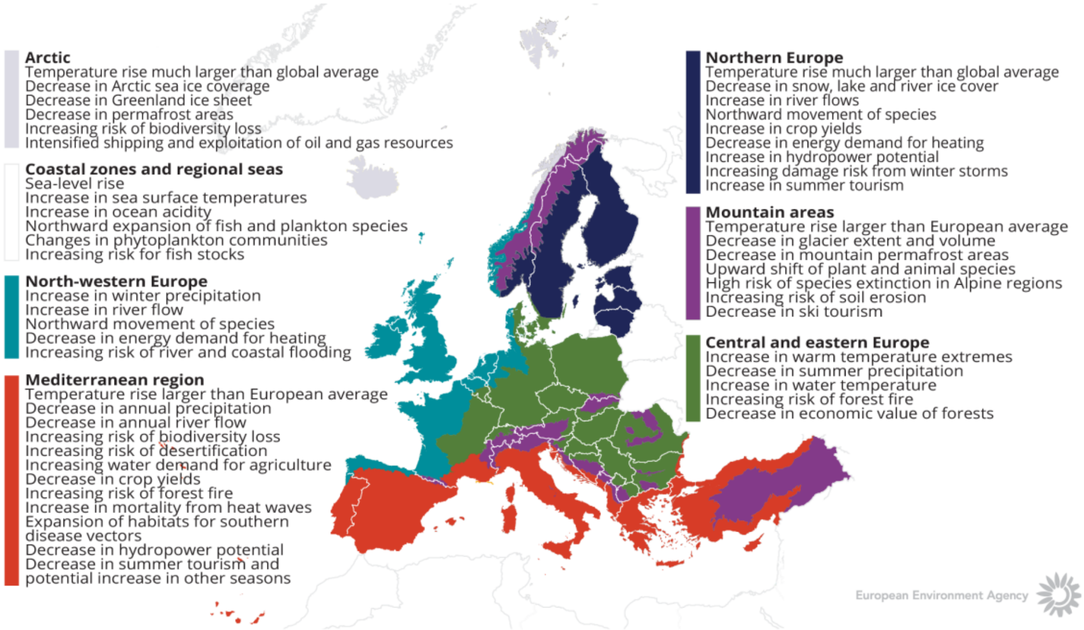


Figure 3.11: European Environment Agency map of projected CC for Europe.

4. METHODOLOGY

The assessment of CC impacts on groundwater and dependent wetlands in the UGB are performed using the TACTIC standard CC scenarios and a chain of hydrological, agricultural and groundwater flow models.

On the other hand, the monitoring and estimation of the water surface in wetlands (groundwater dependent ecosystems) is an important issue in the UGB due to the high environmental value that these lagoons have in the ecosystem functionality. A regression model is applied to estimate the impacts of CC on laggoons.

Finally, we identify and analyse potential adaptation strategies by applying top-down and bottom-up approaches through a participatory process involving groundwater users and skateholders.

The modelling framework is summarised in Figure 4.1.

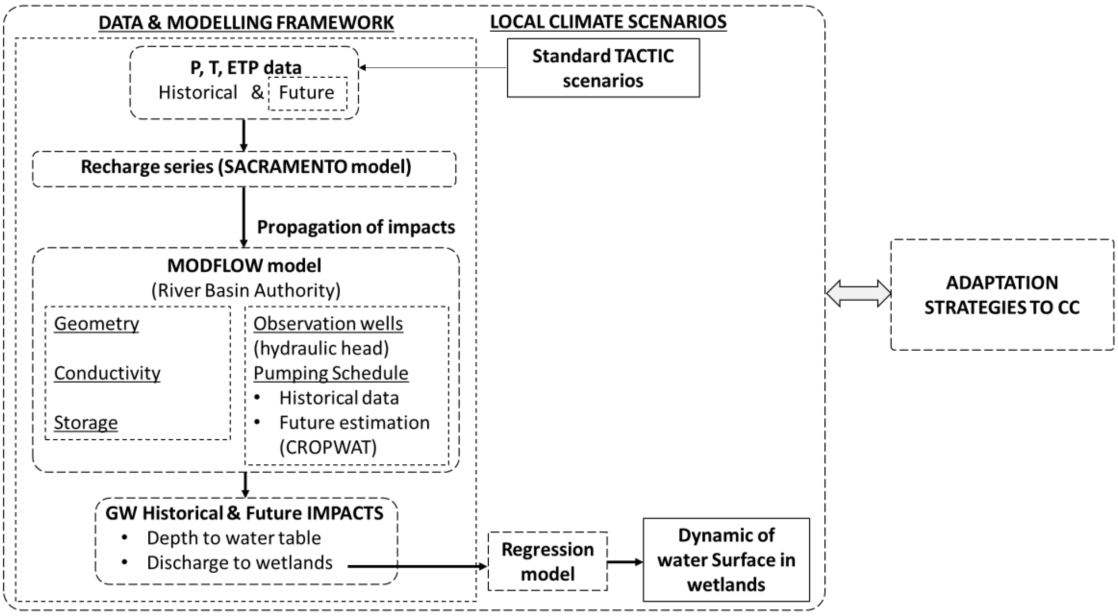


Figure 4.1: Modelling framework.

