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PILOT DESCRIPTION AND ASSESSMENT

Segura Basin

Authors and affiliation:

Juan de Dios Gómez-Gómez, A.J. Collados-Lara, David Pulido-Velazquez, Leticia Baena-Ruiz,.

Geological Survey of Spain (IGME)



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LIST OF ABBREVIATIONS & ACRONYMS

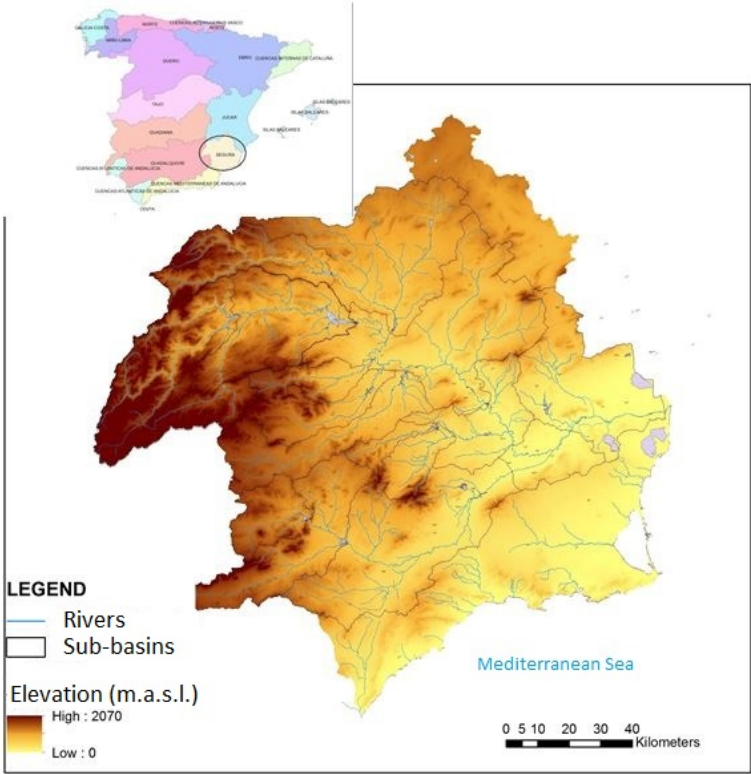
SB: Segura Basin

CU: Conjunctive Use

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1 EXECUTIVE SUMMARY

Pilot name	SEGURA BASIN	
Country	Spain	
EU-region	Mediterranean region	
Area (km ²)	14778 km ²	
Aquifer geology and type classification	Detrital and carbonated. Sedimentary & karstic.	
Primary water usage	Irrigation / Drinking water / Industry	
Main climate change issues	This coastal basin is an example of a Mediterranean area with a significant water demand, mainly for irrigation but also for urban supply (with an important seasonal component for the touristic sector), and low availability of resources. The supply reliability in this case depends on an appropriate conjunctive use (CU) operation of resources taking into account the interaction between surface and groundwater resources. In fact, it is a deficitary system that needs water transfers from Tagus Basin and additional supply from desalination plants. Global change will exacerbate these problems by reducing the availability of resources and increasing irrigation requirements (higher temperatures and lower precipitations). It will also cause an increase in the magnitude and frequency of extreme phenomena such as floods and droughts. An integrated analysis of future climate change impacts and adaptation strategies based on some indexes obtained from the results of a system management model is proposed to help in the decision making process.	
Models and methods used	Generation of local future climate change scenarios to analyse droughts following the method proposed in the framework of this project (Collados-Lara et al., 2018) and definition of adaptation scenarios. Propagation with a chain of auxiliary models (recharge, agricultural) to generate inputs for a CU management model at basin scale, defined with the AQUATOOL code; Assessment of different types of drought and its propagation.	

Key stakeholders	Segura River Basin Authority, farmers associations, Canal del Taibilla (public water supply company), Regional Authorities, Environmental Conservation Groups.
Contact person	J.D. Gómez, D. Pulido, L. Baena, A.J. Collados. IGME (Spain): j.dedios@igme.es; d.pulido@igme.es; l.baena@igme.es; aj.collados@igme.es

This pilot is an example of a Mediterranean coastal basin with a significant water demand, mainly for irrigation but also for urban supply (with an important seasonal component for the touristic sector), and low availability of resources. The supply reliability in this case depends on an appropriate conjunctive use (CU) operation of resources taking into account the interaction between surface and groundwater resources. In fact, it is a deficitary system that needs water transfers from Tagus Basin and additional supply from desalination plants. Global change will exacerbate these problems by reducing the availability of resources and increasing irrigation requirements (higher temperatures and lower precipitations). It will also cause an increase in the magnitude and frequency of extreme events such as floods and droughts. An integrated analysis of future climate change impacts and adaptation strategies based on some indexes obtained from the results of a system management model is proposed to help in the decision making process.

Local future climate change and adaptation scenarios have been developed to analyse droughts following the method proposed in the framework of this project (Collados-Lara et al., 2018). They have been propagated with a chain of auxiliary models (recharge, agricultural) to generate inputs for a CU management model at basin scale, defined with the AQUATOOL code. Finally different types of drought and its propagation have been assessed.

Results observed for the whole Segura Basin system for the period 2071-2100 show lower resources available to meet the different demand elements, which means higher deficits for that demands. Higher pumping rates in aquifers are estimated for future scenarios and the impacts would also be reflected on lower guarantees to meet demands. The four studied scenarios show important reduction of precipitation and increase of temperature and large increments of the number, duration, intensity and magnitude of droughts. The study of the correlation of hydrological and meteorological droughts shows significant correlations for a gap from 0 to 6 months depending of the scenario considered. However the correlation of meteorological and operational droughts shows a maximum of correlation for a gap around 4 months for all cases.

2 INTRODUCTION

Climate change (CC) already have widespread and significant impacts in Europe, which is 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 climate change 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 and identification and analyses of potential adaptation strategies.

TACTIC is centred around 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 Segura basin pilot is one of the basin scale pilots that have been analysed in Tactic, focusing on climate change impacts and adaptation strategies with special attention to the propagation of drought events. So the main challenge of the pilot is to perform an integrated analysis of future climate change impacts and adaptation strategies based on some indexes obtained from the results of a system management model.

3 PILOT AREA

The Segura basin is a representative case of a Mediterranean basin with semi-arid climate. It is located in one of the driest regions of Spain, with low availability of resources but significant water demand. Agriculture is the main socioeconomic activity in the middle and lower basin together with the touristic activity in the coast. The supply reliability in this case depends on an appropriate conjunctive use (CU) operation of surface and groundwater resources. In fact, it is a deficitary system that needs water transfers from Tagus Basin (in Central Spain), causing social conflicts between regions, and additional supply from desalination plants. This problem might be exacerbated in the future due to climate change impacts (higher temperatures, lower precipitations and more extreme phenomena). So the aim of this case study is to perform an integrated analysis of future climate change impacts and adaptation strategies based on some indexes obtained from the results of a system management model.

3.1 Site description and data

- Location, extension and topography of the pilot area

The case study cover and area of 14778 km² located in Southeastern Spain, in the Mediterranean region of the EU (See Fig. 3.1). The River Segura is the main stream of the basin together with its tributaries Mundo, Argos, Quípar, Mula and Guadalentín. The main city of the system is Murcia with a population of 440,000 inhabitants, and also Alicante (330,000) is partially supplied by the system.

The altitude ranges from 2070 m.a.s.l. at the Sierra de Segura mountains (Northwest) to 0 m.a.s.l. at the seashore.

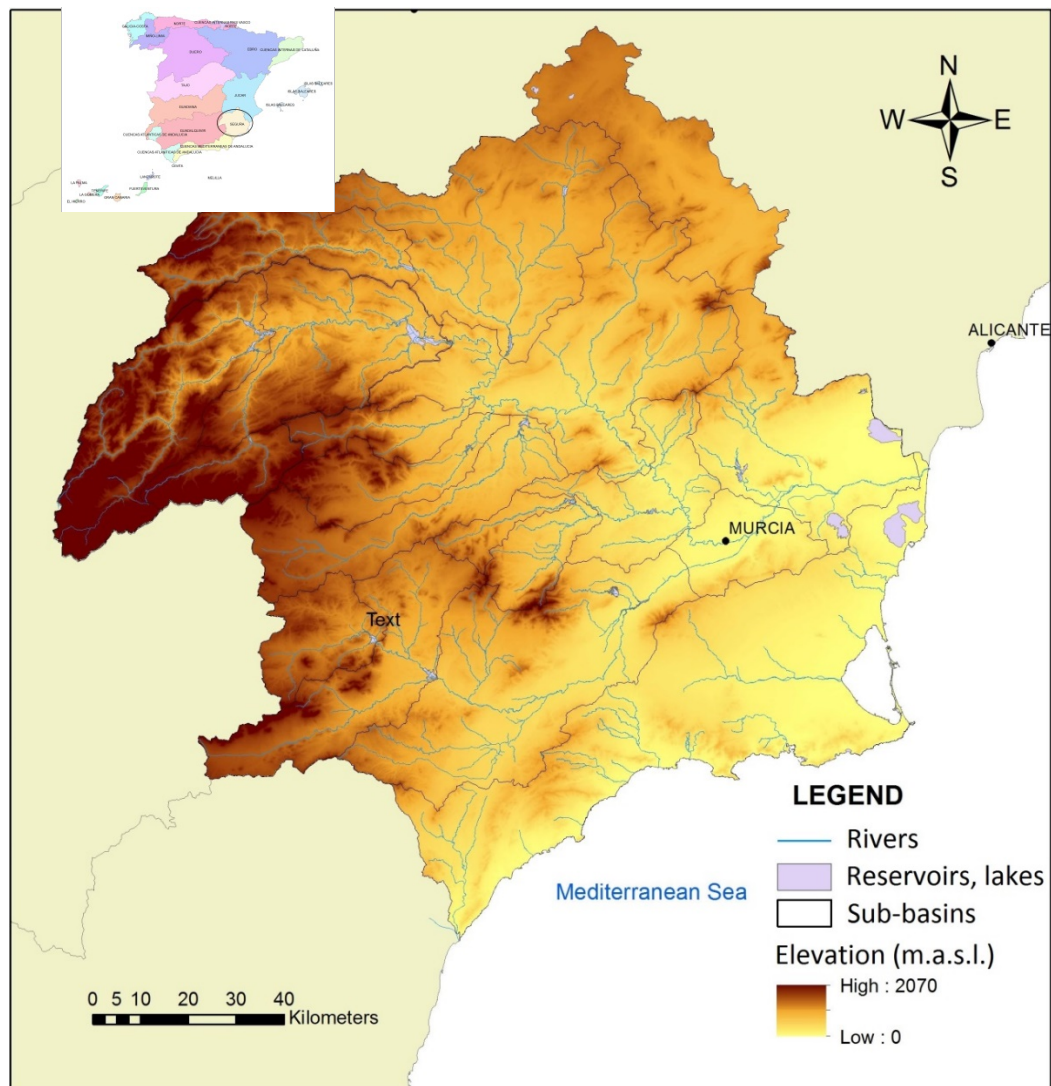


Fig. 3.1. Location of the pilot area

- Geology/Groundwater bodies type

The Segura Basin is almost totally included in the geological domain of the Bética Mountain Range. Only in its northern part, materials from the tabular cover overlying the Hercynian basement can be found. The Bética Mountain Range is the group of mountain chains generated by the Alpine folding that extends across Andalusia, Murcia and south of Valencia.

