CLISWELN

Climate Services for the Water-Energy-Land-Food Nexus

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Joint Call for Transnational Collaborative Research

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European Research Area for Climate Services

Executive summary

With this document, we aim to explain essential features of the water-energy-land nexus (the WELN) with a system dynamics approach in a case study of urban water supply in the Marina Baixa county, Spain. The WELN in Marina Baixa includes complex system features such as feedbacks and non-linearity, and it is necessary to apply an integrated approach in assessing the case study. System dynamics can be seen as a good tool both to provide climate services and to evaluate sustainability in Marina Baixa, especially in terms of economic growth (SDG 8), sustainable cities (SDG 11), and climate action (SDG 13).

Combining the WELN with system dynamics to provide climate services allows to improve management of climate change risks by incorporating science into planning and policy in a detailed manner that captures system understanding and relevant variables from a stakeholder perspective. This document includes descriptions of the hydrological model and the system dynamics model reproducing the patterns observed in the system. Both models successfully reproduce observed system patterns.

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Contents

1. Introduction

The Valencian Community is one of 17 autonomous regions in Spain. Alicante, one of the three provinces in the Valencian Community, consists of 9 counties and 141 municipalities. The Marina Baixa is one of the most important counties in the Valencian community as tourism in the Marina Baixa county contributes to about 60% of the tourism industry in the Valencian community, in terms of the number of tourists. Benidorm, the largest tourist destination in the Marina Baixa, attracts about 2 million visitors a year (Martínez-Ibarra, 2015). This puts Benidorm as the third place of the most visited places in Spain after Barcelona and Madrid.

Geographically, Marina Baixa is part of the Southeast Iberian Peninsula, and amongst the driest parts of the Peninsula, with a low rainfall (less than 350 mm annually) combined with prolonged droughts. Similarly to other regions in Spain, the largest urban areas in the Marina Baixa county are mostly located near the coast. Because the Marina Baixa is expected to experience a decrease in rainfall, especially under RCP6.0 and RCP8.5 scenarios (Greve, Gudmundsson, & Seneviratne, 2018), water stress can be expected to become an increasingly critical factor in the future.

The tourism industry is the most important engine of economic activity in the area, especially in Benidorm municipality (Martinez-Ibarra, 2015; Rico-Amoros, Olcina-Cantos, & Saurí, 2009). Moreover, tourism has a significant contribution on economic growth, income and employment in the area (Morote & Hernandez, 2016; Rico-Amoros et al., 2009). This means that the economic value of water in the tourism industry is high, and relatively higher than that of agriculture (Rico-Amoros et al., 2013), nevertheless in some parts of the county agriculture is also a thriving economic sector, which is a source of resilience to the regional economy. In supporting tourism industry, urban water demand is prioritized in water planning (Martinez-Ibarra, 2015), which in turn might lead to water scarcity owing to limited water supply.

The coastal municipalities in the Marina Baixa county formed a supra-municipal institution for urban water supply management, the “Consorcio Para el Abastecimiento de Aguas y Saneamientos de la Marina Baja” (hereinafter the Consorcio). The municipalities participating in the Consorcio include Alfàs del Pi, Altea, Benidorm, Finestrat, Polop, La Nucia, and La Vila Joiosa, which together hold a permanent population about 170,000 (INE, 2018). Because the municipalities share water needs and geographical scope, the Consorcio was built in 1977 to manage water provision and distribution to all these municipalities (Rico-Amoros et al., 2009).

Under a changing climate, providing water for the county population and tourism industry is expected to be more difficult. The probability of droughts in the Mediterranean has already increased, and climate change is expected to continue increasing it (IPCC, 2018). Furthermore, Greve et al. (2018) projects that under RCP6.0 and RCP8.5, Mediterranean areas will experience, at least, a likely decrease (66–100 % probability) in water availability. Sustainable options are needed to deal with problems related to global environmental change, such as climate change, water scarcity, and other limited natural resources (Leck et al., 2015). In the case of Marina Baixa, a set of measures has been already applied to handle water scarcity in the county, mostly based on additional infrastructure and exchange between users. For instance, there are instances of exchange between potable water and reused water between some municipalities and irrigation associations. Another solution available is to provide water transfers from outside the county (Martinez-Ibarra, 2015). However, as another study (Yoon, Sauri, & Rico Amorós, 2018) explains, consecutive droughts still occurred and affected the county. Moreover, there is a risk of correlated droughts between the Marina Baixa county and the river basins from where water transfers come from. Such occurrence could lead to a very conflicting situation compromising the regional economy. For these reasons, the aforementioned solutions cannot guarantee the sustainability and the availability of water supply for the Marina Baixa county, and there are doubts about what could be the implications of future scenarios with a higher water demand related to changes in land use patterns.

In conclusion, in the Marina Baixa county some critical issues create a tight situation in which water and land use have intimate interactions facilitated by energy. These critical issues include limited water supply owing to limited rainfall and increased water demand, less rainfall under a changing climate, urban land-use change and interconnections between tourism, water and land-use change, and potential non-linear effects on emissions for making water available through pumping in wells and connections with other basis. All of these challenges make the Marina Baixa county an interesting area to investigate the impacts of climate change on water scarcity, its impacts on the tourism sector and how to adapt to them with climate services integrated with the crucial issues described. Additionally, the options to achieve synergies between adaptation to climate change and the Sustainable Development Goals (SDGs), the nexus with land-use change, and the increase in greenhouse gas emissions from the energy use for water management appear to be socially relevant, hence in this case study we aim to find co-benefits among the resources of the nexus so that climate services can be delivered avoiding trade-offs.

1.1. The Water-Energy-Land Nexus

We daily need food, energy and water to survive. In fact, energy, food and water are fundamentally interrelated. To produce food, we need land, energy and water; we also need water to produce energy. Because of that, we daily face a mutual relationship called the Water-Energy-Land Nexus (WELN), and focusing on one resource leads to segmented efficiencies that may lead to unintended consequences , while considering their nexus leads to coherent policies for sustainable development (Cremades et al., 2016; Bazilian et al., 2011; Prasad, Stone, Hughes, & Stewart, 2012; Leck, Conway, Bradshaw & Rees, 2015).

A nexus “can be understood as a network of connections between disparate ideas, processes or objects”, and “alluding to a nexus implies an infinite number of possible linkages and relations” (Stern & Öjendal, 2012). Other reports point out that water is a cobweb that hold the nexus of resource uses and services together, concluding that water is the heart of the nexus (World Economic Forum, 2011a). Owing to this, decisions in the nexus cobweb should consider the roles and the connections of water across the other resources in other economics sectors, and include energy and land in the analysis (Giampietro, Aspinall, Ramos-Martin, 2014).

As a matter of fact, a vast amount of research focused in the individual resources (water, land and energy) and studies them independently, compromising not only a systemic understanding but also a robust and coherent policy action (Bazilian et al., 2011; Rothausen, & Conway, 2011). Owing to the links between these resources, in case of environmental challenges such as resource scarcity, policy- and decision-making choices in each of these three resources can significantly affect the others (Rothausen, & Conway, 2011). Because of this, it is imperative to encourage studies on the WELN. This leads to the necessity of interdisciplinary research, especially taking in to account the multiple resources and sectors involved.

Moreover, interdisciplinary research on the nexus should aim to eliminate or minimize trade-offs and to create opportunities that maximize sustainability synergies across the different resources and economic sectors considering the implications for long-term resilience and the whole of the Sustainable Development Goals under climate change (Bizikova, Roy, Swanson, Venema, & McCandless, 2013; Hoff, 2011; Leck, Conway, Bradshaw, & Rees, 2015).

It is easy to see that the WELN is dynamic. Actions in one resource can affect the other resources at different time scales (Giampietro et al., 2014). But, in some cases, the impacts of change(s) in one the nexus resource may not clear owing to delayed responses. Additionally, when resources are easy to get owing to their low prices, like in the case of water, the connection between the nexus resources appear to be less relevant (Keairns, Darton & Irabien, 2016). But, when resource availability is not comparable to resource demand, the interconnections between relevant resources become more visible (Keairns et al., 2016). In the case of the Marina Baixa county, water demand has increased significantly owing to population and tourism growth, and water supply is limited owing to limited precipitation. In this contextthe connection between water and other resources of the nexus such as land use becomes visible and climate change appears as a threatening factor.

Summarizing, a WELN approach allows to provide quantifiable results that deepen our understanding on the interdependencies among water, energy and land, and their environmental services. By aiming to decrease possible trade-offs, the WELN is a robust support to the SDGs. In addition, the WELN can inform solutions when there are limited resources and multiple interests with possible unintended consequences. The deeper layer of knowledge provided by analysing the WELN helps us to provide climate services that avoid trade-offs and identify synergies in policies, plans and projects aiming to adapt to climate change.

1.2. Integrated Climate Services

Climate services aim to assist decision making through “the transformation of climate-related data—together with other relevant information—into customised products” to enable adaptation, mitigation and disaster risk reduction (Street, Jacob, Parry, Runge, & Scott, 2015). Meaningful climate services must derive from scientifically credible information and expertise and appropriate engagement between users and providers (Street et al., 2015;). Climate services relate to “climate-informed decision making”, “user needs”, “managing climate risks” and “a combination of meteorological and non- meteorological data” (Troccoli, 2018). Climate services must provide information tailored to the needs of policy makers to facilitate decisions-making. This is essential as policy makers need this tailored information to help society to cope with climate change and to limit the economic and social impacts caused by climate-related disasters.

Understanding climate processes and their potential impacts is key to our economy, health and safety. For instance, floods owing to heavy precipitation can lead to death and capital damage. Long droughts also can lead to water stress, loss of economic activity and food shortages. In short, because human activities are vulnerable and exposed to climate risks, climate services should be mainstream in society.

Climate services are not only providing physical data about climate projections but also providing tailored information for policy- and decision- makers so they can anticipate climate impacts.

Integrated climate services contribute to strengthen climate services by embedding climate information in a multidisciplinary manner, that is integrated with the physical and socio-economic variables relevant to the economic sectors involved in the decisions and policies in sight (Changnon et al., 1990; Clements et al., 2013; Tall, Coulibaly, & Diop, 2018; Vaughan & Desai, 2014). The nexus approach detailed above allows to deliver integrated climate services and to understand with sufficient detail the implications of climate change across sectors and resources at the regional and local scales.

To deliver integrated climate services it is necessary to engage multiple stakeholders to co-design climate services products, whether it is tailored information or a tailored tool. In this context, integrated climate services operate at the boundary between climate science, policy and practice.

1.3. Modelling complex systems to support stakeholder policy-making

In this section, we describe three important aspects. The first is about the features of a complex system, the second is about complexity in the WELN, and in the third item, we describe the benefits of using system dynamics. By relating the second and the third item, we explain how the system dynamics approach is a most suited method for assessing and evaluating the WELN.

When the identifiable elements of a complex system are put together, they create in the system an emergent behavior that is more complex than what could be predicted from analyzing the individual elements and the sum of their behavior. The results of the interaction in a complex system are often computationally irreducible and richly diverse. Modeling a complex system is difficult owing to the interactions between its parts, and between the system and its environment (Miller & Page, 2009; Wolfram, 2002; Aziz-Alaoui, & Bertelle, 2009). Sterman (2000) suggests that the behavior of a complex system emerges from its structure.

It is helpful to analyse a complex system with concepts such as emergence, non-linearity and feedback loops. Non-linearity may occur owing to the interaction multiple factors, when a small change in one input may lead to a significantly larger output or action (Aziz-Alaoui, & Bertelle, 2009).

Our actions or decisions can change our environment, and because of the altered environment, we may change our decisions tomorrow. It is also possible that an agent’s action can trigger other agents’ actions. Feedback may occur because of tight connections among actors in the system. Hence, actor’s actions can trigger other actors’ actions, causing changes in the system (Sterman, 2000). Moreover, feedback loops are characteristic feature of the complex systems (Aziz-Alaoui, & Bertelle, 2009; Sterman, 2000). To identify feedback loops in a system, one may use a causal loop diagram (Aziz-Alaoui, & Bertelle, 2009; Sterman, 2000). Causal arrows can be used to identify the relations among the system elements and when causal arrows lead to a loop, this means that system consists of feedback.

In the following paragraphs, the complexity of the WELN is described. There are inherent sources of complexity in the application of the WELN. The most important source of complexity comes from the dynamic relationships among the nexus resources (Sohofi, Melkonyan, Karl, & Krumme, 2016; Wa'el A, Memon, & Savic, 2017). A prominent feedback loop became visible in the dynamics evolution of water and land in the case study: increase in water supply may enable land-use change, leading to a higher population. Afterwards, a higher population leads to a higher water demand, decreasing water supply. Other existing feedbacks have been also identified (see Figure 18): A growing mass tourism in Benidorm led to water shortages (e.g. Martinez-Ibarra, 2015) and significant revenues for the local economy (Rico-Amoros, Saurí, Olcina-Cantos, & Vera-Rebollo, 2013). Since the mass tourism has increased income and employment, water consumption in urban areas is prioritized above other sectors like agriculture. In return, the Consorcio funded improvements in irrigation infrastructure to decrease water application in other sectors (Rico-Amoros et al., 2013). Additionally, hotels in Benidorm applied water-saving technology to decrease water consumption. This is an existing feedback in the Marina Baixa county in which one actor action can change another agent action and have repercussion in the elements of the nexus.

The relationships between nexus resources in the aforementioned feedback may not be linear (e.g. Sterman, 2000). For example, additional water supply can increase population growth but each observed system has a carrying capacity. As population (either resident or temporary population) increases closes to its carrying capacity (water supply is a limiting factor of population growth), population growth will be relatively lower, leading to stable population. This phenomenon draws an analogy with the “limits to growth” at a local scale (Meadows & Randers, 2012).

An additional source of complexity comes from the integration of stakeholders of different economic sectors, policy domains and scales. Stakeholders will be exposed to results that show that segmented policies and narrow sectoral perspectives would not lead to sustainable policies and decision outputs across the nexus resources (Bizikova et al., 2013; Al-Zu’bi, & Keough, 2018).

Despite apparent complexities in the WELN, Rasul & Sharma, (2016) suggests some steps in implementing a successful nexus approach with stakeholders. Initially, identifying the interrelationships among the nexus resources and focus on overall system efficiency, instead of single resource efficiency, in the first step of the nexus application. Afterwards, assessing the interdependence among the nexus resources and related economic sectors to achieve environmental, social and economic objectives. In the third step we should obtain integrated policies to minimize trade-offs, enhance potential cooperation among multiple stakeholders and maximize synergies across the nexus resources.

In term of system dynamics, applying it to the nexus offers some useful benefits. The first benefit is that system dynamics reveals the complex system formed by the structure of the interdependencies among different resources in the nexus (Forrester, 1994; Sterman, 2000). This statement is supported by Ford (1999), who explains that the system dynamics approach can connect interdependencies among relevant resources to capture their dynamic interactions. System dynamics can model coupled human, natural and physical systems (Forrester, 1994). The nexus consists of interrelated human, natural and physical systems, and system dynamics is used to integrate them. All these systems can be fed with quantitative data and qualitative information coming from interviews, questionnaires and policy analysis (Forrester, 1980).

2. Case study description: urban water supply in the touristic sector of Marina Baixa county (Valencian Community, Spain)

The Marina Baixa located in the northeastern part of Alicante (Spain), between 0^{0} 00’ - 0^{0}24’ West Longitude and 38^{0}28’ - 38^{0}43’ North Latitude. The Marina Baixa county is surrounded by the Comtat on the northwest, the Marina Alta county in the northeast, the Alcoià county the west, and the Mediterranean Sea on the east. The topography varies from the coast to inland mountains with the highest peak about 1,500 meters in Serra d’Aitana. Owing to its calcareous terrain, its mountain landscape consists of caves, natural archways and fountains. The county size is about 671 km^2.

The average annual temperature in coastal and inland areas is about 18^{0}C and 9^{0}C respectively (Bellot, Bonet, Pena, & Sánchez, 2007), while average annual precipitation is about 300 mm a year in the coastal areas and about 800 mm in inland areas (Bellot et al., 2007). The county has a significant role in the tourist activity of the Valencian Community region (Bellot et al., 2007). Mostly because of the activity in the tourism sector, the county population increased from 35,000 in 1950s to about 170,000 in 2017 (INE, 2018).

2.1. Water management in the Marina Baixa county

Water resource management comprises processes of different nature, such as biophysical processes influenced by land use (e.g., runoff, percolation, and infiltration), socio economic processes (e.g., economic activity, employment and land-use change) and water management policies and decisions (Bonet, Bellot, Eisenhuth, Peiia, Sanchez & Tejada, 2006; Gössling et al., 2012; Peña et al., 2007). These factors generate a complex system that has significant interactions with climate change. The interactions between the growth of the tourism industry, population growth, and the cycles of economic growth, increased the complexity of water resource management in the case study area in the last decades (Bonet et al., 2006; Gössling et al., 2012; Peña et al., 2007).

Water resource managers in the area introduced circular economy features after an agreement for exchanging potable water and reused water between farmers and the Consorcio, via reused water from wastewater plants (Martinez-Ibarra, 2015; Rico-Amoros et al., 2009). In this context, an increasing complexity is a desirable outcome that could bring sustainability to the regional economy, and may mean involving more parties, more physical systems and more interdependencies. The complexity of water resource management and its energetic implications in Marina Baixa also increases as water supply might come in emergency times from further and more energy intensive sources like water transfers from neighboring regions through the channel of Tajo Segura and the Rabasa-Fenollar conduction (Martinez-Ibarra, 2015).

Previous studies on the case study area explore to a degree the relationships between land-use change, tourism, and water scarcity (e.g., Morote & Hernandez, 2016; Rico-Amoros et al., 2009). The tourism industry is relatively vulnerable to water scarcity, and water scarcity could increase owing to the complexity of relations between land, water and climate. This is supported by a series of droughts occurred in the county: 1969-1970; 1976-1985 and 1995-2001. Martinez-Ibarra (2015) argues that these droughts were related to massive land-use change in1960s and onwards, poor water management in the Guadalest reservoir and limited precipitation (Martinez-Ibarra, 2015).

All the above-cited studies explain that water scarcity is influenced in the area by water availability, land-use change and water consumption (Martinez-Ibarra, 2015). Furthermore, existing studies explore the relationships between tourism, land-use change, and water supply (e.g. Bonet et al., 2006; Gössling et al., 2012; Peña et al., 2007), but they do not take into account their dynamic impact on the remaining aspects of the nexus and the impact of climate change.

This leads to a number of knowledge gaps about this region, which has a high economic relevance. First, existing studies did not consider the impacts of climate change on water supply. This means that adaptation policies involving climate services are required to sustain the tourism industry, and the natural resources on which it depends. Second, we need to consider and integrate all aspects relevant to sustainable development, because of the knowledge needs expressed in the above sections and because existing studies only focus on one aspect either social or physical. Third, existing studies did not consider community-based participation and integration in formulating sustainable development in the Marina Baixa. We strongly believe that involving local stakeholders will enhance our ability to contribute to the design and implementation of adaptation policies, and to find better options for sustainable development.

And last but not least, there is an unsolved challenge about water scarcity in the area that poses a significant risk to the local economy, especially considering that the last recourse water source, the external water transfer, comes from areas that are also drought-prone and in which droughts could occur simultaneously, which shows that existing policies could trigger problems of economic sustainability to the Marina Baixa. Summarizing, an integrative approach to climate services associated with sustainable development is needed to help policymakers in elucidating a range of viable alternatives to adapt to a changing climate.

3. Water demand

The Mediterranean coastal areas in Spain, such as in Benidorm or Altea and many other municipalities in Alicante, have experienced a considerable increase in urban land use since 1960s. The tourism expansion along the Mediterranean coastline is owing to convenient characteristics like mild temperature and low living costs, which has led to land use change and a higher water demand (Rico-Amoros, Olcina-Cantos, & Saurí, 2009).

In understanding water demand in a case study with economic predominance of touristic activities, it is important to list water demand for each housing and each accommodation type. In Spain, there is limited available data of water demand owing to many factors. The first factor is data confidentiality because water companies refuse to provide their data. The second factor is that available data is aggregated at municipal scales, making difficult to analyse data in smaller detail. In the context of a tourism case study, an important barrier is that data does not contain discrimination of water demand between registered residents and tourists i.e. temporary population. Because of this, this study uses the secondary data on water consumption per accommodation type from water companies and fieldwork from Rico-Amoros et al. (2009). This detailed information is complemented with primary data about the monthly consumption patterns and consumption amounts per municipality.

Table 1 exhibits water demand based on accommodation types. Campsites are probably the least water demand per person per day at 84 litres/person/day (lpd). Water consumption increases in line with hotel categories or hotel facilities. Tourists who stay in a star hotel and a three-star hotel consume water about 174 lpd and 287 lpd respectively. The highest water demand is in four-star hotels, 361 lpd. This can be understood as the higher hotel class leads to more facilities such as larger size swimming pools and larger size gardens (Rico-Amoros et al., 2009).

Types of accommodations	Annual average consumption (m3/year)	Monthly average consumption (m3/month)	Monthly maximum consumption (September) (m3/month)	Monthly minimum consumption (February) (m3/month)	average consumption per person per day (liters / person/ day)
Campsites	-	-	-	-	84
1 star hotels	2,808	217	420	0	174
2 Star Hotels	22,494	1,874	2,707	1,436	194
3 Star Hotels	29,222	2,435	3,224	1,917	287
4 star hotels	40,090	3,340	4,812	2,220	361

Table 1. Water consumption in Benidorm for different accommodation types (Rico-Amoros et al., 2009)

Table 2 shows that water consumption is relatively higher in low-density areas as housing in low-density areas are usually equipped with a swimming pool and a garden (Rico-Amoros et al., 2009). The seasonality is another important factor in describing water demand. For instance, water consumption in apartment for registered and temporary population are about 122 lpd and 47 lpd respectively. In addition, people who live in detached houses of low-density areas (with garden and pool) consume about 359 lpd while people in detached houses without garden and without pool consume about 130 lpd.

Types of accommodations	Average daily consumption (liters / house / day)	Mean daily consumption per person (liters / person / day)
Community owners (seasonal settlement)	252	72
Community owners (permanent settlement)	446	127.5
Housing block (seasonal settlement)	163	46.5
Housing block (permanent settlement)	426	122
Single Family Home (seasonal settlement)	865	247
Detached house (permanent settlement)	1257	359
Detached house (permanent settlement)	**456**	**130**

Table 2. Water consumption in Benidorm for different housing types (Rico-Amoros et al., 2009)

Data shows that total water consumption in Marina Baixa was about 22 hm^3 in 2012-2013 and that about 50% of total water consumption goes to Benidorm. Although high-density areas require a lower daily water consumption per person than low-density areas, table 3 shows that high-density coastal areas with larger permanent and seasonal populations such La Vila Joiosa and Alfaz del Pi require a higher annual water consumption than inland areas such as La Nucia and Polop.

Municipalities	Total water supply (m3)	Total water consumption (m3)	Inefficiency **(total network losses)**
Altea	2,702,403	1,902,579	29.60%
Benidorm	10,183,737	9,509,432	6.62%
Finestrat	918,187	753,656	17.92%
Polop	485,033	364,696	24.81%
La Nucía	1,920,767	1,512,536	21.25%
La Vila Joiosa	2,564,007	2,102,100	18.02%
Alfaz del Pi	2,721,460	1,829,454	32.78%
Total	21,495,594	17,974,453	16.38%

Table 3. Water demand in each municipality and their water losses (private communication with Diputación de Alicante, 2018)

Water demand in the Marina Baixa is influenced by the seasonal population dynamics, i.e. by the dynamic of registered and temporary population (Rico-Amoros et al., 2009), and in all municipalities it fluctuates according to the tourism pattern. As seen in Figure 1, a higher demand occurs during July, August and September while January and February show the lowest water demand throughout the year. This contrasts with the local climate pattern as precipitation mainly occurs during September, October and November (Martinez-Ibarra, 2015).

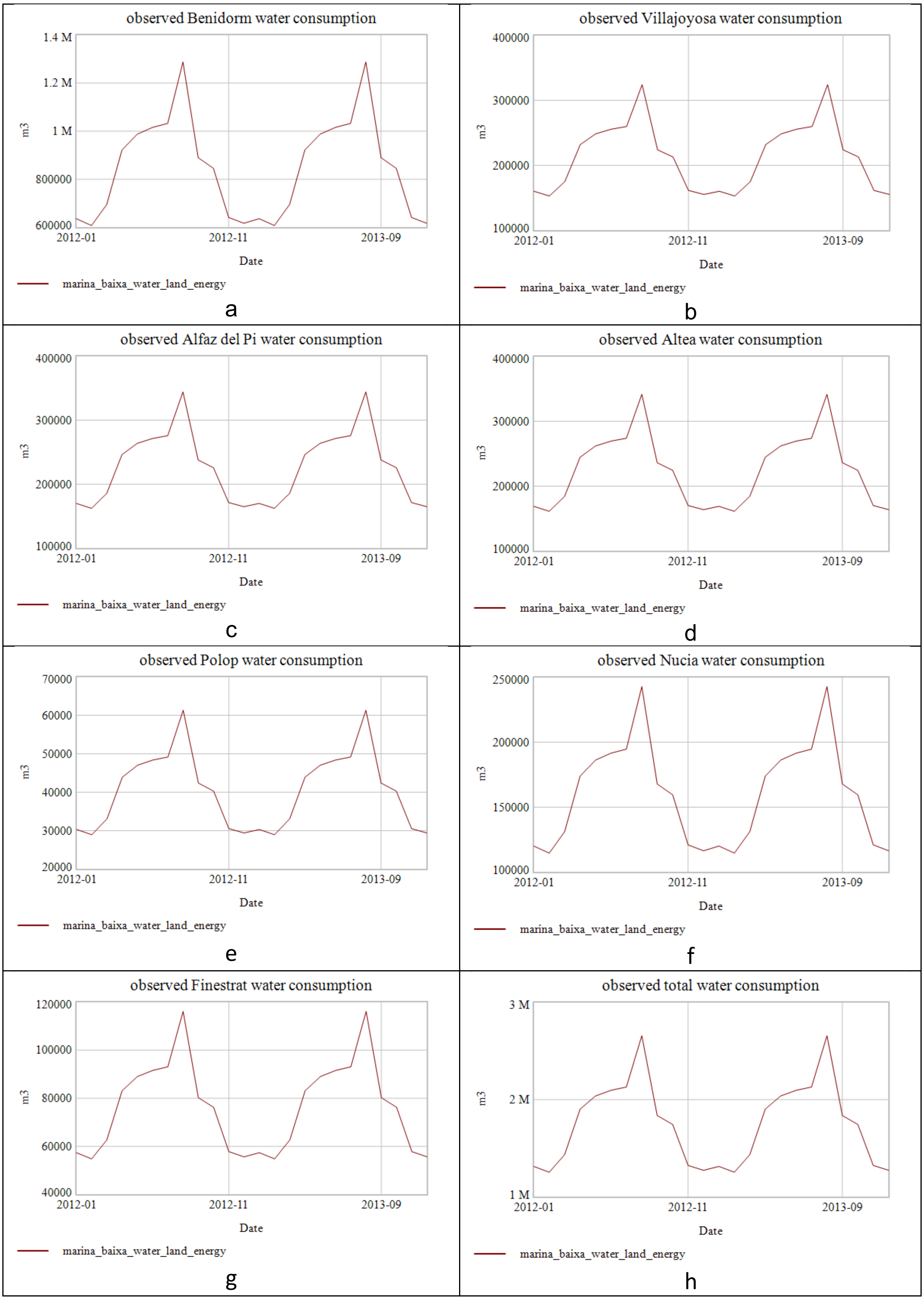


Figure 1. water demand in Benidorm (a), La Vila Joiosa (b), Alfaz del Pi (c), Altea (d), Polop (e), La Nucia (f), Finestrat (g) and total water demand (h) (Source: priv. comm. Diputación de Alicante)

3.1. Trends in urban water consumption

It is projected that water consumption in touristic areas will increase by 2020 owing to a diversity of factors (Gössling, Peeters, Hall, Ceron, Dubois, & Scott, 2012). The World Tourism Organization (UNWTO) forecasts over 93 million international arrivals to Spain by 2020, which is about 2.6% annual growth between 2000 and 2020. Another factor that increases in tourism water consumption is higher hotel standards. Since higher hotel standards means more complete facilities, such as gymnasium and spas, higher-class hotels might lead to a higher water consumption (Rico-Amoros et al. 2009). The third factor is an increase in tourist activities that require water, such as golf courses (Gössling et al., 2012).

Another factor should be considered in describing trends of water consumption is related to more private accommodation types such as individual houses (Rico-Amoros et al, 2009). These houses are usually accompanied by individual facilities such as swimming pools and private gardens. These private accommodation types, as they provide more private facilities (Rico-Amoros et al, 2009), can lead to a higher water consumption. The sustainability of future trends of water consumption in touristic areas should be considered as a fundamental element to sustain the role of tourism in providing employment and supporting economic growth, because ignoring this trend may lead to risks for the regional economy.

3.2. Modelling urban water consumption

A system dynamics model is needed to explain relationships among dynamic factors in the Marina Baixa. Dynamic factors are, for example, the number of tourists, the number of available beds and the proportion of low-density areas and high-density areas. Another dynamic factor is accommodation types such as hotels, rural-area accommodation and campsites. Each type of accommodation has its unique features, for instance, water consumption and the number of staying tourists. Among different accommodation types, hotels are tourists' main option to stay in the Marina Baixa, however non-registered tourists through online portals represent a challenge to the tourism industry and for water management. The number of non-registered tourists has been estimated around a 10-20% by local experts from the tourism sector.

Hotels are the main option to stay in the Marina Baixa and Benidorm's hotels offer nearly 40,000 beds (INE, 2018). As detailed above, accommodation in high-density areas such as hotels in Benidorm tends to consume less water than accommodation in low-density areas such as accommodation based in individual houses. To anticipate different water consumption in different accommodation types as well as in low-density and high-density areas, this study assesses the patterns of water consumption in each accommodation type. This study also separates water consumption in low-density and high-density areas.

4. Water supply

Figure 2 shows the water distribution scheme from the two main water sources in the Marina Baixa; surface water and groundwater. Surface water comes from the Guadalest and Amadorio river dams and groundwater is obtained from a diversity of wells. Among these aquifers, the Carrascal Ferrer aquifer is the most important aquifer. There are also smaller wells located in each municipality (except Benidorm), mostly in coastal aquifers; their roles in term of water supply will be explained in section 7.

During rainy seasons, the Guadalest reservoir gets water mainly from the Guadalest River and the Algar pump station in the Carrascal Ferrer aquifer, but in dry seasons, the Guadalest reservoir gets most of the water from the Algar pump station. The water from the Algar aquifer is brought to the Guadalest reservoir and then shared with all municipalities in the Consorcio. The second reservoir is the Amadorio reservoir which gets water from the Amadorio River, but this river has low water flow. From there, water supply is distributed to the closest municipalities: Benidorm and La Vila Joiosa.

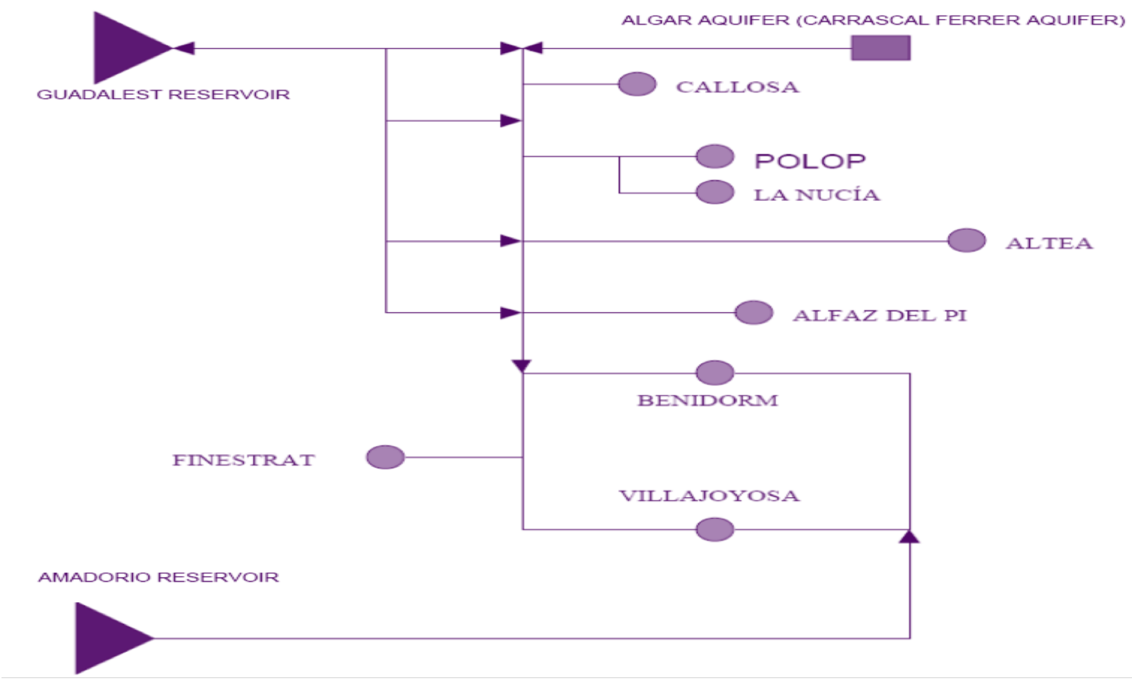


Figure 2. Water supply distribution in the Marina Baixa (CHJ, 2015)

An additional factor still makes water demand increase above sufficient amounts in practical terms. Unregistered water consumption and water losses have a large impact in the area. According to Amoros et al., (2009), water loss usually occurs due to network deterioration. Table 4 details total water loss in each municipality. As seen in table 4, Benidorm has the highest efficiency in water supply as non-controlled consumption (in some cases municipal uses for cleaning etc. are not controlled) and losses are about 6%, while Alfaz del Pi experiences the highest water loss.

No	Municipality	Water losses (%)
1	Altea	29.6
2	Alfaz del Pi	32.78
3	Benidorm	6.62
4	Finestrat	17.92
5	La Nucia	21.25
6	Polop	24.81
7	La Vila Joiosa	18.2

Table 4. Water losses and non-controlled consumption in the Marina Baixa (Source: priv. comm. Diputación de Alicante)

4.1. Hydrological modelling

Hydrological models reproduce the processes that occur in a basin in the most rigorous way, so that, subsequently, can be used to know the evolution of water resources under different scenarios of climate change. There are many hydrological models currently available, distinguishing between global models (calculations are done at basin level), semi-distributed (at sub-basin level) and distributed (at pixel level).

The calibration and validation processes of hydrological models are key to obtaining acceptable results compared with the reality. These processes are done through the comparison of the model results with observed data from gauging stations of the basin under study. The calibration involves adjusting the model so output values are close or similar to values recorded at the gauging station. The validation measures the model prediction capacity through the comparison between simulated results and observed data in a time period different from the calibration.

One of the CLISWELN project objectives is to evaluate future impacts of climate and global change scenarios on water resources. This process includes three main steps: 1) calibrating and validating the hydrological models for a historical period with observed stream flow and climate data; 2) generating climatic scenarios, and 3) incorporating climatic scenarios into the calibrated and validated hydrological models to evaluate the future effects of the scenarios in the water cycle. In this project we have used SWAT model under the following approach displayed in Figure 3.