4.1. Climate data

The present study relies on the TACTIC standard CC dataset to reflect future climate conditions, which include a “wet” and a “dry” climate for a +1 and +3 degree global warming scenario.

4.1.1. TACTIC standard CC scenarios

The TACTIC standard scenarios are developed based on the ISIMIP (Inter Sectoral Impact Model Intercomparison Project, see www.isimip.org) datasets. The resolution of the data is 0.5°x0.5°C global grid and at daily time steps. As part of ISIMIP, much effort has been made to standardise the climate data (a.o. bias correction). Data selection and preparation included the following steps:

1. Fifteen combinations of RCPs and GCMs from the ISIMIP data set where selected. RCPs are the Representative Concentration Pathways determining the development in greenhouse gas concentrations, while GCMs are the Global Circulation Models used to

simulate the future climate at the global scale. Three RCPs (RCP4.5, RCP6.0, RCP8.5) were combined with five GCMs (noresm1-m, miroc-esm-chem, ipsl-cm5a-lr, hadgem2-es, gfdl-esm2m).

2. A reference period was selected as 1981 – 2010 and an annual mean temperature was calculated for the reference period.
3. For each combination of RCP-GCM, 30-years moving average of the annual mean temperature where calculated and two time slices identified in which the global annual mean temperature had increased by +1 and +3 degree compared to the reference period, respectively. Hence, the selection of the future periods was made to honour a specific temperature increase instead of using a fixed time-slice. This means that the temperature changes are the same for all scenarios, while the period in which this occur varies between the scenarios.
4. To represent conditions of low/high precipitation, the RCP-GCM combinations with the second lowest and second highest precipitation were selected among the 15 combinations for the +1 and +3 degree scenario. This selection was made on a pilot-by-pilot basis to accommodate that the different scenarios have different impact in the various parts of Europe. The scenarios showing the lowest/highest precipitation were avoided, as these endmembers often reflects outliers.
5. Delta change values were calculated on a monthly basis for the four selected scenarios, based on the climate data from the reference period and the selected future period. The delta change values express the changes between the current and future climates, either as a relative factor (precipitation and evapotranspiration) or by an additive factor (temperature).
6. Delta change factors were applied to local climate data by which the local particularities are reflected also for future conditions.

For the analysis in the present pilot the following RCP-GCM combinations were employed:

Table 4.1: Combinations of RCPs-GCMs used to assess future climate.

		RCP	GCM
1-degree	"Dry"	4.5	gfdl-esm2m
	"Wet"	4.5	noresm1-m
3-degree	"Dry"	8.5	miroc-esm-chem
	"Wet"	6.0	ipsl-cm5a-lr

4.2. Integrated hydrological modelling of CC (method 1)

The assessment of impacts of CC is performed by propagating the local climate scenarios within a chain of auxiliary models (recharge, agricultural) that generate the inputs for a distributed flow model defined with the MODFLOW code.

The numerical groundwater flow (Modflow) model was developed by the River Basin Authority in 2010 and it has been has been updated until 2015 (SURGE, 2018). The Modflow model simulates the groundwater flow and river-aquifer relationship in the eight groundwater bodies that compose the UGB. It covers a total area around 14000 km^2 and the cell size is 1000x1000

m. The model is discretized into three layers to simulate the different hidraulic properties in some areas of the model.

The model was calibrated against hydraulic head data from the River Basin Authority and the Spanish Geological Survey (IGME) in the period 1974-2015. It was not possible to perform an automated model optimization (with PEST calibration tool) probably due to the complexity of the model. The groundwater levels were adjusted in 23 piezometers (of the 91 available in the UGB) by varying hidrogeological parameters (within reasonable ranges) through a trial-error procedure. Figure 4.2 shows some xamples of results of the calibration of the Modflow model in the UGB in terms of groundwater levels.