A total of 60 GW bodies are included in the Segura Basin, with a complex geology and different lithologies such detrital as carbonate and mixed (see Fig. 3.2).

One of the main groundwater bodies in the system is the Middle-Lower Segura Plain, a Plioquaternary aquifer located in the lower part of the basin, partially connected to the sea,



wich concentrates most of the urban and agricultural water demands of the system. It has been thoroughly studied and described, and several models have been developed.

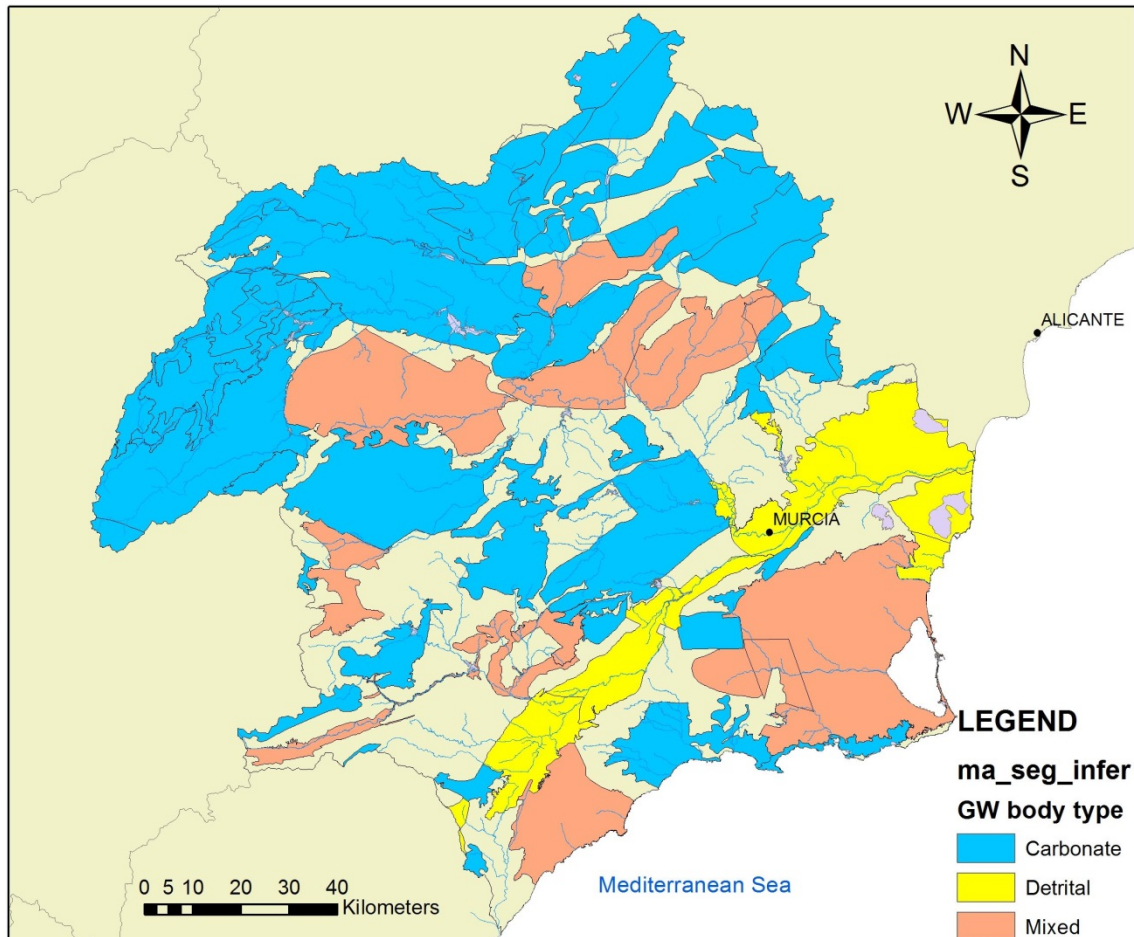


Fig. 3.2 Groundwater bodies type

CODE	NAME	EXTENSION (KM2)	GROUP	TIPOLOGY
070.001	CORRAL RUBIO	170	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.002	SINCLINAL DE LA HIGUERA	210	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.009	SIERRA DE LA OLIVA	73	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.005	TOBARRA-TEDERA-PINILLA	151	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.008	ONTUR	155	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.004	BOQUERÓN	283	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.007	CONEJEROS-ALBATANA	159	CARBONATE	Folded sedimentary (Mesozoic and



				Cenozoic)
070.013	MORATILLA	29	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.012	CINGLA	379	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.003	ALCADOZO	505	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.024	LÁCERA	8	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.023	JUMILLA-YECLA	264	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.010	PLIEGUES JURÁSICOS DEL MUNDO	985	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.006	PINO	48	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.011	CUCHILLOS-CABRAS	209	MIXED	Carbonate and detrital
070.027	SERRAL-SALINAS	97	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.017	ACUIFEROS INFERIORES DE LA SIERRA DE SEGURA	1524	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.021	EL MOLAR	288	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.022	SINCLINAL DE CALASPARRA	332	MIXED	Carbonate and detrital
070.025	ASCOY-SOPALMO	369	MIXED	Carbonate and detrital
070.026	EL CANTAL-VIÑA PI	40	MIXED	Carbonate and detrital
070.029	QUIBAS	137	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.028	BAÑOS DE FORTUNA	86	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.020	ANTICLINAL DE SOCOVOS	751	MIXED	Carbonate and detrital
070.030	SIERRA DEL ARGALLET	6	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.031	SIERRA DE CREVILLENTE	20	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.036	VEGA MEDIA Y BAJA DEL SEGURA	705	DETRITAL	Alluvial, litoral and other Pliocuaternal deposits
070.035	CUATERNARIO DE FORTUNA	19	DETRITAL	Alluvial, litoral and other Pliocuaternal deposits
070.034	ORO-RICOTE	66	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.032	CARAVACA	677	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.033	BAJO QUÍPAR	61	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.040	SIERRA ESPUÑA	630	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.019	TAIBILLA	69	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)



070.042	TERCIARIO DE TORREVIEJA	169	DETRITAL	Tabular detrital from Neogene basins
070.041	VEGA ALTA DEL SEGURA	27	DETRITAL	Alluvial, litoral and other Pliocuaternary deposits
070.039	BULLAS	279	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.018	MACHADA	43	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.038	ALTO QUÍPAR	181	MIXED	Carbonate and detrital
070.051	CRESTA DEL GALLO	25	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.053	CABO ROIG	62	DETRITAL	Alluvial, litoral and other Pliocuaternary deposits
070.052	CAMPO DE CARTAGENA	1240	MIXED	Carbonate and detrital
070.037	SIERRA DE LA ZARZA	17	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.050	BAJO GUADALENTÍN	324	DETRITAL	Alluvial, litoral and other Pliocuaternary deposits
070.055	TRIÁSICO DE CARRASCOY	108	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.047	TRIÁSICO MALÁGUIDE DE SIERRA ESPUÑA	30	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.048	SANTA-YÉCHAR	42	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.043	VALDEINFIERNO	152	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.049	ALEDO	73	MIXED	Carbonate and detrital
070.046	PUENTES	121	MIXED	Carbonate and detrital
070.054	TRIÁSICO DE LOS VICTORIA	110	MIXED	Carbonate and detrital
070.045	DETRÍTICO DE CHIRIVEL-MALÁGUIDE	93	MIXED	Carbonate and detrital
070.044	VÉLEZ BLANCO-MARÍA	72	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.057	ALTO GUADALENTÍN	275	DETRITAL	Alluvial, litoral and other Pliocuaternary deposits
070.058	MAZARRÓN	284	CARBONATE	Metamorphic
070.063	SIERRA DE CARTAGENA	66	CARBONATE	Metamorphic
070.061	ÁGUILAS	379	MIXED	Carbonate and detrital
070.056	SIERRA DE LAS ESTANCIAS	7	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)
070.059	ENMEDIO-CABEZO DE JARA	50	CARBONATE	Metamorphic
070.060	LAS NORIAS	18	DETRITAL	Alluvial, litoral and other Pliocuaternary deposits
070.062	SIERRA DE ALMAGRO	20	CARBONATE	Folded sedimentary (Mesozoic and Cenozoic)

Table 3.1. Groundwater bodies in the SB system.

- **Surface water bodies**



The River Segura is the main stream of the basin together with its tributaries Mundo, Argos, Quípar, Mula and Guadalentín. Traditionally, surface water in this basin has been strongly regulated due to the water scarcity in the region and the extreme events (such droughts as floods) that historically have affected it. A complex network of reservoirs and canals has been set up in the system to regulate internal and external water resources (water transfer from Tagus basin), and more recently to also incorporate desalination resources.