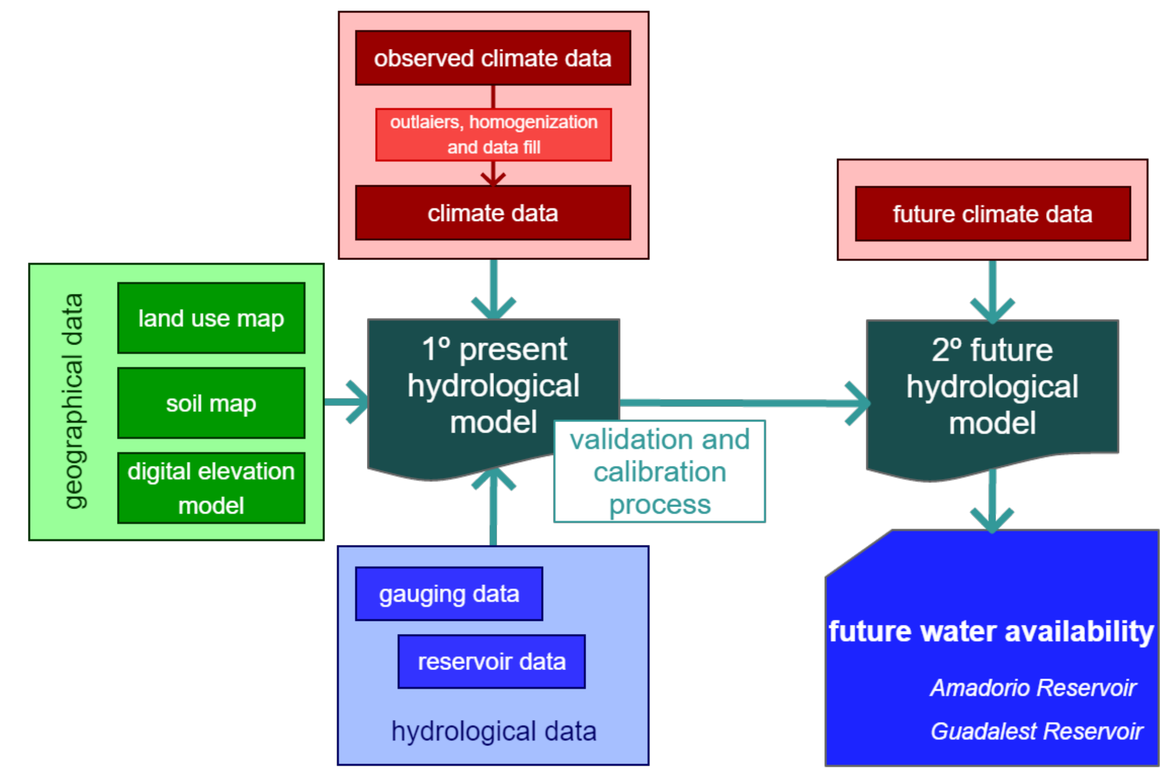


Figure 3. General methodology

The Soil and Water Assessment Tool (SWAT) (Arnold et al.,1998) is a physically based, semi-distributed and continuous hydrological model that estimates surface and subsurface flow, erosion, sediment deposition and nutrient movement within a catchment, at daily time steps (Gassman et al., 2007). The model is able to make predictions of the long-term behavior of complex basins, especially to evaluate the effects of different management scenarios and changes in the environmental conditions. The model can be connected to GIS (ArcSWAT version), allowing the spatial parameters and input variables of the model at each point of the basin. Although the model is widely applied, it has been rarely used in Mediterranean basins (Nunes et al., 2008).

SWAT is based on the water balance equation in the soil, including processes such as interception, infiltration, surface runoff, evapotranspiration, percolation, lateral flow and groundwater recharge. Precipitation may be intercepted by vegetation or reach the soil surface (Neitsch et al. 2005). Water on the soil surface may infiltrate or flow over the surface as runoff contributing to surface drainage. Infiltrated water is stored in the soil profile and later evaporates, is used by plants, contributes to the streams through lateral flow or percolates into the groundwater system. Groundwater can be stored in the aquifer, but it can also leave the soil and discharge into the streams, move upward in the soil profile or percolate to a deeper aquifer. For a full description of SWAT and its methods, see Neitsch et al. (2005). For the CLISWELN project, the surface runoff volume was estimated using a modification of the curve number (CN) method used by the Soil Conservation Service (SCS). PET (Potential Evapotranspiration) was calculated using the Thornthwaite method, whereas lateral flow was predicted through a kinematic storage model and channel flood routing was estimated using the Variable Storage method.

SWAT model divides the study area into sub-basins, which allows to distinguish areas with similar land use, soil types and altitudinal range that influence in processes such as evapotranspiration or the distribution of precipitation. Meanwhile, the sub-basins are divided into hydrological response units (HRU), which are areas with the same land cover, soil type and slope. SWAT considers that these units have a similar hydrological response and estimates the main physical processes (runoff, actual evapotranspiration, soil moisture) at this level.

4.2. Input data

Hydrological models require climate, topography, land use, soil type and stream flow data as inputs for the assessment of water resources. The quality and level of detail of the input data will determine the capacity of the model to adequately simulate the water cycle.

4.2.1. Climate data

Modelling water resources requires long climate series with continuous and reliable precipitation and temperature data (Pascual et al. 2015). Daily meteorological data were obtained from stations managed by the Spanish State Meteorological Agency (AEMET) and by the Hydrographic Confederation of Jucar (CHJ). The stations were chosen according to their locations within or close to the basins, considering climatic heterogeneity and continuity in data series. Climate data was subjected to a process of quality control, gap filling and homogenization.

We collected 34 precipitation series, 11 temperature series, 1 radiation series, 1 wind series and 1 relative humidity series. Finally, we selected 23 precipitation series and 3 temperature series. The rest of the series have been discarded because they are older than the time range of the study.

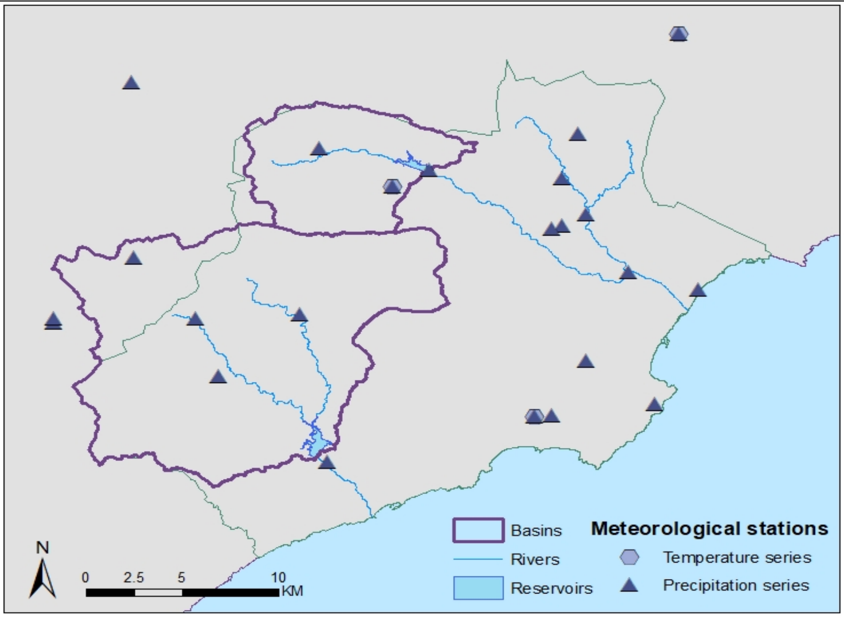


Figure 4. Location of meteorological stations used in the hydrological modelling.

4.2.2. Digital elevation model

The Digital Elevation Model (DEM) was provided by the Spanish Geographic Institute (IGN) at a spatial resolution of 5 m. Digital Elevation Model is the basic information for almost all the hydrological models, since it allows to obtain different essential information: slope, aspect, hydrologic response unit (HRU), wetness index, etc. Figure 5 shows the spatial distribution of elevation according to the available DEM at the spatial resolution of 5 m.

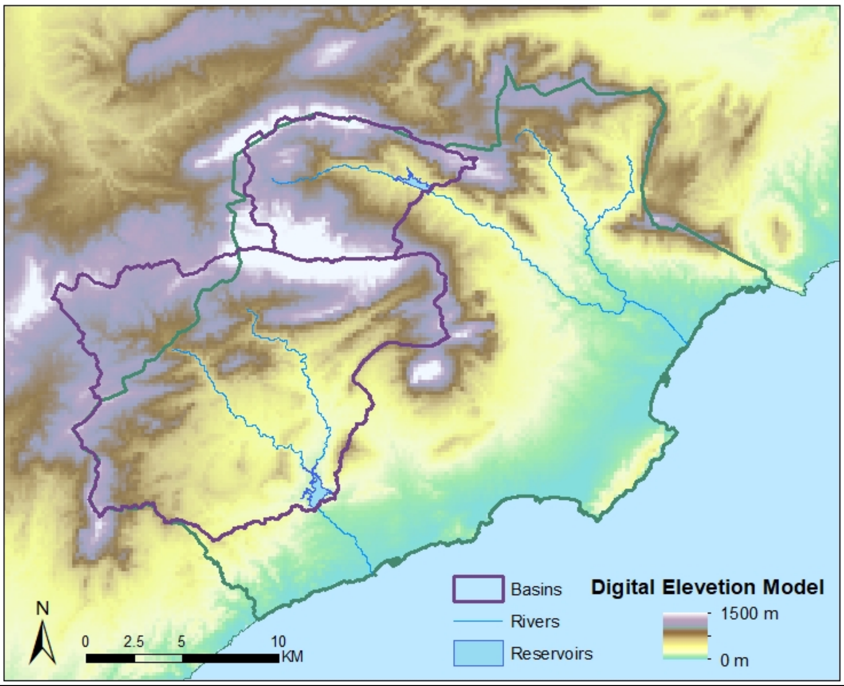


Figure 5. Digital elevation model.

4.2.3. Land use and land cover data

Land use and land cover data were obtained from the Spanish Land use System for 2011 (SIOSE 2011) at the spatial scale of 1:25000. The SIOSE cartography has a complex methodology to characterize the land uses of the territory that results in a wide range of different types of land uses. We have synthesized the different categories of SIOSE into the following categories of hydrological interest: pastures (40.2%), agricultural zones (18.2%), forest (15.2%), scrublands (11.6%), urban zones (7%), areas with scarce vegetation (4.6%), rocks (3%) and water surfaces (0.05%).

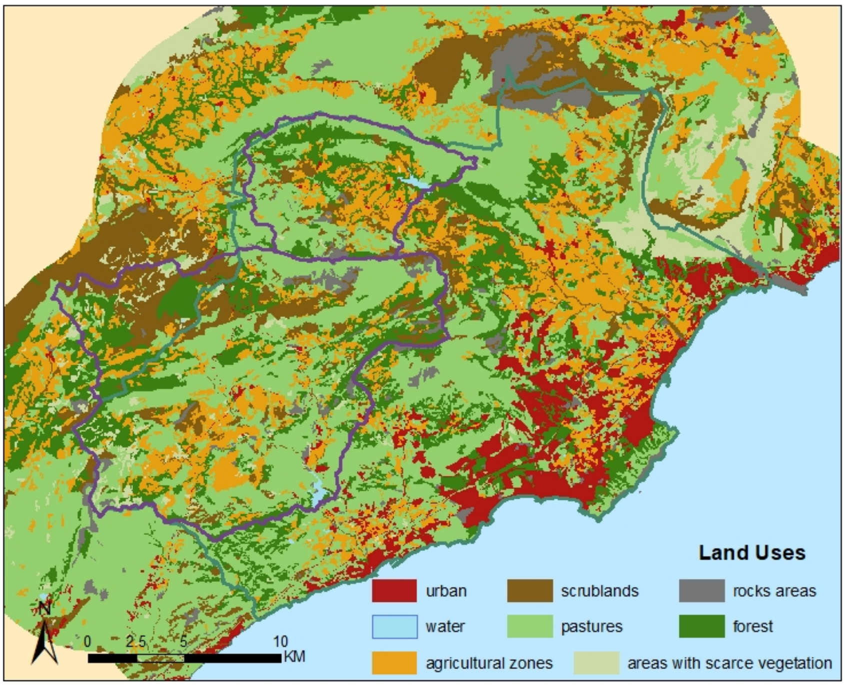


Figure 6. Land uses.

4.2.4. Soil data

Soil data has been obtained from the SoilGrid project. SoilGrids is a system for automated soil mapping based on global soil profile and covariate data (Hengl et al., 2014; Hengl et al., 2016). SoilGrids1km, SoilGrids250m are outputs of spatial predictions produced using the SoilGrids system, i.e. a collection of updatable soil property and class maps of the world produced using machine learning and statistics. These predictions represent the initial outputs of a planned series of global map products (SoilGrids1km, SoilGrids250m, SoilGrids100m) (Montanarella & Vargas 2012).

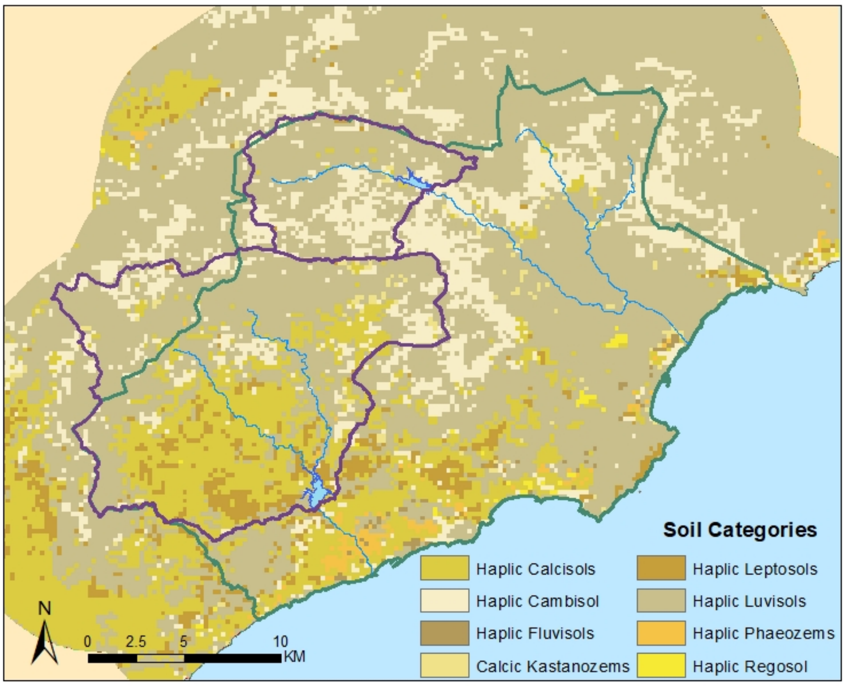


Figure 7. Soil Categories

4.2.5. Hydrological data

Daily stream flows data from gauging stations, reservoir management data and water abstraction through channels and collections are needed to calibrate and validate the hydrological models. However, in our case, due to the lack of data from gauging stations, only the data from the reservoirs management have been used.

Reservoir management data used by CLISWELN project were provided by the Jucar Hydrographical Confederation (CHJ). However, it is necessary to point out that both the reservoirs of the study, Amadorio and Guadalest, have water impulsions. These impulsions must be taken into account to model the surface water resources of the basins. In the case of the Guadalest reservoir, we have obtained data about the impulsions from the Water Cycle Institution of the "Diputación de Alicante" referring to the 1980s. However, we have declined the use of this data due to inconsistency with the data observed from the Guadalest Reservoir. In the case of the Amadorio reservoir, it has not been possible to obtain the data on the impulsions. However, in this case the impulsions are not very significant (Castaño et al. 2005).

Reservoir	Capacity (hm3)	Surface (ha)	Construction year	Available data
Amadorio	16	103	1957	Daily (1957-2017)
Guadalest	13	67	1969	Daily (1969-2017)

Table 5. Reservoirs used in the hydrological modelling.

Impulsions	Available data
Algar river to Guadalest reservoir	Daily (1957-2017)

Table 6. Available water impulsions

Hydrological data were highly diverse, and in some periods incomplete and of poor quality. We needed to select a common reference period to ensure the quality and consistency of the model. In the case of Guadalest we decided to model with monthly data in years of abundant rainfall and where the reservoir was moderately full, due to the fact that pumping is less intense at this time of year (Castaño et al. 2005). Therefore the calibration was performed between 1989 and 1994 and the validation period was performed between 2003 and 2012. In the case of Amadorio, the model was made with monthly data from 1990 to 2010 and validated with data from 2011 to 2017.

4.3. Calibration of the hydrological models

The first phase of the modelling and the most important part of the process is the calibration of the hydrological model. This process is done by comparing model results with observed data at gauging stations. Model calibration implies to modify the model parameters to obtain stream flow values similar to those registered in the gauging station, especially in regard to peak flows and base flows.

Model calibration was carried out with three main objectives: (1) to obtain simulated stream flow curves comparable with observed stream flow curves; (2) to obtain mean stream flow values and total contributions similar between simulated and measured data; and (3) to check the quality of simulated data with the Nash-Sutcliffe efficiency (NSE) coefficient, the RMSE-observations standard deviation ratio (RSR) and the percent bias (PBIAS, %), following Moriasi et al. (2007). The NSE coefficient, the RSR ratio and PBIAS equations and the statistics performance ratios are shown in table 7. The r-factor will also be assessed. This factor is the ratio of the average width of the 95 % prediction uncertainty (ppu) band and the standard deviation of the measured variable. For R < 1.5 model will be accepted (Abbaspoure et al., 2004, 2015, Szezesniak și Piniewski, 2015 in Thavhana et al., 2018).

Performance rating	$RSR = \left[\frac{\sqrt{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim} \right)}}{\sqrt{\sum_{i=1}^{n} \left(Y_i^{obs} - Y^{mea} \right)}} \right.$	$NSE = 1 - \left[\frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim} \right)^2}{\sum_{i=1}^{n} \left(Y_i^{obs} - Y^{mean} \right)^2} \right.$	$PBIAS = \left[\frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim} \right) * (100}{\sum_{i=1}^{n} \left(Y_i^{obs} \right)} \right.$
Very good	0.00 ≤ RSR ≤ 0.50	1.00 ≤ NSE < 0.75	PBIAS < ± 10
Good	0.50 < RSR ≤ 0.60	0.75 ≤ NSE < 0.65	± 10 ≤ PBIAS ≤ ± 15
Satisfactory	0.60 < RSR ≤ 0.70	0.65 ≤ NSE < 0.5	± 15 ≤ PBIAS ≤ ± 25
Unsatisfactory	RSR > 0.70	NSE ≤ 0.5	PBIAS ≥ ± 25

Table 7. Equations for the statistics Nash-Sutcliffe efficiency (NSE) coefficient, RMSE-observations standard deviation ratio (RSR), Percent bias (PBIAS) and general performance ratings for the statistics for a monthly time step. Yiobs is the ith observation values sample for the constituent being evaluated, Yisim is the ith simulated sample for the constituent being evaluated, Ymean is the mean of observed data for the constituent being evaluated, and n is the total number of observations.

4.3.1. SWAT model

Climate, topography, land use, soil type data were introduced in SWAT model. Previously to calibration, some steps were accomplished. First, we divided each basin in sub-basins with quite homogeneous topographic characteristics. Sub-basins delimitation was based on elevation, creating units with similar area. We identified 12 sub-basins in Amadorio Reservoir basin, and 2 in Guadalest Reservoir (Figure 8). The sub-basins are used by the model to assign a specific climate. To do so, SWAT model uses the data from the meteorological station nearest the centroid of each sub-basin. As some temperature stations were located at low altitude, the precipitation data used in some sub-basins in mountainous areas were underestimated. For this reason, temperature series were corrected for the effects of topography using GIS techniques. The relationship between temperature and topography was derived from the digital elevation model (DEM, 5 m spatial resolution) of Alicante (Spanish Cartographic Institute, 2016) and the Digital Climatic Atlas (Ninyerola et al. 2000). However, for the precipitation series this process cannot be carried out due to the lack of correlation between attitude and the climate atlas. In consequence, we have interpolated precipitation data using Thiessen polygons.

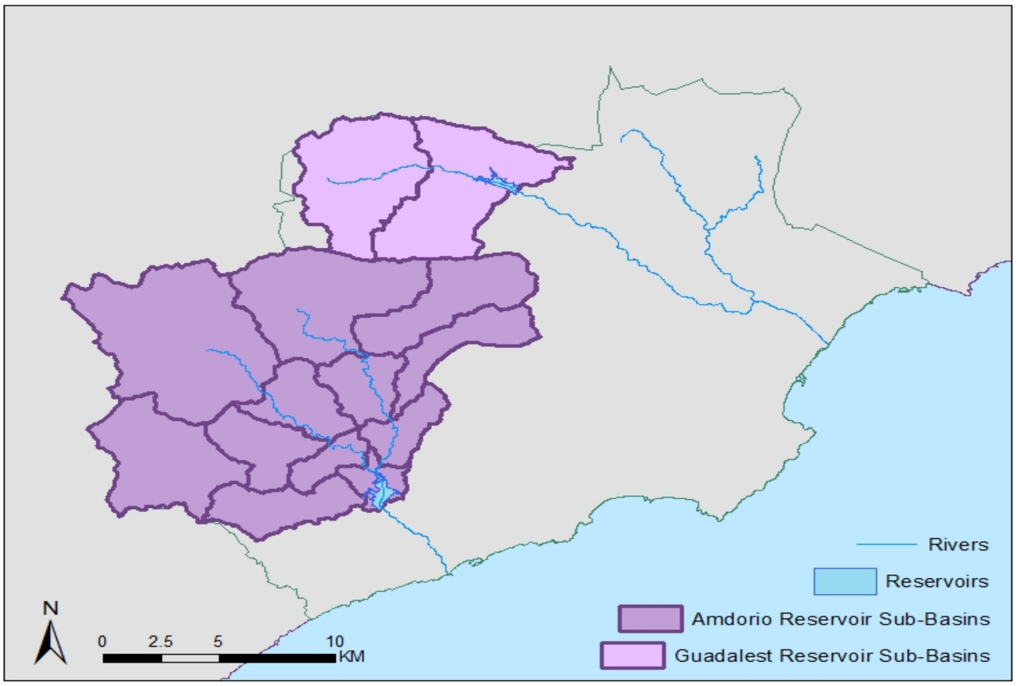


Figure 8. Soil Categories

Finally, we introduced reservoir data into the model, including: 1) reservoir capacity to the principal and emergency spillway (hm3); 2) reservoir surface area when the reservoir is filled to the principal and emergency spillway (ha); 3) reservoir volume at the beginning of the simulation period (hm3), 4) year the reservoir became operational; and 5) management data. Management data were measured daily outflow of each reservoir in m3/s.

Calibrations were performed at monthly time step. In both cases, we have calibrated the model with the average monthly flow rate at the entrance, based on the variation in the monthly volume of the reservoir. In the Amadorio Reservoir there is a drive from the Torres Station that pumps the excess water from the Algar Canal to the Amadorio Reservoir. However, different sources cite this drive as not very significant in the final volume of the reservoir (Castaño et al. 2005), which is why we decided not to take this drive into account. In the case of the Guadalest Reservoir there is also an impulsion from the Algar River to the Guadalest Reservoir. The same sources quantify this contribution as significant in the total estimation of the reservoir volume in years of drought. For this reason, periods of abundant rainfall have been identified to calibrate and validate the model at the Guadalest Reservoir.

Reservoir	Calibration Period	Validation Period
Amadorio	1994-2010	2011-2017
Guadalest	1989-1994	2003-2012

Table 8.Calibration and validation periods.

Sensitivity analysis and preliminary model trials were developed using the Sensitivity Analysis Tool provided by SWAT (Van Griensven 2005) to identify the most influential parameters, which were adjusted during the calibration. The algorithm used was SUFI-2 (Sequential Uncertainty Fitting ver.2) which has been successfully tested in cases similar to our case study (Thavhana et al., 2018). These were parameters related to base flow generation, surface runoff, soil parameters, orographic correction and catchment response. Calibration was performed through the SWAT Calibration and Uncertainty Program (SWAT-CUP, Abbaspour 2013). Parameters related to groundwater (groundwater delay time, base flow alpha factor, groundwater revap coefficient), soil (available water capacity of the soil, saturated hydraulic capacity) land cover (plant uptake and soil compensation factor, curve number) or orographic correction (precipitation and temperature lapse rate) were adjusted using SWAT-CUP, estimating the best fit possible.

Therefore, in the calibration and validation process, the degree of sensitivity of 19 parameters was determined. Parameter sensitivity analysis is a process that determines the rate of change in model outputs based on the variance of model's input parameters (Arnold et al., 2012). Therefore, in the calibration and validation process, the degree of sensitivity of 25 parameters was determined. Parameter sensitivity analysis is a process that determines the rate of change in model outputs based on the variance of model's input parameters (Arnold et al., 2012). While there are a number of techniques available for conducting sensitivity analysis (Saltelli, 2000), all can be broadly grouped as local and global approaches (Saltelli et al., 1999). In local techniques, output responses are determined by sequentially varying each of the input factors and by fixing all other factors to constant nominal values. The further the perturbation moves away from the nominal value, the less reliable the analysis results become (Helton, 1993). Also, the more nonlinear the relationship between inputs and output variables, which is typical in hydrologic models, the more difficult and unreliable it is to employ local techniques.

SWAT Input Parameter	
CN2	Initial SCS runoff curve number for moisture condition II
ALPHA_BF	Base flow alpha factor (l/day)
GW_DELAY	Groundwater delay time (day)
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)
ESCO	Soil evaporation compensation factor
EPCO	Plant uptake compensation factor
GW_REVAP	Groundwater “revap” coefficient
RCHRG_DP	Deep aquifer percolation fraction
SOL_AWC	Available water capacity of the soil layer (mm/mm soil)
SOL_K	Saturated hydraulic conductivity (mm/hr)
PLAPS	Precipitation lapse rate (mm/km)
TLAPS	Temperature lapse rate (mm/km)
REVAPMN	Threshold depth of water in the shallow aquifer for “revap” or percolation to the deep aquifer to occur (mm)
ALPHA_BNK	Base flow alpha factor for bank storage (days)
CANMX	Maximum canopy storage (mm)
CH_N2	Manning`s”n” value for the main channel
CH_N1	Manning`s”n” value for the tributary channels
OV_N	Manning`s”n” value for overland flow

Table 9. Parameters used in calibration.

4.3.2. Calibration of Amadorio Reservoir

Figure 9 shows calibration outputs for monthly reservoir inflow (m3/s). The graphical comparison between simulated and observed data showed a good fit, although in simulation underestimated high flood peaks and slightly overestimated base flows. One explanation could be the high spatial variability of the precipitation in the area, where the complex mountainous landscape causes orographic precipitation or convective phenomena that affect the climate (Barrera-Escoda and Cunillera 2011). This means that the precipitation measured in the meteorological station may be different than the total registered in the upstream area of the gauging station. Another reason can be the low capacity of the SWAT model structure to adequately account for hydrological extreme events (Ndomba et al. 2008).

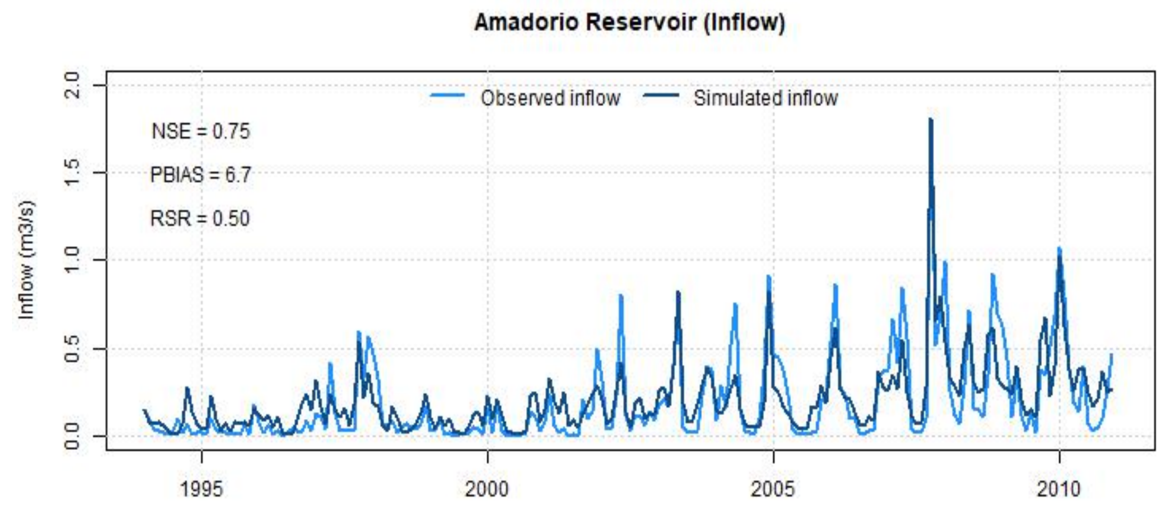


Figure 9. Amadorio Reservoir calibration

The average flow rate simulated is 0.2 m3/s and the average flow rate observed is 0.19 m3/s, therefore in average terms we consider that the result is quite accurate. The NSE (0.75), PBIAS (-6.7) and RSR (0.5) statistics show a very good simulation (Moriasi et al. 2007). The r-factor of the model it has a value of 0.16, so we consider that the model is acceptable (Abbaspoure et al., 2004, 2015, Szezesniak și Piniewski, 2015 in Thavhana et al., 2018).

4.3.3. Calibration of Guadalest Reservoir

Figure 10 shows calibration outputs for monthly reservoir inflow (m3/s). We performed the calibration between 1989 and 1994. This period corresponds to one of the periods with the highest annual rainfall registered and where the volume of the reservoir was around the maximum. We have chosen this period with the intention of minimizing the influence of pumping from the Algar River. The explanation for this fact may be due to the same reasons as in the calibration of the Amadorio Reservoir: spatial variability of precipitation due to orography.

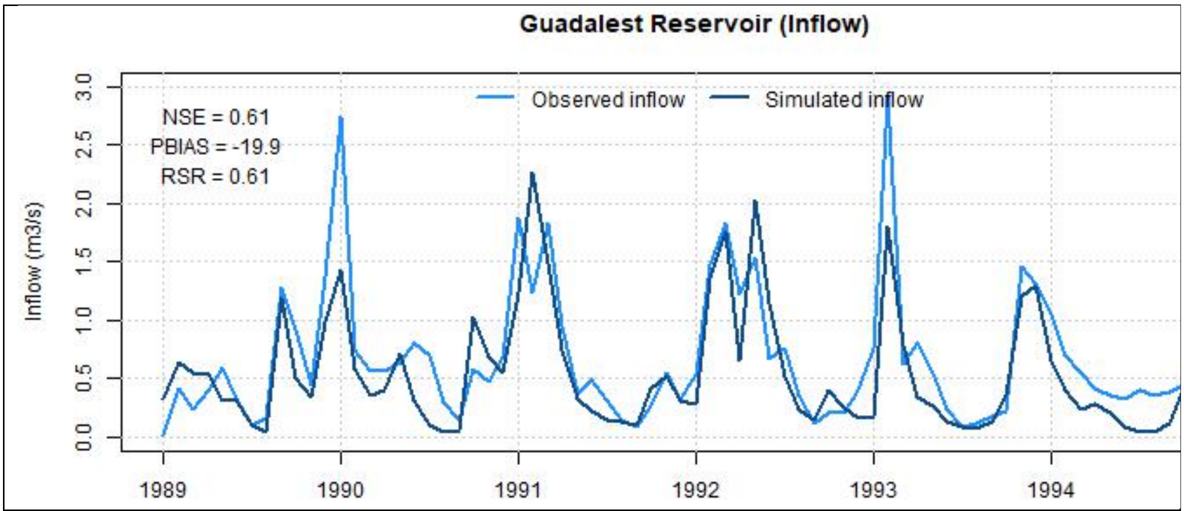


Figure 10. Guadalest Reservoir calibration

The average flow rate simulated is 0.53 m3/s and the average flow rate observed is 0.67 m3/s. This difference may be due to the fact that the model is directly dependent on precipitation. Although the calibration has been carried out in a wet season in a few months, the pumping may have more influence than the precipitation and due to this factor there may be a difference between the average flow observed and simulated. The NSE (0.61), PBIAS (-19.9) and RSR (0.61) statistics show a satisfactory simulation (Moriasi et al. 2007). The r-factor of the model it has a value of 0.61, so we consider that the model is acceptable (Abbaspoure et al., 2004, 2015, Szezesniak și Piniewski, 2015 in Thavhana et al., 2018).

After the results obtained, we try to improve the results by incorporating new parameters for calibration. We added 7 (table 10) new parameters to the 18 (table 9) with which the calibration was done. However, the result did not improve. This fact is due to the new parameters have little impact on the functioning of the model and create greater uncertainty. Therefore this new calibration was discarded.

SWAT Input Parameter	
SOL_Z	Depth from soil surface to bottom of layer (mm).
FFCB	Initial soil water storage expressed as a fraction of field capacity water content.
SOL_BD	Moist bulk density (Mg/m3 or g/cm3).
CH_K(1)	Effective hydraulic conductivity in tributary channel alluvium (mm/hr).
CH_K(2)	Effective hydraulic conductivity in main channel alluvium (mm/hr).

Table 10. Parameters used in the second calibration.

4.4. Validation of the hydrological models

The validation measures the model prediction capacity through the comparison between simulated results and observed data in a time period different from the calibration.

4.4.1. Validation of Amadorio Reservoir

The validation was performed within the 2011-2017 period (7 years). Land cover map and water abstraction data were as in the calibration. Reservoir inflow was simulated at monthly time-step.

Figure 11 shows validation outputs for monthly stream flow (m3/s) for Amadorio Reservoir. The graphical comparison between simulated and observed data shows a fit less satisfactory than the calibration. In the data observed, an output value was identified (January 2017), so we decided not to use this value for validation. In general terms, we observe that the simulated model reflects the trend of the observed values. We have observed that in December 2011 and January 2012 there is a mismatch between the model and the data observed. We have verified that in these months the tendency of precipitation does not follow the tendency of the observed data, therefore we can intuit that in these months there was a significant pumping from the Torres Station.

The average monthly simulated flow rate is 0.21 and the average observed flow rate is 0.22. Therefore the validation period between the observed and simulated series continues to show the flow rate trend. The NSE (0.59) and and RSR (0.62) statistics show a satisfactory performance ratio and PBIAS (3.6) statistic was very good simulation. The r-factor of the model it has a value of 0.11, so we consider that the model is acceptable (Abbaspoure et al., 2004, 2015, Szezesniak și Piniewski, 2015 in Thavhana et al., 2018).

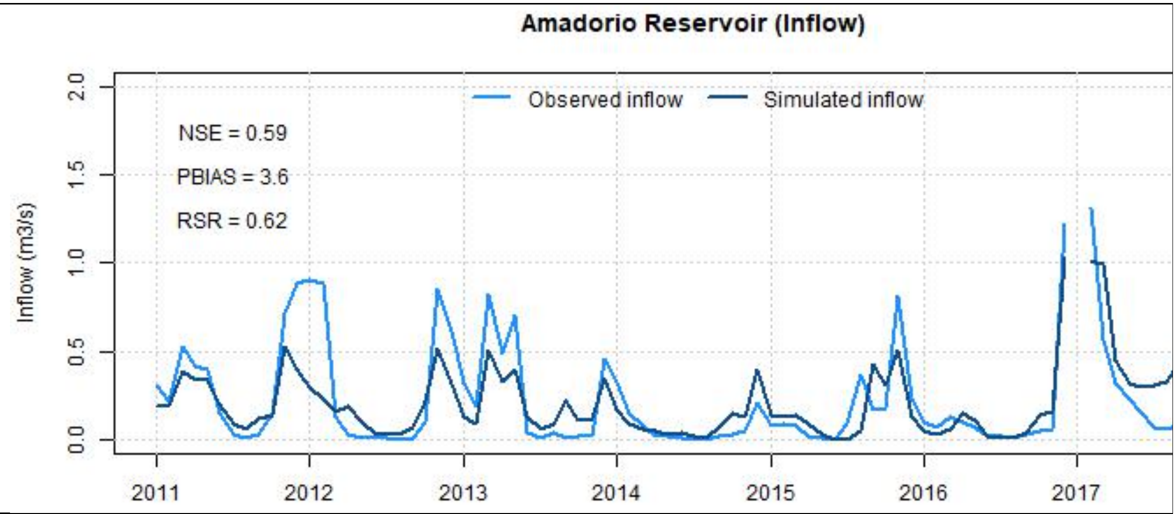


Figure 11. Amadorio Reservoir validation

4.4.2. Validation of Guadalest Reservoir

The validation was performed within the 2003-2012 period (10 years). Land cover map and water abstraction data were as in the calibration. Reservoir inflow was simulated at monthly time-step.

The graphical comparison between the simulated and the observed data shows an irregular fit. In some sections we observed that there are no major differences between the model and the data observed, and on the contrary in other sections there are more significant differences. We associate this fact with the influence of pumping on the supply of the reservoir which, as we have already said, depends significantly on the annual rainfall.

The average monthly simulated flow rate is 0.39 and the average observed flow rate is 0.43. Therefore the validation period between the observed and simulated series continues to show the flow rate trend. The NSE (0.58), RSR (0.64) and PBIAS (13.8) statistics show a satisfactory performance ratio. The r-factor of the model it has a value of 0.11, so we consider that the model is acceptable (Abbaspoure et al., 2004, 2015, Szezesniak și Piniewski, 2015 in Thavhana et al., 2018).