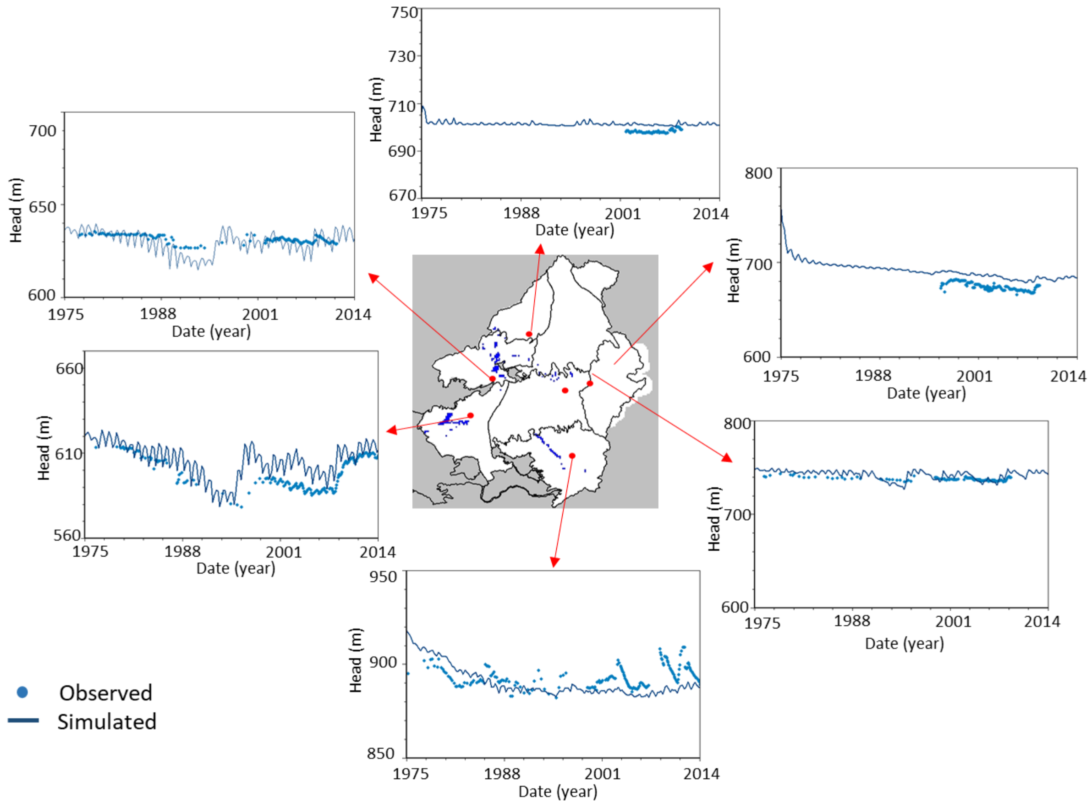


Figure 4.2: Examples of observed and simulated groundwater levels in the Modflow model (UGB).

The flow model requires recharge series as input, which are obtained from a calibrated Sacramento Soil Moisture Accounting (SAC-SMA) model of the US National Weather Service River Forecast System. This model uses precipitation and evapotranspiration time series as input, along with parameters on soil moisture states and the basin's relative permeability to estimate the amount of water that enters, is stored in, and leaves the basin. Five SAC-SMA models were calibrated in the historical period (1974-2015) by a trial and error process to fit the simulated flow rates to the observed ones from five flow gauges in the UGB (see Figure 3.5). Climate series of precipitation came from Spain02 (Herrera et al., 2016) and evapotranspiration series were calculated by using Hargreaves formulation. The period of calibration for each subbasin varied depending on the data availability. The Nash-Surcliffe and R^2 were used to compare the simulated and observed flow for the five subbasins.

Figure 4.3 shows the results of calibration of SAC-SMA model in subbasin EA4004.

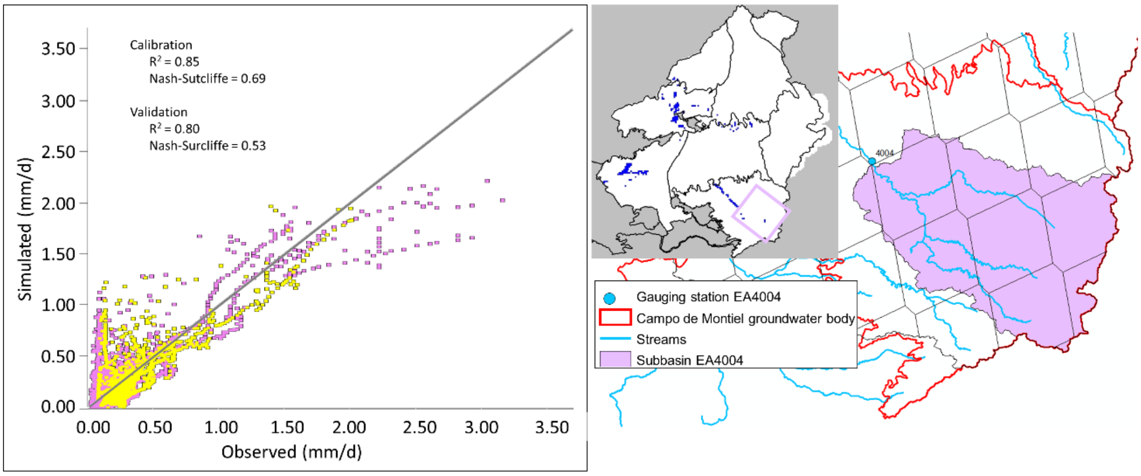


Figure 4.3: Results of SAC-SMA model calibration in subbasin EA4004 in the UGB.

The calibrated SAC-SMA models are used to propagate the impacts of CC on recharge, which is used as input data in the Modflow model.

The future pumping schedule in the Modflow model is generated by using the CROPWAT model (Smith, 1992) to calculate net irrigation demands according to the CC scenario. This tool allows estimating water requirements for each kind of crop from precipitation and temperature data. Thus, the future climatic series has been applied to two management scenarios (MS) with different objectives:

- Maintaining the current (2015) pumping schedule in the future (MS 1).
- Maintaining the current (2015) spatial crop distribution in the future (MS 2);

The Modflow model is used in this study to propagate the impacts of CC on groundwater levels and discharges to wetlands.

4.3. Estimation of the dynamic of surface water in wetlands (method 2)

The monthly dynamic of surface water in Lagunas de Ruidera wetlands in Campo de Montiel (South of UGB) has been estimated from an ensemble of regression models that were calibrated by using satellite data and hydro-climatological variables. Figure 4.4 shows the location of Lagunas de Ruidera in the UGB.