So the flow series measured at most gauges are in altered regime, and only in the upper basin can be found a natural regime. However the series have been restored to natural regime by the River Basin Authority and in some IGME project.

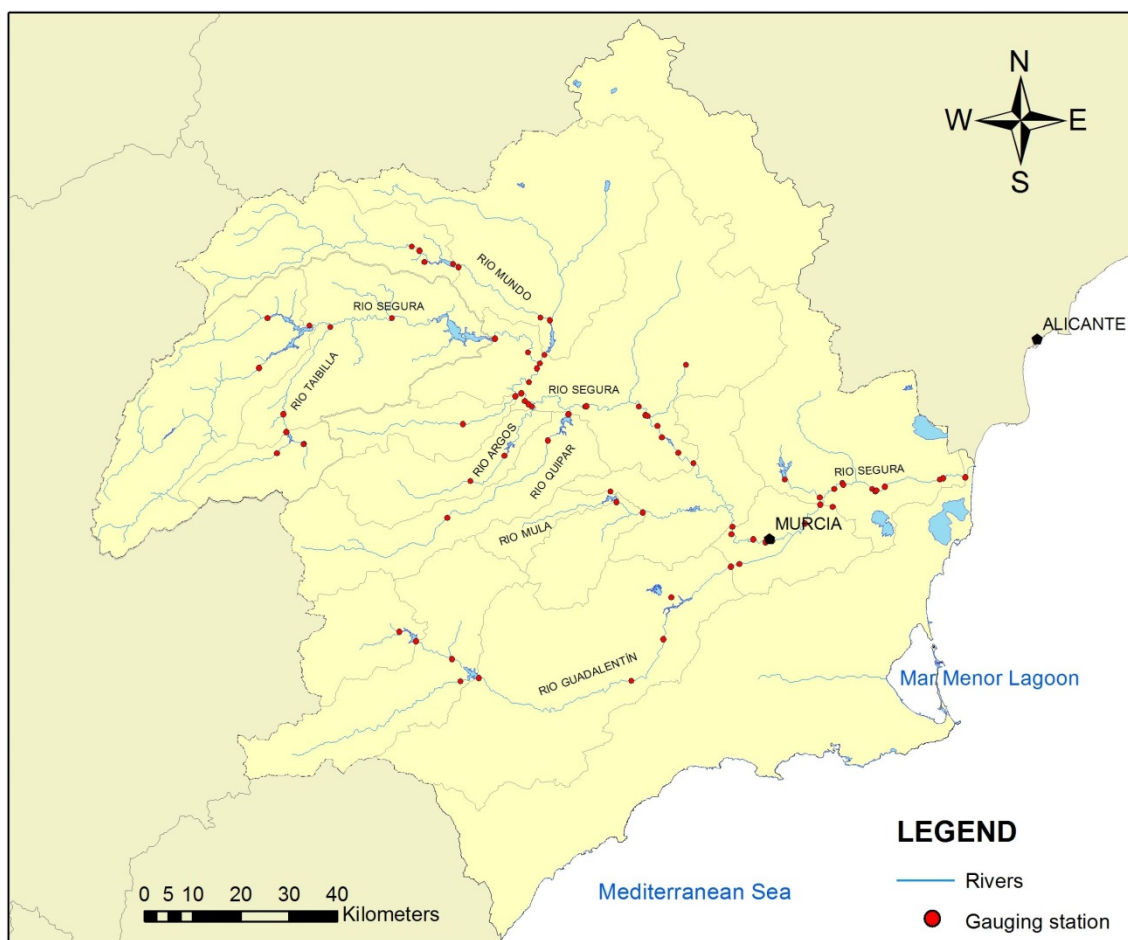


Figure 3.3. Surface water bodies and stream gauges.

- ***Climate***

- ***climate type***

The general predominant climate in the Segura Basin is Mediterranean, with specific typologies in different areas. So half of the basin, the highest lands at the North and West, has a temperate Mediterranean climate. At middle altitudes the climate becomes continental Mediterranean, and at the rest of the territory (second in



extension) it is subtropical Mediterranean, except in a coastal strip at the South where it is semi-arid subtropical Mediterranean (CHS, 2018).

- *precipitation, temperature and evapotranspiration*

The annual average rainfall in the basin is 382 mm according to historical series (1940/41-2005/06) and 362 mm considering the short period (1980/81-2005/06). The regime of precipitation is extremely variable in space and time, with clear differences between the upper and lower basin.

The mean potential evapotranspiration is around 700 mm and the mean real evapotranspiration is estimated about 328 mm for the long period series. The overall mean runoff has been calculated as 13% of the overall mean precipitation, which is the lowest in the Iberian Peninsula.

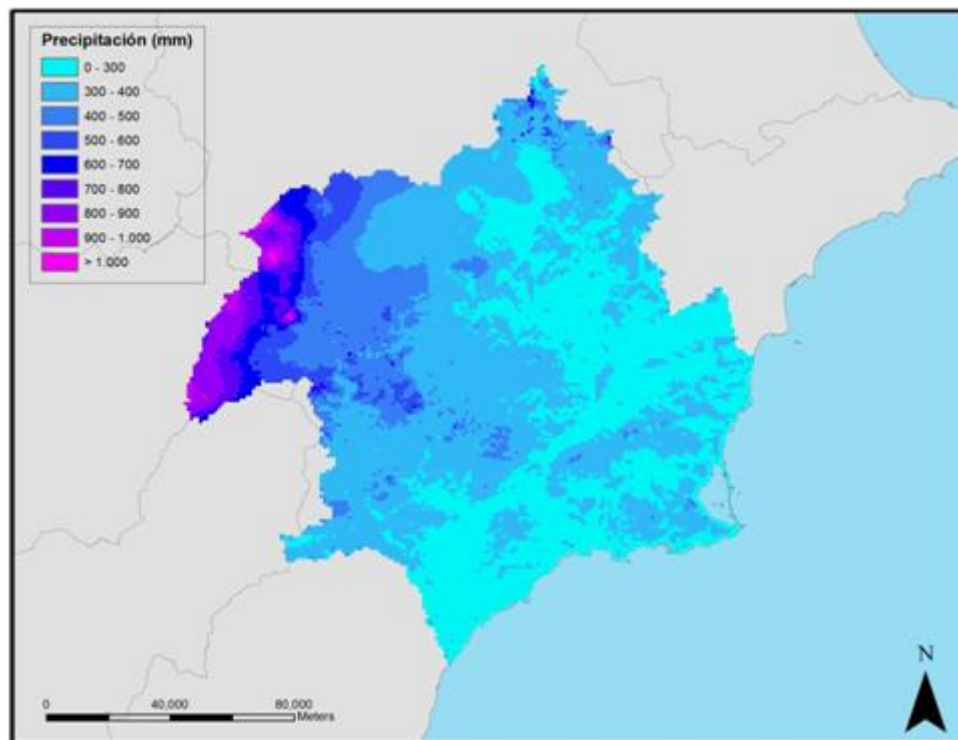


Figure 3.4. Mean annual precipitation distribution in the Segura Basin District (CHS, 2018)

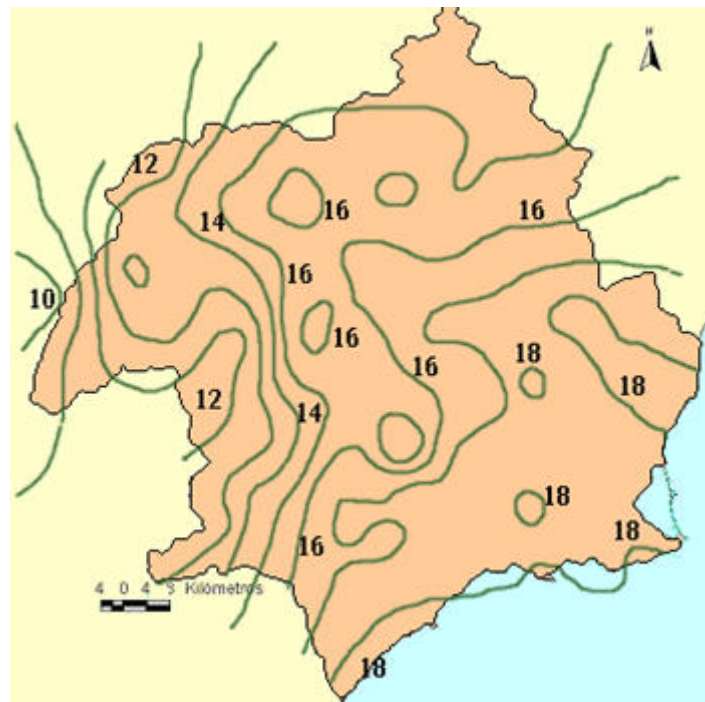
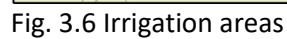


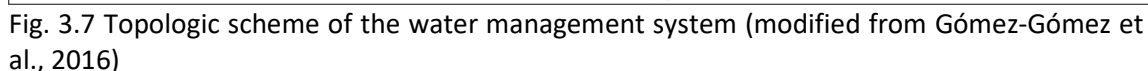
Figure 3.5. Mean annual temperature distribution in the Segura Basin District (CHS, 2018)

- Land use

The main socioeconomic activity is irrigated agriculture, traditionally concentrated in the alluvial and coastal plains. The main crops are citrus and fruit trees, and also green and other vegetables.



This complex conjunctive use system includes different types of water resources such as groundwater, surface water, external water transfer from Tagus basin (Central Spain) and unconventional resources (wastewater reuse and desalination). The system integrates a network of reservoirs and canals in order to regulate and distribute such resources and meet the different demands. The simplified topologic scheme of the lower part of the system shows such complexity (see Fig. 3.7).