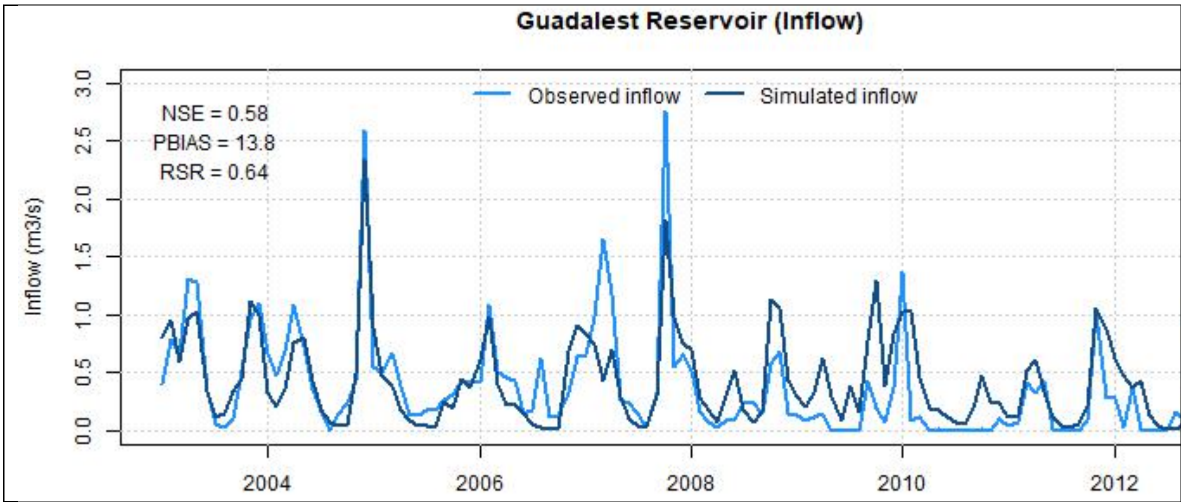


Figure 12. Amadorio Reservoir validation

4.5. The Algar aquifer (The Carrascal Ferrer aquifer)

The Carrascal Ferrer aquifer is the largest aquifer in the Marina Baixa, its permeable surface is about 30 km^2 (Diputacion de Alicante, 2015). This permeable surface can be classified in two categories: surface of high permeability and surface of low permeability (Ballesteros-Navarro, et al., n.d). The highly permeable surface absorbs rainfall through a process with higher levels of infiltration, while the surface of low permeability absorbs rainfall through a process with lower levels of infiltration, which related to higher and lower infiltration coefficients, respectively (Ballesteros-Navarro, et al., n.d). A lateral transfer coming from surrounding aquifers and seepage water from closest ravines also support the aquifer volume (Ballesteros-Navarro, et al., n.d). Despite its importance for water supply in the county, data related to the behaviour of this aquifer is very limited.

Figure 13. Carrascal Ferrer aquifer: the bottom from the *Sierra de Ferrer* (Diputacion de Alicante, 2015)

The main aquifer comprises three permeable surface formations; the limestone sections of Aptian-Albian and Cenomian-Turanian, the pararecifal limestones of the low Oligocene Miocene in the southern of the aquifer, and the limestones of Eocene in the section of *Serrella de Serrella-Aixorta* and Peña Severino (Diputacion de Alicante, 2015).

In the western side, the aquifer coincides with a major fault of northwest-southeast direction. In the eastern, the aquifer is delimited by the structural direction of the *Sierra de Ferrer*. There are several southern boundary sections such as the impermeable areas between Benasau and the northern side of Serella, and the western limits of Bernia. In the northern side, the main aquifer is bounded by the frontal overthrusting of the Sierra Serella Aixorta (Diputacion de Alicante, 2015). The model of the aquifer is integrated in the system dynamics modelling tool and detailed in Section 7 (see Figure 20 for details).

5. Land use

Land-use change is amongst the most important non-climatic factors in water resource management in the case study (Martinez-Ibarra, 2015; Rico-Amoros et al., 2013). Land-use change such as replacing forest and rainfed agricultural land use with urban land use can increase water consumption as development of urban areas is associated with a higher population (Martinez-Ibarra, 2015; Rico-Amoros et al., 2013). Because of this, the following subsections describe the land-use change and the feature of low- and high-density urban areas in the Marina Baixa.

5.1. Land-use change in the coastal areas of the Marina Baixa county

There many factors driving land-use change in regional and local scales (Raskin, 2005). These factors include, for example, economic development, globalization, socio-economic and cultural differentiation, geopolitical conflicts, government policies, and population movement. Among those factors, economic development and government policies have been the main driving forces of land-use change in the case study area (Rico-Amoros et al., 2009; Braimoh & Vlek, 2005); in the following paragraphs we explain these two main driving forces on land-use change in the Marina Baixa, detailing how the tourism industry is the main economic activity that has induced land-use change in the county and that Spanish and Regional Valencian government policies have been very intense factors enabling land-use change.

The main economic activities of the Alicante coastline such as the Marina Baixa county in 1956 were farming and fishing (Morote & Hernandez, 2016). Although tourism activity existed, the impacts of tourism development did not have a large effect on the land-use change in Alicante. The most intense urban land use development happened along the Spanish Mediterranean coastline contemporarily with the real state booms that affected the entire country in 1985-1991 and 1996-2008 (Rico-Amoros et al., 2009; Bellot et al., 2007; Morote & Hernandez, 2016; Cremades, 2008).

Figure 14. The Marina Baixa, Alicante, Spain (http://www.icv.gva.es/)

The demand for land development has been reinforced by a mild climate in comparison to the international resident’s home countries mostly by northern and eastern European countries (Amoros et al., 2009; Morote & Hernandez, 2016). This is visible in the population census, in 2017 the population in Alicante province was comprised by a 19% of foreign residents (The Alicante Statistical Bureau, 2018).

Figure 15. Benidorm in the 1960s (above) and in 2012 (below) (Cabrera, 2012)

Among the municipalities in Alicante province, Benidorm has experienced the highest urban growth owing to the development of the tourism sector. Benidorm also holds the most significant role in the area in terms of tourist stays, about 12 million in 2016 (Sánchez-Galiano, Martí-Ciriquián, & Fernández-Aracil, 2017). Again, owing to a large-scale urban development, Benidorm's urban areas have increased by a factor of eighteen since 1956 (Bellot et al., 2007). In line with this land-use change, Benidorm's population has increased significantly from 3,000 inhabitants in 1950s to about 67,000 inhabitants by 2017, with a 29% of foreigners in its total population, mostly from the UK and Romania (INE, 2018).

Another factor affecting the demand for urban land use are the low-cost carriers since the late 1990s. These low-cost carriers have enabled millions of tourists to frequently travel to the case study area from different places. Owing to these low-cost carriers, the Alicante airport is categorised as one of the European busiest airports, which gives an clear impression of the relevance of the tourism industry in Alicante. At the regional and local scale, the implementation of local and regional urban planning and policies i.e. the “LRAU” or Act for Regulating the Urban Activity in the Autonomous Community of Valencia in 1994 massively supported urban developments in the entire region (Cremades, 2008). The potential income source from building development and a speculative housing market also propagated land-use change and urban growth. This massive land-use change ended around 2007, with the burst of a bubble in housing prices at the national scale (Bellot et al., 2007).

5.2. Low- and high-density urban areas in the Marina Baixa

Because the development of tourism in the county predominantly relates to the “3S” model (sand, sea and sun), coastal areas are more populated compared to inland areas (Amoros et al., 2009). To support tourism development in coastal areas, a lot of vertical buildings were constructed to support climate-tourism activities. Since Benidorm is associated with high-density areas (Morote & Hernandez, 2016; Rico-Amoros et al., 2009), occupied areas in Benidorm are highly populated compared with other urban areas in La Nucia or other municipalities in the Marina Baixa. In high-density areas such as Benidorm, properties such as skyscrapers, apartment flats and other high buildings are common. These tourism characteristics are related to the so-called the mass tourism model (Amoros et al., 2009).

Moreover, because existing studies (Morote & Hernandez, 2016; Rico-Amoros et al., 2009) did not define density values for low- and high-density areas, this study categorises urban areas with an average density of 80 people/ha or higher as high-density areas, and areas with an average density of 9 people/ha or lower as low-density areas. These average density values are supported by another study (Sánchez-Galiano et al., 2017) and these average density values also very useful because we successfully model resident population (compare to observed resident population) based on the size of low- and high-density areas and average density values.

In the opposite end of high-density, many locals and foreigners tend to buy houses in low-density areas (Morote & Hernandez, 2016). While Spanish residents tend to buy compact houses or apartments, foreigners tend to buy detached houses with a swimming pool and a garden (Morote & Hernandez, 2016). The impacts of swimming pool and garden in water consumption are important (Rico-Amoros et al., 2009). For example, a daily water consumption per person in a single house with pool and garden (359 lpd) is higher about 45 % than that of a single house without pool and garden (247 lpd).

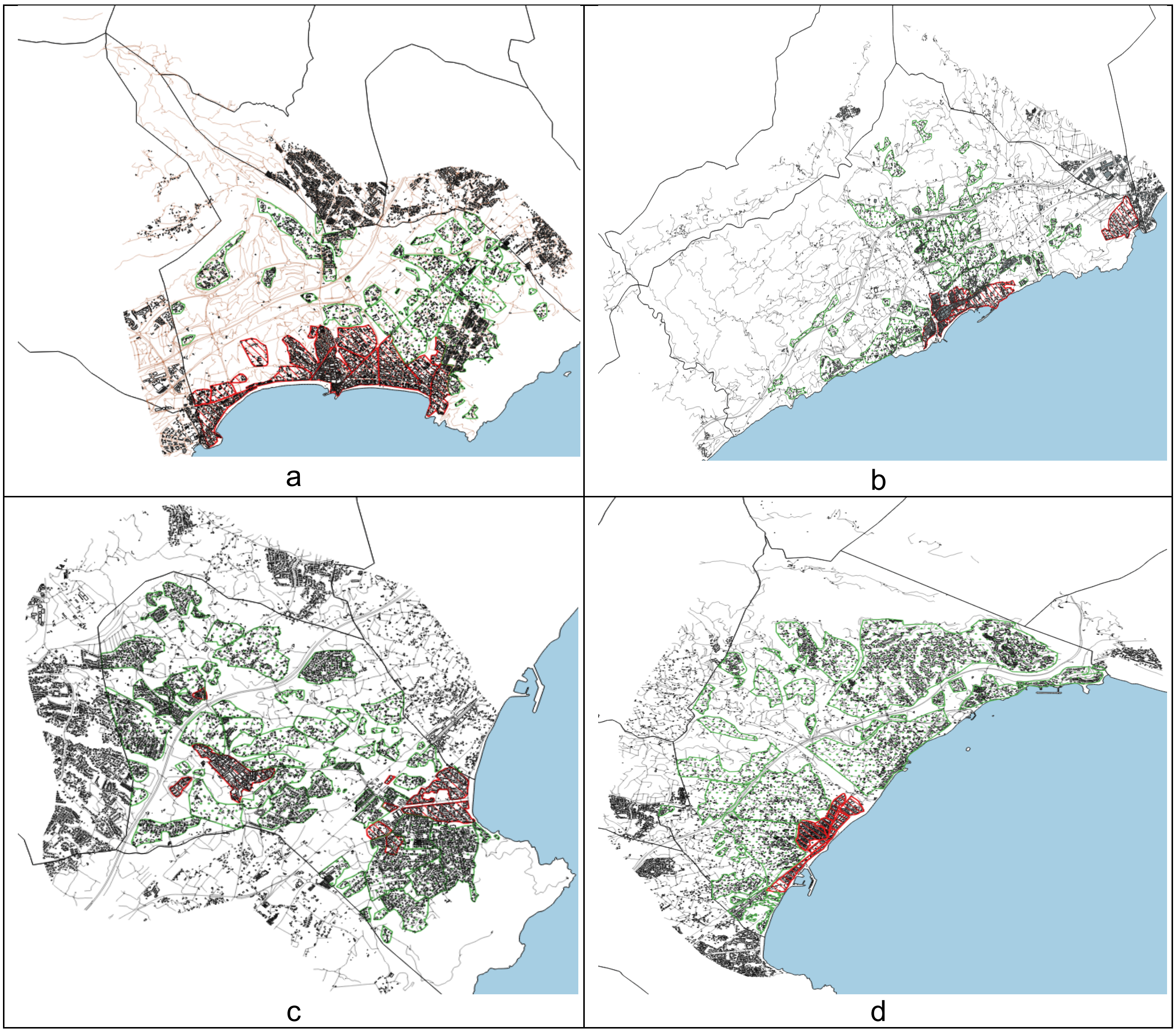


Figure 16. High (red) and low-density areas in Benidorm (a), La Vila Joiosa (b), Alfaz del Pi (c) and Altea (d). (source: own elaboration, after Institute Cartografic Valencia (2018)

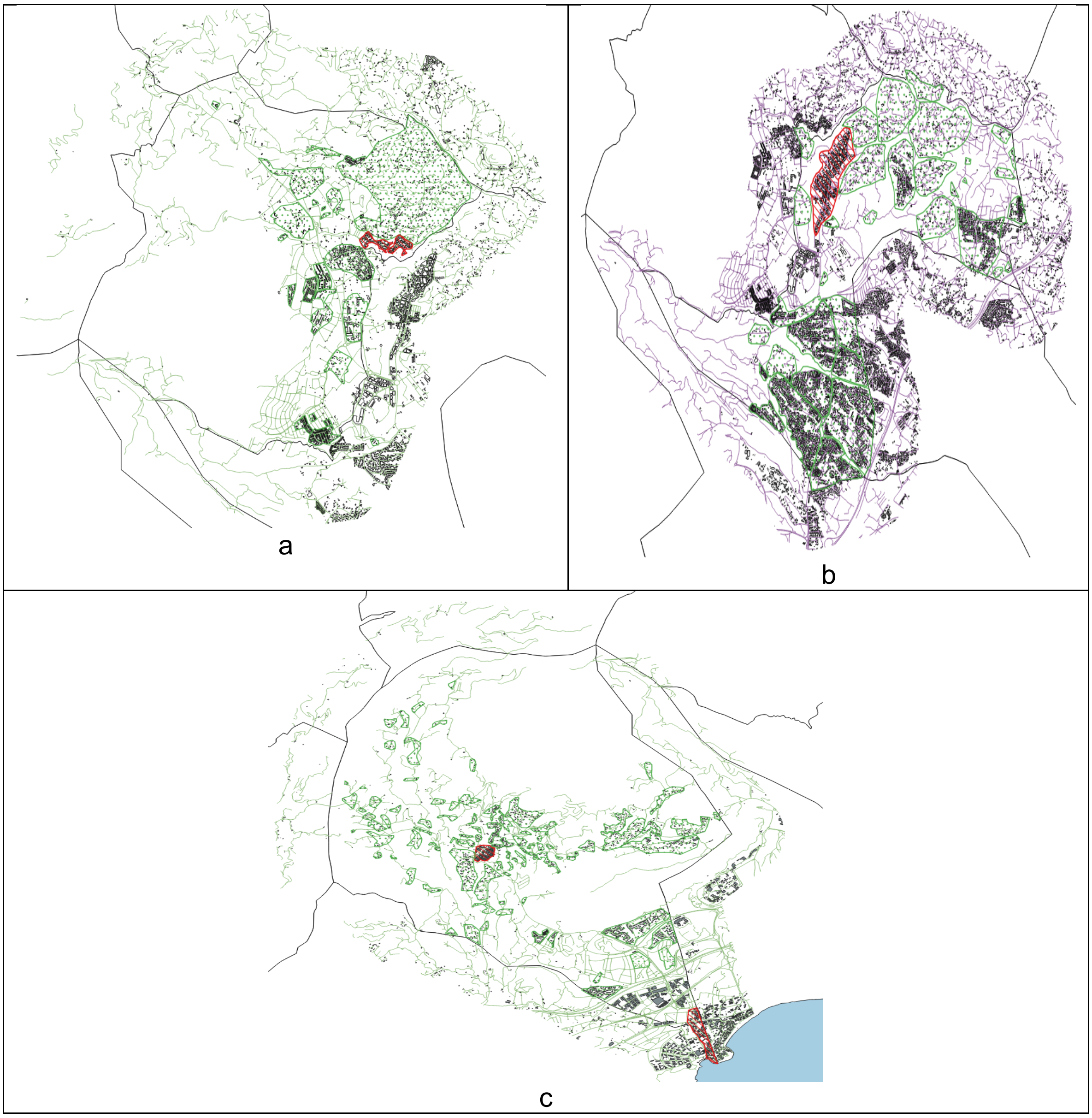


Figure 17. High (red) and low-density areas in Polop (a), La Nucia (b), and Finestrat (c) (source: own elaboration, after Institute Cartografic Valencia (2018)

Figures 16 and 17, and Table 11, exhibit the size of low-density and high-density areas in each municipality. Benidorm has high-density areas about 489 ha and relatively limited low-density areas about 2 ha. In contrast, Polop only has high-density areas about 12 ha but it has low-density areas about 407 ha.

No	Municipalities	low-density size (ha)	high-density size (ha)
1	Polop	407.10	11.83
2	Finestrat	462.52	32.97
3	Callosa en Sarria	375.25	54.50
4	Nucia	1,085.38	78.09
5	Alfaz del Pi	720.28	101.93
6	Altea	1,606.05	88.68
7	La Vila Joiosa	675.40	185.52
8	Benidorm	2.32	488.66

Table 11. The size of low-density and high-density areas in each municipality. (source: own elaboration, after Institute Cartografic Valencia (2018)

6. Energy consumption in water supply

The Marina Baixa county is a water-stressed area, meaning securing a sufficient water with a low associated energy consumption is a challenging task for decision makers.

Energy is used while extracting, treating, distributing and in the end-use consumption of water. In Spain, considering the total energy consumed for urban water uses, most of the energy consumption occurs in the stages of extraction and treatment. During stages of extraction and treatment, consumed energy is about 64% of the total energy consumption in the Spanish water cycle (Hardy, Garrido & Juana, 2012). The rest of energy consumption goes to water distribution and end-use (21%) and wastewater treatment (16%). This study focuses on energy consumption along the stages of water extraction, water treatment and water distribution, which contribute to about 85 % of total energy consumption in the Spanish water cycle (Hardy, Garrido & Juana, 2012). In the next step, the energy consumed by wastewater treatment will be also included.

Table 12 displays the required energy required for each of the stages in the Spanish water cycle in kWh/m^3 (Yoon et al., 2018). Wastewater treatment has the highest energy consumption per m^3 of water. This study uses the equation below (Equation 1) to estimate energy consumption after groundwater extraction. For water distribution, the energy use is parametrized from the distribution system.

No	Stage	Estimated Energy consumption (kWh/m^3)
1	Water treatment	0.013 - 0.073
2	Water distribution	0.012 - 0.148
3	Wastewater treatment	0.346 - 0.542

Table 12. A range of energy intensities in Spanish water cycle (Yoon et al., 2018)

The electric energy to extract groundwater will be calculated using an equation reflecting the theoretical physical relationship to pump a mass of water. This equation is as follows (Cremades et al., 2016):

$$\text{Energy (kWh)} = \frac{9.8\, m.s^{-2}\ x\ lift\ (m) x\ Mass\ (kg)}{3.6\ x\ 10e6\ x\ Pumping\ efficiency} \ \ldots\ldots\ldots\ (1)$$

where:

$9.8\ ms^{-2}$ = gravity (ms^{-2});
Lift = depth or distance of water movement vertically (m);
Mass = mass of water in kilograms (1 m^3 of water has 1 tonne of mass);
3.6 x 10e6 = a conversion factor from Joule to kilowatt-hours (kWh);
Pumping Efficiency= the effectiveness of pumping measured in percentage (%). This study assumes that the pumping efficiency is 60% (Yoon et al., 2018).

7. Integrated water-energy-land nexus model

In this study, multiple stakeholders such as policy makers at the national, regional, provincial and local scales, tourism sector representatives, municipality councils and water companies can explore the different dynamic behaviours of the water-energy-land system behind urban water consumption. These stakeholders also face a degree of pressure from increased droughts due to climate change (Schleussner et al., 2016; Greve et al., 2018; Lehner et al., 2017; Porter et al., 2014). Besides, because economic development and urban growth increased water demand, energy consumption also increases owing to a higher volume of water supply and the non-conventional water processes involved.

These interconnected interactions require integrated and holistic solutions (Bazilian et al. (2001, Nair et al., 2014). The nexus can be holistically analysed using system dynamics (Nasiri et al., 2013; Nair et al., 2014). Our research aims to develop a dynamic nexus model that can assist the municipality councils, investors and policy makers in simulating land- and water-related decisions to minimise water consumption and energy for water consumption in the Marina Baixa, Spain, under diverse climate change scenarios.

System dynamics (SD) modelling has been used to assess urban water studies extensively (e.g. Zhang et al., 2008; Zhang et al., 2009; Karamouz et al., 2012). Other studies such as Qi and Chang (2011), Wang (2014), Tong and Dong (2008), and Nawarathna et al. (2009) independently studied the dynamic effects such as of macro-economy, water price, socio-economic environmental system, or changing land-use on water demand and supply. However, to the best of our knowledge, existing SD-based studies did not include the impacts of climate change on water supply in the context of nexus studies.

7.1. A causal loop diagram

The Marina Baixa study can be seen as the interaction between water demand and water supply. On a side of water demand, resident population (registered population) and temporary population, such as tourists that can increase water demand. Hence, we categorise two population types including the first population, which is called resident population or registered population, and the second one, which is temporary population such as tourists and holidaymakers. Land-use change may lead to low-density and high-density urban areas. These categories of urban density lead to different water consumption levels. Inhabitants in low-density areas tend to consume higher levels of water per capita than those in high-density areas.

In terms of water supply, it can be surface water (reservoirs and rivers) and groundwater (aquifers), both are influenced by the precipitation pattern. As visible in Figure 18, an increase in water supply can enable urban land-use change, increasing tourism resorts and resident housing in the area, leading to a higher population and water demand. Albeit counterfactual, this systemic interaction has been observed in the area.

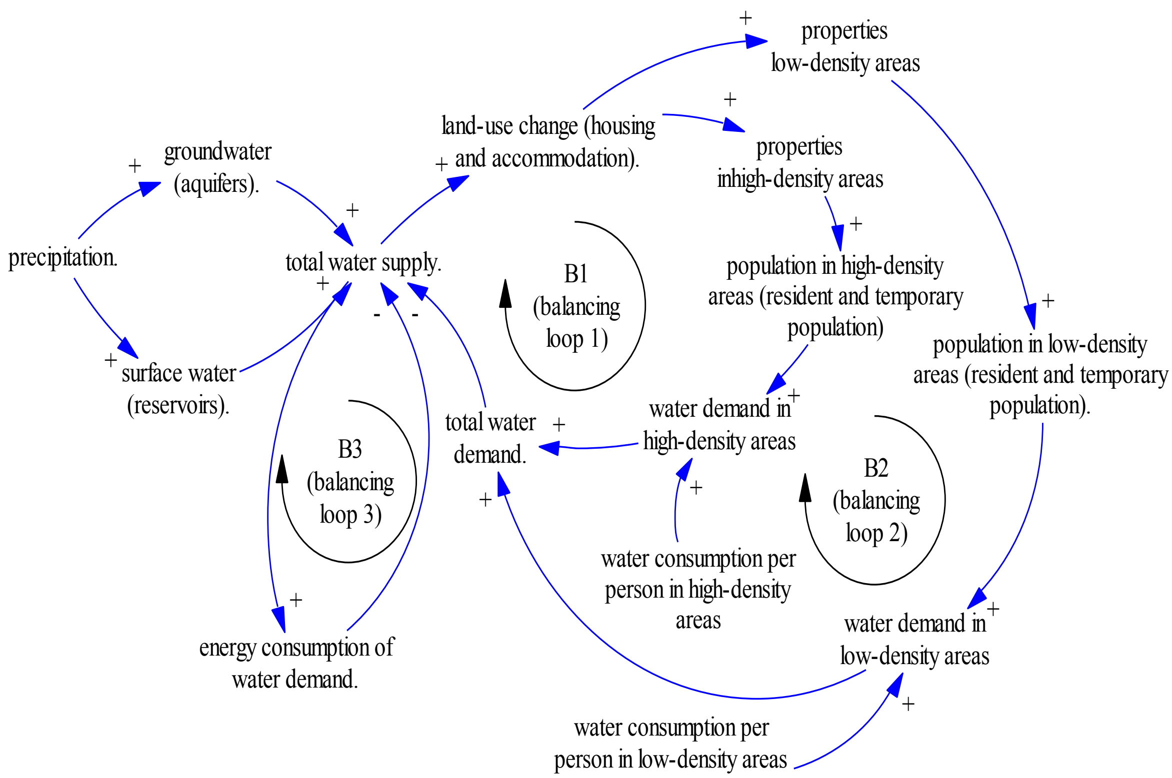


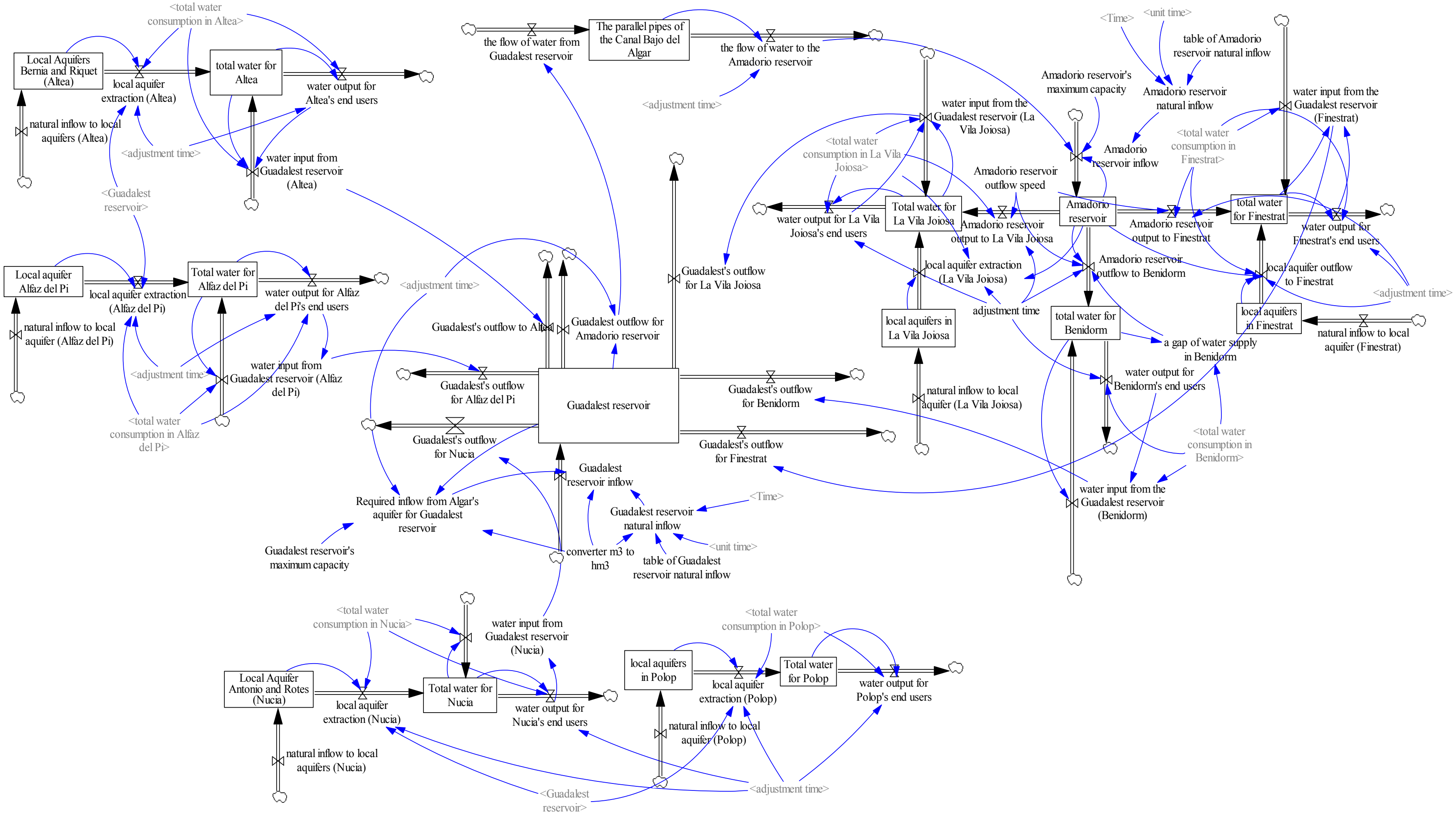
Figure 18. A conceptual causal loop diagram of the WELN of the dynamics of urban water supply

As water demand decreases water availability, two balancing loops (B1 and B2) may hinder population growth and land-use change. This also means that water scarcity can influence population dynamics. The other balancing loop (B3) tells us that energy consumption owing to water consumption may have an effect on total water demand as per the increasing costs of energy consumption related to water resources that would be increasingly difficult to obtain. In short, our causal loop diagram represents the WELN in the Marina Baixa.

7.2. A stock-flow diagram

A stock-flow (SF) diagram is needed to simulate the real world with system dynamics. In this research, a stock-flow flow model is constructed to understand the dynamics of water, land and energy in the urban water supply of the Marina Baixa county in Alicante, Spain. Compared to a causal loop diagram in the section above, a SF diagram (e.g. Figures 19-21) is more complicated as it consists of mathematical formulations and cause-effect relationships. The model is divided into five main modules including “urban water distribution", "the main aquifer (Carrascal Ferrer aquifer)", "land and population", "energy consumption", and "urban water consumption".

In the module of urban water distribution and reservoirs (Figure 19), the roles of the Guadalest and Amadorio reservoirs are described (like in Figure 2 of section 4). The Guadalest and Amadorio dams provide water to Finestrat, Benidorm, La Vila Joiosa, Alfaz del Pi, Nucia and Altea. Polop is relatively independent as its local aquifer provides sufficient water. The module also captures how water is distributed to the municipalities through the channel of the Canal Bajo del Algar. This study presumes that coastal groundwater extraction by local wells is required when the main aquifer and the reservoirs cannot provide sufficient water supply.



Local Aquifers Bernia and Riquet (Altea)
local aquifer extraction (Altea)
<total water consumption in Altea>
total water for Altea
water output for Altea's end users
natural inflow to local aquifers (Altea)
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water input from Guadalest reservoir (Altea)
<Guadalest reservoir>
Local aquifer Alfaz del Pi
local aquifer extraction (Alfaz del Pi)
Total water for Alfaz del Pi
water output for Alfaz del Pi's end users
natural inflow to local aquifer (Alfaz del Pi)
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water input from Guadalest reservoir (Alfaz del Pi)
<total water consumption in Alfaz del Pi>
the flow of water from Guadalest reservoir
The parallel pipes of the Canal Bajo del Algar
the flow of water to the Amadorio reservoir
<adjustment time>
<adjustment time>
Guadalest's outflow to Altea
Guadalest outflow for Amadorio reservoir
Guadalest's outflow for La Vila Joiosa
Guadalest's outflow for Alfaz del Pi
Guadalest reservoir
Guadalest's outflow for Benidorm
Guadalest's outflow for Nucia
Guadalest's outflow for Finestrat
Guadalest reservoir inflow
Required inflow from Algar's aquifer for Guadalest reservoir
Guadalest reservoir natural inflow
<Time>
<unit time>
Guadalest reservoir's maximum capacity
converter m3 to hm3
table of Guadalest reservoir natural inflow
water input from the Guadalest reservoir (La Vila Joiosa)
<total water consumption in La Vila Joiosa>
water output for La Vila Joiosa's end users
Total water for La Vila Joiosa
Amadorio reservoir output to La Vila Joiosa
local aquifer extraction (La Vila Joiosa)
adjustment time
local aquifers in La Vila Joiosa
natural inflow to local aquifer (La Vila Joiosa)
Amadorio reservoir's maximum capacity
<Time>
<unit time>
table of Amadorio reservoir natural inflow
Amadorio reservoir natural inflow
Amadorio reservoir inflow
Amadorio reservoir outflow speed
Amadorio reservoir
Amadorio reservoir output to Finestrat
Amadorio reservoir outflow to Benidorm
total water for Benidorm
a gap of water supply in Benidorm
water output for Benidorm's end users
<total water consumption in Benidorm>
water input from the Guadalest reservoir (Benidorm)
<total water consumption in Finestrat>
water input from the Guadalest reservoir (Finestrat)
total water for Finestrat
water output for Finestrat's end users
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<adjustment time>
local aquifers in Finestrat
natural inflow to local aquifer (Finestrat)
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water input from Guadalest reservoir (Nucia)
Local Aquifer Antonio and Rotes (Nucia)
local aquifer extraction (Nucia)
Total water for Nucia
water output for Nucia's end users
natural inflow to local aquifers (Nucia)
<Guadalest reservoir>
<adjustment time>
local aquifers in Polop
local aquifer extraction (Polop)
<total water consumption in Polop>
Total water for Polop
water output for Polop's end users
natural inflow to local aquifer (Polop)

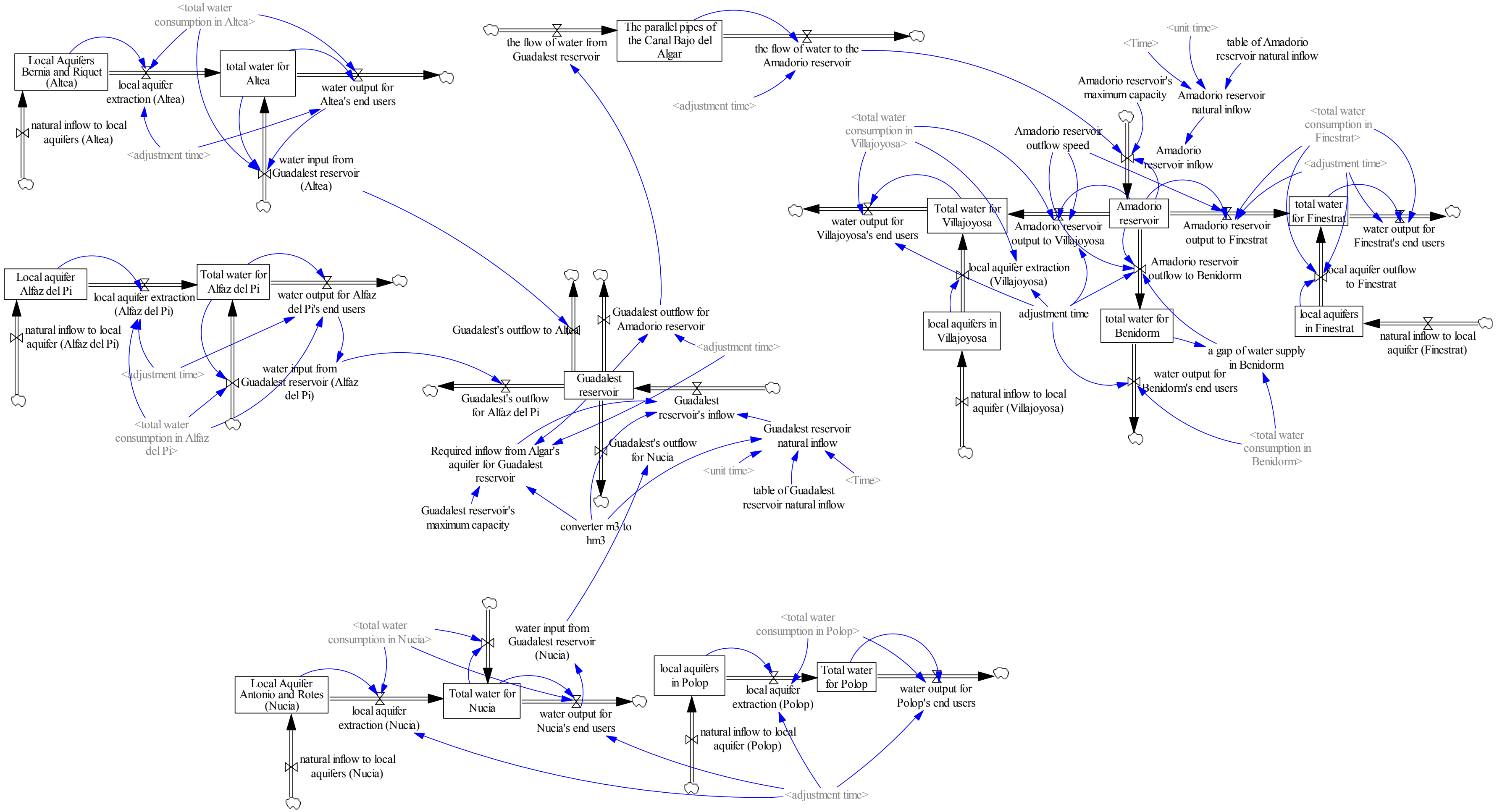


Figure 19. A part of the stock-flow model of the WELN (urban water distribution and reservoirs).