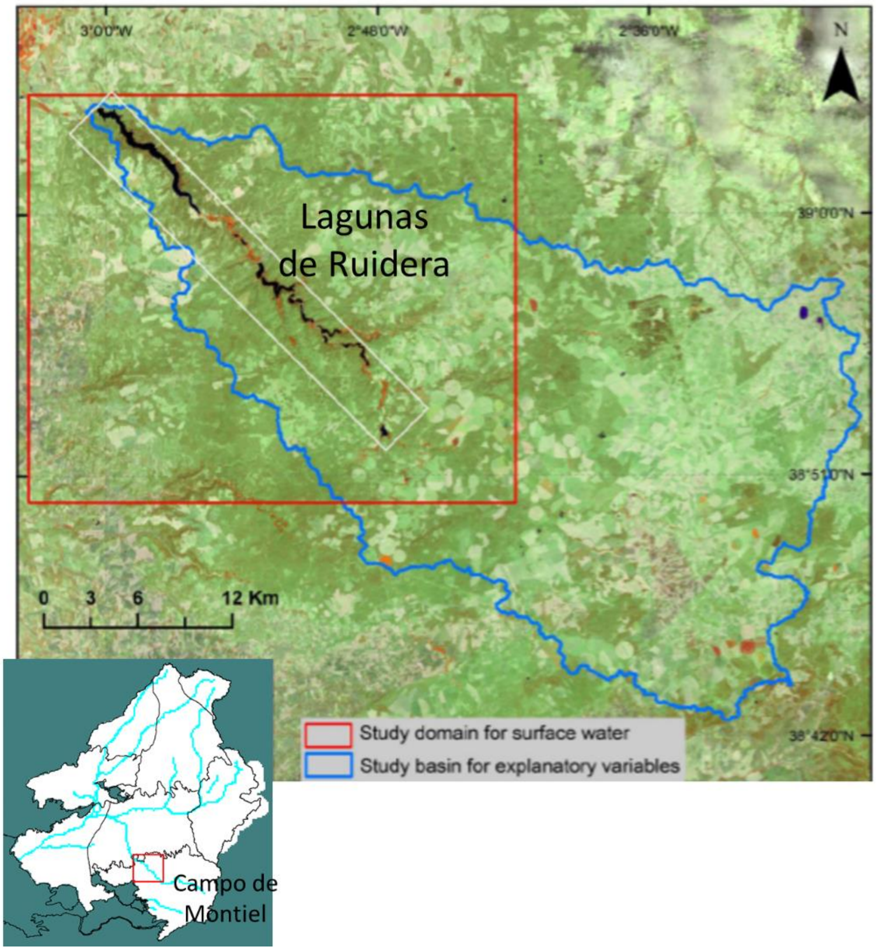


Figure 4.4: Location of the pilot area for the estimation of the dynamic of surface water in the UGB.

The purpose of these regression models is to complete the information provided by satellite data in order to obtain long monthly series of surface water in small lagoons that require high spatial resolution information. This ensemble of regression models also allows estimating future changes in surface water on lagoons due to CC.
The explanatory variables used for the calibration of the multiple regression model were: precipitation; effective precipitation; temperature; potential evapotranspiration; and aquifer discharge in the period 1984 to 2015.

4.4. Adaptation strategies to CC (method 3)

In this project, a participatory method has been designed to define local future socio-economic scenarios, establish adaptation strategies and validate the model developed in the pilot area. This participatory process involves local agents of agricultural communities in the UGB including farmers, the Guadiana River Basin Authority, the General Directorate of Agriculture and Natural Environment of Castilla La Mancha, local municipalities, national environmental officers and environmental organizations.

Three local scenarios were defined and presented in a workshop that was held in the study area (Bolaños de Calatrava), were some exercises were carried out to elicit their knowledge in relation to the previous results obtained with the physical flow model. The three socio-economic scenarios are:

1) Business as usual: a vision of future evolution with current trends;
2) Innovation and globalization: trend to globalization and opening of borders and markets with reinforcing economic subsidies, promoting environmental practices and crops and a high rural innovation;
3) Fragmentation and protectionism: the European Union promotes market protectionism and the economic subsidies support for productivity.

5. RESULTS AND CONCLUSIONS

Results from the work in the UGB pilot (Spain) will focus on changes on shallow groundwater levels and the impacts on dependent ecosystems. This pilot area reveals the strong conflict between groundwater-dependent ecosystems and groundwater pumping to supply demands (mainly irrigation demands). This problem will be exacerbated in the future due to CC impacts, although some CC scenarios show hopeful results.
The ensemble of regression models calibrated to estimate the water surface in wetlands are useful to understand the impacts of CC in groundwater dependent ecosystems.
The knowledge of these impacts (groundwater levels and dependent ecosystems) allows us to establish and assess adaptation measures, which are defined in the framework of a participatory process that includes all groundwater users of the area.