In accordance with the EEA map the main expected issues due to climate change in this case study are those described in the Figure 8 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., 2018)



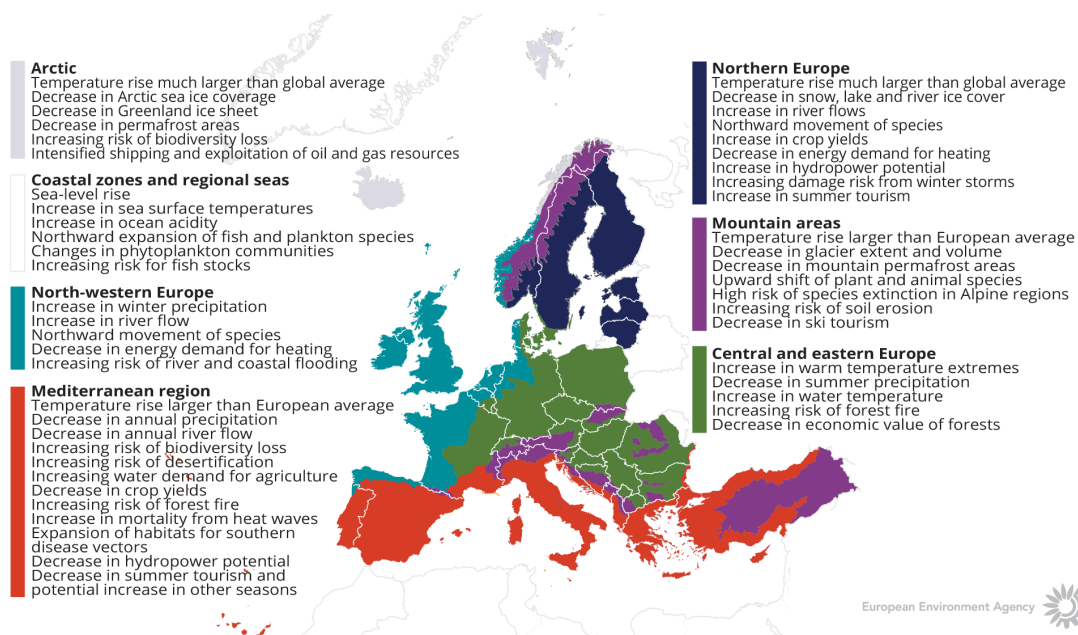


Figure 3.8. How is climate expected to change in Europe. The European Environment Agency map

4 METHODOLOGY

The assessment of climate change impacts on the Segura basin water resources management system (groundwater, surface water and alternative water sources) have been performed using the climate change scenarios from Euro-Cordex (RCP8.5 emission scenario) and the integrated hydrological management model of the basin. The Segura Basin management model is based on the AQUATOOL code, coupled with a rainfall-runoff model (Temez) and a CROPWAT model for irrigation demands assessment (TACTIC toolbox reference).

4.1 Climate data

The present pilot study relies on the Euro-CORDEX regional climate models to reflect future climate conditions. The TACTIC standard CC scenarios have not been used for this pilot.

4.1.1 Euro-CORDEX climate change scenarios

Future climatic series (temperature and rainfall) have been generated applying a statistical downscaling technique for the period 2071-2100. The applied method have been “delta-change” type. It intends to obtain series considering the differences between control and future of the regional climate models and to apply them to the historical series (Fowler et al., 2007). More specifically we have been followed the methodology proposed by Pulido-Velazquez et al., 2011.

The regional information about climate change has been got from CORDEX project, which has resolution about 12,5x12,5 Km for version EUR-11. In this project four emissions scenarios are considered. They are called Representative Concentration Pathways (RCP) and they are related to a possible range of radiative forcing (FR) values in the year 2100 depending on CO2 concentration values. The most pessimistic scenario (RCP8.5) has been considered in this study.

Nine regional climate models nested to different global climate models (see Table 4.1), with RCP 8.5 emission scenario, were used to assess future conditions for the Segura Basin pilot area.

Table 4.1. Euro-CORDEX climate change ensemble.

RCM \ GCM	CNRM-CM5	EC-EARTH	MPI-ESM-LR	IPSL-CM5A-MR
CCLM4-8-17	X	X	X	
RCA4	X	X	X	
HIRHAM5		X		
RACMO22E		X		
WRF331F				X

We tested several statistical techniques to generate local scenarios from the considered RCMs (correction of first- and second-order moments, regression approach, quantile mapping) under two different conceptual approaches: bias correction and delta change techniques. The bias corrections intend to apply a perturbation of the control series obtained with the RCM



simulations to reduce their statistical differences with the historical ones. Future series will be generated by assuming that this bias with the real values will be maintained invariant also in the future. The delta change corrections are defined by using the relative difference in the statistic of future and control of the RCM simulations to perform a perturbation of the historical series in accordance with these estimated changes. It assumes that the RCM simulation approach properly the deltas due to climate change, but not the absolute values. We considered four options to define the most representative future scenarios by applying different ensembles of the potential scenarios deduced from the available climate models. Two ensemble scenarios were considered by combining, as equi-feasible members, all the future series (that correspond to different RCM simulations) generated by delta change (E1) or bias correction (E2). Two other options were defined by combining only the non-eliminated models (E3) (in delta change approach) or the non-eliminated combinations of models and correction techniques (E4) (bias correction techniques), assuming that we do not trust on the eliminated ones. We eliminated the projections considered as 'inferior' in terms of goodness of fit (see detail of the method in Collados-Lara et al., 2018). The criteria employed to identify the inferior approaches is the next one: An approach is inferior if any other approach provides approximations significantly better for all the statistics (basic and drought statistics).

4.1.2 Differences between the TACTIC standard CC scenarios and the used Euro-CORDEX climate change scenarios

The methodology of the assessment of climate change impacts on groundwater conditions are slightly different between the TACTIC standard scenarios and the Euro-CORDEX ensemble. Whereas the TACTIC scenarios apply four selected scenarios representing a 1 and 3 degree temperature change in the 2nd most dry and 2nd most wet scenario, the Euro-CORDEX uses a larger ensemble with no specific attention to most wet or dry scenario. Furthermore, the TACTIC scenarios are not targeted to a specific future time-period but to a specific temperature rise relative to the reference period, of 1 and 3 degrees, respectively. The Euro-CORDEX scenarios targets the specific time-period of 2071-2100, or the changes between this future period and the reference period. The reference period for the CORDEX approach has been 1971-2000.

There are also additional differences in the application of climate model scenario data in forcing of the hydrological models. The TACTIC scenarios apply local datasets of precipitation, temperature and reference evapotranspiration to which the delta change factors are multiplied (or added) to generate the dataset representing the future conditions. Therefore, the dynamics between different events (e.g. numbers of rainy days) in the historical dataset are transferred to the dataset representing the future. With the approach for applying the Euro-CORDEX ensemble, the output from the climate models, is used for both the reference and future periods, and thus dynamics of the input may be projected differently.

4.2 Integrated hydrological management modelling of climate change

The Segura Basin management model is based on the AQUATOOL code, coupled with a rainfall-runoff model (Temez) and a CROPWAT model for irrigation demands assessment (TACTIC toolbox reference).

It is based in a previous integrated model developed for the Vega Baja del Segura system (Gomez-Gomez et al. 2016), and subsequently updated and extended to the whole Segura basin.

4.2.1 Model description

The decision support system of Segura Basin (SB) was developed using the code AQUATOOL, and specifically its module SIMGES (Andreu et al. 1996).

This is a software for integrated management modelling of water resources at a basin scale (similar to MIKE BASIN), appropriate for simulation of the river-aquifer interaction, regulation elements such as reservoirs and aquifers, and many other elements involved in water management such as river flows, demands, return flows, ecological flows, canals and other connections, pumpings and artificial recharge. The simulation uses a monthly time step.

The Segura alluvial plain (Fig. 4.1) aquifer has been integrated in the conjunctive use model by means of a flow model made with the code AQUIVAL, which simulate transient state groundwater flow by the eigenvalues method (Pulido-Velazquez et al. 2007).

The activities carried out to develop the model can be grouped into three phases:

- Characterisation of the SB hydrological system, setting and describing the different elements to be considered, available resources (surface water, groundwater and alternative resources), demands to be met and current hydraulic infrastructures.
- Once the integrated management model was set up with SIMGES, the current management scenario was calibrated and simulated for the historical period.
- The generated future CC scenarios were applied to the model to analyse the impacts on the different elements of the hydrological management system (aquifers, satisfaction of demands, river flows...), with special focus on drought propagation.

Different types of water resources such as groundwater, surface water, external water transfer from Tagus basin (Central Spain) and unconventional resources (wastewater reuse and desalination) have been considered in the model. The system integrates a network of reservoirs and canals in order to regulate and distribute such resources and meet the different demands. The simplified topologic scheme of the lower part of the system shows such complexity (see Fig. 3.7).

A total of 60 GW bodies are included in the Segura Basin integrated management model, with a complex geology and different lithologies such as detrital as carbonate and mixed (see Fig. 3.2). Special attention has been paid to the Middle-Lower Segura Plain, a Plioquaternary aquifer located in the lower part of the basin partially connected to the sea, which concentrates most of the urban and agricultural water demands of the system.

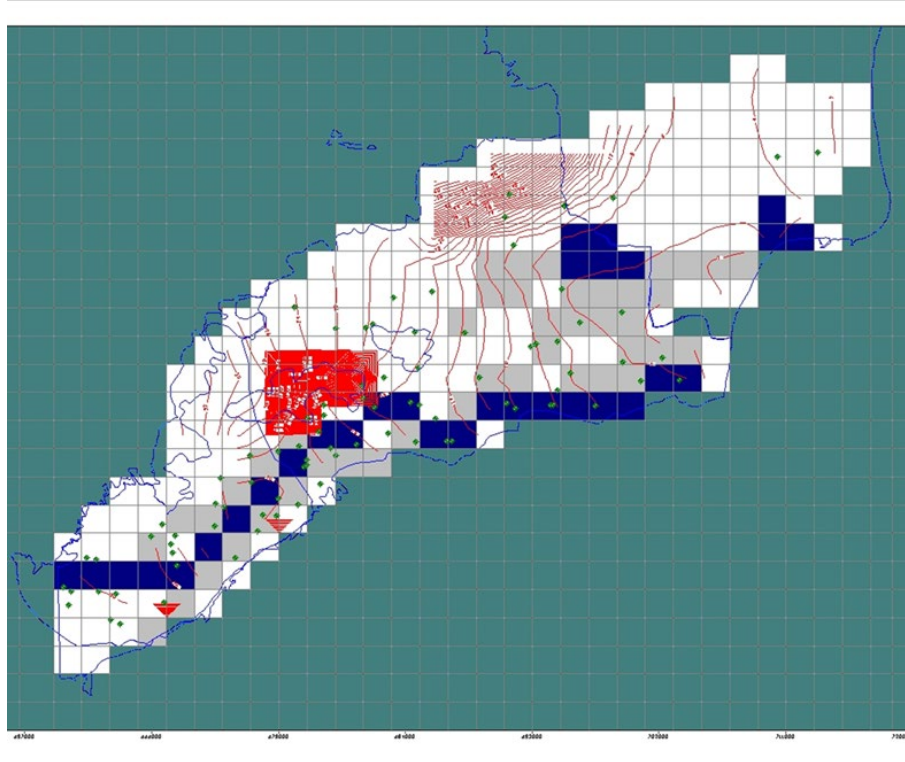


Figure 4.1. Discretization of the Segura alluvial plain aquifer

The basin has been divided into 11 subbasins for different Segura reaches and tributaries: Guardamar, Beniel, Contraparada, Paso de los Carros, Puentes, Baños de Mula, Cenajo, Camarillas, Alfonso_XIII, Argos and Archena. A rainfall-runoff model (Témez) has been developed to calculate river flow series for the subbasins.