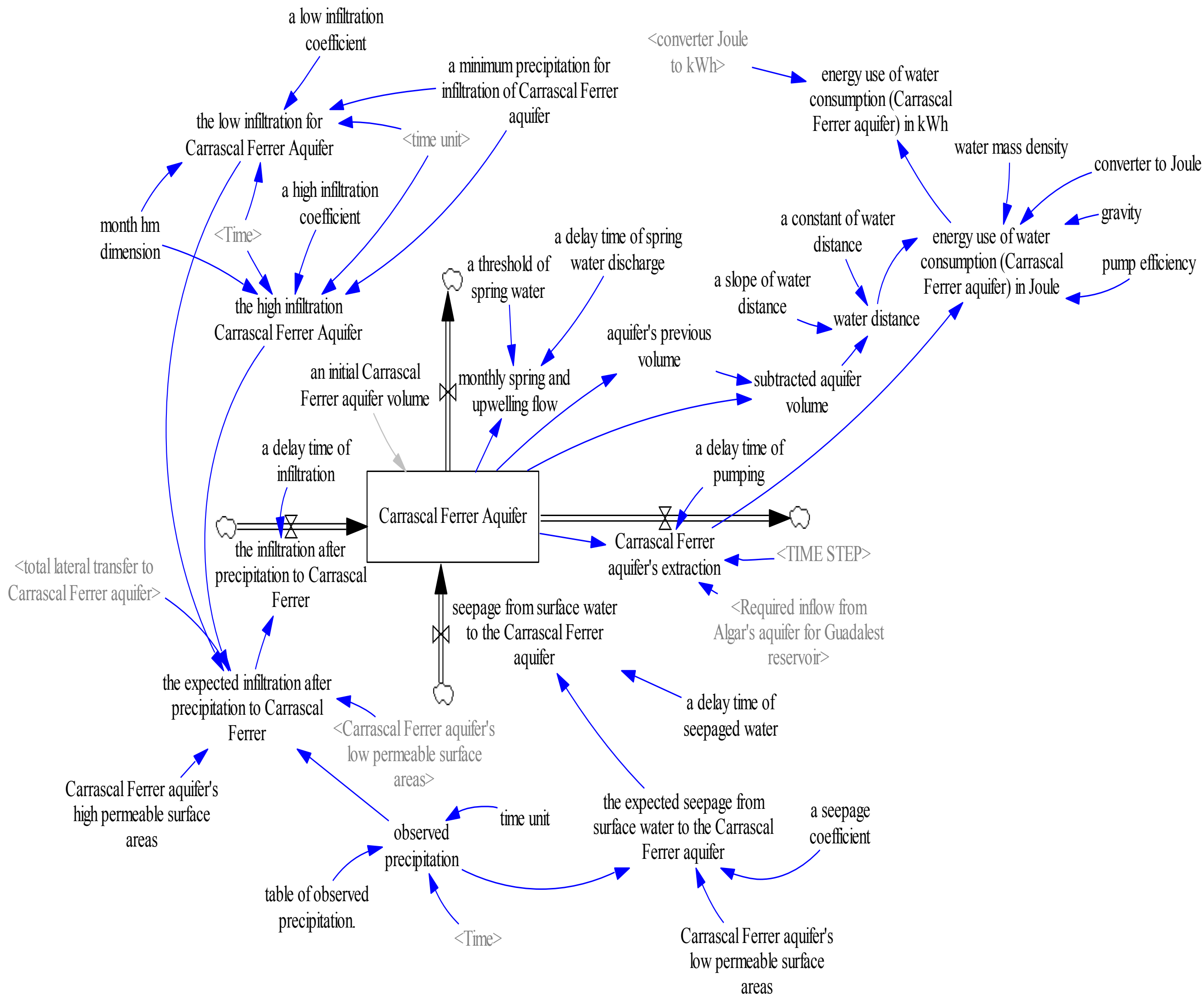


Figure 20. A module of the stock-flow model of the WELN (the Carrascal Ferrer Aquifer and precipitation)

The main source of aquifer recharge is infiltrated water, but the main aquifer also get water from ravines in the area through the seepage process (Ballesteros-Navarro, et al., n.d) as seen in Figure 20. The infiltration coefficient can reach about 80% in high permeable surface while in low permeable surface the infiltration coefficient is about 15%. Another source of water input into the Algar aquifer is lateral transfer from surrounding aquifers (Ballesteros-Navarro, et al., n.d). As shown in Figure 20, the volume of the Algar aquifer increases through rainfall infiltration, seepage, and lateral transfer from surrounding aquifers

(Ballesteros-Navarro, et al., n.d). At the same time, the Aquifer volume decreases if its volume reaches its threshold of spring water, and with the groundwater pumping to fulfil the urban demand in the Marina Baixa county.

The Algar aquifer is the main source of groundwater for the Marina Baixa county coastal areas. The contribution of the Algar aquifer can reach about 32 hm^3/year, especially in dry years, while in wet years, the Algar aquifer usually provides water about 10 hm^3/year (Castano, Murillo & Rodriguez, 2001). Other sources of urban water are surface water inputs into the Guadalest and Amadorio dams, with an average contribution about 8 and 6 hm^3/year respectively (Castano et al., 2001). The Algar aquifer presents about 3,000 hectares of high-permeability areas and about 8,700 hectares of low-permeability areas (Lechado et al., 2013). The Algar aquifer also provides spring water through the Algar river if the Algar aquifer volume reaches about 705 hm^3 (Lechado et al., 2013).

Another part of the stock-flow model is an interaction between urban areas with different densities (low- and high-density urban areas) and resident population as seen in Figure 21. In general, low-density urban areas have a lower density than that of high-density urban areas. It is also important to say that all municipalities have different combinations of low- and high-density urban areas, as seen in section 5 (Figures 16-17).

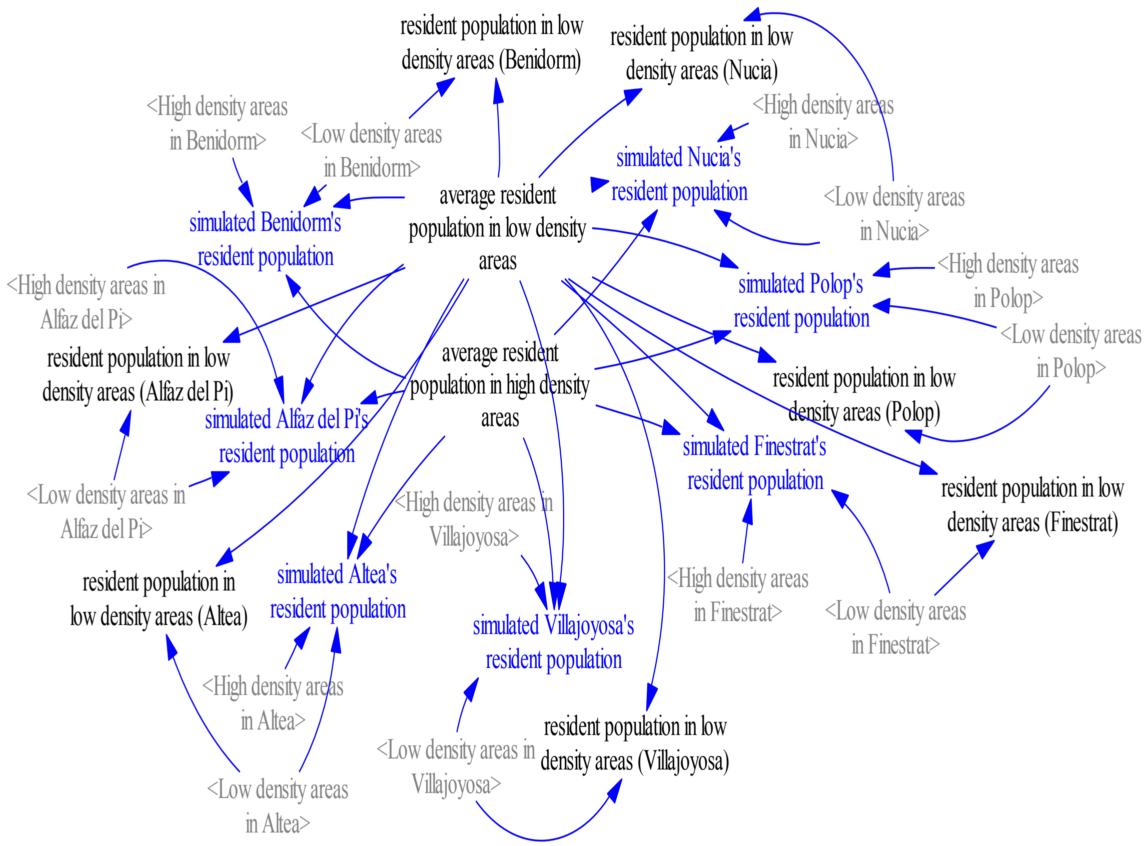


Figure 21. A part of the module of the stock-flow model of the WELN (population and low-high density areas)

The fourth part is the energy module that describes energy consumption for water management, that is, to extract water from aquifers, distribute water from the main aquifer to the Guadalest reservoir, and to distribute water to urban areas. As seen in Figure 22, energy consumption is influenced by total water extraction in the main aquifer, total water consumption, and the mentioned processes.

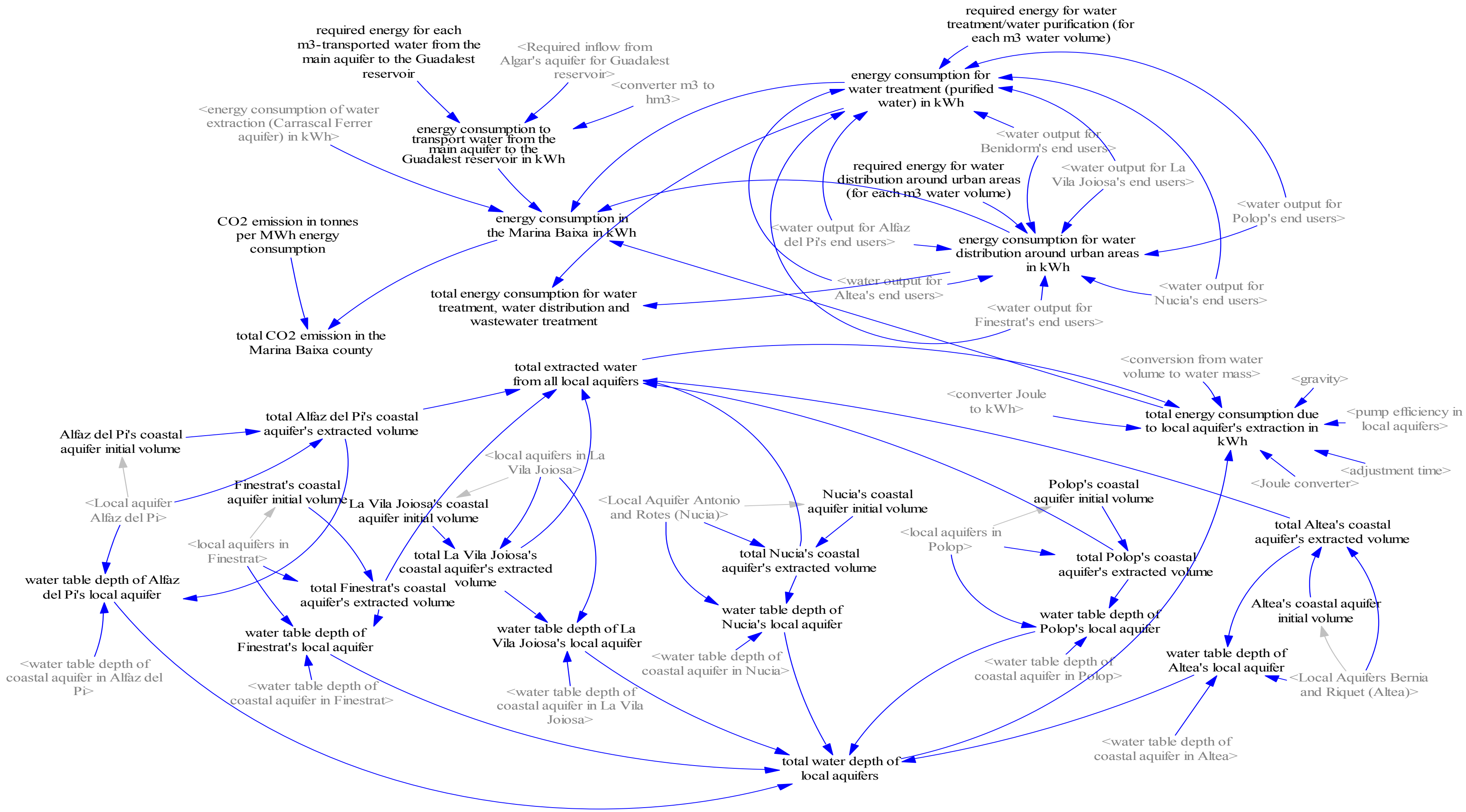


Figure 22. An energy module

Figure 23 displays energy consumption to transport extracted water from the main aquifer to the Guadalest reservoir.

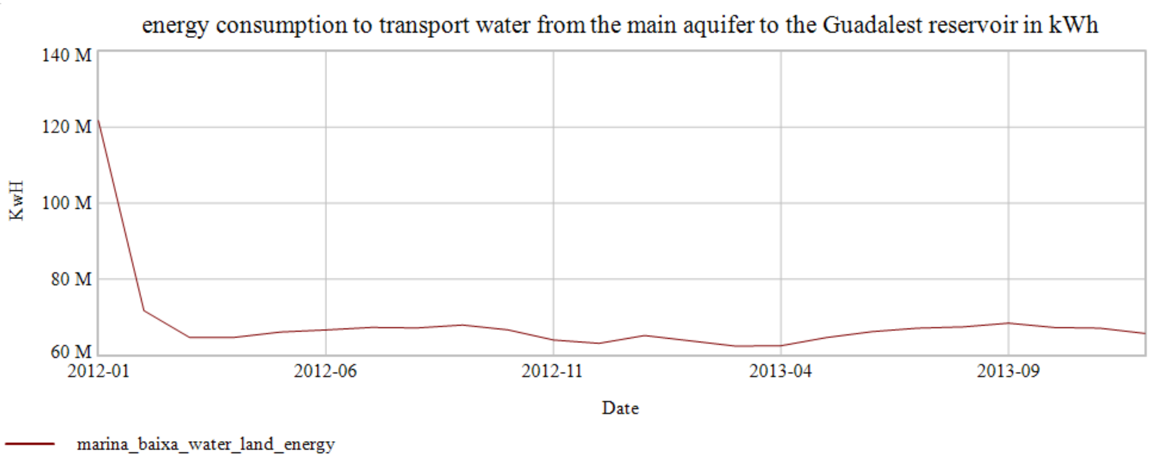


Figure 23. Energy consumption of water transportation from the main aquifer to the Guadalest reservoir in kWh

The energy consumption from the Carrascal Ferrer aquifer can be seen in Figure 24. Figure 24 shows total energy consumption for extraction of the Carrascal Ferrer aquifer's groundwater. Using equation 1, we can calculate energy consumption of water extraction as follows:

Energy (kWh) of water extraction from the aquifer = $\frac{9.8\ m.s^{-2}\ x\ water\ depth\ (m) x\ 1000\ (kg)}{3.6\ x\ 10e6\ x\ 0.6}$ …… (5)

Please note that water depth of the main aquifer is fluctuated according to total water extraction.

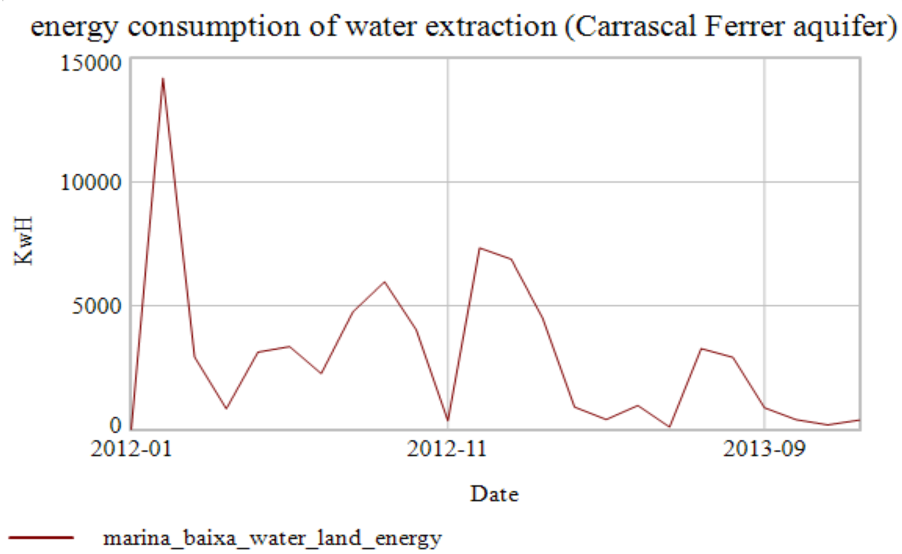


Figure 24. Energy consumption of water extraction from the Carrascal Ferrer aquifer in kWh;

Furthermore, water distribution from the Guadalest reservoir and/or the main Aquifer to urban areas, is transported through the gravitational force without additional energy. Before arriving in the city, water is purified or treated (water treatment) which requires energy 0.0311 – 0.0726 kWh/m^3 (an average value is 0.051 kWh/m^3). Afterwards, purified water is transported to each municipality. This process requires energy to meet minimum water pressure about 0.0134 kWh/m^3 (Yoon et al., 2013).

Energy consumption for water distribution, water treatment and their total energy are displayed in Figures 25. Energy consumption for each of these stages peaks in August each year, as the highest water consumption month. The patterns shown in Figures 25 are similar to the pattern of water consumption in the county (see Figure 1).

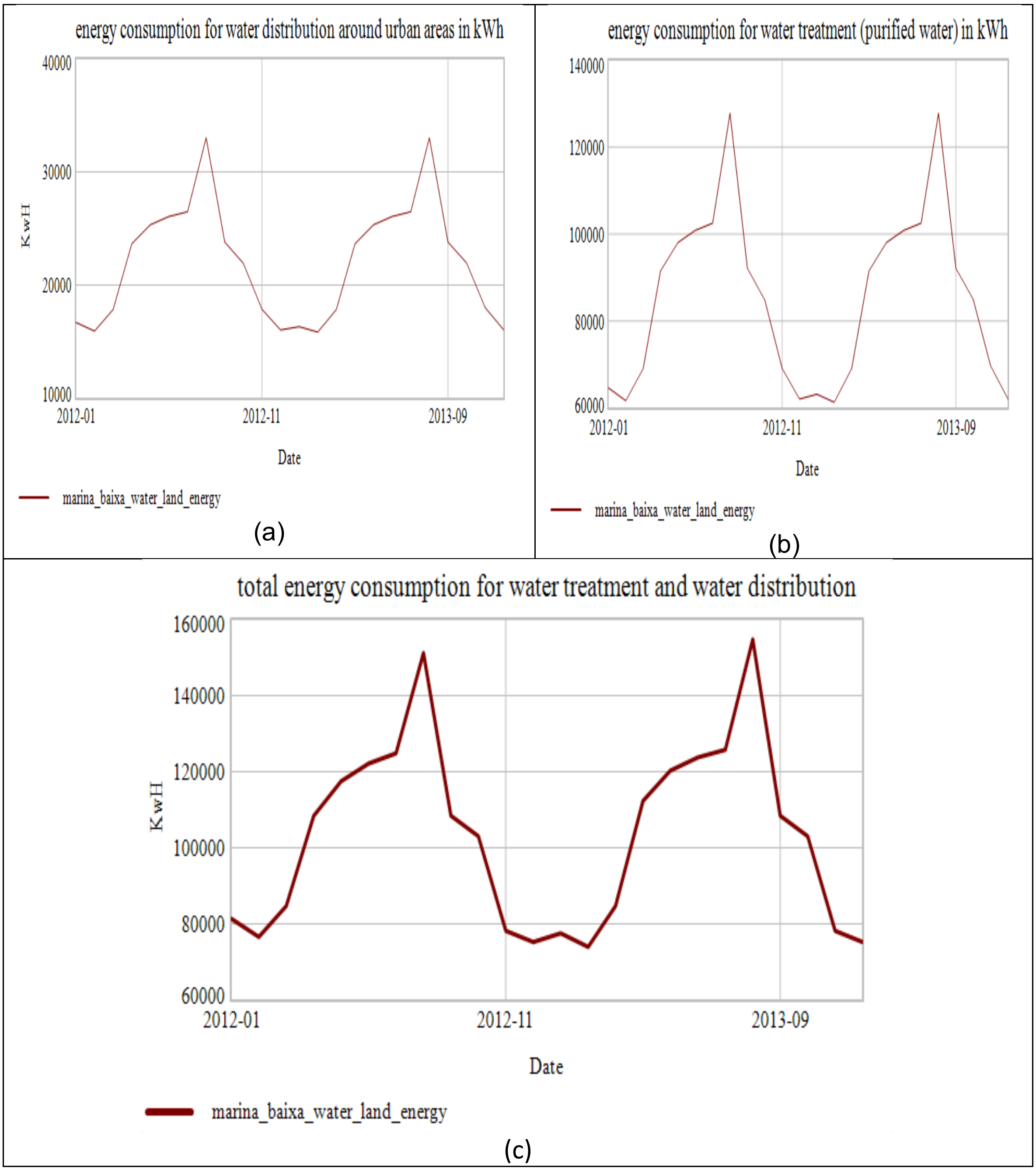


Figure 25. Energy consumption in kWh for water distribution (a); water treatment (b); (c) their total energy

The energy module also describes CO_2 emission owing to energy consumption. This study assumes that for each MWh, there will be about 0.297 tCO_2 emission (Koffi, Cerutti, Duerr, Iancu, Kona, & Janssens-Maenhout, 2017). Total CO_2 emission after energy consumption is displayed in Figure 26. As seen in Figure 26, monthly CO_2 emission in early 2012 was about 3,500 tonnes CO2 and later decreased about 2,000 tonnes CO2.

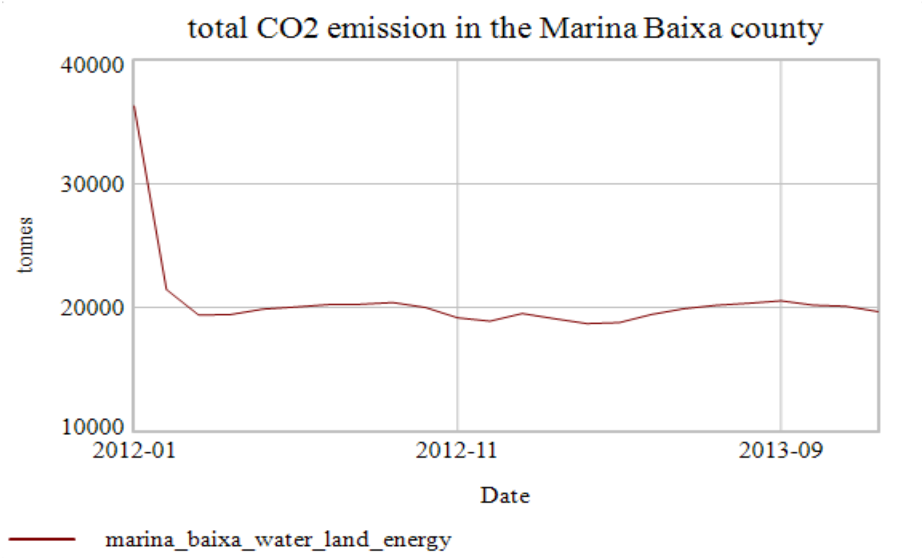
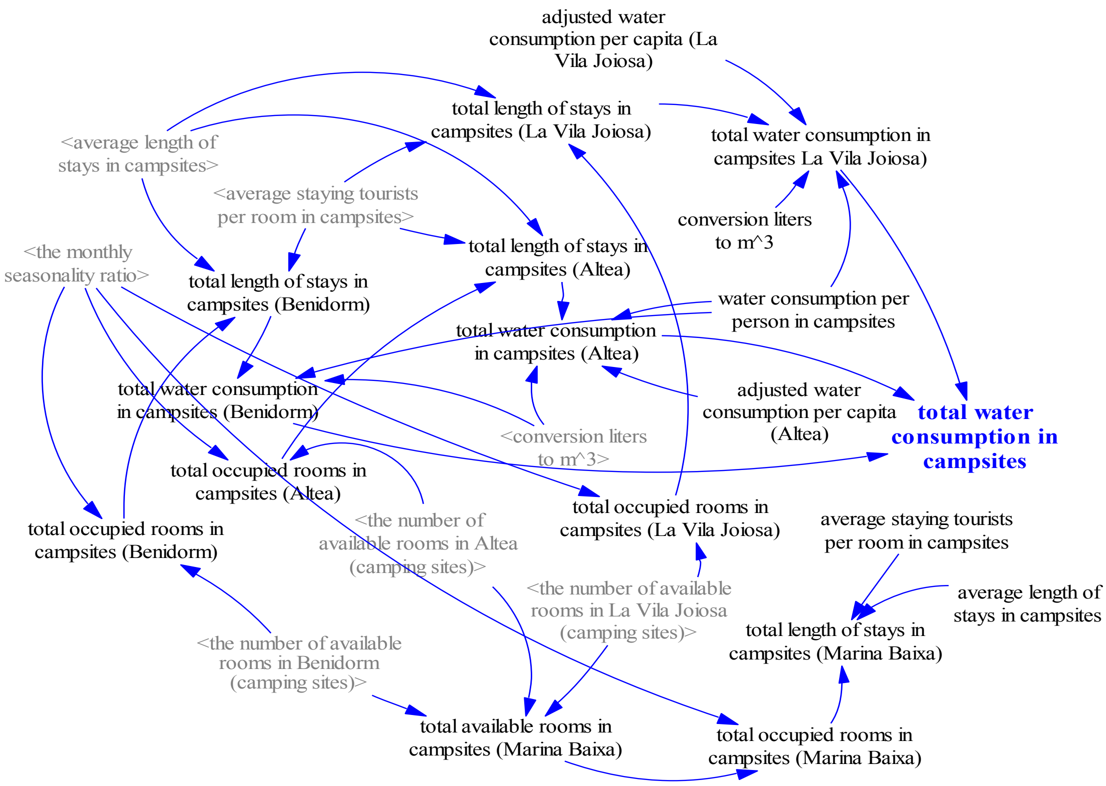
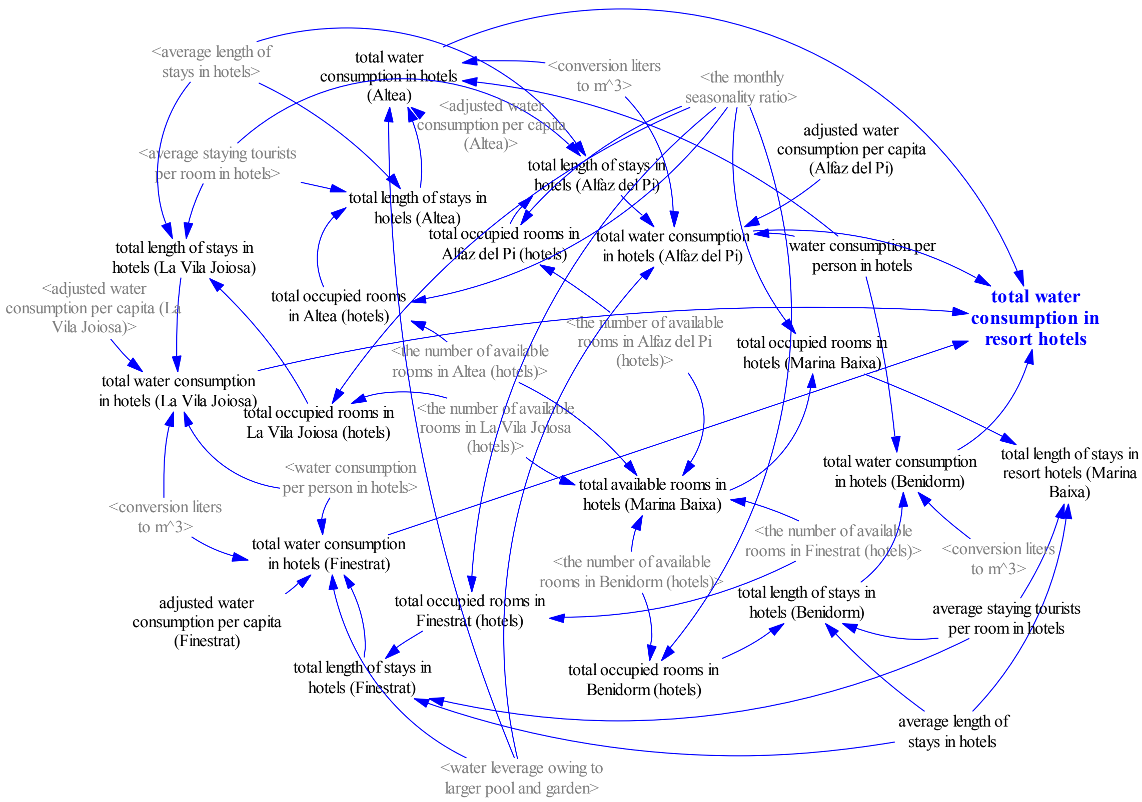


Figure 26. Total CO_2 emission after energy consumption

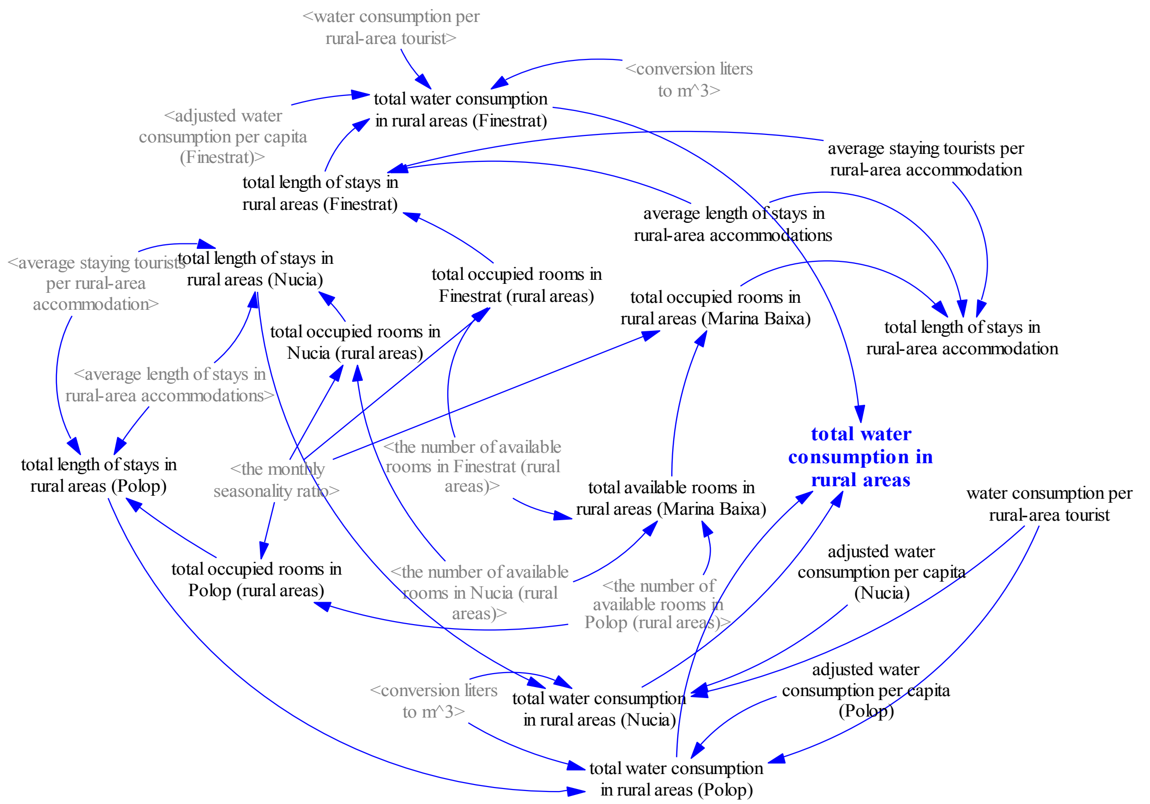
The other part of the stock-flow model is "urban water consumption" as seen in Figures 27. This module consists of water consumption based on non-permanent population (tourists and holidaymakers stay either in campsites, hotels, hostels or accommodations in rural areas) and the registered population (resident population). In total, there are 5 sub modules for different accommodation types, 1 sub module for resident population and 1 sub module to measure total water consumption in each municipality. The sub module of measuring total water consumption in each municipality aims to summarize total water consumption in other modules.