5.1. Climate data: TACTIC standard CC scenarios

The TACTIC standard scenarios show differences in the mean value of climatic variables. The mean annual precipitation in the historical period (1974-2015) was 433 mm/year and the mean annual temperature was 14.6 ^{o}C (Herrera et al., 2016). All the CC scenarios estimate an increase in the mean temperature (between 0.8 and 3.1 ^{o}C). The minimum change scenarios (1 and 3 degree) show a decrease in mean annual precipitation (drier conditions) whereas the maximum change scenarios (1 and 3 degree) show an increase in this variable (wetter conditions).

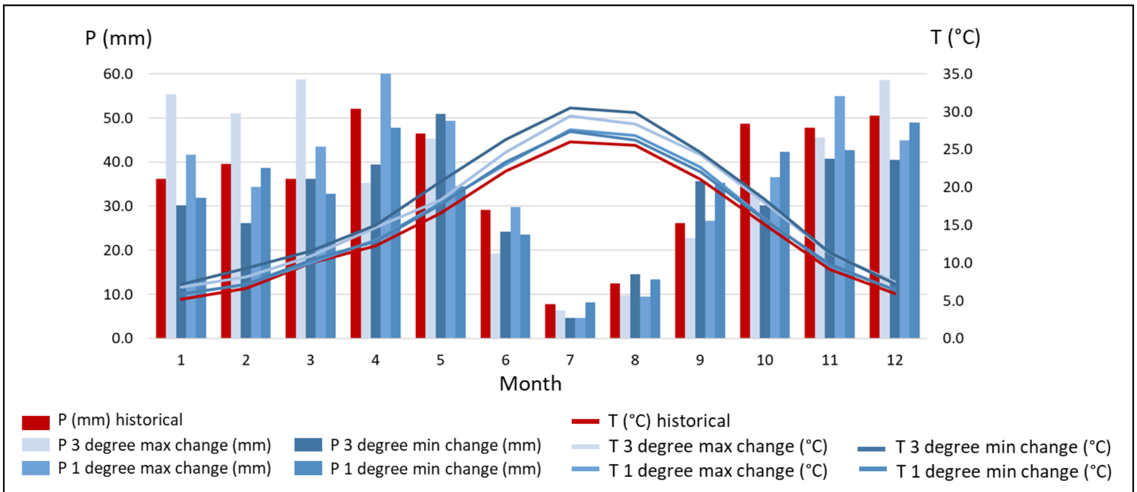


Figure 5.1: Monthly mean historical and future estimated climatic variables (precipitation P (mm) and temperature T (^{o}C)) for the four TACTIC standard CC scenarios.

5.2. Integrated hydrological modelling of CC (method 1)

The results generated by the TACTIC standard scenarios are consistent for the minimum and maximum changes between the 1 and 3 degree scenarios. The minimum change shows "drier" conditions in the future and the maximum changes show "wetter" conditions in the future. As expected, the 3 degree minimum scenario is the most extreme and therefore, it will cause a higher decrease in rainfall recharge (figure 5.2).

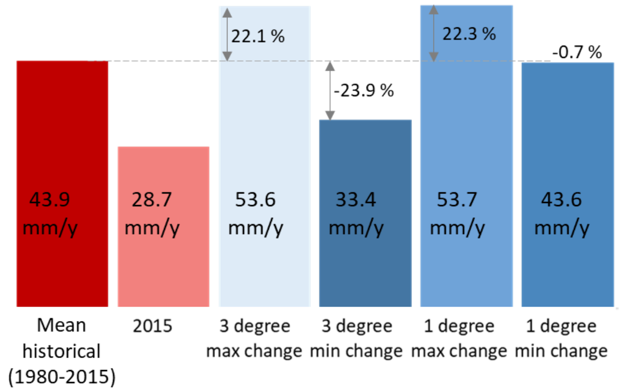


Figure 5.2: Recharge obtained by SAC-SMA models and change (Δ%) caused by CC scenarios regarding to the mean historical recharge.

The MS simulated by using CROPWAT model also show different results depending on the CC scenario (Figure 5.3), although all of them move in the same direction regarding the reference year (2015).

Although maximum change scenarios (1 and 3 degree) estimate an increase in groundwater recharge, the increase in the mean annual temperature will produce higher crop water requirements. If the pumping schedule is maintained in the future as in the year 2015 (MS 1), the CC will led to decrease the irrigation area. The reduction in the irrigation area will be larger in the most extreme CC scenario (3 degree, minimum change) and it will be smaller under the 1 degree maximum change scenario.

The MS 2 will require an increase of groundwater abstractions in order to maintain the irrigation area as in 2015. Under this MS, 3 degree minimum change CC scenario will mean the highest increase in pumping whereas 1 degree maximum change CC scenario will imply the smallest increase in pumping.

Although the 3 degree maximum change scenario estimates a significant increase in future groundwater recharge, the strong increase in mean temperature (2.3 °C above the historical mean temperature) will imply a drastic reduction in the irrigation area (MS 1) or a large increase in pumping (MS 2), depending on the MS. On the contrary, the 1 degree minimum change scenario estimates a slight reduction in future groundwater recharge (regarding the mean historical) and the small increase in the mean temperature (0.8 °C above the mean historical temperature) will contribute to moderate changes in both irrigation area and pumping in the future.