Figure 4.2. River subbasins and gauge stations to calibrate TEmEZ model.

A total of 103 demand elements have been included in the model considering urban, industrial, agricultural, environmental and golf demands. Irrigation areas corresponding to agricultural demands are shown in figure 3.6.

Table 4.2. Total annual demands by uses (Mm3)

Urban	Agricultural	Environmental	Industrial	Golf
244.31	1582.38	273.36	10.79	6.20

Surface water regulation infrastructure has also been considered. 15 reservoirs have been included in the model.

4.2.2 Model calibration

The integrated model has been calibrated with a total of 70 gauge stations (Fig. 4.2) for the surface water flow (Temez rainfall-runoff model) and 82 observation wells for the Vega Media-Baja del Segura aquifer (Fig. 4.3).



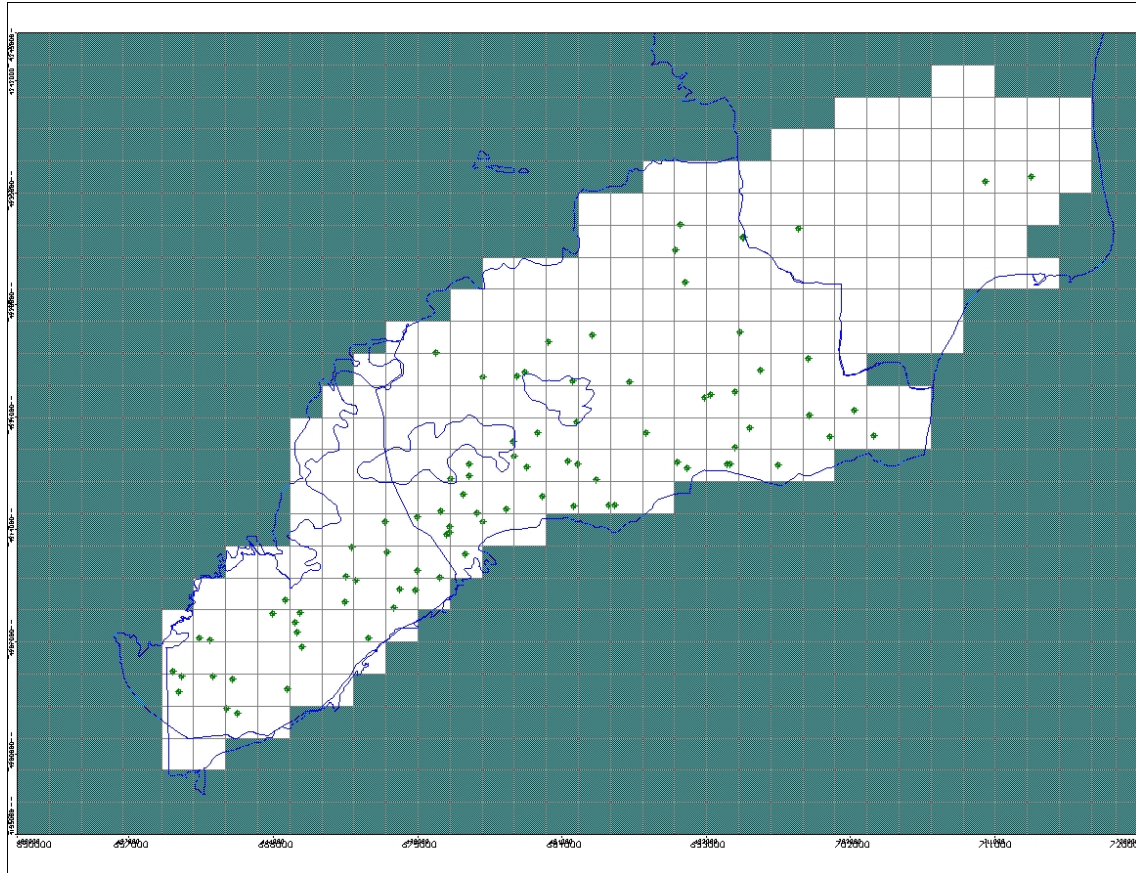


Figure 4.3. Observation wells in Vega Media-Baja del Segura aquifer.

The calibration period was 1994-2010 for the groundwater flow model of Vega Media-Baja del Segura aquifer and 1972-2001 for the rainfall-runoff model of the basin.

Fog 4.4 shows the simulated pezometric levels for September-2010 in Vega Media-Baja del Segura aquifer.



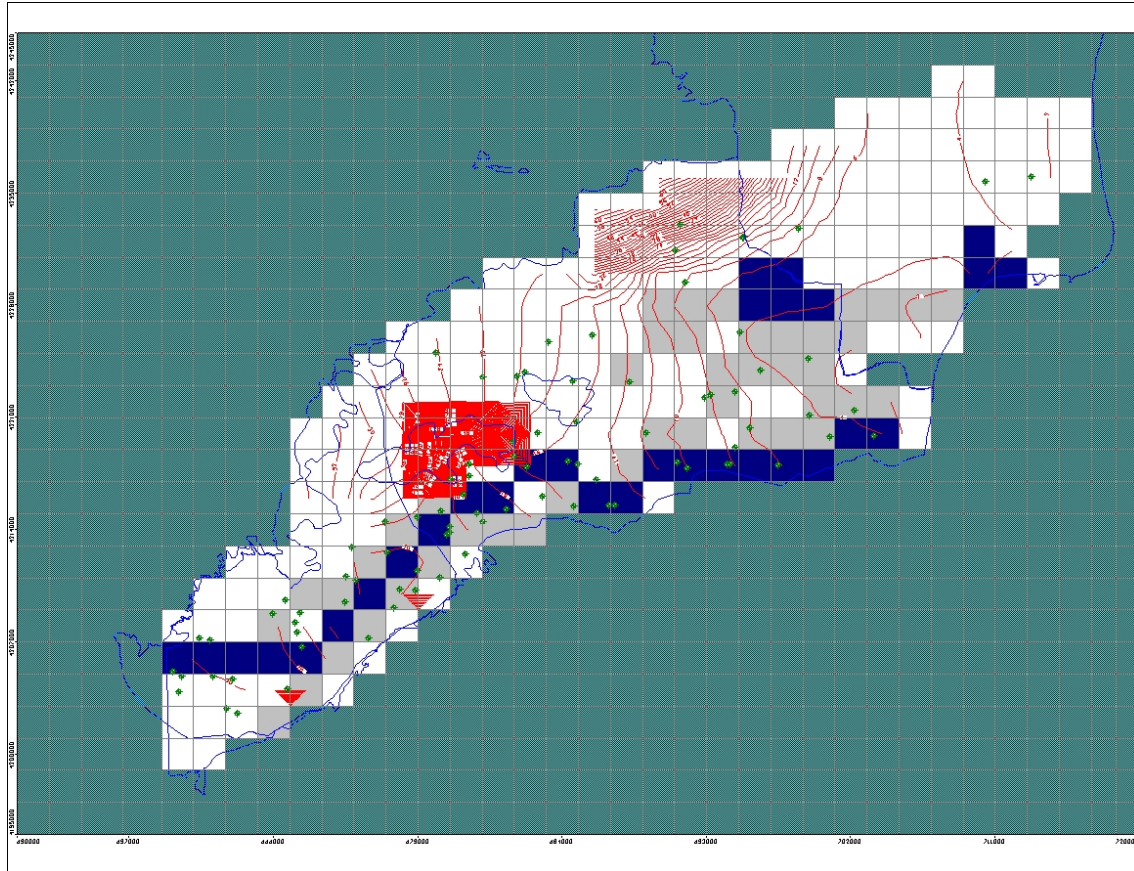


Figure 4.4. Calculated piezometric levels for sep-2010 in Vega Media-Baja del Segura aquifer.

4.3 Assessment of droughts and their propagation

In order to assess meteorological, agricultural and hydrological droughts we will employ the next series of inputs and outputs of the hydrological models: precipitation, humidity and streamflow. The operational drought was assessed by considering a “demand satisfaction index”, which is obtained for each month dividing the total supply by the total demand.

The first step needed to assess droughts from the series of outputs of the model is to aggregate them at a yearly scale for each proposed spatial homogeneous units. For all these aggregated series of results (precipitation, humidity, streamflow, and satisfaction indices) we propose to apply the same statistical procedure, the standard precipitation index (SPI), in order to identify and assess the main statistical properties (duration, magnitude or intensity) of the different types of drought in each spatial unit. Note that the probability of occurrence of precipitation for the SPI calculation, in the control and future simulations, was obtained using parameters calibrated from the observed series, in order to perform an appropriate comparison. From the SPI series, the statistics (number of droughts, duration, magnitude and intensity) were obtained by applying run theory

We also studied the temporal correlation of different kinds of drought assuming different time lags. We intend to identify which is the time lag that provides the best correlation between the meteorological drought and the other types of droughts (agricultural, hydrological and



operational). It allows us to estimate the inertial or time lags between each type of droughts and the meteorological ones.