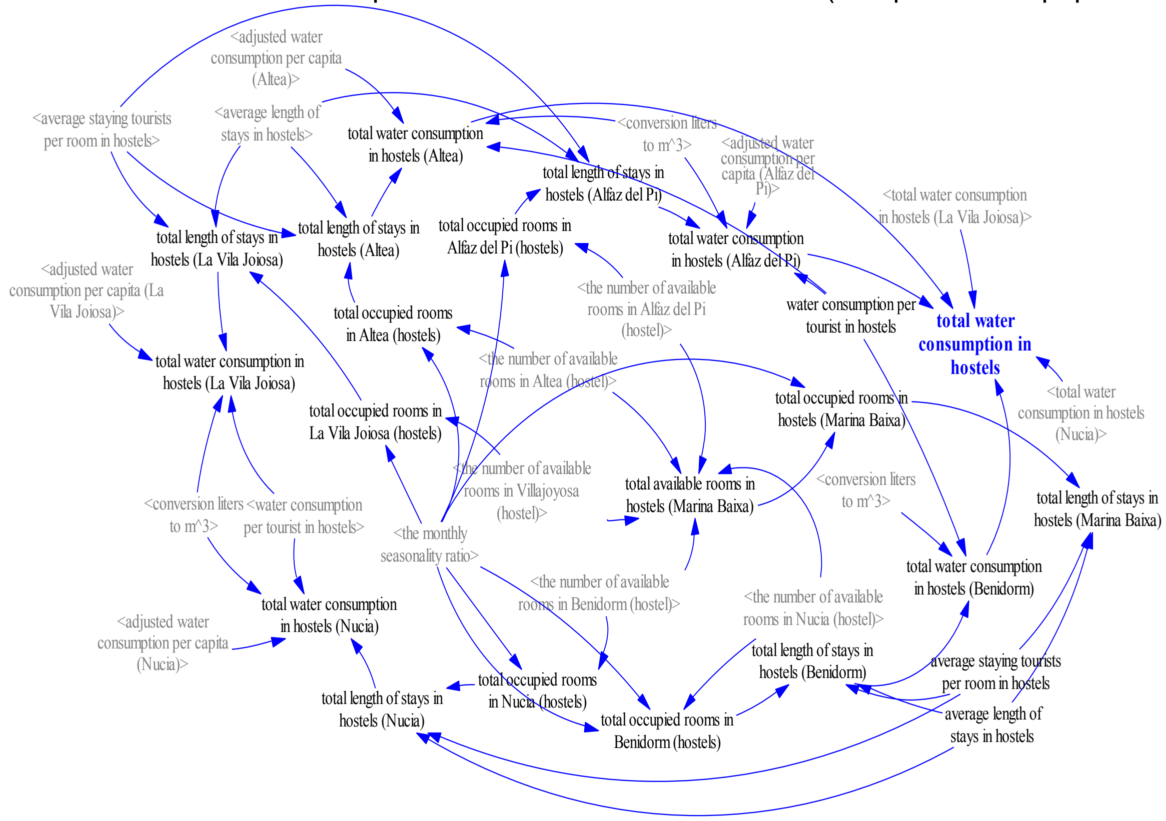
a. A module of water consumption in campsites (non-permanent population)



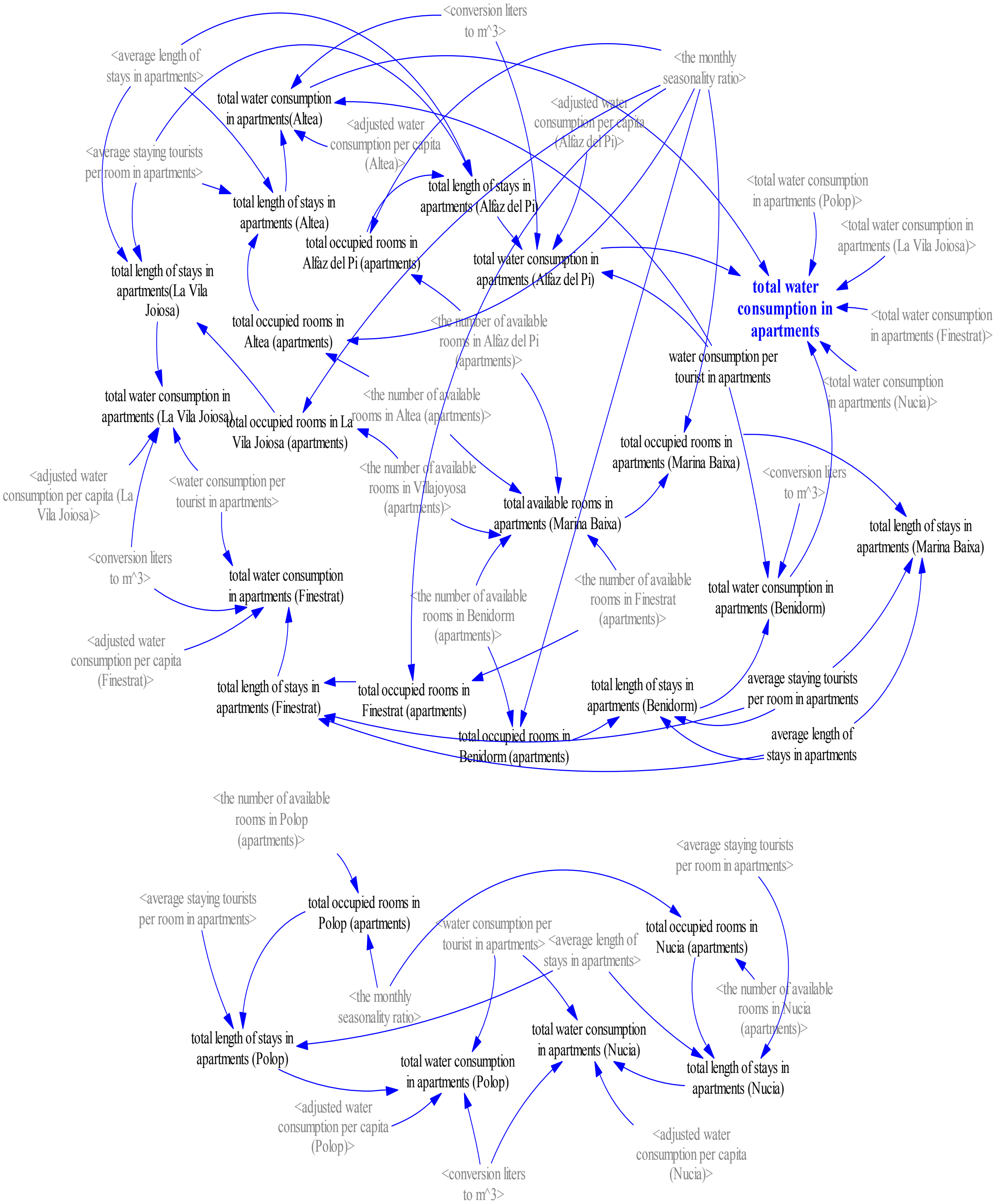
b. A module of water consumption in hotels (non-permanent population)



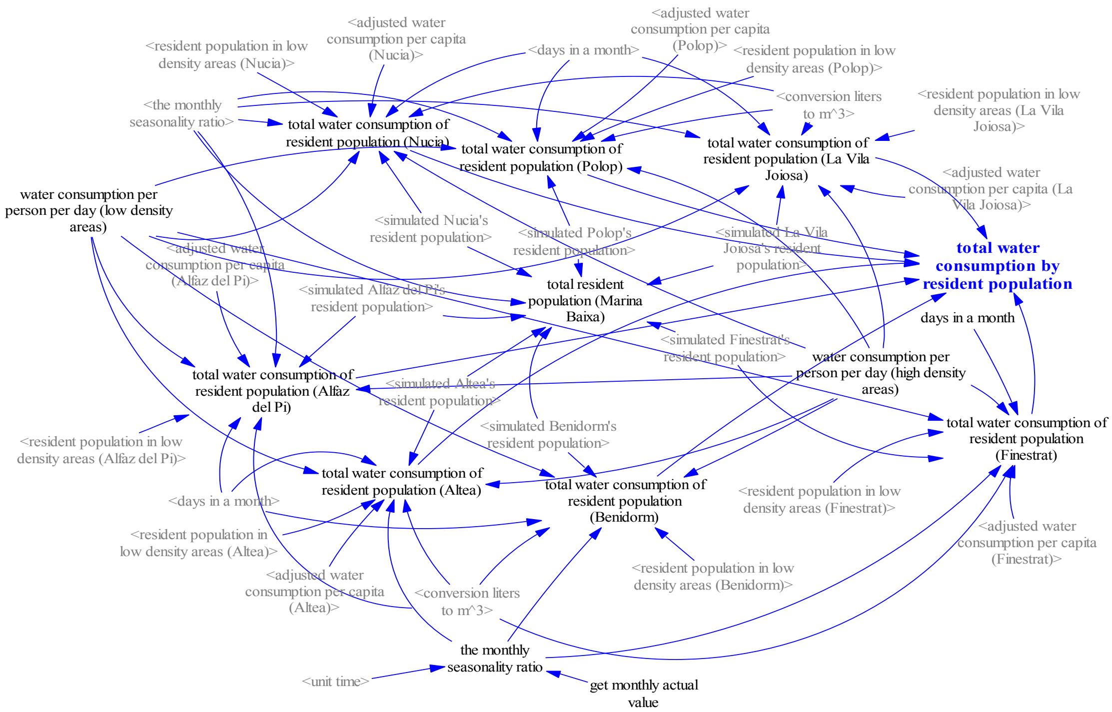
c. A module of water consumption in rural area accommodation (non-permanent population)



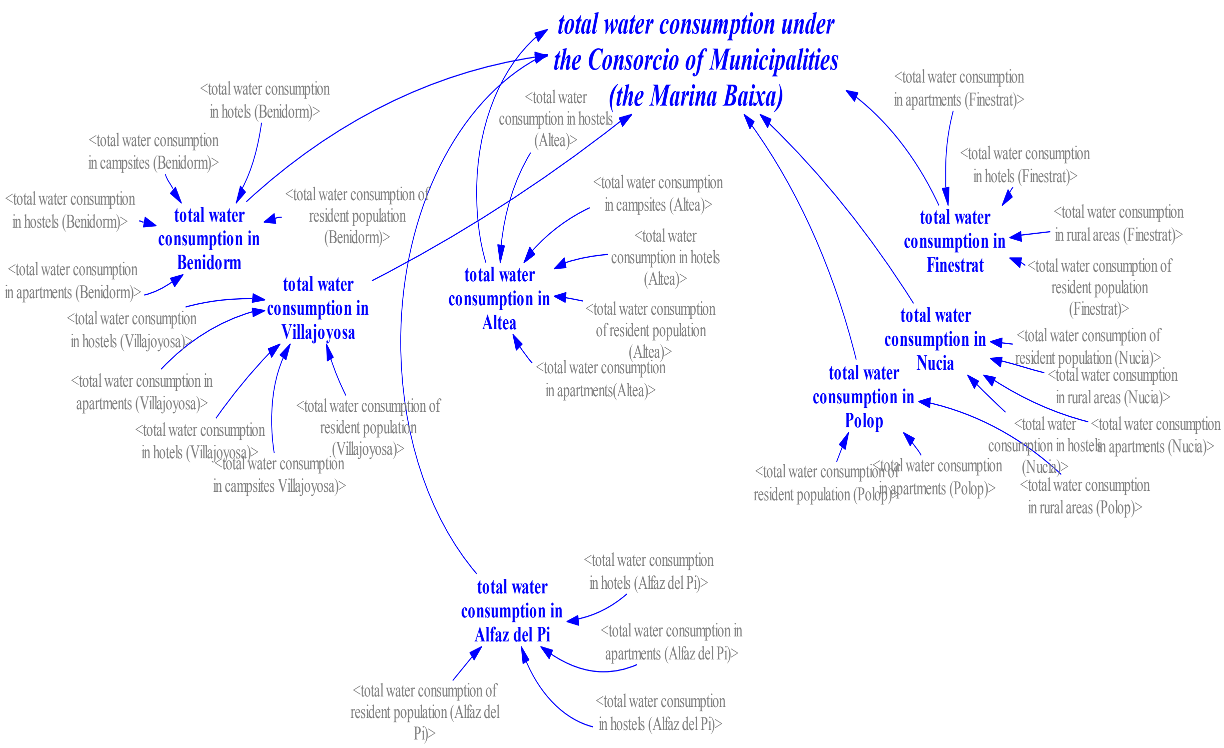
d. A module of water consumption in water consumption in hostels (non-permanent population)



e. A module of water consumption in apartments (non-permanent population)



f. A module of water consumption for resident population



g. A module to measure total water consumption per municipality

Figures 27. Urban water consumption

Figure 28 describe total water consumption for each municipality. It clearly visible that Benidorm is the highest water consumer in the county. Figure 27 also tells us that inland areas (Nucia and Finestrat) consume less water than coastal areas (Benidorm, Alfaz del Pi and Altea).

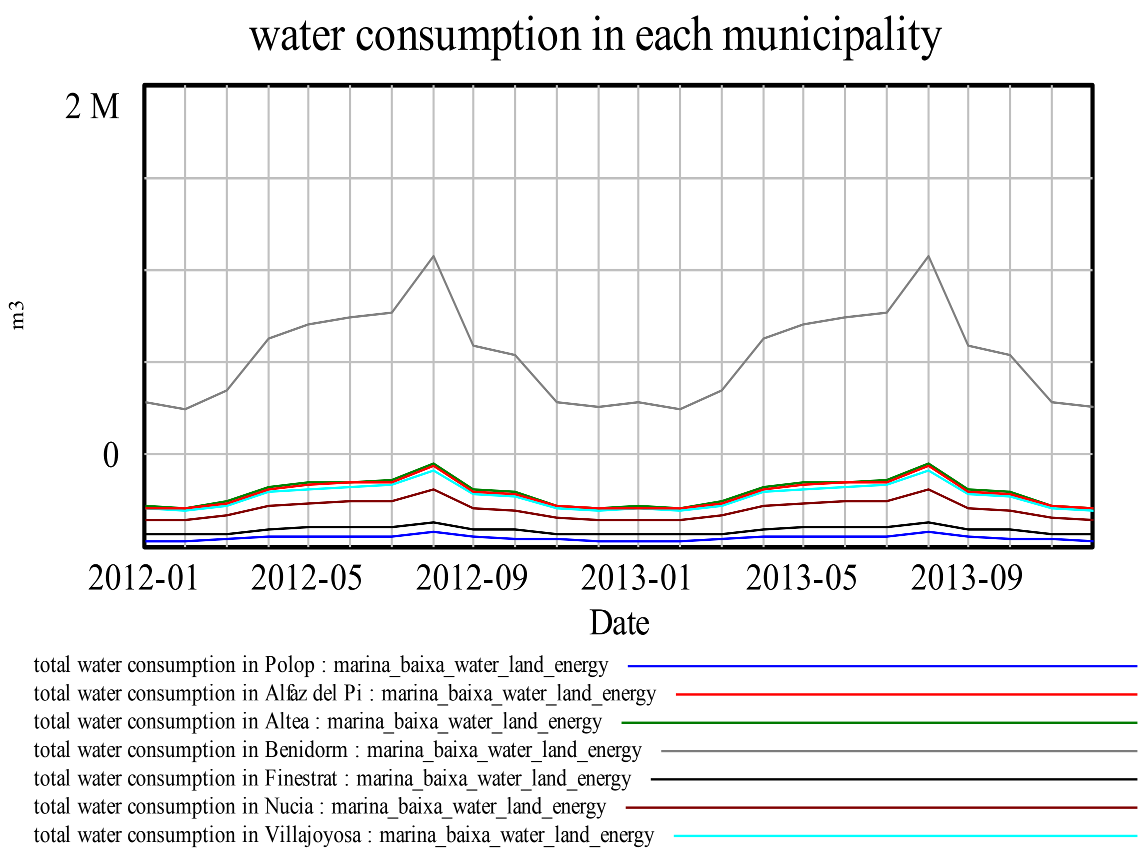


Figure 28. Water consumption for each municipality

7.3. Model Validation

According to Forrester and Senge (1980), there are some useful assessments procedures in the process of validation of SD models. Methods for the assessments of system dynamics models are, for instance, boundary adequacy, structure verification, dimensional consistency and behaviour reproduction. In summary, these assessments aim to validate the model structure and model behaviour (Bahri, 2017; Forrester & Senge, 1980; Sterman, 2000). In earlier paragraphs of this section, the model structure is validated, and followed by the validation of the model behaviour.

Below it is shown how the SD model is structurally verified. The previous sections explain that the SD model is supported by existing scientific studies in the area. For instance, "the Algar aquifer also provides spring water through the Algar river if the Algar aquifer volume reaches about 705 hm^3 (Lechado et al., 2013)" and "Other source of the Algar aquifer is a lateral transfer from surrounding aquifers (Ballesteros-Navarro, et al., n.d)". Vensim© also shows that the SD model has dimensional consistency (i.e no "unit errors" identified).

Good SD models should not have negative stocks (Sterman, 2000). The SD model is also equipped with relevant mathematical equations so that the model will not ever have negative stocks or negative quantities. To prevent negative stocks the SD model has appropriate mathematical forms. For example, the stock "Local Aquifers Bernia and Riquet (Altea)" is equipped by an equation *MIN (total water consumption in Altea/adjustment time,"Local Aquifers Bernia and Riquet (Altea)"/adjustment time)*. This secures that this stock will never get any negative value during the simulation.

Following paragraphs explain the validation of the model behaviour. To calibrate the model, we compare available observed outputs with simulated data. Due to limited data, the stock-flow model (the system dynamics model) is validated using the different period data. The Carrascal Ferrer aquifer model is validated using available in the period 2002-2007 and the other parts is validated using data in the period 2012-2013.

Using available data in the period 2002-2007, we can validate a system dynamics model as a representation the Algar aquifer behaviour. Figure 29 compares simulated and observed the aquifer's volume. Simulated and observed volume of the aquifer are relatively similar and follow a similar pattern, despite dissimilar values in some years. According to Healy (2010) possible errors may come from precipitation differences between station data and actual precipitation in the area. Another study (Mollah, 2017) claims that errors may be occur owing to the frequency and the timing of piezo metric measurements, leading to mismatched between observed and simulated outputs.

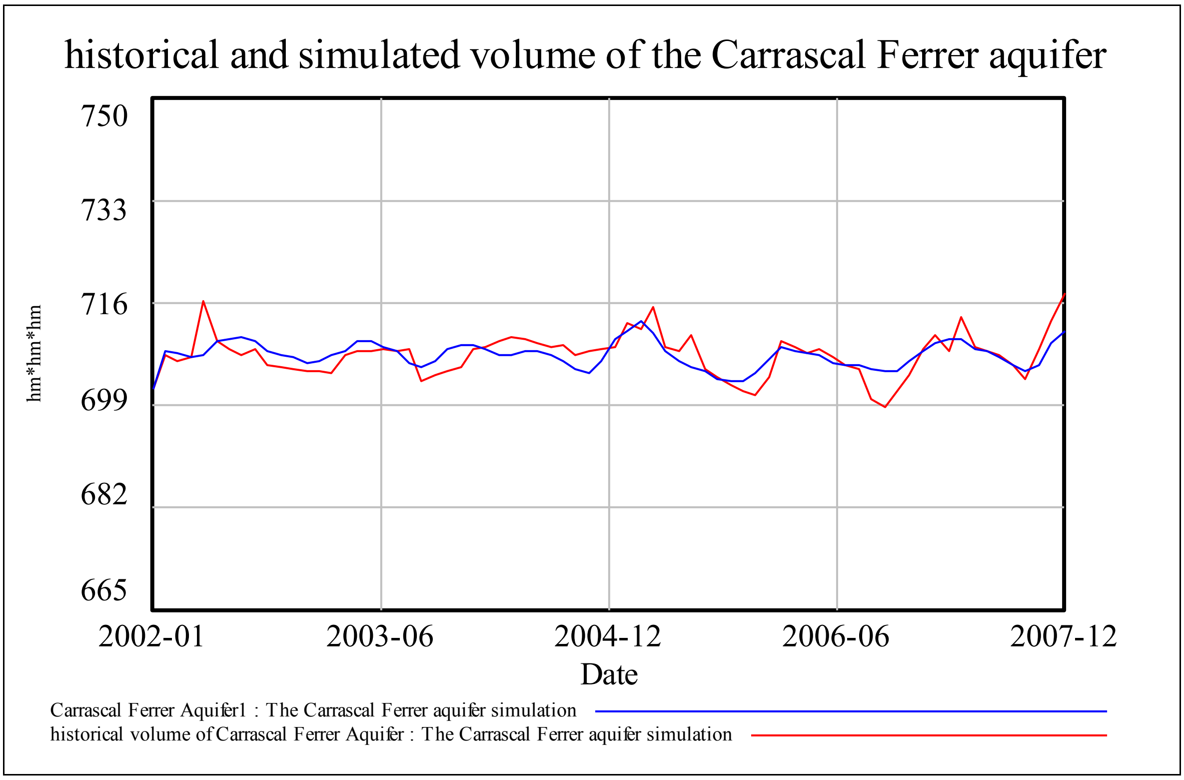


Figure 29. Simulated and observed volume of the Algar aquifer (2002-2007)

In terms of performance, the system dynamics model shows an excellent result. Mean Absolute Percentage Errors (MAPE) between simulated and observed outputs relatively lower, less than 5 %, showing that the models are highly accurate to reproduce respective observed outputs (Hauke, Wicharn, & Reitch, 2001).

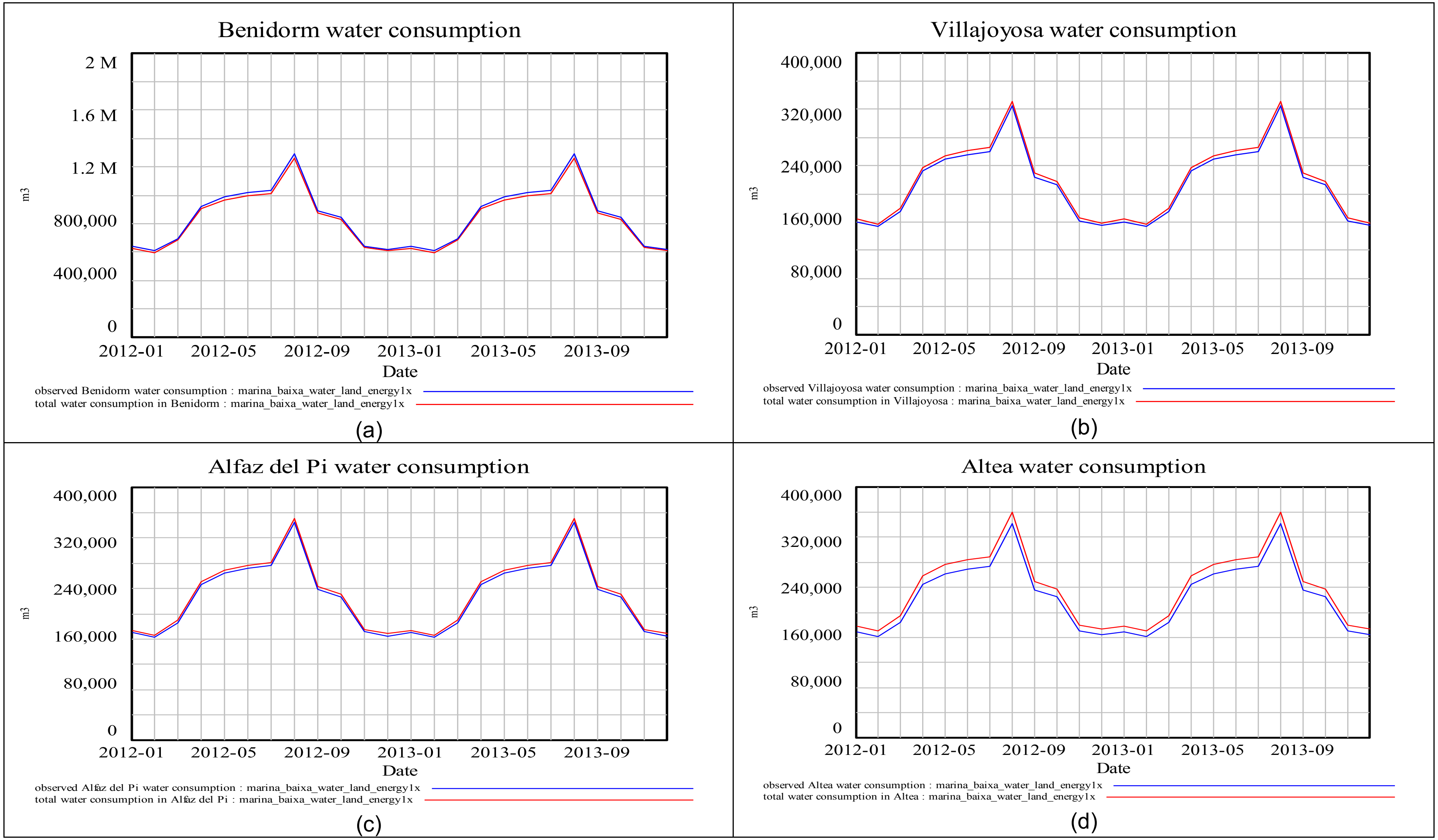
For water consumption, the system dynamics model shows the model can reproduce similar patterns of water consumption in all municipalities and total water consumption as seen in the panels of Figure 30. However, owing to unavailable data, a part of energy model (Figures 23-24) is not validated but approximated according to the existing processes in the case study area and to the parametrizations obtained from the scientific literature.

Please kindly note that for part of urban water distribution (Figure 19), two main variables i.e. the flow of Guadalest and Amadorio rivers are validated using the hydrological models as seen in section 4.5.1 and 4.5.2 respectively.

Year	simulated volume	observed volume	MAPE
Jan 02	701.8	701.8	0.0%
Feb 02	707.9	707.2	0.1%
March 02	707.6	706.4	0.2%
Apr 02	706.9	706.9	0.0%
Mai 02	707.3	716.4	1.3%
Jun 02	709.5	709.7	0.0%
Jul 02	710.1	708.5	0.2%
Aug 02	710.4	707.4	0.4%
Sep 02	709.7	708.5	0.2%
Okt 02	708	705.6	0.3%
Nov 02	707.2	705.4	0.3%
Dez 02	706.9	704.9	0.3%
Jan 03	705.9	704.8	0.2%
Feb 03	706.3	704.7	0.2%
March 03	707.3	704.3	0.4%
Apr 03	708	707.4	0.1%
Mai 03	709.7	707.9	0.3%
Jun 03	709.5	708.1	0.2%
Jul 03	708.8	708.3	0.1%
Aug 03	707.9	707.9	0.0%
Sep 03	706.1	708.2	0.3%
Okt 03	705.3	703	0.3%
Nov 03	706.3	703.9	0.3%
Dez 03	708.4	704.7	0.5%
Jan 04	709.1	705.4	0.5%
Feb 04	709	708.3	0.1%
March 04	708.2	708.7	0.1%
Apr 04	707.3	709.5	0.3%
Mai 04	707.4	710.5	0.4%
Jun 04	708.1	710	0.3%
Jul 04	708	709.2	0.2%
Aug 04	707.4	708.7	0.2%
Sep 04	706.3	709.1	0.4%
Okt 04	704.9	707.3	0.3%
Nov 04	704.4	708.1	0.5%
Dez 04	706.3	708.5	0.3%

Year	simulated volume	observed volume	MAPE
Jan 05	709.8	708.8	0.1%
Feb 05	711.4	712.5	0.2%
March 05	713	711.8	0.2%
Apr 05	710.9	715.3	0.6%
Mai 05	708	708.6	0.1%
Jun 05	706.5	707.9	0.2%
Jul 05	705.3	710.5	0.7%
Aug 05	704.6	705.1	0.1%
Sep 05	703.4	703.7	0.0%
Okt 05	703	702.3	0.1%
Nov 05	702.9	701.2	0.2%
Dez 05	704.5	700.7	0.5%
Jan 06	706.4	703.7	0.4%
Feb 06	708.5	709.8	0.2%
March 06	708	708.7	0.1%
Apr 06	707.8	707.7	0.0%
Mai 06	707.4	708.2	0.1%
Jun 06	705.9	706.9	0.1%
Jul 06	705.6	705.7	0.0%
Aug 06	705.6	705.1	0.1%
Sep 06	705.1	700.1	0.7%
Okt 06	704.6	698.6	0.9%
Nov 06	704.7	701.4	0.5%
Dez 06	706.2	704.1	0.3%
Jan 07	707.8	708.2	0.1%
Feb 07	709.4	710.7	0.2%
March 07	710	708.1	0.3%
Apr 07	709.9	713.5	0.5%
Mai 07	708.5	708.8	0.0%
Jun 07	707.9	707.9	0.0%
Jul 07	706.9	707.4	0.1%
Aug 07	705.6	705.6	0.0%
Sep 07	704.8	703.5	0.2%
Okt 07	705.4	708.2	0.4%
Nov 07	709	712.9	0.5%
Dez 07	711.2	717.6	0.9%
TOTAL MAPE			0.3%

Table 14. MAPE of the main aquifer module – observed and simulated volume of Carrascal Ferrer aquifer


Benidorm water consumption
2 M
1.6 M
1.2 M
800,000
400,000
0
m3
2012-01
2012-05
2012-09
2013-01
2013-05
2013-09
Date
observed Benidorm water consumption : marina_baixa_water_land_energy1x
total water consumption in Benidorm : marina_baixa_water_land_energy1x
(a)
Villajoyosa water consumption
400,000
320,000
240,000
160,000
80,000
0
m3
2012-01
2012-05
2012-09
2013-01
2013-05
2013-09
Date
observed Villajoyosa water consumption : marina_baixa_water_land_energy1x
total water consumption in Villajoyosa : marina_baixa_water_land_energy1x
(b)
Alfaz del Pi water consumption
400,000
320,000
240,000
160,000
80,000
0
m3
2012-01
2012-05
2012-09
2013-01
2013-05
2013-09
Date
observed Alfaz del Pi water consumption : marina_baixa_water_land_energy1x
total water consumption in Alfaz del Pi : marina_baixa_water_land_energy1x
(c)
Altea water consumption
400,000
320,000
240,000
160,000
80,000
0
m3
2012-01
2012-05
2012-09
2013-01
2013-05
2013-09
Date
observed Altea water consumption : marina_baixa_water_land_energy1x
total water consumption in Altea : marina_baixa_water_land_energy1x
(d)

CLISWELN

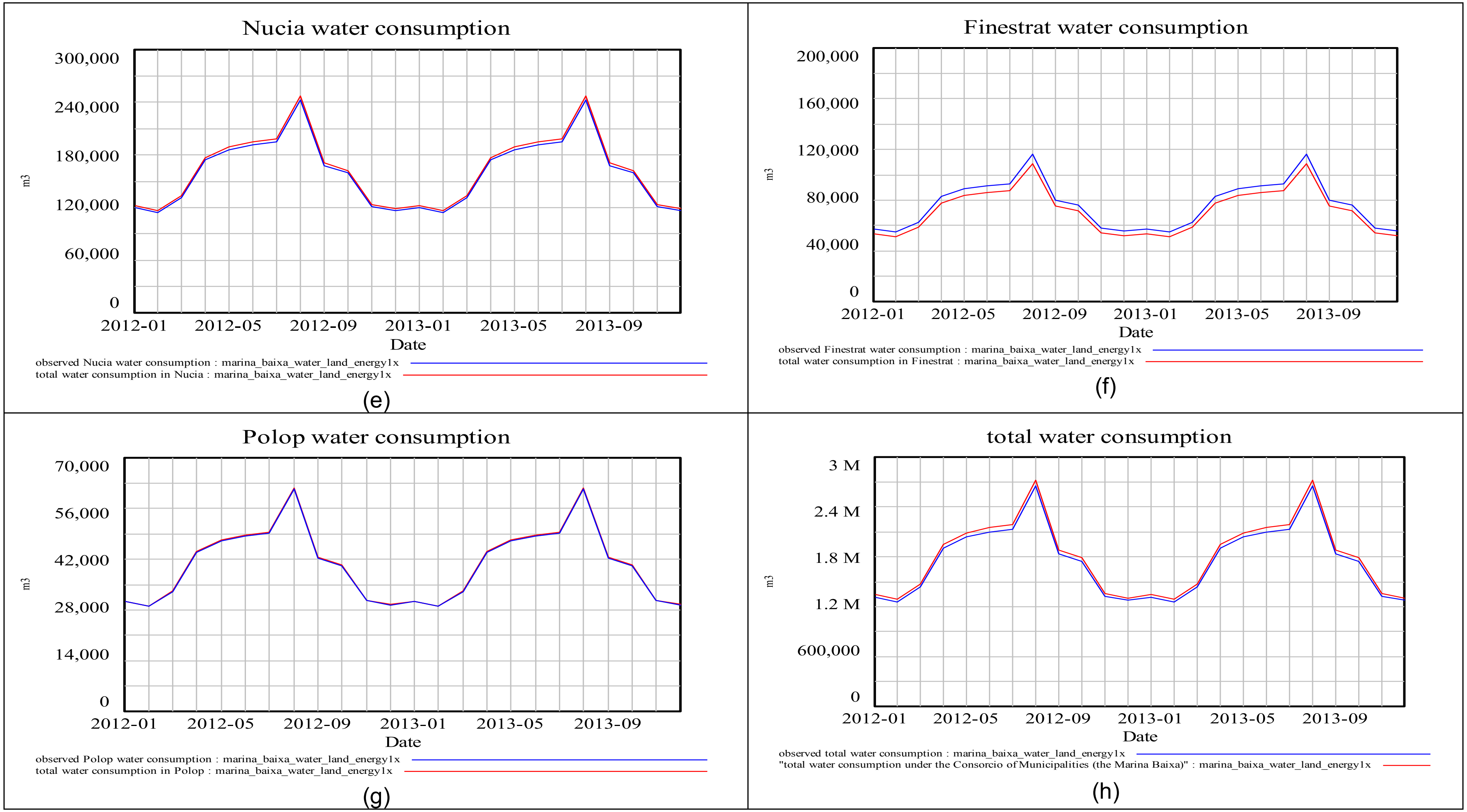


Figure 30. Observed and simulated water consumption in Benidorm (a), La Vila Joiosa (b), Alfaz del Pi (c), Altea (d), Nucia (e), Finestrat (f), Polop (g) and total water consumption (h).

The MAPE for total water consumption and resident population in the Marina Baixa county are displayed in table 15 and table 16 respectively. As seen both tables, MAPE for these modules are relatively low, showing that the models are highly accurate to reproduce respective observed outputs in these models (Hauke et al., 2001).

Year	The Marina Baixa county		
	observed water consumption	**simulated water consumption**	**MAPE**
Jan 12	1,315,000	1,244,710	5.35%
Feb 12	1,255,000	1,187,570	5.37%
March 12	1,436,000	1,360,850	5.23%
Apr 12	1,903,000	1,804,570	5.17%
Mai 12	2,038,000	1,933,070	5.15%
Jun 12	2,097,000	1,988,950	5.15%
Jul 12	2,131,000	2,022,030	5.11%
Aug 12	2,658,000	2,521,550	5.13%
Sep 12	1,837,000	1,744,480	5.04%
Okt 12	1,746,000	1,658,250	5.03%
Nov 12	1,325,000	1,258,410	5.03%
Dez 12	1,275,000	1,211,540	4.98%
Jan 13	1,315,000	1,248,790	5.03%
Feb 13	1,255,000	1,191,450	5.06%
March 13	1,436,000	1,365,490	4.91%
Apr 13	1,903,000	1,810,360	4.87%
Mai 13	2,038,000	1,939,420	4.84%
Jun 13	2,097,000	1,995,540	4.84%
Jul 13	2,131,000	2,028,520	4.81%
Aug 13	2,658,000	2,529,510	4.83%
Sep 13	1,837,000	1,750,030	4.73%
Okt 13	1,746,000	1,663,650	4.72%
Nov 13	1,325,000	1,262,600	4.71%
Dez 13	1,275,000	1,215,560	4.66%
MAPE			4.99%

Table 15. MAPE of observed and simulated total water consumption

Year	The Marina Baixa county		
	observed population	simulated population	MAPE
Jan 12	183162	182279	0.48%
Feb 12	183162	182279	0.48%
March 12	183162	182279	0.48%
Apr 12	183162	182279	0.48%
Mai 12	183162	182279	0.48%
Jun 12	183162	182279	0.48%
Jul 12	183162	182279	0.48%
Aug 12	183162	182279	0.48%
Sep 12	183162	182279	0.48%
Okt 12	183162	182279	0.48%
Nov 12	183162	182279	0.48%
Dez 12	183162	182279	0.48%
Jan 13	183162	182279	0.48%
Feb 13	183162	182279	0.48%
March 13	183162	182279	0.48%
Apr 13	183162	182279	0.48%
Mai 13	183162	182279	0.48%
Jun 13	183162	182279	0.48%
Jul 13	183162	182279	0.48%
Aug 13	183162	182279	0.48%
Sep 13	183162	182279	0.48%
Okt 13	183162	182279	0.48%
Nov 13	183162	182279	0.48%
Dez 13	183162	182279	0.48%
MAPE			0.5%

Table 16. MAPE of observed and simulated resident population

8. Summary and conclusions

In this case study, we build models and connect the interdependencies among the nexus resources: water, energy and land. Modelling the WELN in the Marina Baixa county allows us to assess the interdependencies among energy, water and land, revealing a connection between land use planning, water consumption and energy consumption. Low- and high-density areas and accommodation types are decisive to the water demand in the Marina Baixa. Meanwhile, the pattern of successive infrastructure investments for water supply enabled the growth of urban areas.

The case study also tells us that population owing to tourism development and water consumption are drivers of the nexus in the Marina Baixa county. In the county, tourism development leads to a higher population and then a higher water consumption. Another driver of the nexus is climate change, as climate change will increase the probability of droughts. If the nexus concept is not applied into planning, the county will undoubtedly experience more severe water shortages with higher energetic implications, leading to an unsustainable economic growth.

As the interaction between the nexus drivers, the nexus resources and their stakeholders are complex, the nexus approach requires the involvement of multiple actors such as scientists, municipality councils, regional governments, and private companies, working together to embed adaptation to climate change and sustainability in long term planning. This means that we need a holistic and interdisciplinary approach to achieve sustainable development goals, especially economic growth (SDG 8), sustainable cities (SDG 11), and climate action (SDG 13).

This deliverable presents an integrated systems model of urban water supply, which aims to reproduce patters in the current system, so that it can be used later to analyse the impact of climate change and co-created future scenarios. The historical data is consistently well reproduced, in the elements of the causal diagrams and in the statistical parameters of the hydrological modelling, and some exemplary instances are provided as a brief summary: First, observed and simulated population in the touristic are have relatively low mean absolute percentage error (0.5%), showing the accuracy of the models. Second, observed and simulated data of water consumption seasonal patterns has been matched using a combination of water consumption data, land use data, and tourism demand data (see Figure 30). And third, average flow rate simulated is 0.2 m3/s for the Amadorio river basin, and the average flow rate observed is 0.19 m3/s, therefore in average terms we consider that the result is quite accurate, while the statistics show a very good simulation.

To conclude, integrated climate services, i.e. the use of climate information in a regional or local scale socio-economic model co-designed with stakeholders to produce decision-relevant information, offer a pathway to model climate risks across resources and sectors and to produce information relevant for society. A combination of the WELN concept, climate services and system dynamics is needed to assess the impacts of climate change and to formulate policies that minimize the impacts of climate change, leading to a sustainable tourism industry.

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Annexes

Appendix A. Data collection

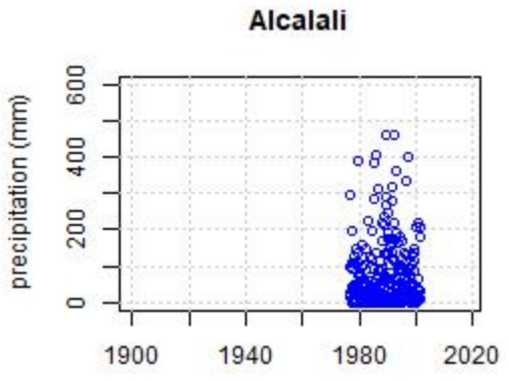
The data collection objective is the study of the following data: (1) temperature and precipitation of the AEMet stations and (2) reservoir data provided directly from the CHJ, and (3) precipitation obtained directly from the CHJ. Once the data collection is completed, the quality of the data and the feasibility of their use in the case study will be studied.