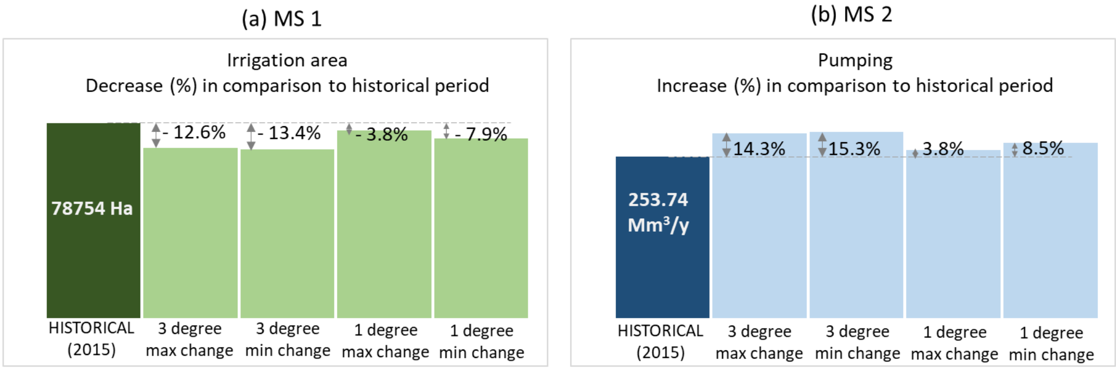


Figure 5.3: Changes (%) in irrigation area (a) and pumping (b) regarding to the reference year (2015) caused by CC scenarios.

Figure 5.4 shows the distributed impacts of the most adverse CC scenario (3 degree minimum change) on the pumping and/or the irrigated area under the two MS. All the groundwater bodies will experiment similar changes in irrigation area and pumping except La Obispalía, which will require a large increase in pumping to maintain the irrigation area as in 2015.

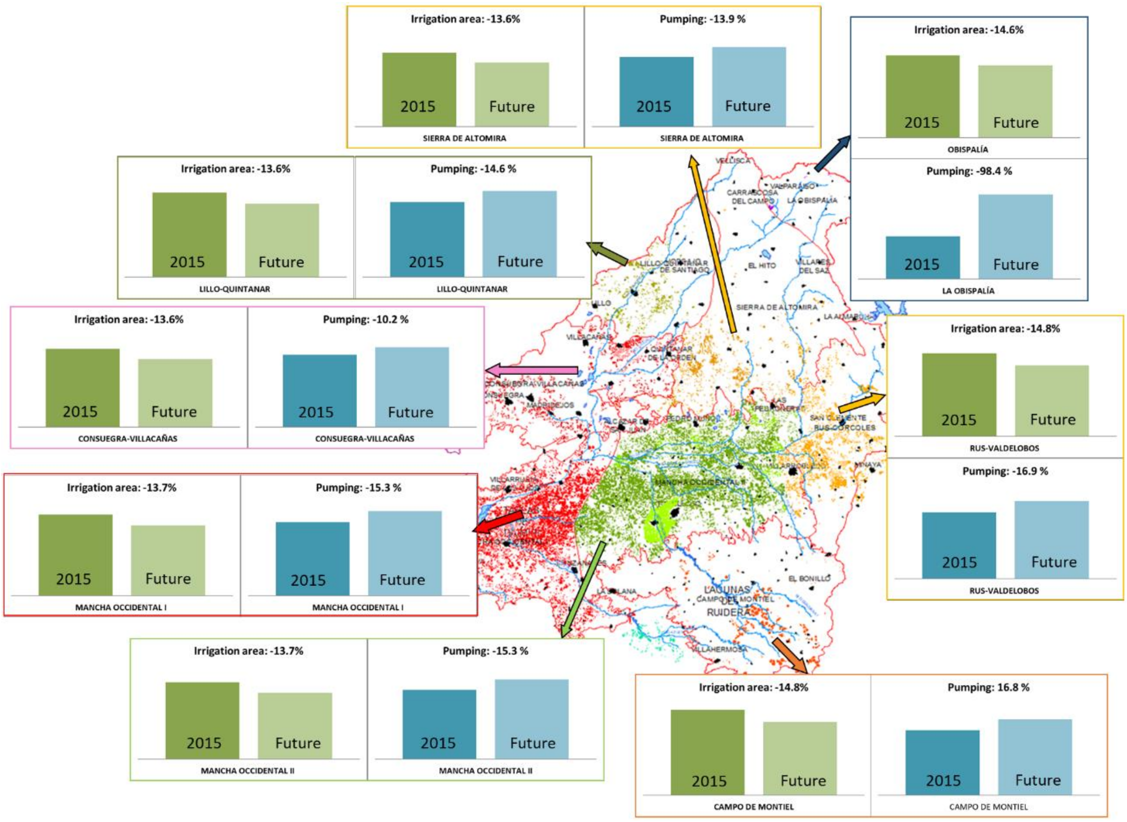


Figure 5.4: Impacts of 3 degree, minimum change CC scenario on irrigation area and pumping regarding the reference year (2015).

These MS and CC scenarios will reflect their impacts in the groundwater levels producing changes of different magnitude and direction (Figure 5.5).