We also propose to perform a sensitivity analyses to the spatial scale, assessing droughts and temporal correlations also for the whole basin that integrates different homogeneous units.

5 RESULTS AND CONCLUSIONS

5.1 Results based on the integrated hydrological modelling

Once the model was calibrated, the generated future series (P, T) of four climatic scenarios for the period 2071-2100 were applied. Results were obtained for the whole Segura Basin system in terms of lower resources available to meet the different demand elements, which means higher deficits for that demands.

Results were also obtained and analysed with a monthly step on water volumes stored in reservoirs and aquifers, river flows, piezometric levels in Vega Media-Baja aquifer, pumpings, demands and supplies. Propagation of drought events were also analysed for the four future scenarios. All these results were aggregated by subbasins to be analysed.

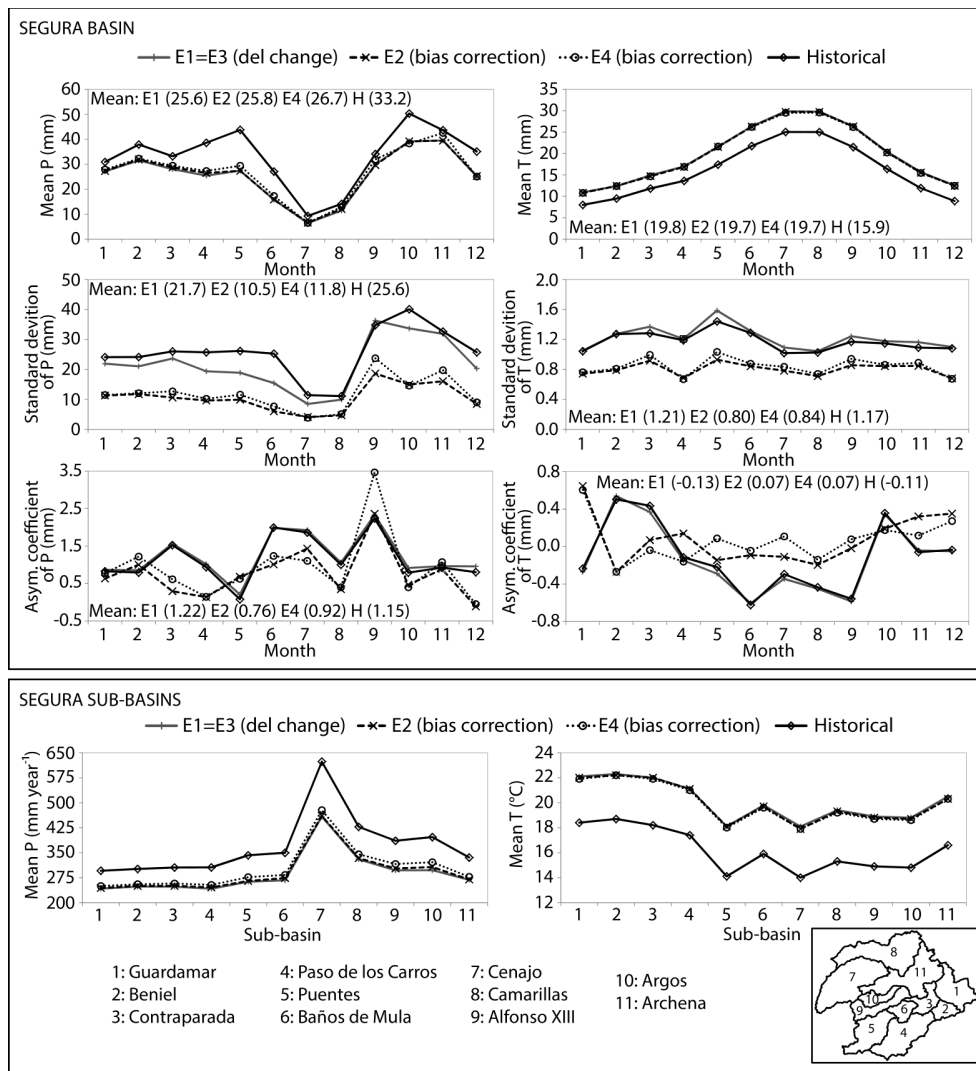


Figure 5.1. Future P and T series for the four ensembles



Statistics of precipitation and temperature for the four scenarios (E1 to E4) are shown in figure 5.1. Main statistics on runoff and demands are also reflected for these four scenarios and compared to historical data (Fig. 5.2) both for the whole Segura Basin and for the subbasins.

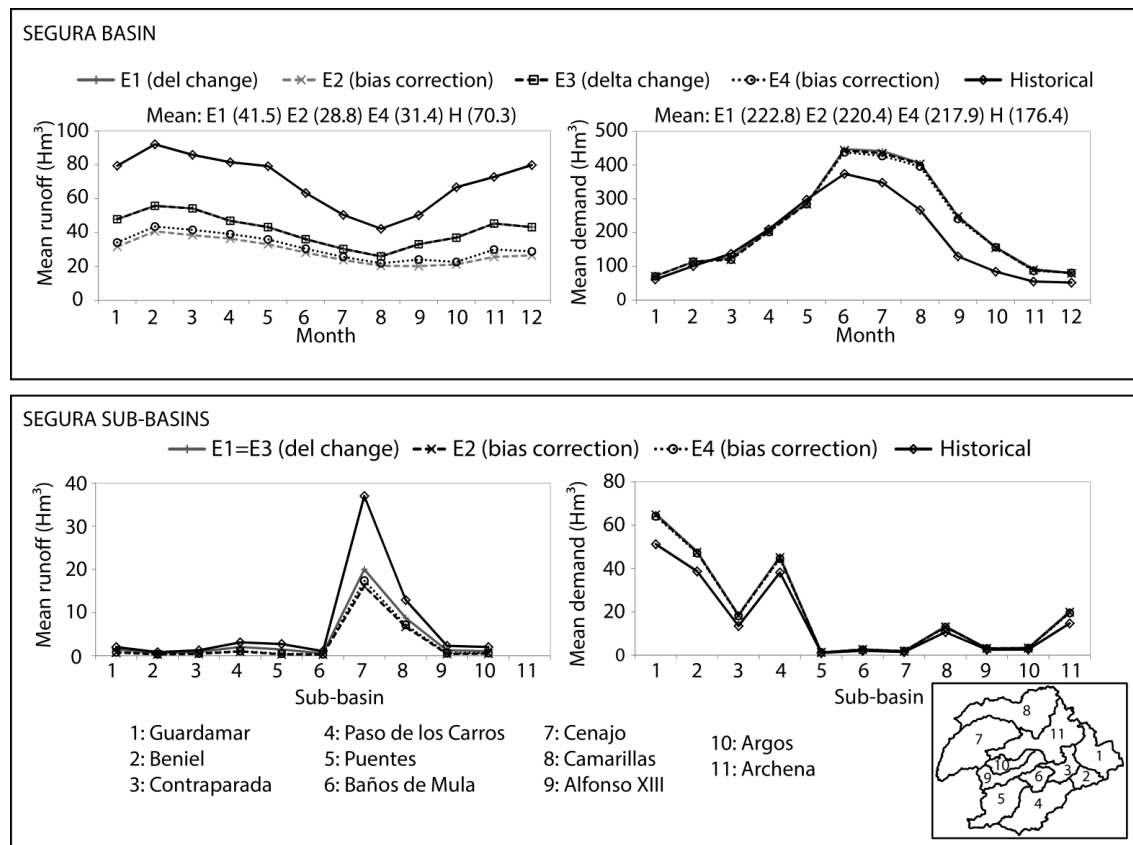


Figure 5.2. Runoff and demand for the four scenarios

A summary of results respect to guarantees of satisfaction of demands are reflected in table 5.1. Once again, these results are aggregated for the whole Segura Basin and the different subbasins. We can observe how guarantees are estimated to decrease significantly for the three future scenarios. The worst scenario is E2 with more than 21% of reduction of guarantee for the whole basin.

Table 5.1. Mean monthly volumetric guarantees (supply/demand)

Basin-Subbasin \ Scenario	Historical	E1=E3	E2	E4
Total Basin	96.25%	77.61%	75.02%	76.04%
S. 1 Guardamar	99.58%	86.28%	86.02%	86.59%
S. 2 Beniel	98.89%	92.32%	91.52%	92.10%
S. 3 Contraparada	95.83%	62.87%	55.40%	56.95%
S. 4 Paso de los Carros	90.36%	66.35%	63.84%	65.15%
S. 5 Puentes	70.35%	55.79%	51.30%	52.69%



S. 6 Baños de Mula	83.46%	67.20%	66.19%	66.71%
S. 7 Cenajo	95.36%	62.48%	56.58%	59.35%
S. 8 Camarillas	96.35%	67.98%	61.61%	63.09%
S. 9 Alfonso_XIII	95.55%	68.07%	64.66%	66.17%
S. 10 Argos	83.46%	52.71%	47.20%	48.90%
S. 11 Archena	96.23%	73.25%	68.26%	69.50%

Future CC scenarios would also have a negative impact in aquifers according to the results obtained on groundwater pumpings (table 5.2). For the worst scenario (E2) there would be an increase of 275 Mm³ in groundwater exploitation for the whole basin.

Table 5.2. Mean annual pumping in aquifers (Mm³)

Basin-Subbasin \ Scenario	Historical	E1	E2	E4
Total Basin	645.84	880.84	921.47	908.29
S. 1 Guardamar	63.99	134.27	134.56	133.39
S. 2 Beniel	84.06	137.99	137.15	136.20
S. 3 Contraparada	56.42	62.48	64.12	63.45
S. 4 Paso de los Carros	126.85	126.63	127.86	127.33
S. 5 Puentes	10.41	10.53	10.53	10.53
S. 6 Baños de Mula	19.25	19.72	19.77	19.70
S. 7 Cenajo	0.00	0.00	0.00	0.00
S. 8 Camarillas	41.26	59.11	64.33	63.32
S. 9 Alfonso_XIII	3.33	3.73	3.83	3.76
S. 10 Argos	51.33	71.91	80.10	77.75
S. 11 Archena	188.96	254.48	279.22	272.86

Finally figures 5.3, 5.4, 5.5 and 5.6 show a summary of results obtained for the propagation of droughts according to different parameters: meteorological, agricultural, hydrological and operational respectively. These results are showed for the different Segura basins and homogeneous areas. We observe important increases of the number of droughts and its duration, magnitude and intensity for the period 2071-2100 with respect the historical period for the different series studied (precipitation, humidity, streamflow and demand satisfaction index).