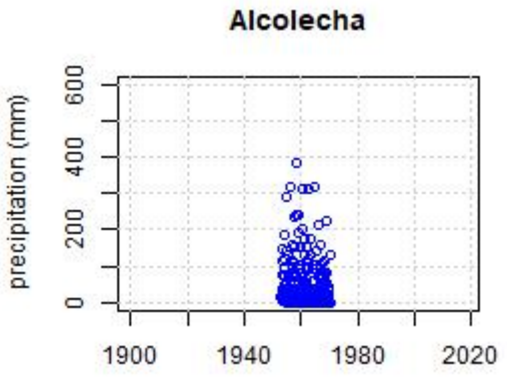
In this process, the trend of the data and the time series of each value (time interval and continuity) have been studied. The data analysed were as follows:

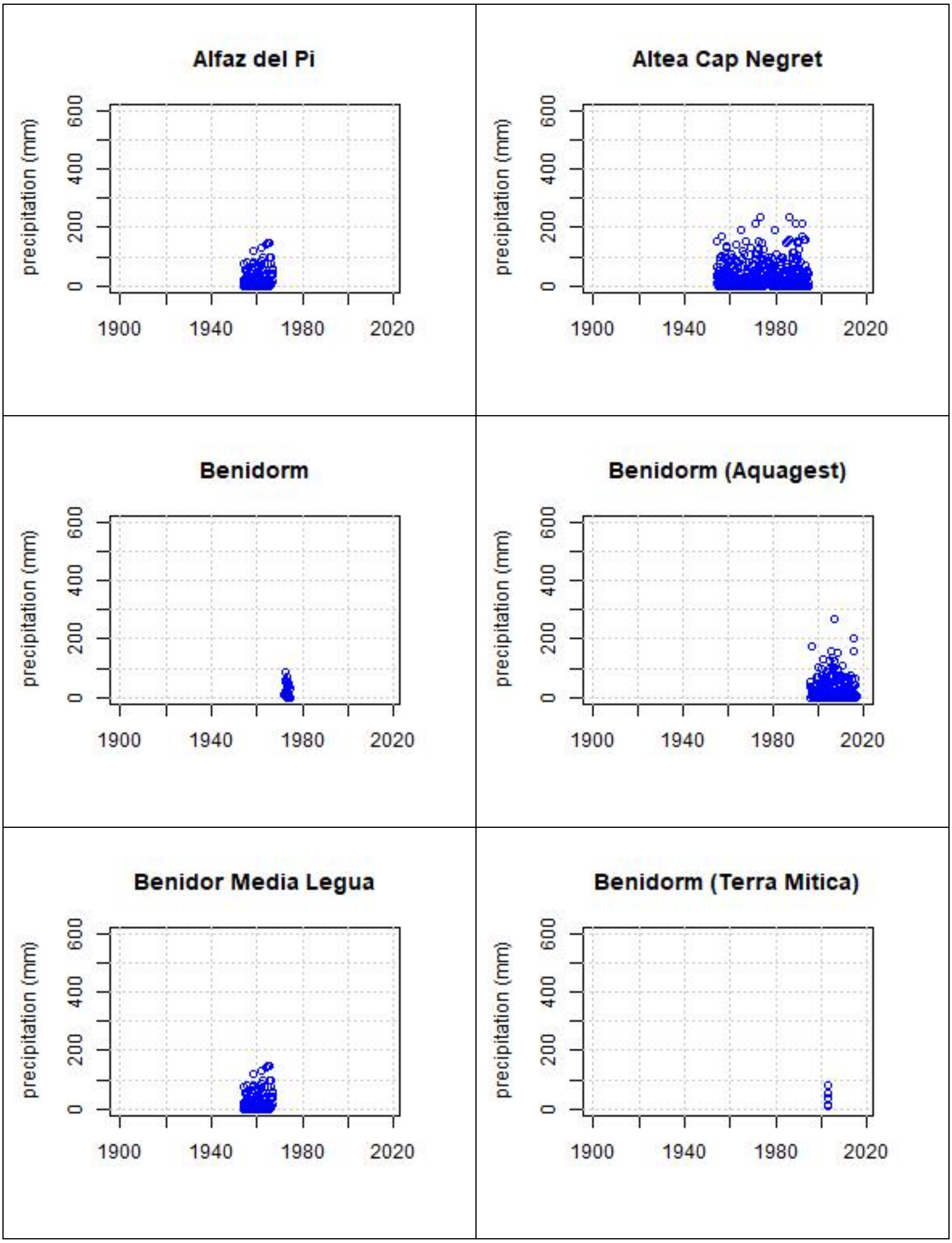
- Precipitation daily data from 26 Spanish Agency of Meteorology (AEMet) stations
- Precipitation daily data from 7 Hydrographic Confederation of Jucar (CHJ) stations (directly from CHJ)
- Temperature daily data from 11 AEMet stations
- Amadorio and Guadalest Reservoir daily data from CHJ (directly from CHJ)

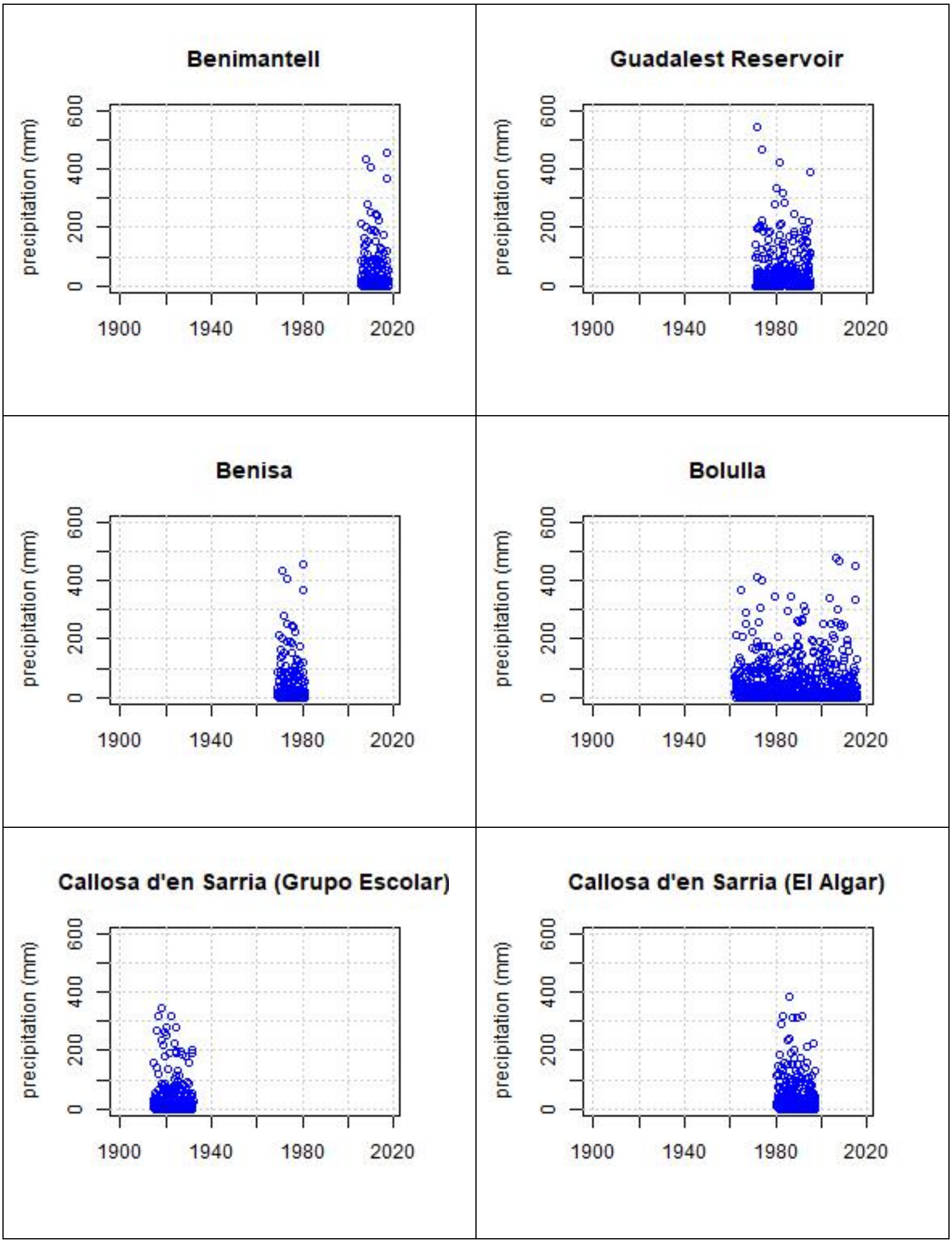
Precipitation data from AEMET

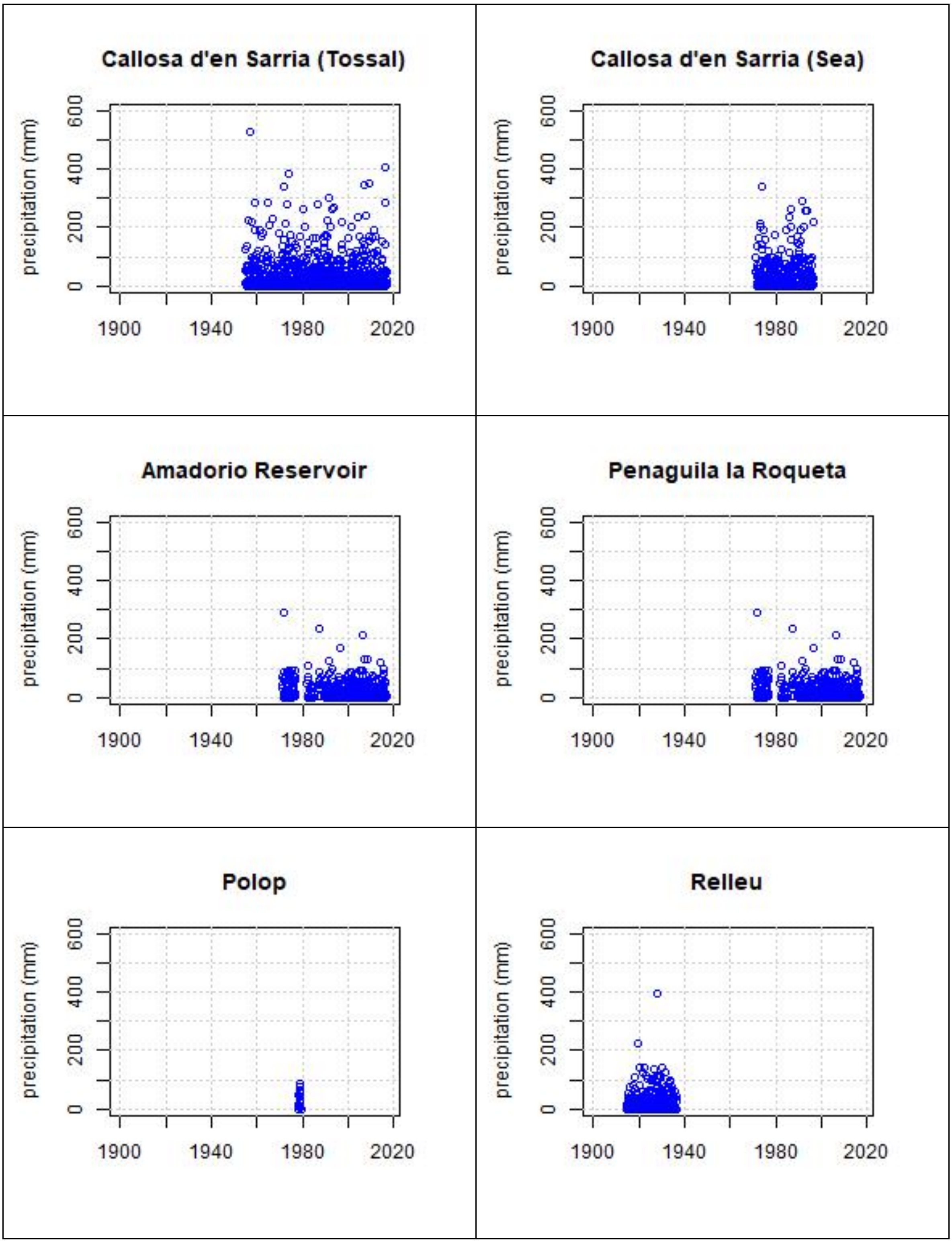
STATION	START	END
ALCALALI	1977	2001
ALCOLECHA	1953	1970
ALFAZ DEL PI AYUNTAMIENTO	1995	2017
ALTEA CAP NEGRET	1954	1994
BENIDORM	1972	1980
BENIDORM (AQUAGEST)	1997	2017
BENIDORM MEDIA LEGUA	1954	2017
BENIDORM-TERRA MITICA	2002	2003
BENIMANTELL POLIDEPORTIVO	2007	2017
BENIMANTELL-EMBALSE DE GUADALEST	1971	2005
BENISA PINOS	1969	1978
BOLULLA	1962	2017
CALLOSA DE ENSARRIA (GRUPO ES-COLAR)	1915	1967
CALLOSA D'EN SARRIA EL ALGAR	1980	2017
CALLOSA D'EN SARRIA TOSSAL DE SALOM Ŧ	1955	2017
CALLOSA D'EN SARRIA-SEA	1971	1997
EMBALSE DE AMADORIO	1971	2017
PENAGUILA LA ROQUETA	2000	2017
POLOP	1978	1974
RELLEU	1955	2000
RELLEU C H JUCAR	1955	1979
RELLEU LES PALANQUETES	2009	2017
SELLA	1955	2017
TARBENA C H JUCAR POBLE DE DALT	1955	2017
TORREMANZANAS (AYUNTAMIENTO)	1994	2017
LA VILA JOIOSA	1947	1947

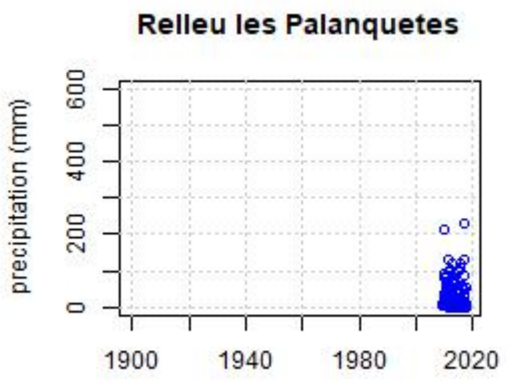


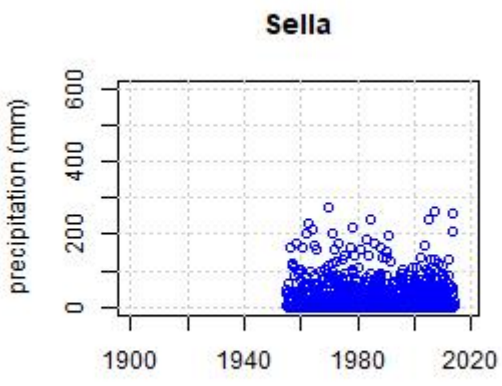


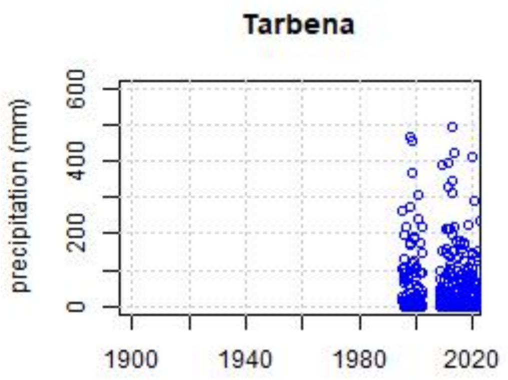

Alfaz del Pi
Altea Cap Negret
Benidorm
Benidorm (Aquagest)
Benidor Media Legua
Benidorm (Terra Mitica)
precipitation (mm)
0
200
400
600
1900
1940
1980
2020

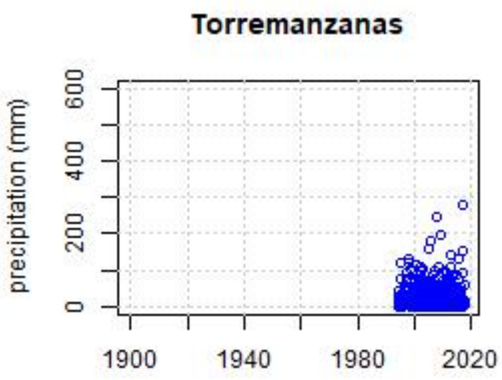

Benimantell
Guadalest Reservoir
Benisa
Bolulla
Callosa d'en Sarria (Grupo Escolar)
Callosa d'en Sarria (El Algar)
precipitation (mm)
0
200
400
600
1900
1940
1980
2020

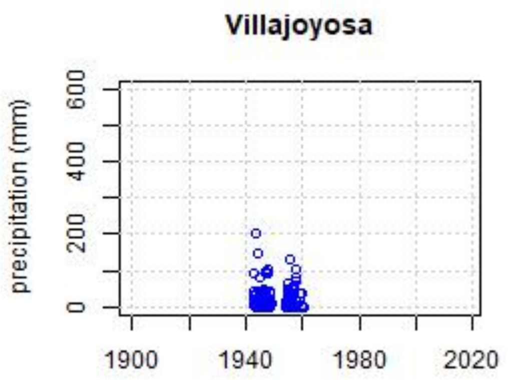

Callosa d'en Sarria (Tossal)
Callosa d'en Sarria (Sea)
Amadorio Reservoir
Penaguila la Roqueta
Polop
Relleu
precipitation (mm)
0
200
400
600
1900
1940
1980
2020







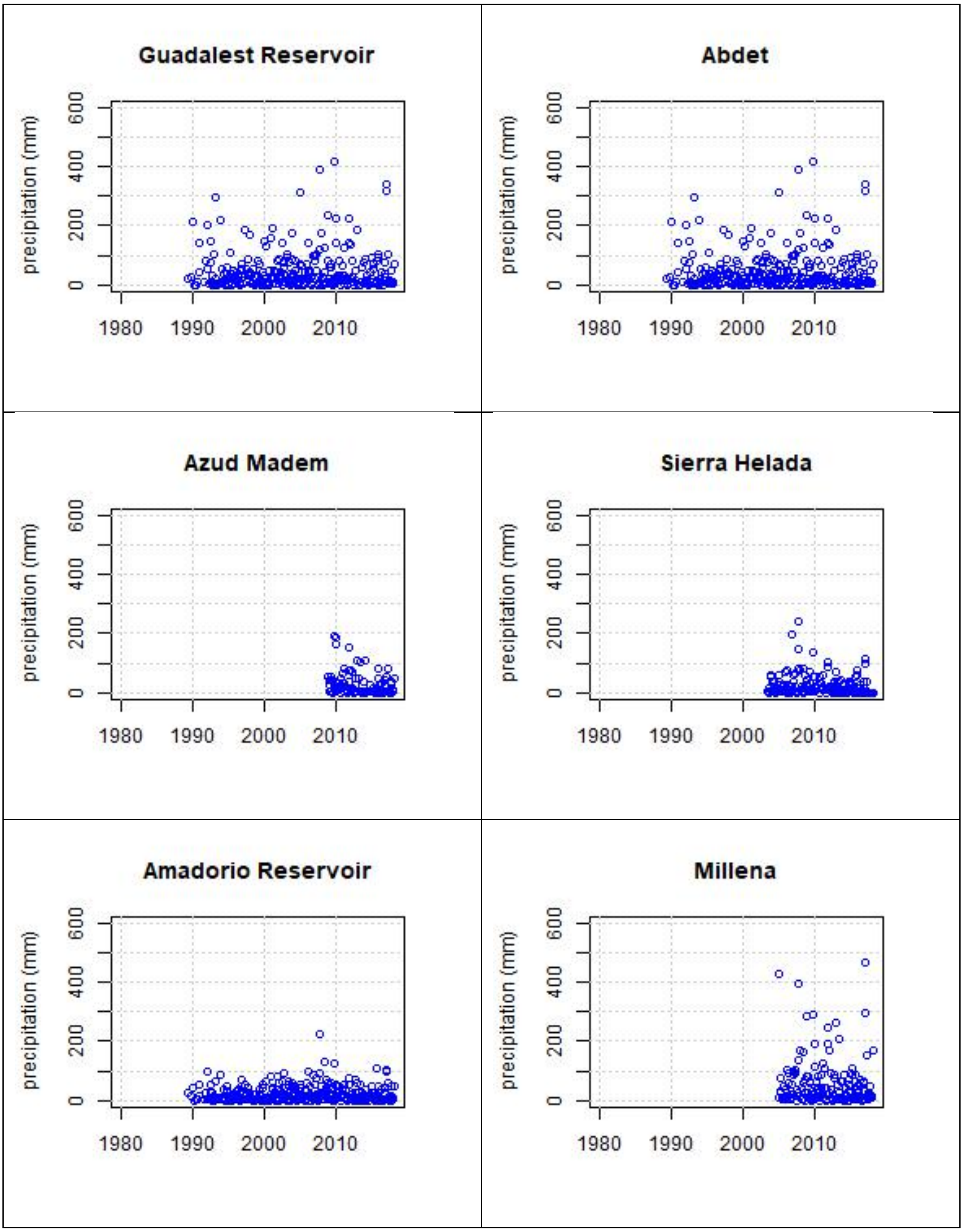


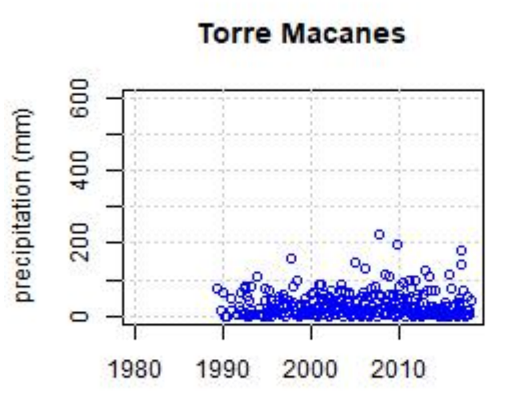


Precipitation data from CHJ

STATION	START	END
Guadalest	1992	2017

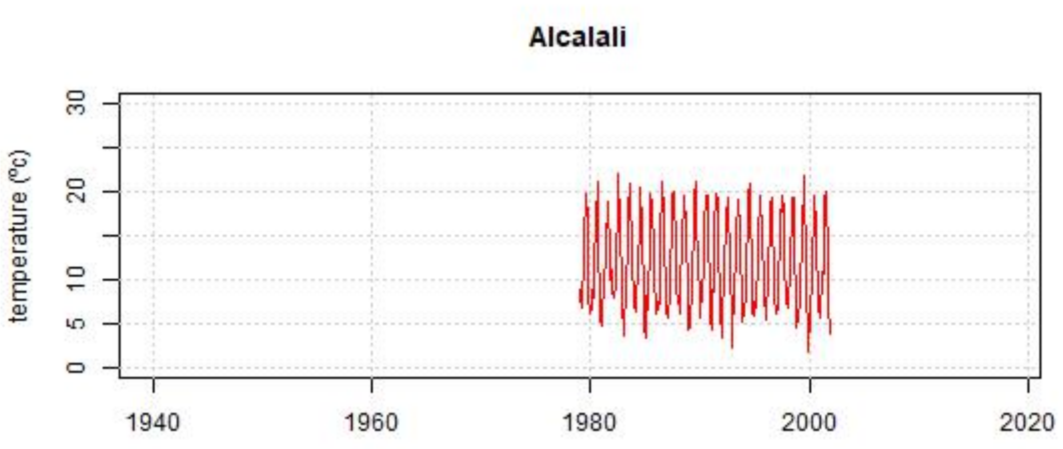
Abdet	1992	2017
Azud Madem	2008	2017
Sierra Helada	2003	2017
Amadorio	1999	2017
Millena	2005	2017
Torre Macanes	1992	2017

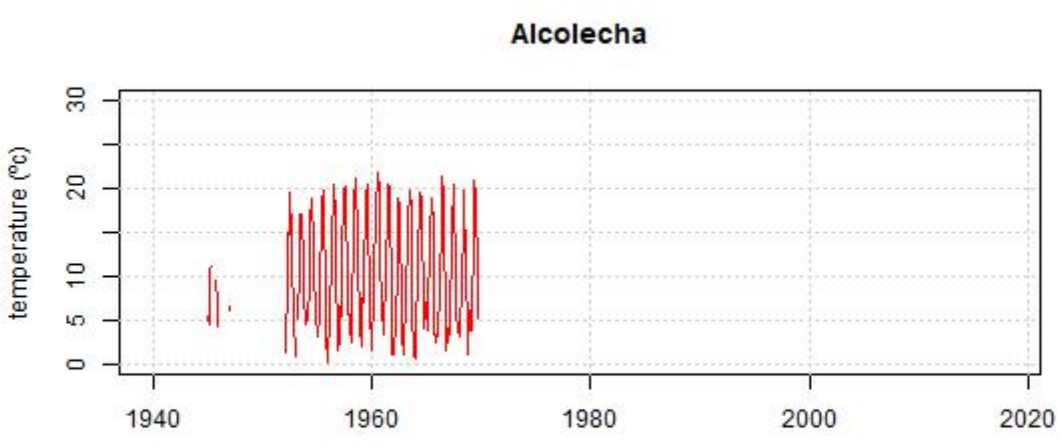


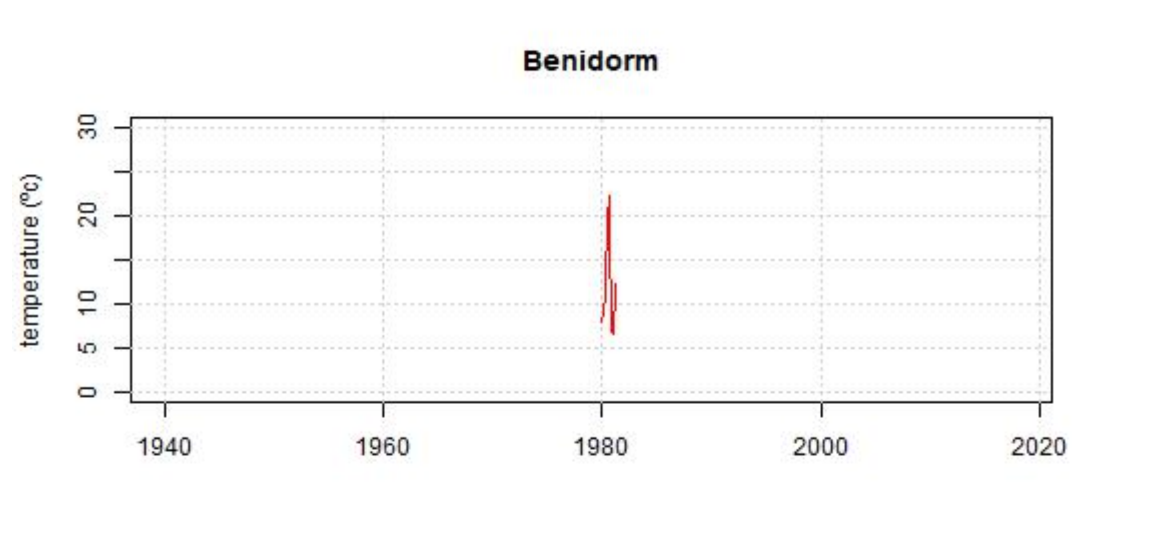

Torre Macanes
precipitation (mm)
0
200
400
600
1980
1990
2000
2010

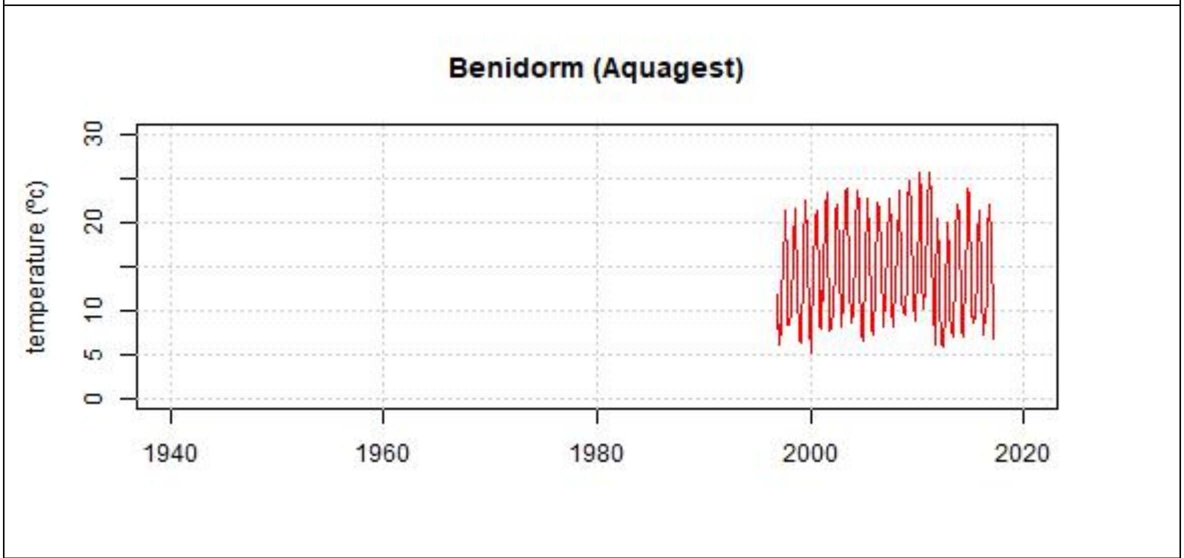
Temperature data from AEMet

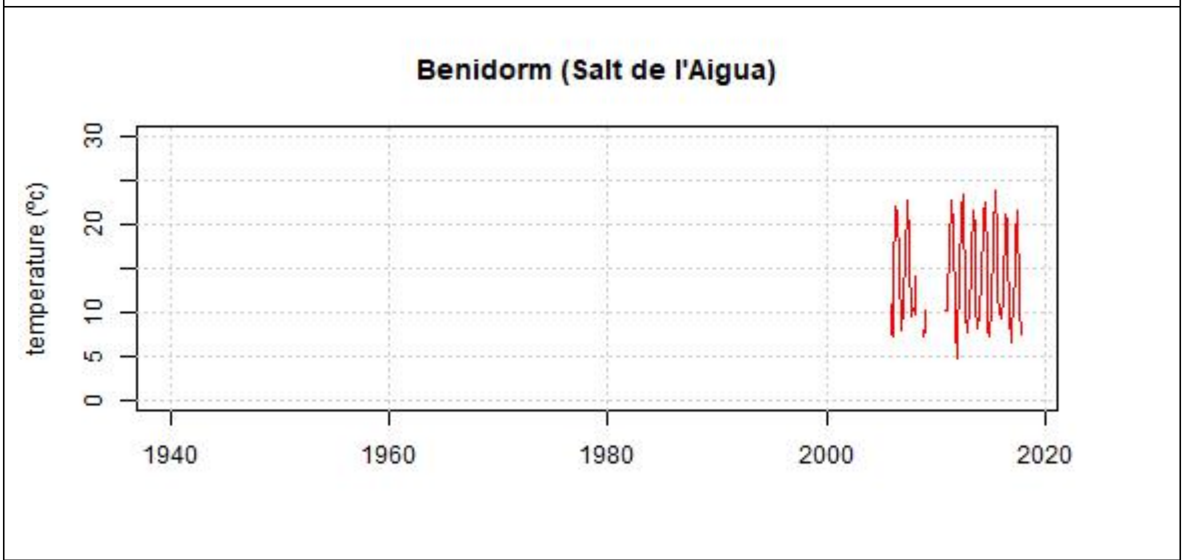
STATION	START	END
ALCALALI	1979	2001
ALCOLECHA	1945	1970
BENIDORM	1980	1981
BENIDORM (AQUAGEST)	1997	2017
BENIDORM MEDIA LEGUA	1958	1968
BENIDORM-SALT DE L'AIGUA	2006	2017
BENIDORM-TERRA MITICA	2002	2002
BENIMANTELL POLIDEPORTIVO	2005	2017
CALLOSA DE ENSARRIA (GRUPO ES-COLAR)	1943	1967
CALLOSA D'EN SARRIA-SEA	1956	1996
LA VILA JOIOSA	1943	1961