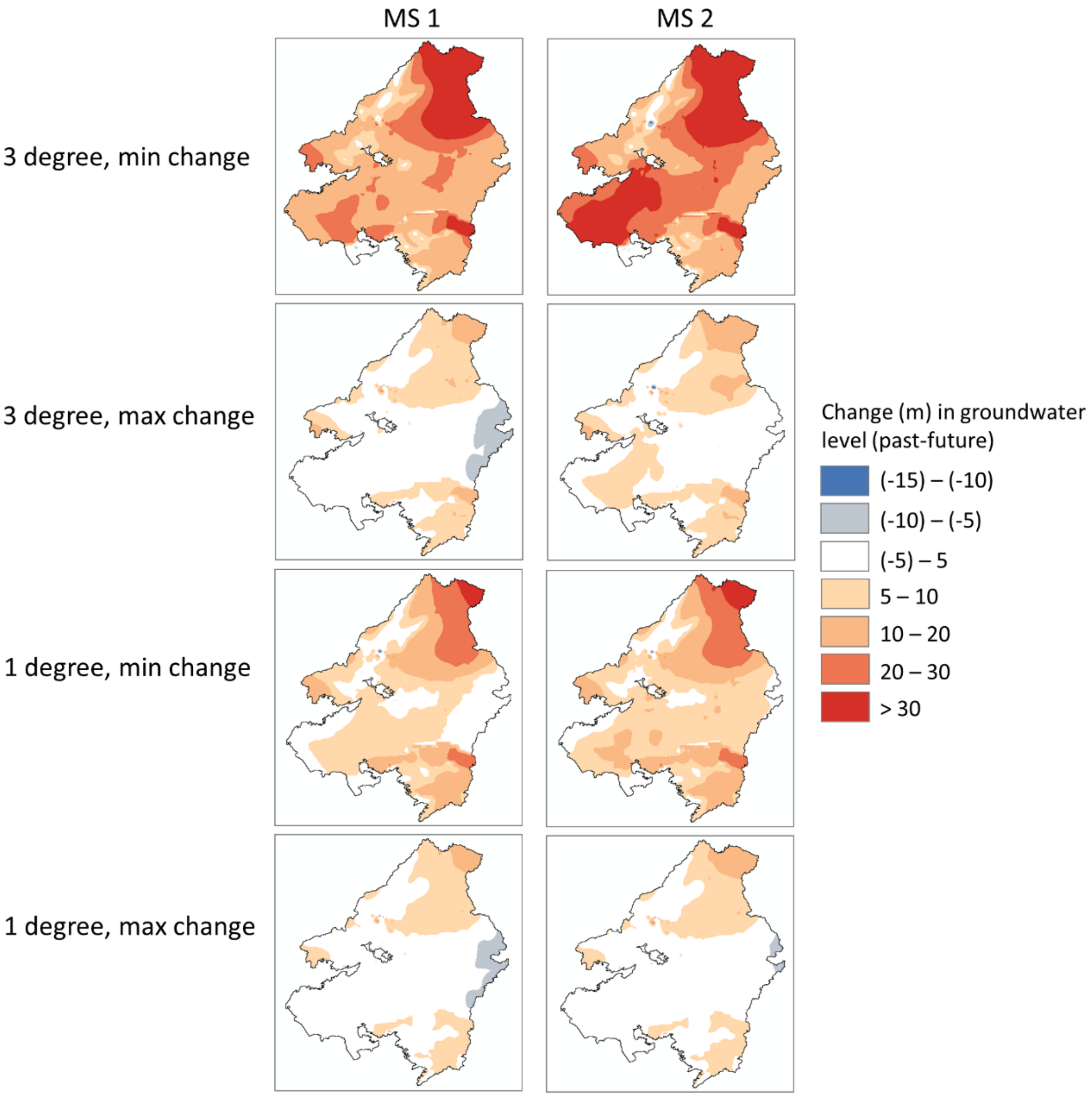


Figure 5.5: Maximum changes regarding 2015 in groundwater levels simulated with the 4 TACTIC standard scenarios

The minimum change scenarios shows "drier" conditions (lower groundwater levels) in the future regarding the maximum change scenarios (1 degree and 3 degree). Maximum change scenarios show "wetter" conditions (higher groundwater levels) in the future in some zones in the pilot area. As expected, the 3 degree scenarios are more extreme for both the minimum and maximum change than the 1 degree scenarios.

In general, the most adverse scenario would be 3 degree maximum change CC scenario in combination with the MS 2. On the contrary, the MS 1 under the 1 degree maximum change scenario would be the most favourable. For this scenario, a large area will maintain the groundwater level as the past (or it will experiment slight changes, between (-5) – 5 meters).

Under this scenario, some aquifers mainly in northern and southern areas will decrease the groundwater level and a small area in the east will increase the groundwater level.

5.3. Estimation of the dynamic of surface water in wetlands (method 2)

The ensemble of regression models calibrated in Lagunas de Ruidera wetland area (Campo de Montiel, UGB) is used to estimate the water surface under CC scenarios. Figure 5.6 shows the future estimation for the most extreme CC scenario (3 degree, minimum change). The water surface is expressed in pixels with a resolution of 30x30 m. This CC scenario will involve a decrease of the water surface of 12.6% regarding the mean historical water surface. It might lead the disappearance of the smallest lagoons in this area.