We also studied the correlation between the different types of droughts (Figure 5.7). Meteorological droughts show a good correlation with hydrological and operational droughts. The maximum correlations are reached for different gaps in each case. In the case of hydrological the maximum correlation is obtained without gap and in the case of operational the gap is 3-4 months.

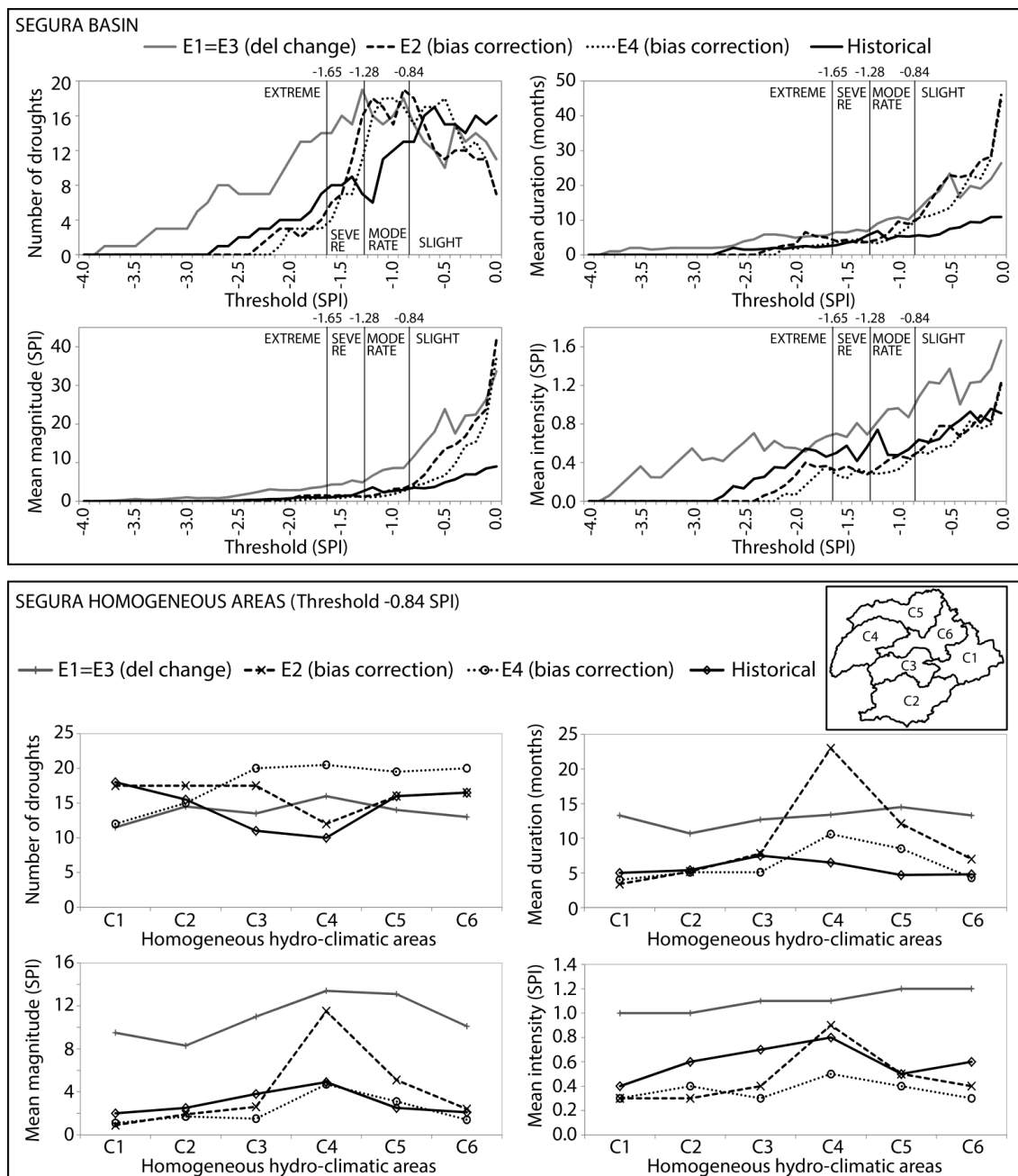


Figure 5.3. Statistics of meteorological droughts (Precipitation)

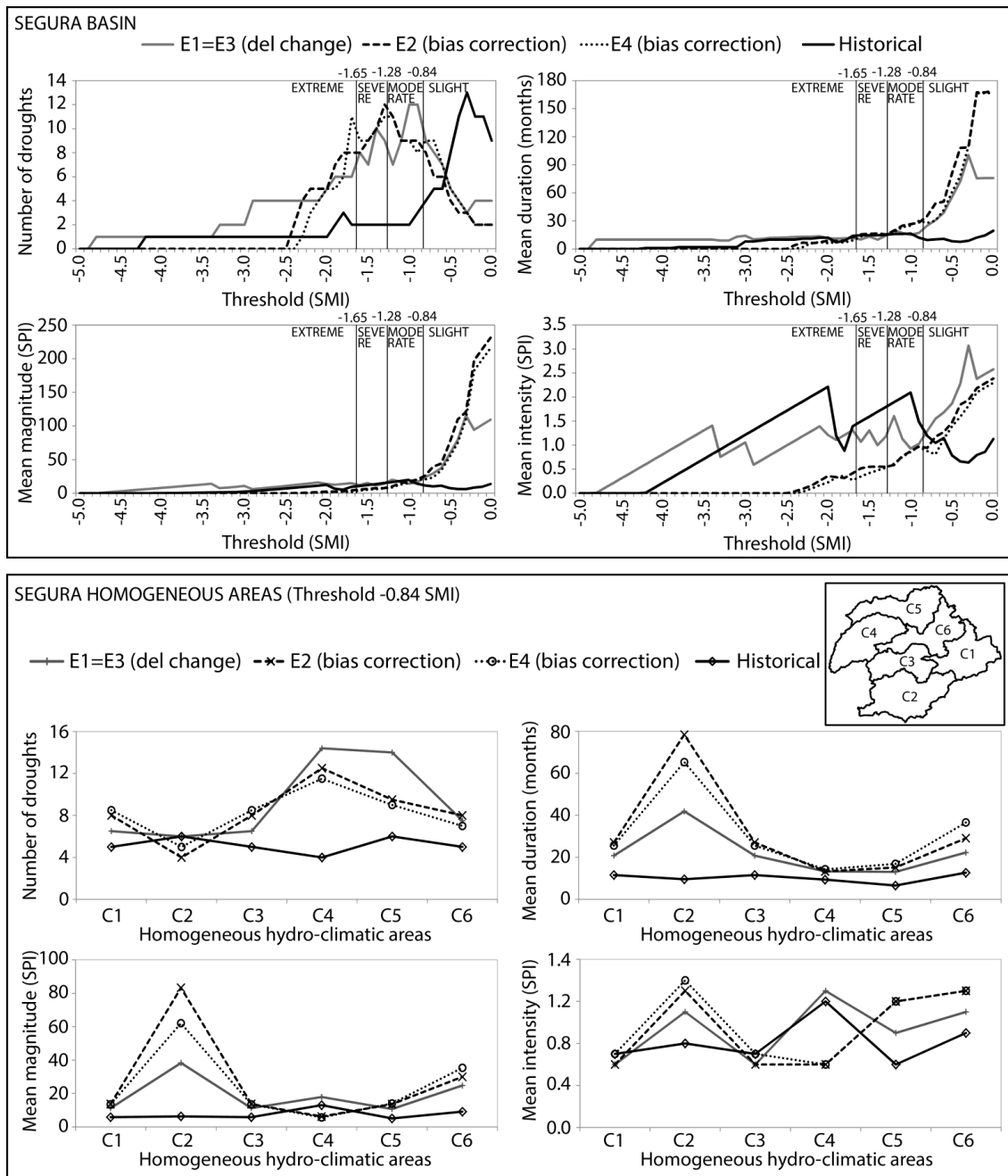


Figure 5.4. Statistics of agricultural droughts (Moisture)