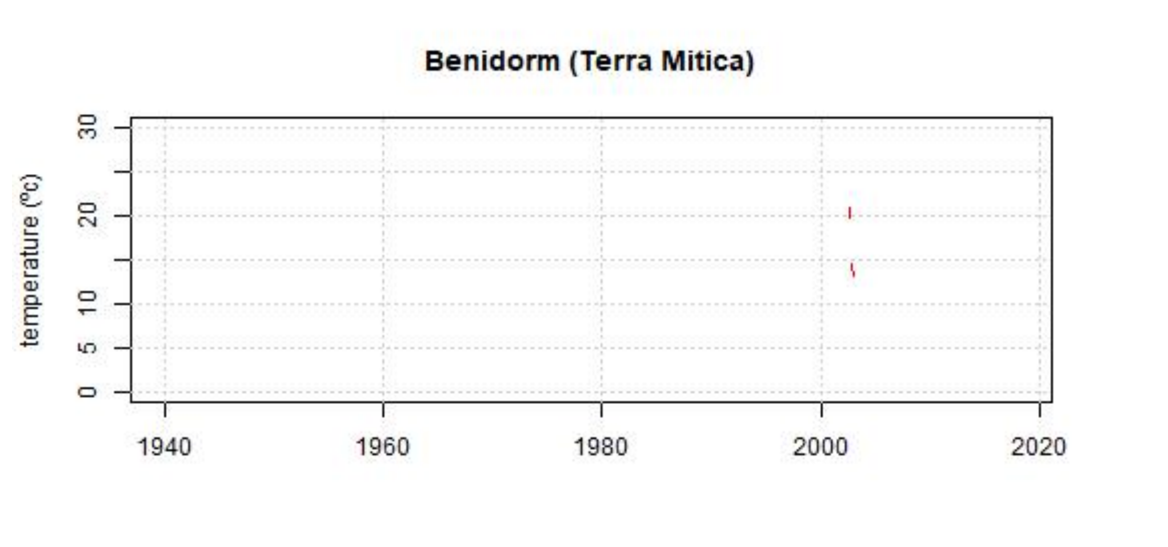


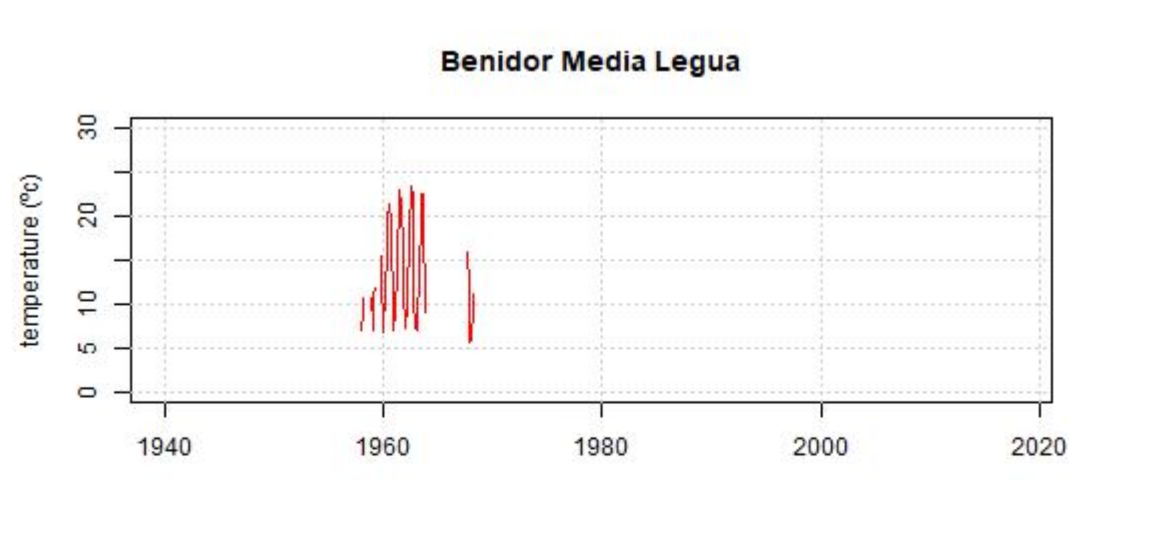


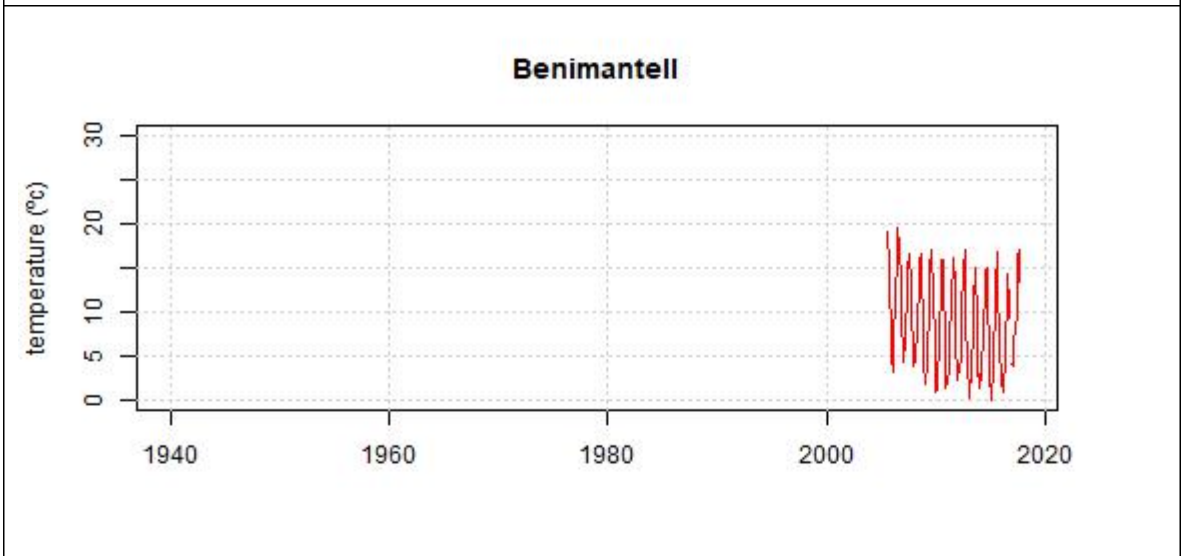

Benidorm
temperature (ºc)
0
5
10
20
30
1940
1960
1980
2000
2020

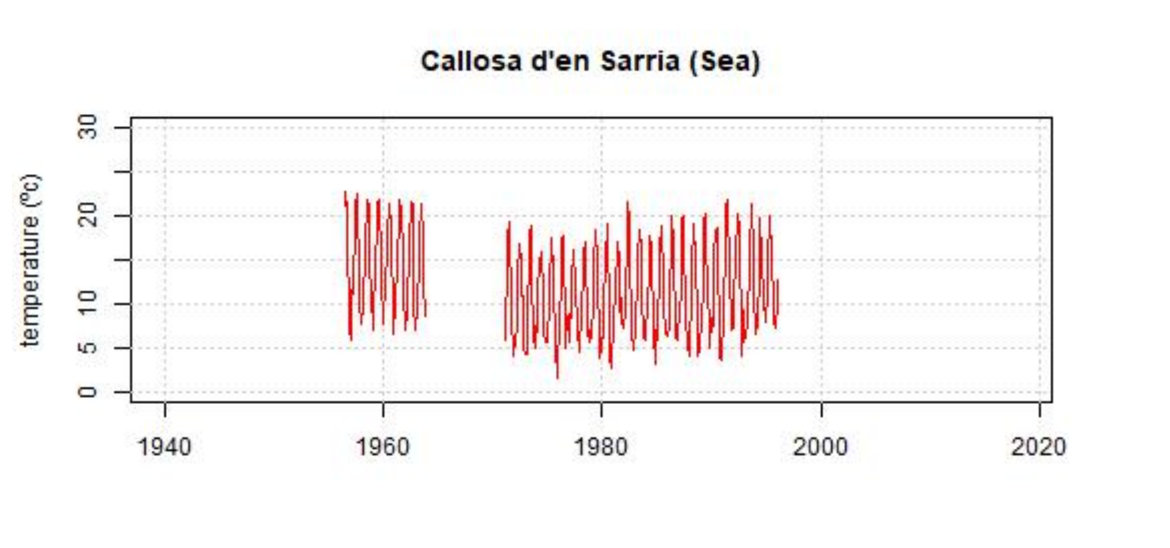

Benidorm (Aquagest)
temperature (ºc)
0
5
10
20
30
1940
1960
1980
2000
2020

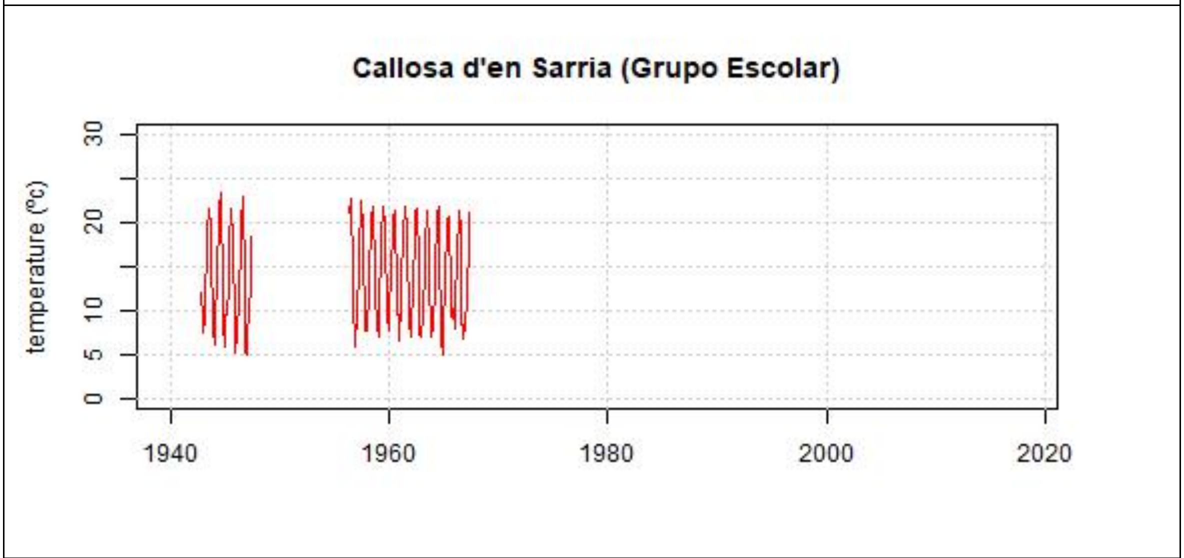

Benidorm (Salt de l'Aigua)
temperature (ºc)
0
5
10
20
30
1940
1960
1980
2000
2020

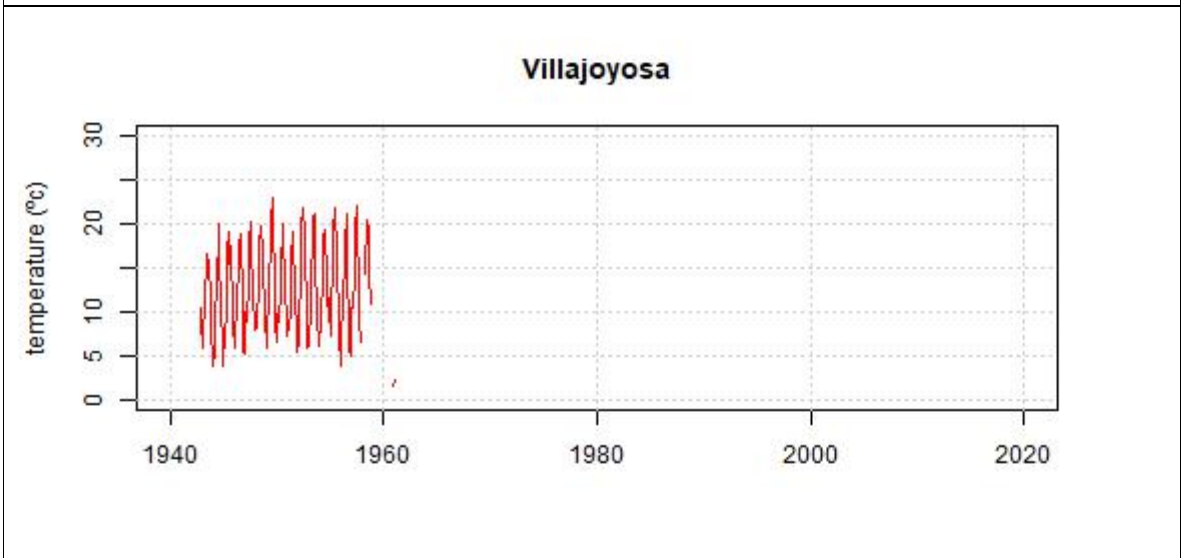

Benidorm (Terra Mitica)
temperature (ºc)
0
5
10
20
30
1940
1960
1980
2000
2020


Benidor Media Legua
temperature (ºc)
0
5
10
20
30
1940
1960
1980
2000
2020


Benimantell
temperature (ºc)
0
5
10
20
30
1940
1960
1980
2000
2020


Callosa d'en Sarria (Sea)
temperature (ºc)
0
5
10
20
30
1940
1960
1980
2000
2020


Callosa d'en Sarria (Grupo Escolar)
temperature (ºc)
0
5
10
20
30
1940
1960
1980
2000
2020


Villajoyosa
temperature (ºc)
0
5
10
20
30
1940
1960
1980
2000
2020

Amadorio and Guadalest Reservoir data

STATION	START	END
Guadalest	1967	2017
Amadorio	1959	2017

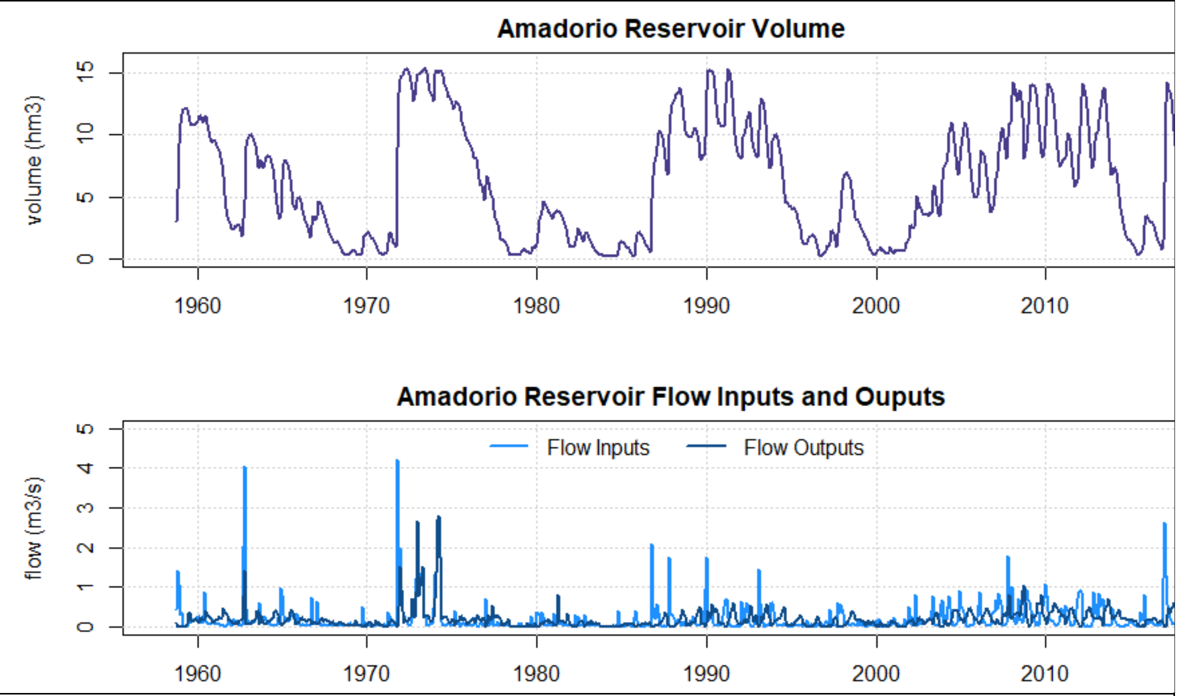


Figure . Amadorio reservoir data

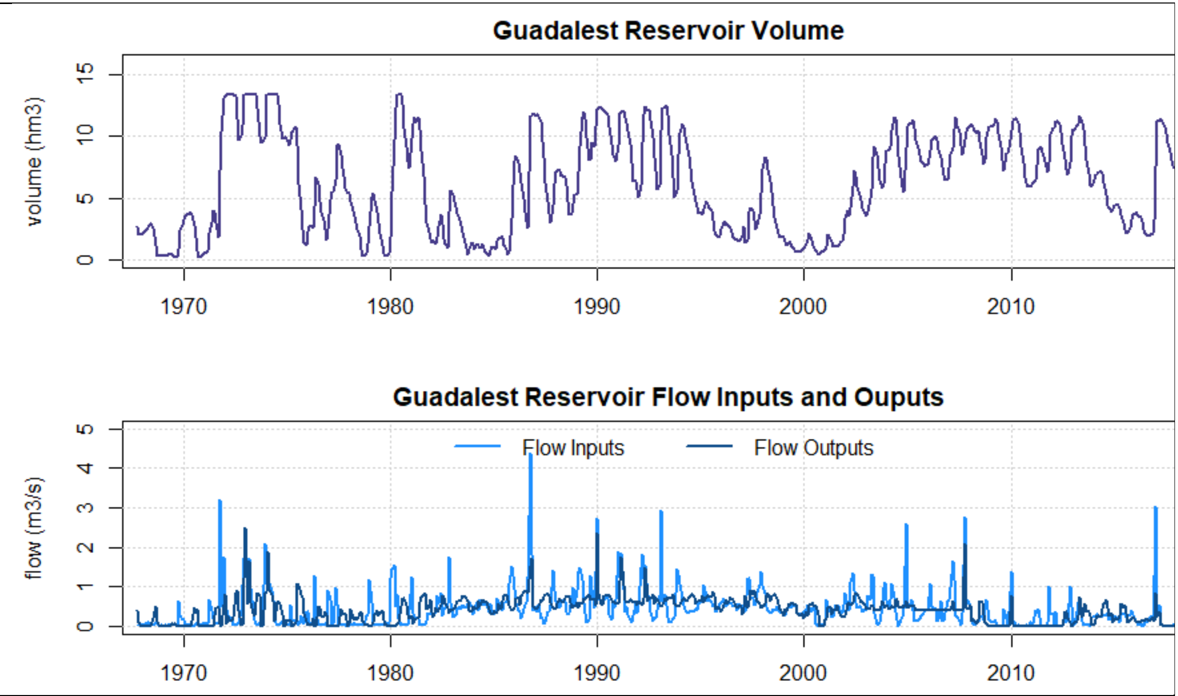


Figure 7. Guadalest reservoir data

Appendix B. Temperature variable regressions

The objective of this section is to find the relationship between altitude and climatic variables, to later apply them to the input climatic variables in the SWAT model
The material that has been used is the following:

- Digital Elevation Model (DEM) of 5 meters resolution. This DEM has been obtained from the Spanish Geographic Institute. http://centrodedescargas.cnig.es/CentroDescargas/index.jsp
- Digital Climatic Atlas of the Iberian Peninsula (Ninyerola 2000) provided by the Universidad Autonoma de Barcelona.

The process carried out was as follows:

1. The geographical area has been the buffer of 7 km of the study area (Region of Marina Baixa)
2. We have obtained the DEM value for each pixel center Of Digital Climatic Atlas of the Iberian Peninsula. In this way, we have obtained an altitude value for each Atlas pixel.
3. We have carried out a statistical study to obtain a relationship between altitude and temperature. We have also assessed the reliability of the regression obtained.

The result was as follows:

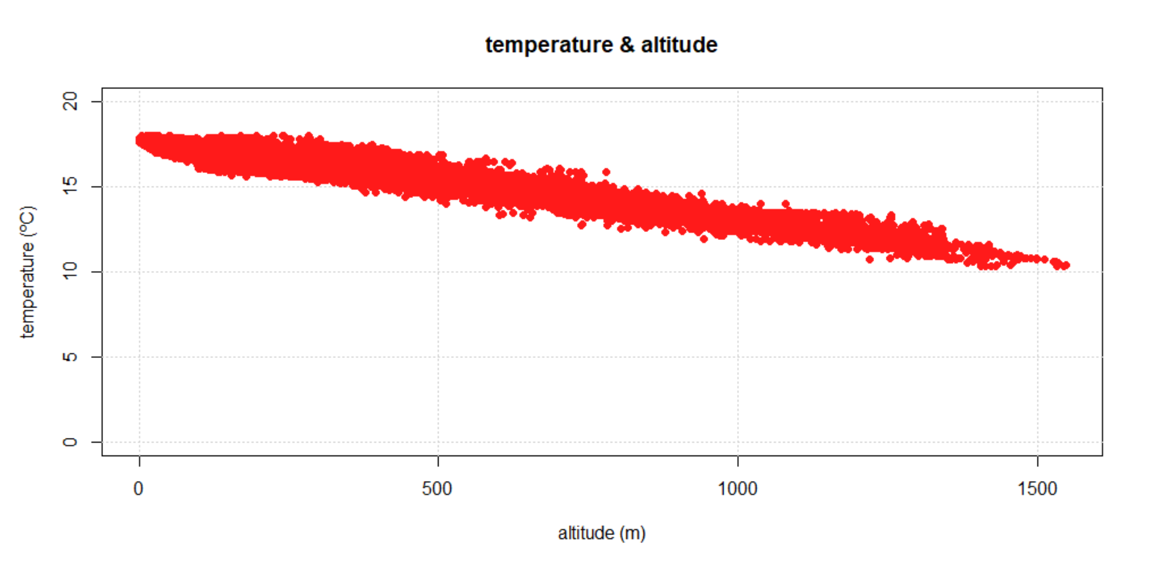


Figure. Dispersion graph (Ninyerola 2000)

- Pearson correlation coefficient of 0.97. Very good data.
- The regression explains 94% of the variability of the distribution. Very good data.
- The independent term and the regression slope are significant
- Y(tºC) =17.793-0.004729*altitud(m)
- The distribution presents: homoscedasticity, normality and linearity. Good predictive ability.

As a conclusion we can take for granted the use of this regression.

Appendix C. Correction of precipitation data

The objective of this section is to obtain current precipitation series that are homogenized, outlier-free and without gaps.

According to AEMET, events exceeding 250 mm per day in the area are considered extreme. We've erased days over 250 mm per day

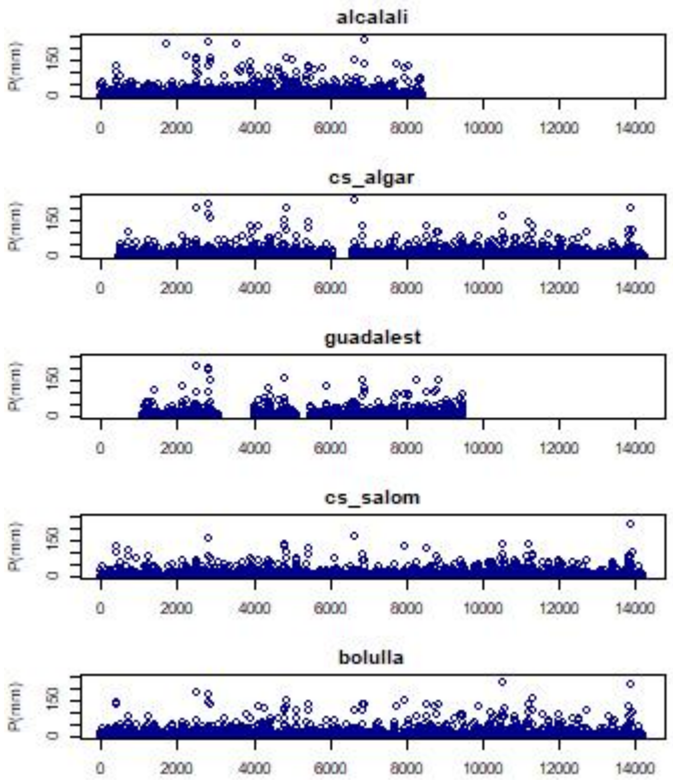
For homogenization, •we have calculated the SNHT test for all stations.

The data filling process was as follows

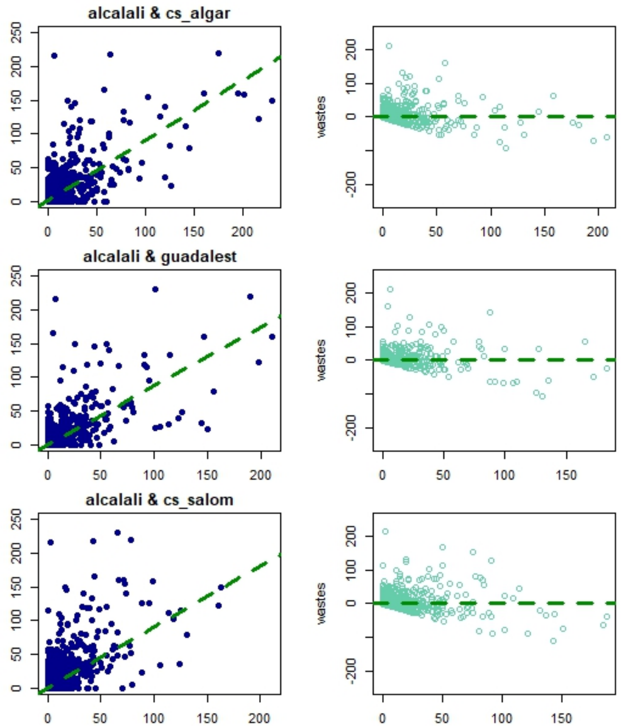
1. We have filled in data from the stations, through re statistical relationships between stations...
2. The criteria for selecting the stations were: (1) correlation between the series, (2) proximity and (3) minimum overlap between the series.
3. Statistical relationships have always been proportional (multiplication of a factor) in order to keep days without precipitation and extreme events.
4. Three stations have been selected for filling. If the station has not been filled with these stations, we have performed a second filling through the simulated data and the same statistical relationships.

ALCALALI

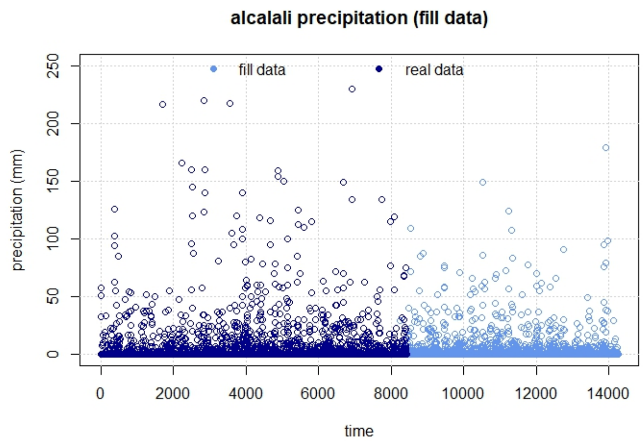
Used stations



Regressions



Results



Error MAE

1.5

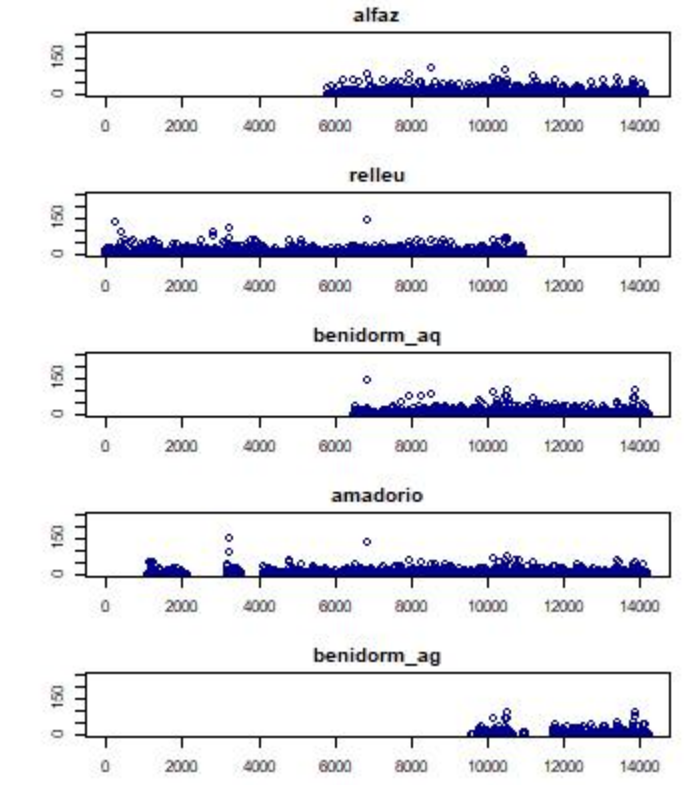
Pearson correlation coefficient

#cs_algar_aemet	0.736566675
#guadalestaemet	0.723481426
#cs_salom_aemet	0.708596245
#bolulla_aemet	0.682094727

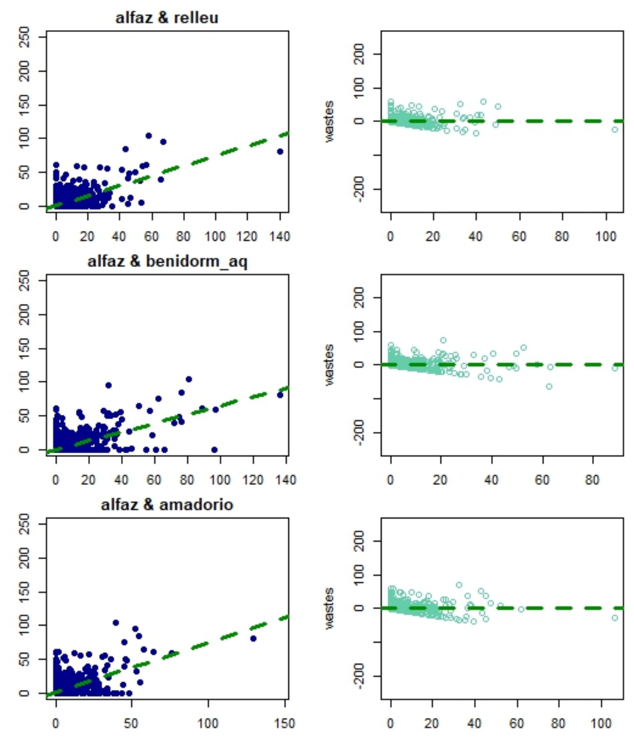
#1° cs_algar y=0+x0.900531 R2 0.5544
#2° guadalest y=0+x0.87154 R2 0.5366
#3° cs_salom y=0+x1.15535 R2 0.5165

ALFAZ

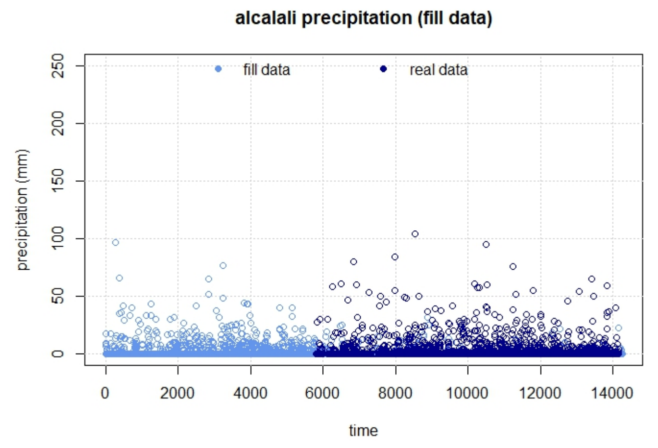
Used stations



Regressions



Results



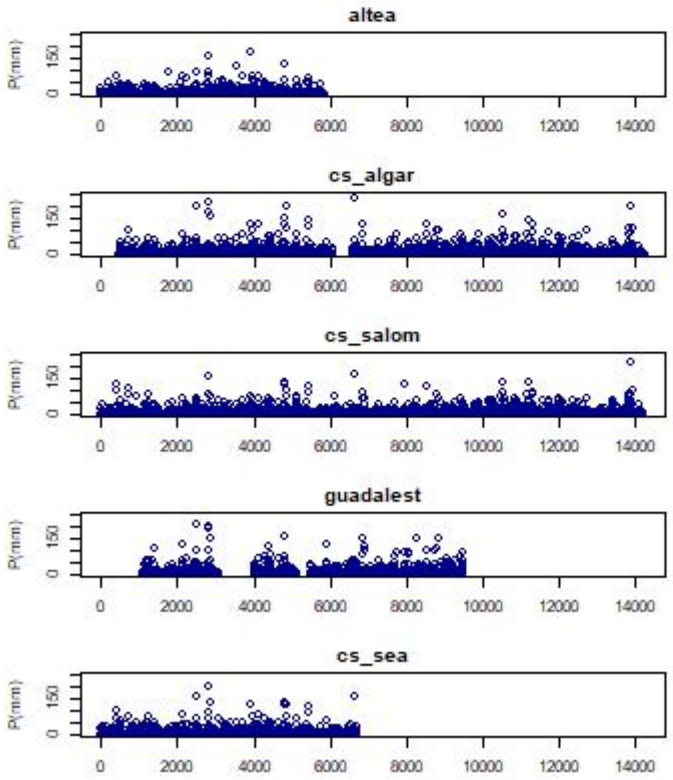
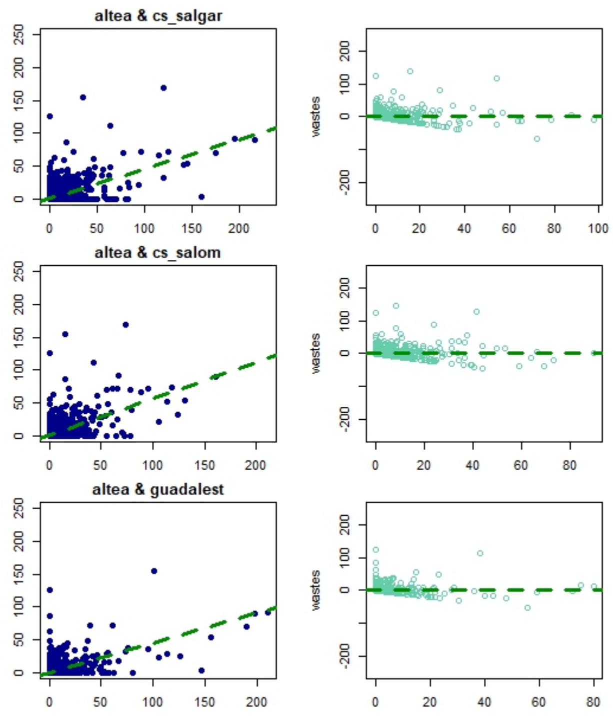
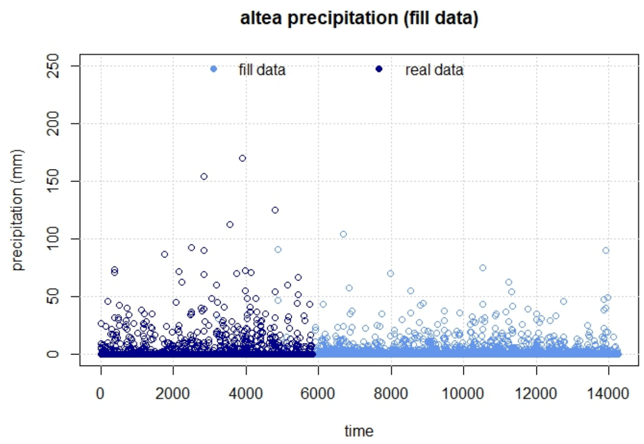
Error

0.88

Pearson correlation coefficient

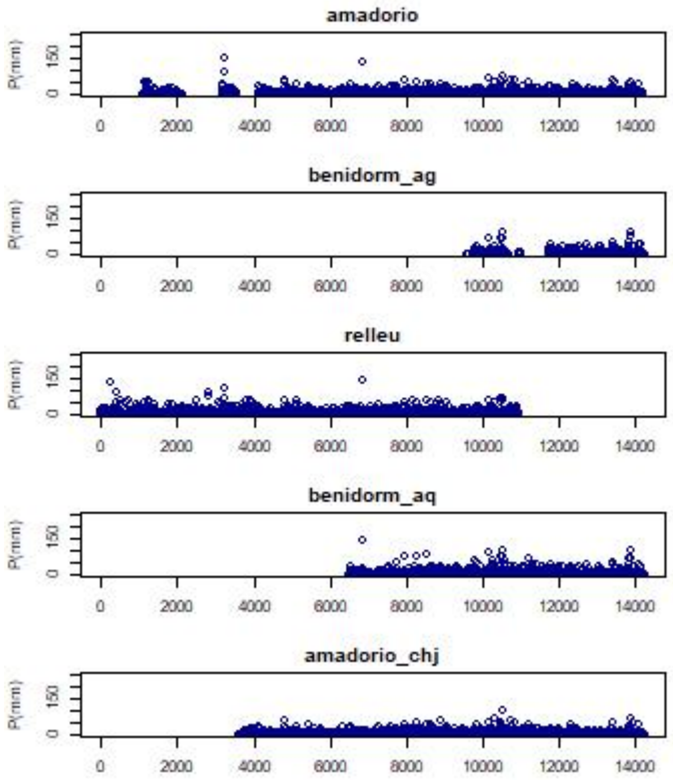
#relleu_aemet 0.668226919
#benidorm_aq_aemet 0.646101239
#amadorio_aemet 0.63476194
#benidorm_ag_aemet 0.622085376

#1° relleu y=0+x0.74335 R2 0.4633
#2° benidorm_aq y=0+x0.647882 R2 0.4332
#3° amadorio y=0+x0.81667 R2 0.4196

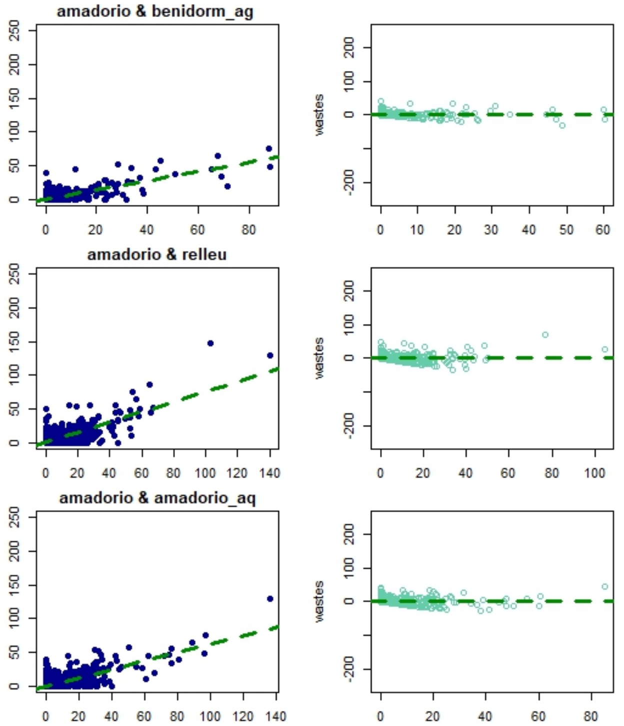
ALTEA		
Used stations	Regressions	Results
		
		Error MAE
		1.03
Pearson correlation coefficient #¹cs_algar_aemet 0.607444945 #cs_salom_aemet 0.594810655 #guadalestaemet 0.581902509 #cs_sea_aemet 0.535803771	#1° cs_algar y=0+x0.450552 R2 0.3827 #2° cs_salom y=0+x0.558301 R2 0.3691 #3° guadalest y=0+x0.380575 R2 0.3527	