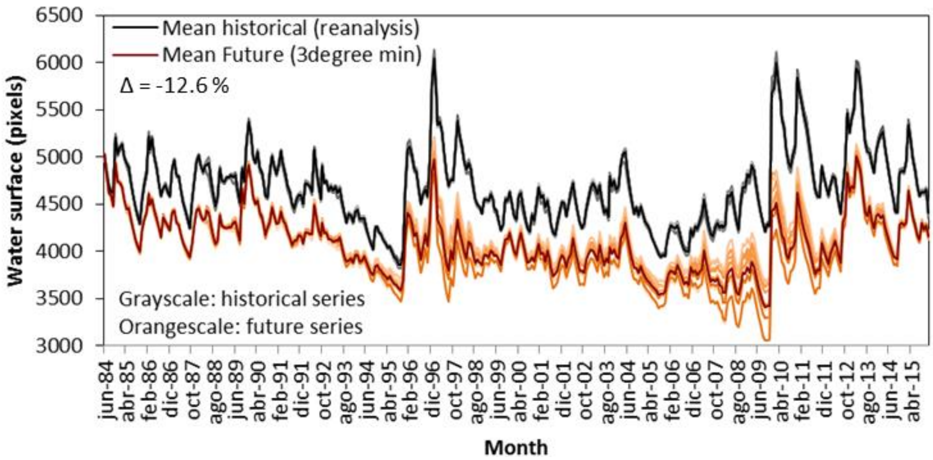


Figure 5.6: Monthly time series of the surface water for the historical period and future estimation

5.4. Adaptation strategies to CC (method 3)

In the workshop held with skateholders in the UGB, the participants discussed the main environmental, social, economic characteristics and the expected evolution of some indicators of the three proposed local scenarios. Most of the participants were aware of the need to preserve the groundwater status and dependent ecosystems and they revealed the importance of the wetlands to the region development.

Some of the most valued adaptation strategies in the workshop were the land use change through the development of other activities and the improvement of the control of the extractions, among other measures (innovation, optimization of crop water use, etc).

Some of these measures will lead to a reduction of the irrigation area, which could be materialized through the MS 1 described in Sections 4.2 and 5.2.

Figure 5.5 shows that MS 1 will help to counter the CC impacts and it will be possible to maintain and/or increase the groundwater levels in some areas in the UGB.

The impacts of the reduction of the irrigated area are also analysed in terms of discharge to wetlands in Figure 5.7.

These results are also consistent for the minimum and maximum changes between the 1 and 3 degree scenarios. Two CC scenario (3 degree, minimum change and 1 degree, minimum change) show a decrease in groundwater discharge to wetlands regarding the discharge in the reference year (2015). Although the recharge in 2015 was notably lower than the mean historical, the groundwater bodies have experimented a recovery due to the decrease in pumping since 2010 (see Figure 3.9). However, in the past (1980-2015), the overexploitation in the UGB lead to some wetlands to disappear due to the reduction in the discharge.

Under the MS1, the CC scenarios with higher recharge will experiment also an increase in discharge to wetlands.

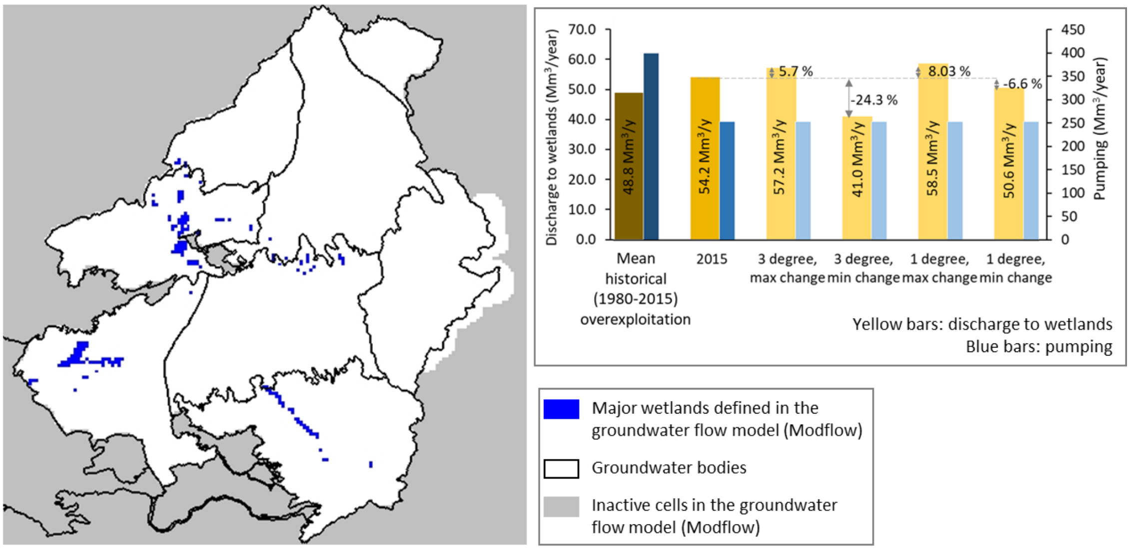


Figure 5.7: Location of the major lagoons in the UGB and mean future groundwater discharge to wetlands simulated with the 4 TACTIC standard scenarios

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