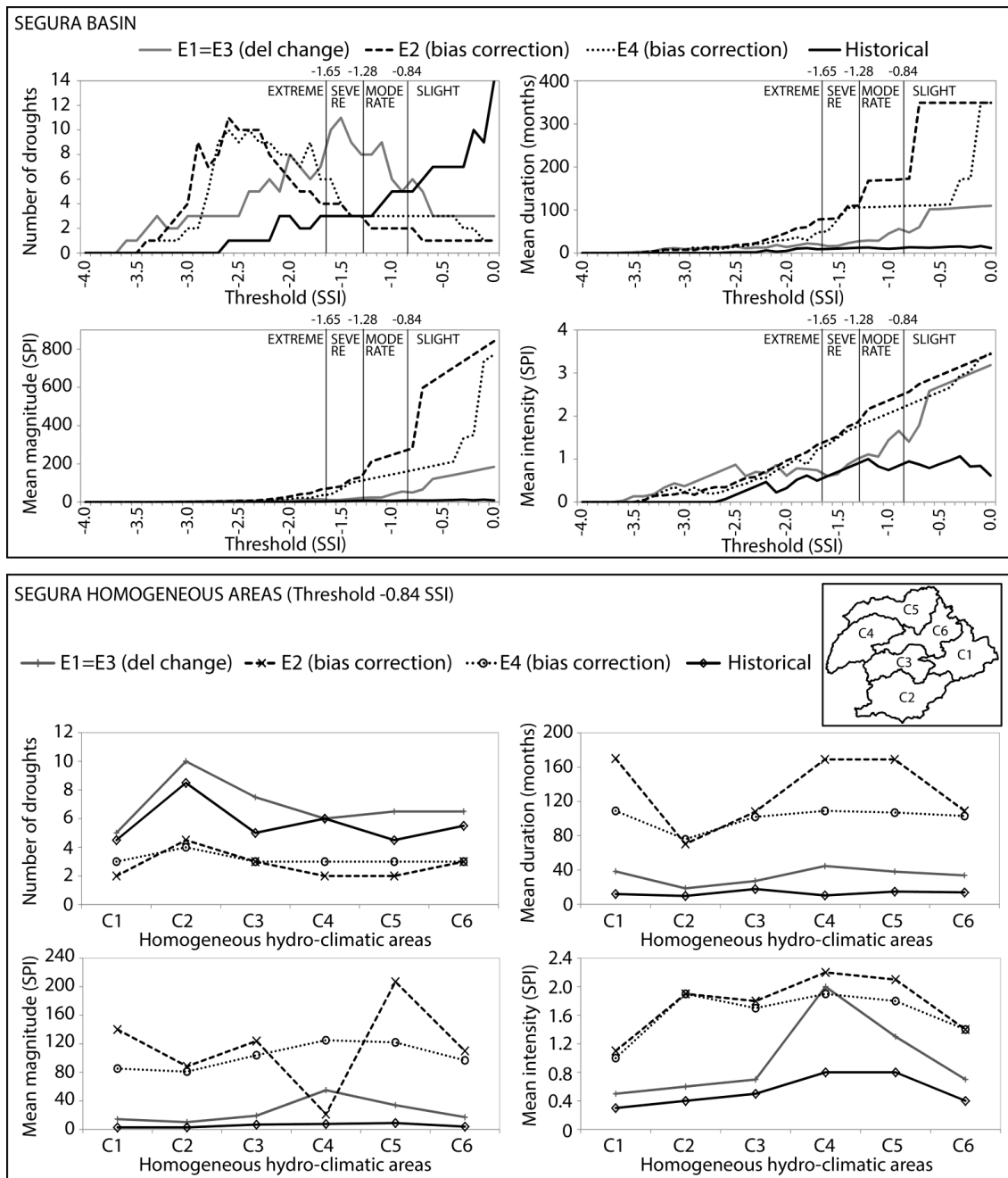


Figure 5.5. Statistics of hydrological droughts (Streamflow)

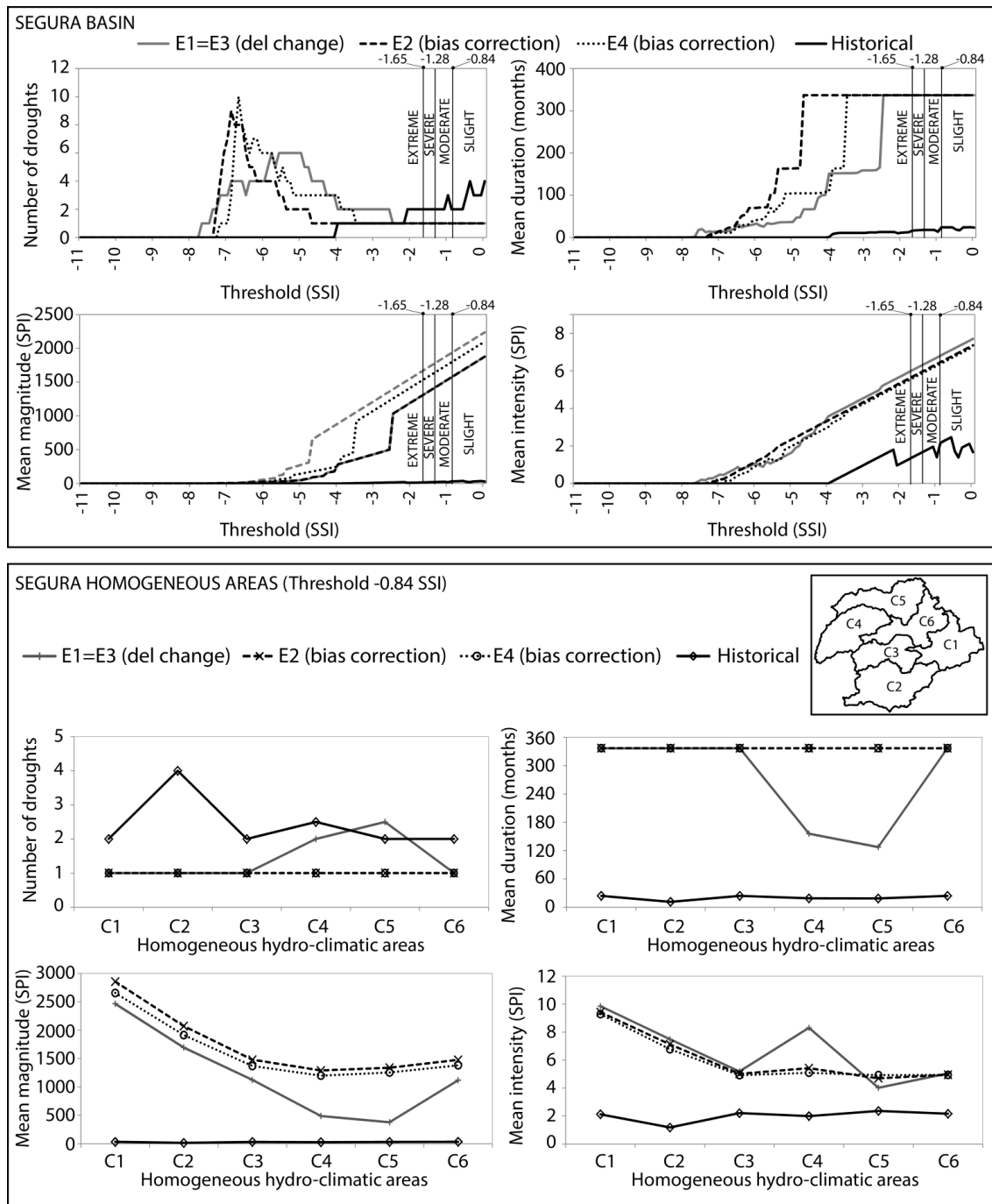


Figure 5.6. Statistics of operational droughts (Satisfaction)

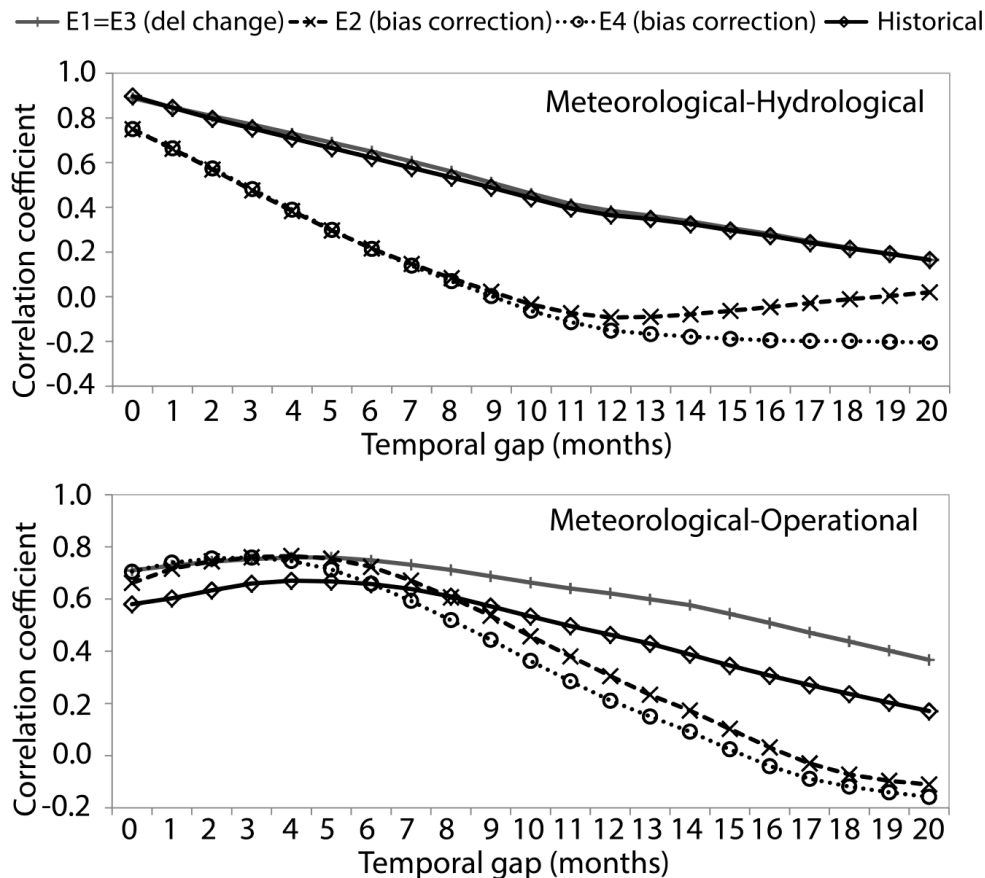


Figure 5.7. Droughts correlation

5.2 Conclusions of the assessment based on integrated hydrological modelling

This method has been applied to assess impacts of future potential climate change scenarios on the Segura Basin management system and on meteorological, agricultural, hydrological and operational droughts providing consistent pictures of monthly plausible future scenarios taking into account basic and drought statistics of the historical series and the climatic model simulations.

Results observed for the whole Segura Basin system with the four climatic scenarios for the period 2071-2100 show lower resources available to meet the different demand elements, which means higher deficits for that demands. Higher pumping rates in aquifers are estimated for future scenarios and the impacts would also be reflected on lower guarantees to meet demands. Scenario E2 has the worst impacts on the system according to this assessment.

The four studied scenarios show important reduction of precipitation and increase of temperature and large increments of the number, duration, intensity and magnitude of



droughts. The study of the correlation of hydrological and meteorological droughts shows significant correlations for a gap from 0 to 2 months in E2 and E4 cases and for a gap from 0 to 6 months in historical and E1=E3 cases. However the correlation of meteorological and operational droughts shows a maximum of correlation for a gap around 4 months for all cases.

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