AMADORIO

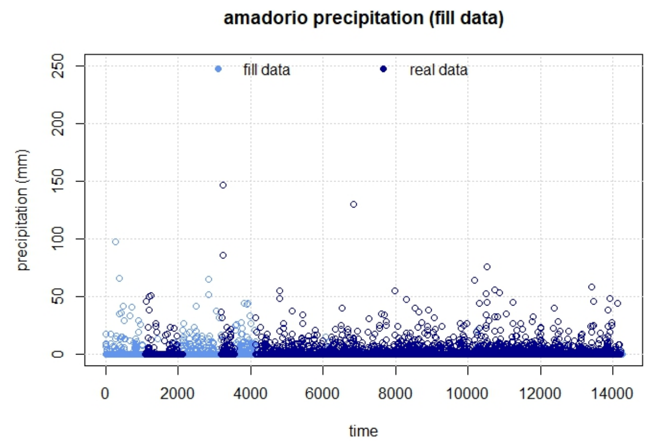
Used stations



Regressions



Results



Error MAE

0.49

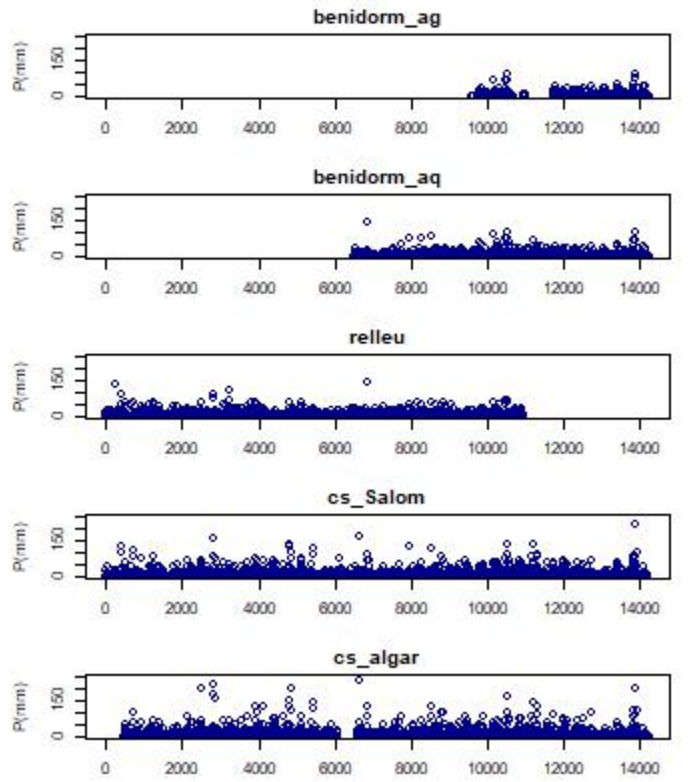
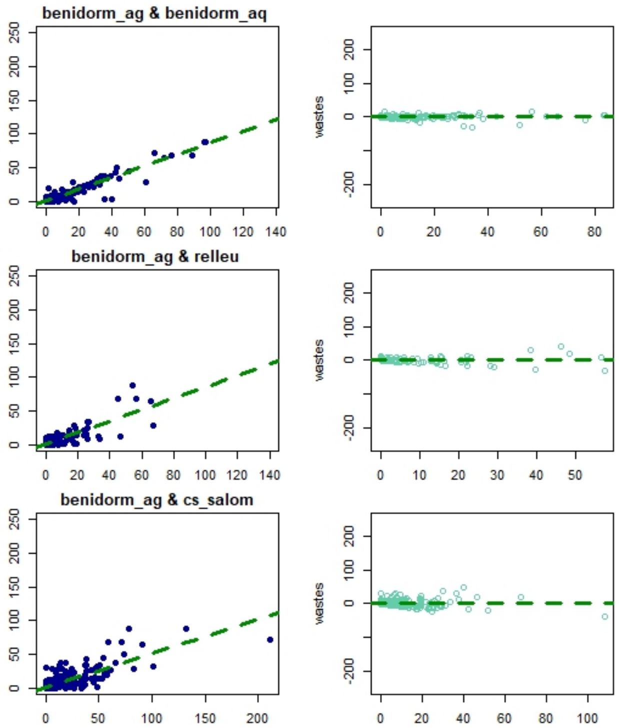
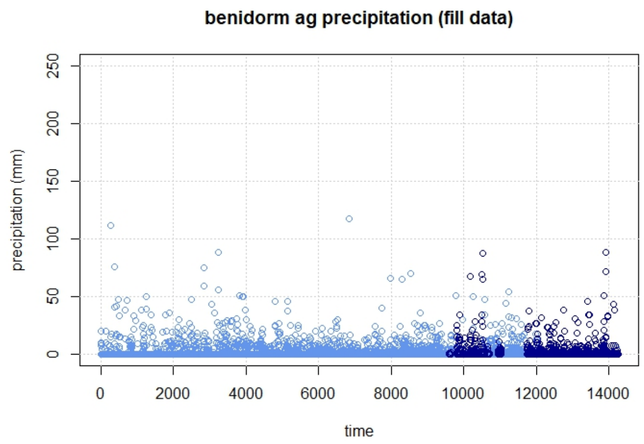
Pearson correlation coefficient

#benidorm_ag_aemet 0.817241572
#relleu_aemet 0.813039324
#benidorm_aq_aemet 0.774343126
#amadorio_chj 0.772127203

#1° benidorm_ag y=0+x0.683500 R2 0.678
#2° relleu y=0+x0.746898 R2 0.6715

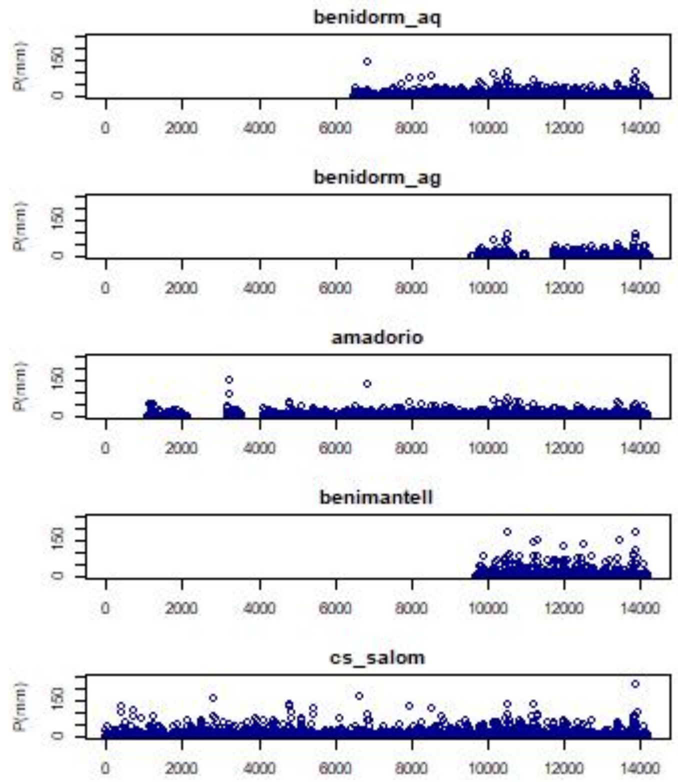
- #3° benidorm_aq y=0+x0.622659 R2 0.6117

BENIDORM_AG

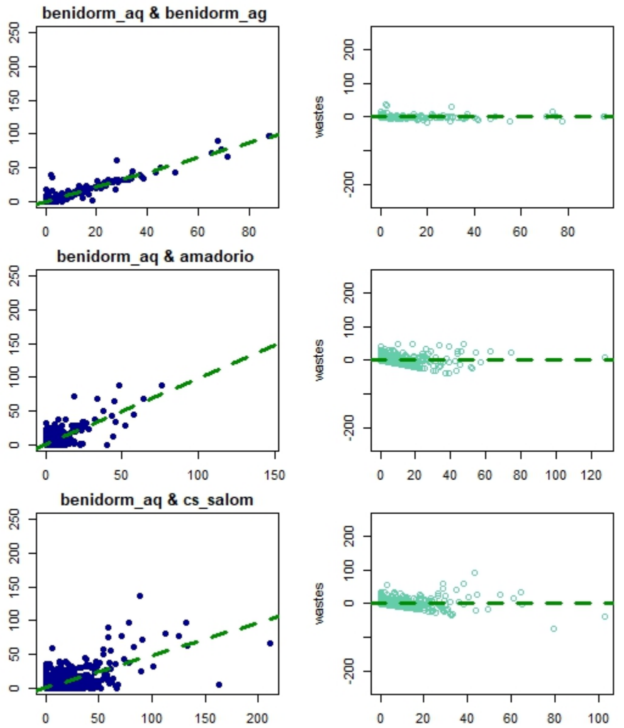
Used stations	Regressions	Results
		
		Error MAE
		0.21
Pearson correlation coefficient #benidorm_aq_aemet 0.964358102 #relleu_aemet 0.849911312 #cs_salom_aemet 0.839697886 #cs_algar_aemet 0.819928966	#1° cs_algar y=0+x0.859111 R20.9321 #2° guadalest y=0+x0.85690 R2 0.7327 #3° cs_salom y=0+x0.512375 R2 0.7139	

BENIDORM_AQ

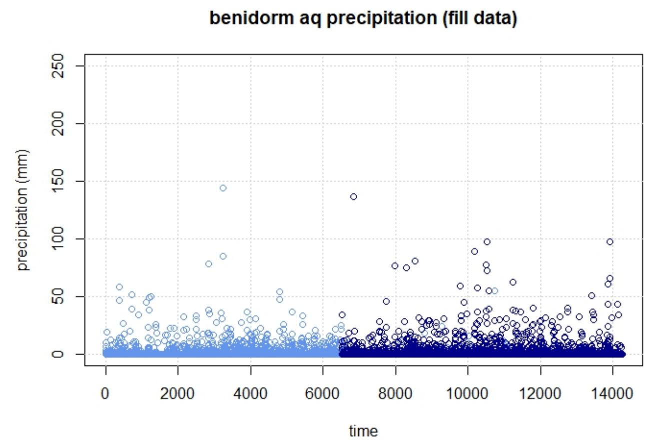
Used stations



Regressions



Results



Error MAE

0.21

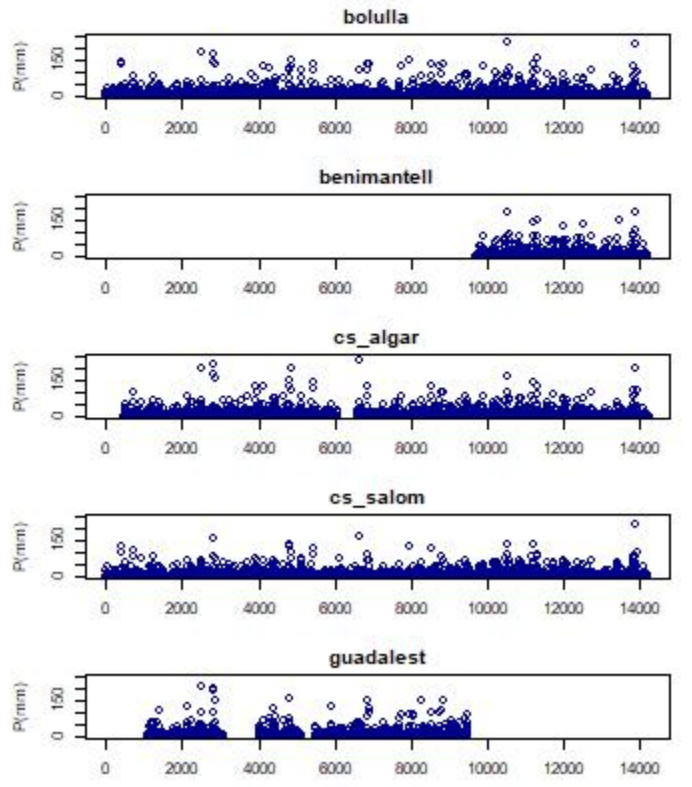
Pearson correlation coefficient

#benidorm_ag_aemet 0.964358102
#amadorio_aemet 0.774343126
#benimantell_aemet 0.762537563
#cs_salom_aemet 0.719726633

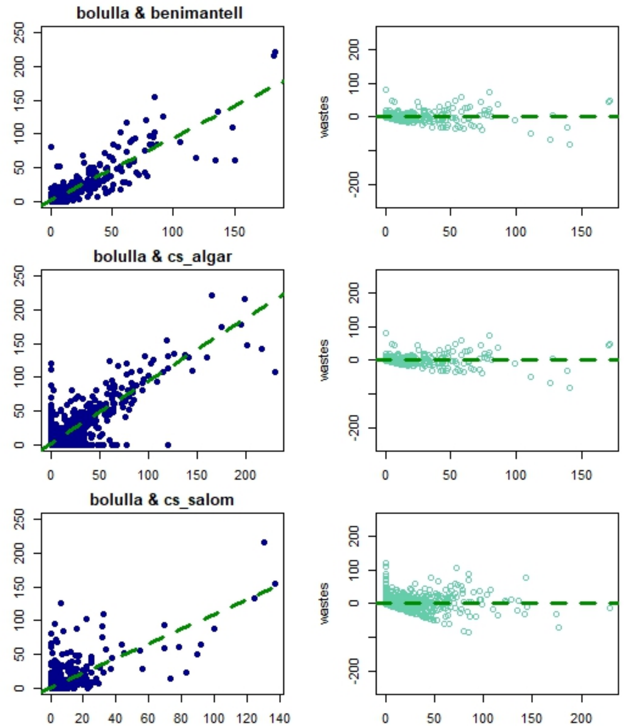
#1º benidorm_ag y=0+x1.0850091 R2 0.9321
#2º amadorio y=0+x0.982469 R2 0.6117
#3º cs_salom y=0+x0.487195 R2 0.5314

BOLULLA

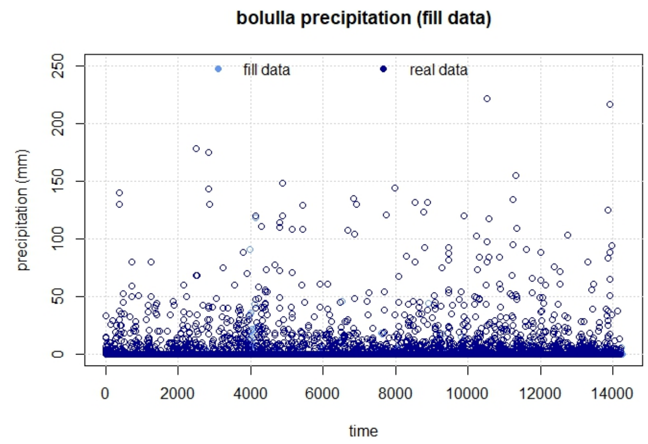
Used stations



Regressions



Results



Error MAE

0.89

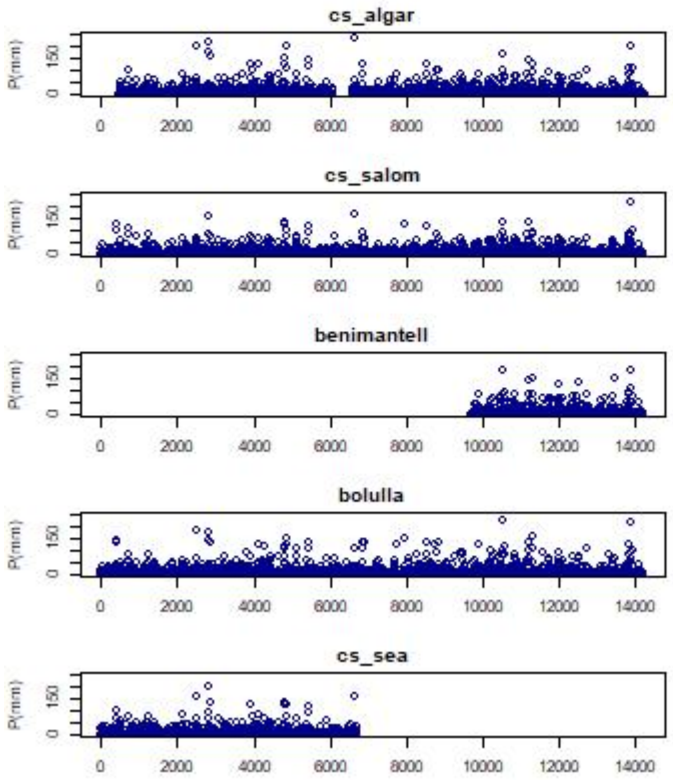
Pearson correlation coefficient

#benimantell_aemet 0.905233778
#cs_algar_aemet 0.858933144
#cs_salom_aemet 0.848713766
#guadalestaemet 0.833806226

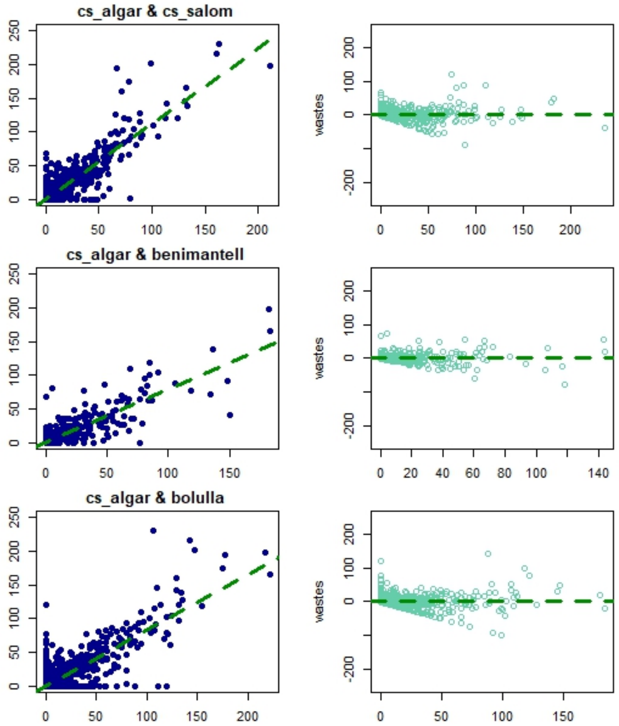
#1° benimantell y=0+x0.937357 R2 0.0.8255
#2° cs_algar y=0+x0.937357 R2 0.8255
#3° cs_salom y=0+x1.084837 R2 0.7291

CS_ALGAR

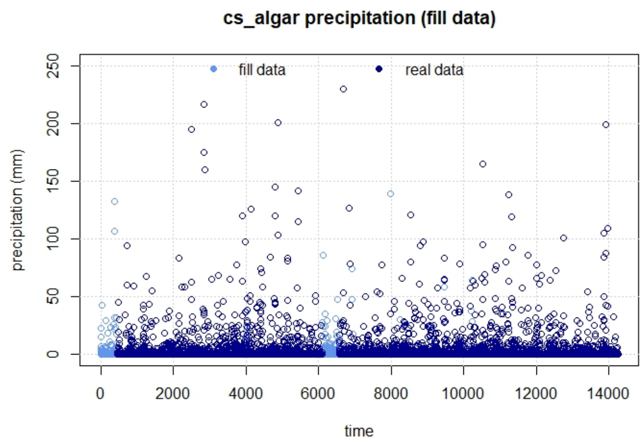
Used stations



Regressions



Results



Error MAE

0.68

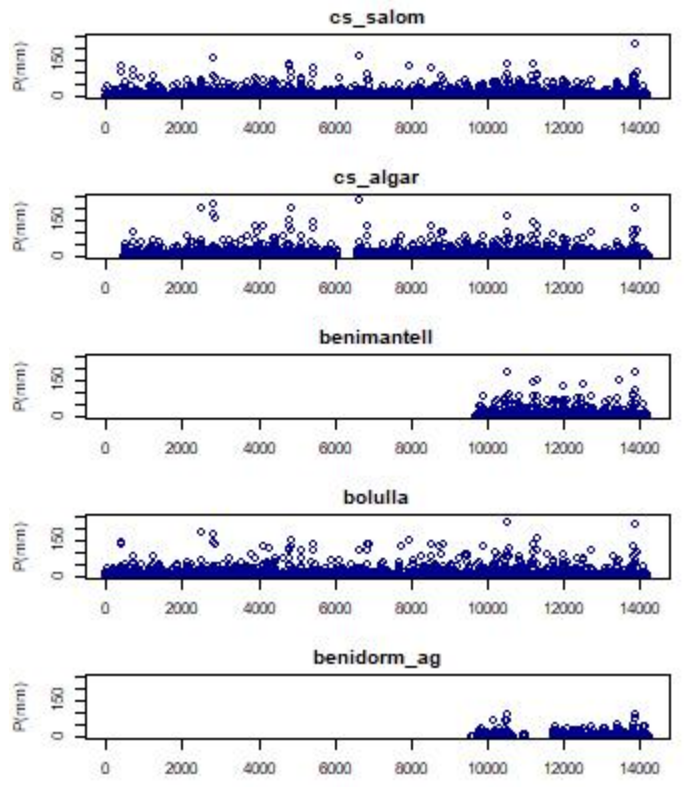
Pearson correlation coefficient

#cs_salom_aemet 0.909721733
#benimantell_aemet 0.880372934
#bolulla_aemet 0.858933144
#cs_sea_aemet 0.854756995

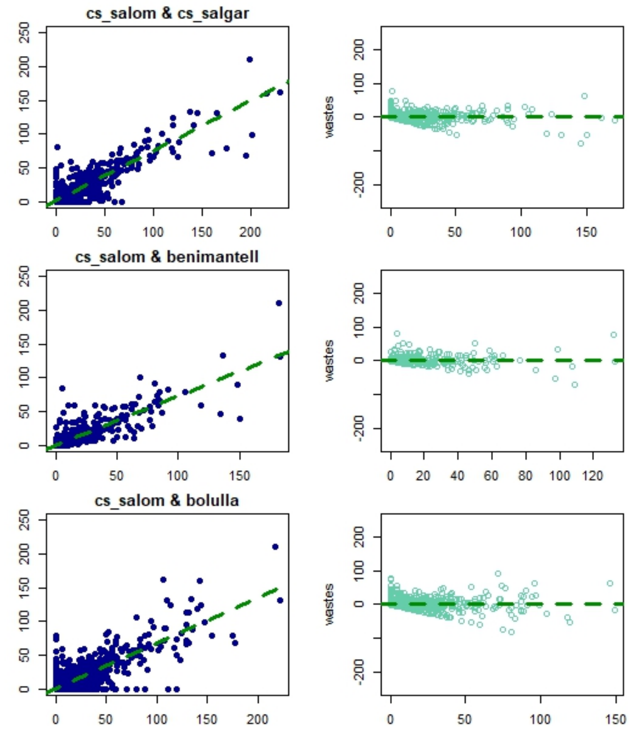
#1° cs_salom y=0+x1.117482 R2 0.8329
#2° benimantell y=0+x0.78530 R2 0.7825
#3° bolulla y=0+x0.826735 R2 0.7455

CS_SALOM

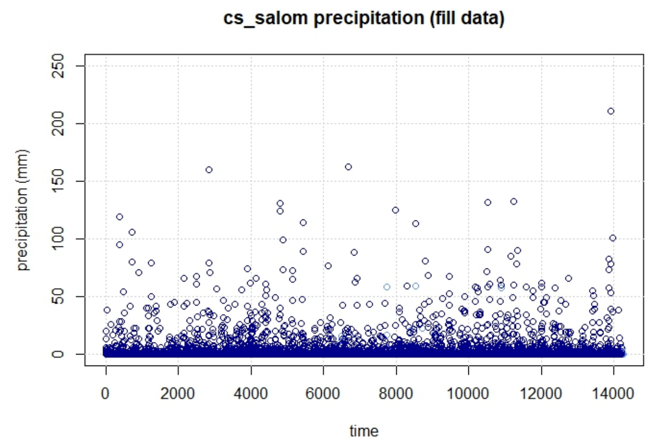
Used stations



Regressions



Results



Error MAE

0.6

Pearson correlation coefficient

#cs_algar_aemet 0.909721733
#benimantell_aemet 0.878083449
#bolulla_aemet 0.848713766
#benidorm_ag_aemet 0.839697886

#1º cs_algar y=0+x0.745366 R2 0.8329
#2º benimantell y=0+x0.724526 R2 0.7791
#3º bolulla y=0+x0.672103 R2 0.7291

<table>
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<tr><th>Used stations</th><th>Regressions</th><th>Results</th></tr>
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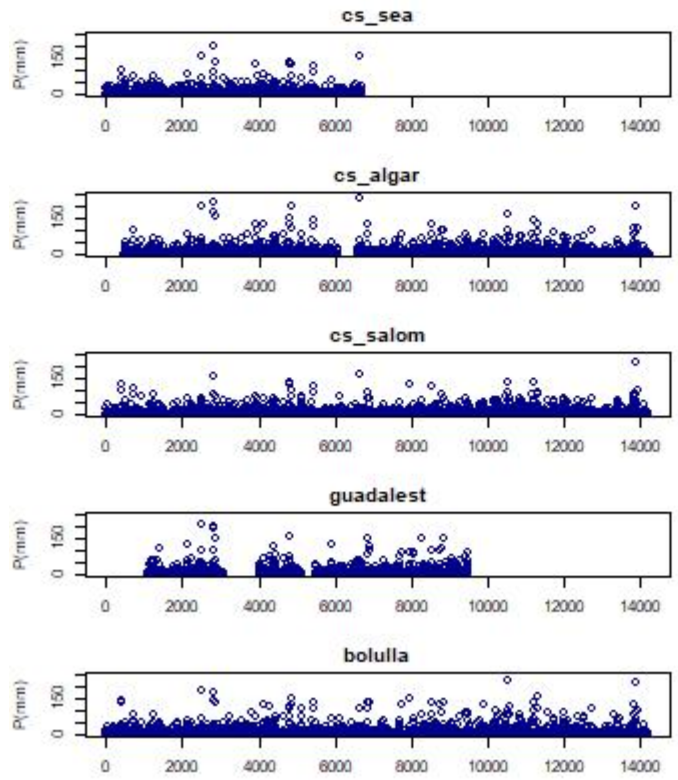
<td>
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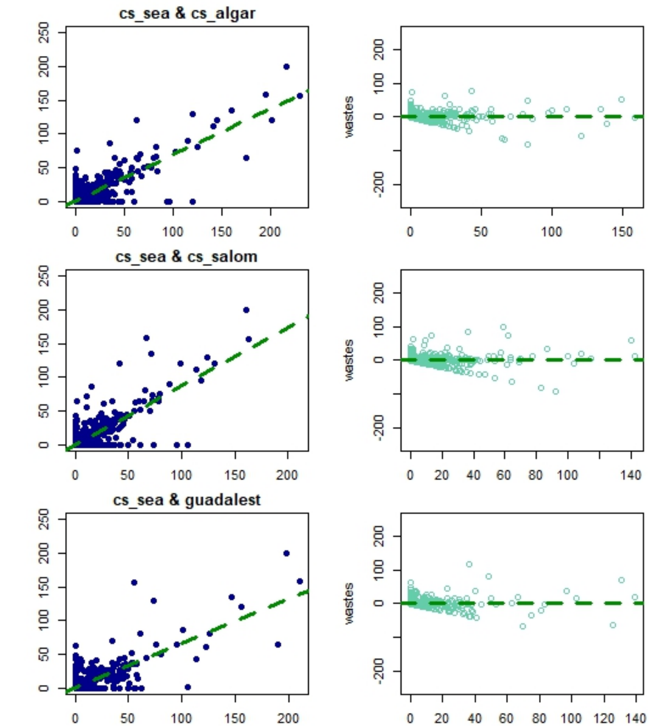
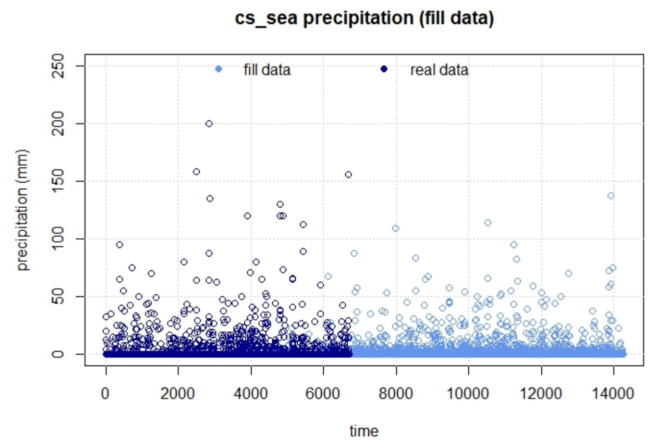
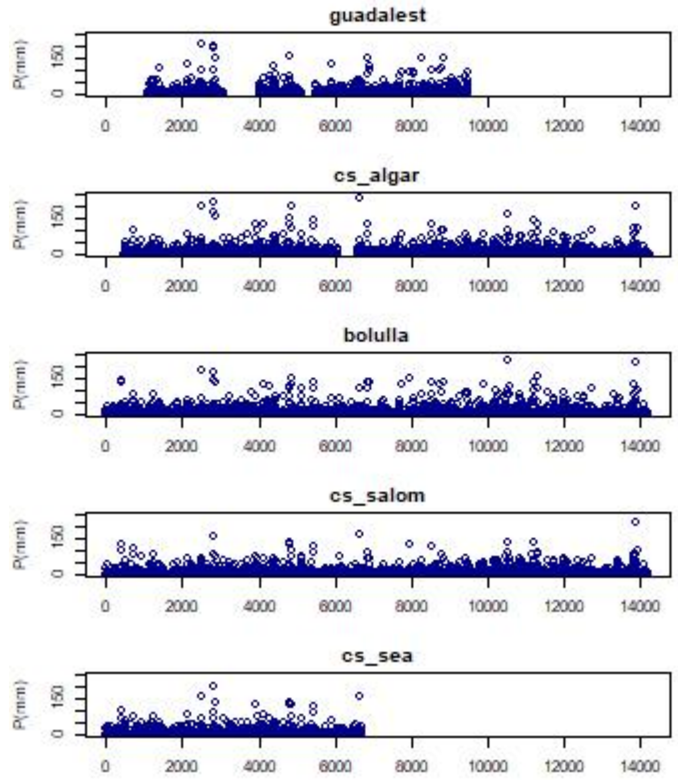
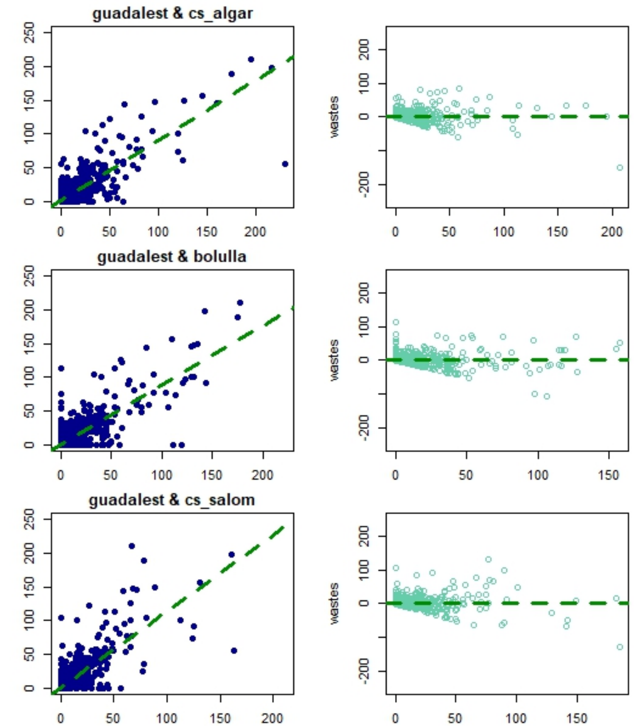
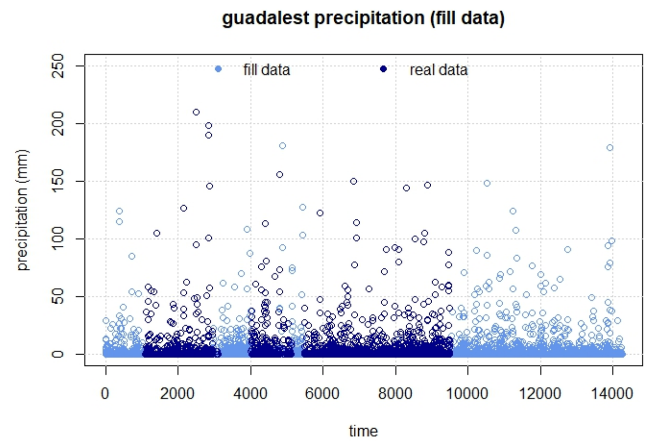
<td>
</td>
<td>

Error MAE
0.88</td>
</tr>
<tr>
<td>#cs_algar_aemet 0.854756995
#cs_salom_aemet 0.821643938
#guadalestaemet 0.801755856
#bolulla_aemet 0.713138714</td>
<td>#1° cs_algar y=0+x0.688666 R2 0.7378
#2° cs_salom y=0+x0.872996 R2 0.6846
#3° guadalest y=0+x0.660996 R2 0.6522</td>
<td></td>
</tr>
</table>

<table>
<tr><th colspan="3">GUADALEST</th></tr>
<tr><th>Used stations</th><th>Regressions</th><th>Results</th></tr>
<tr><td rowspan="2">
</td><td rowspan="2">
</td><td>
</td></tr>
<tr><td>Error MAE</td></tr>
<tr><td>Pearson correlation coefficient
#cs_algar_aemet 0.853623728
#bolulla_aemet 0.833806226
#cs_salom_aemet 0.817489409
#cs_sea_aemet 0.801755856</td><td>#1° cs_algar y=0+x0.898380 R2 0.7365
#2° bolulla y=0+x0.884573 R2 0.7045
#3° cs_salom y=0+x1.136245 R2 0.6786</td><td>1.00</td></tr>
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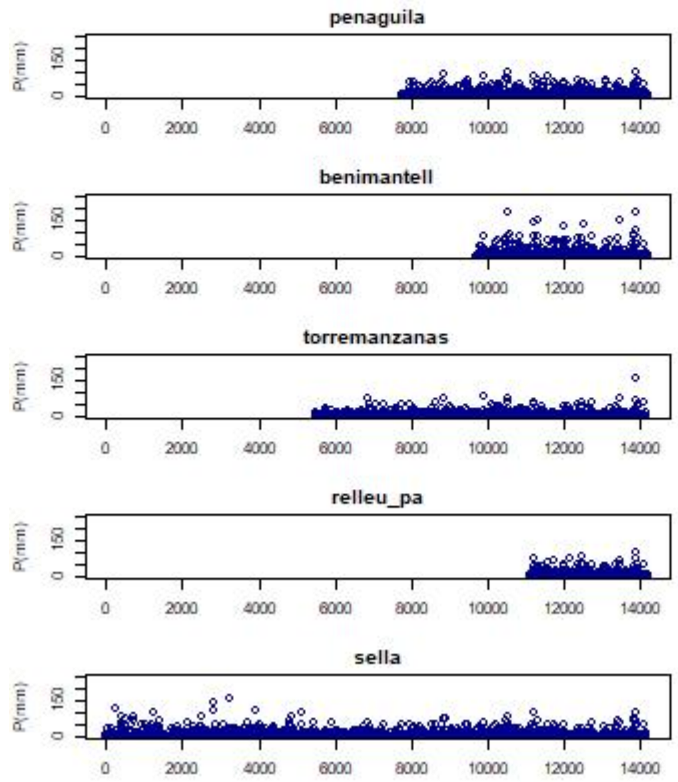
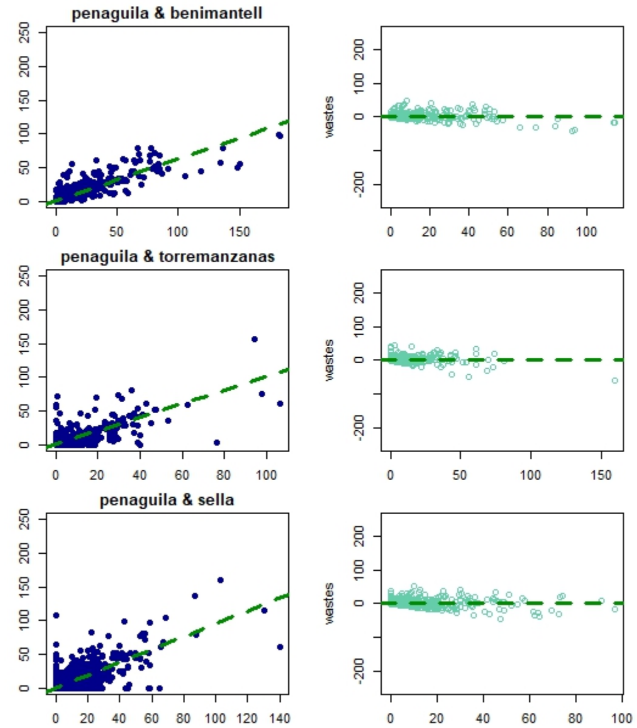
PENAGUILA

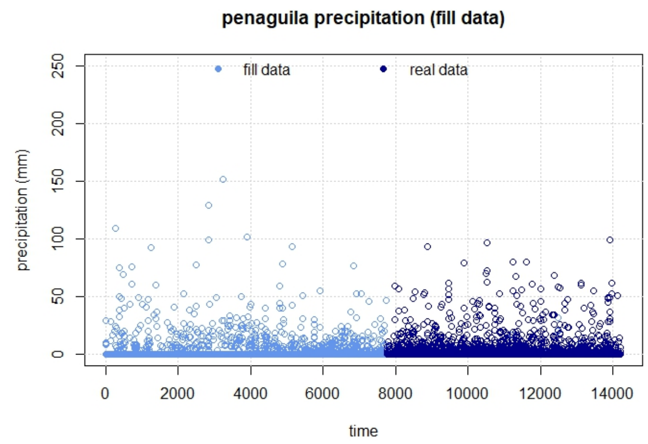
Used stations



Regressions



Results



Error MAE

0.78

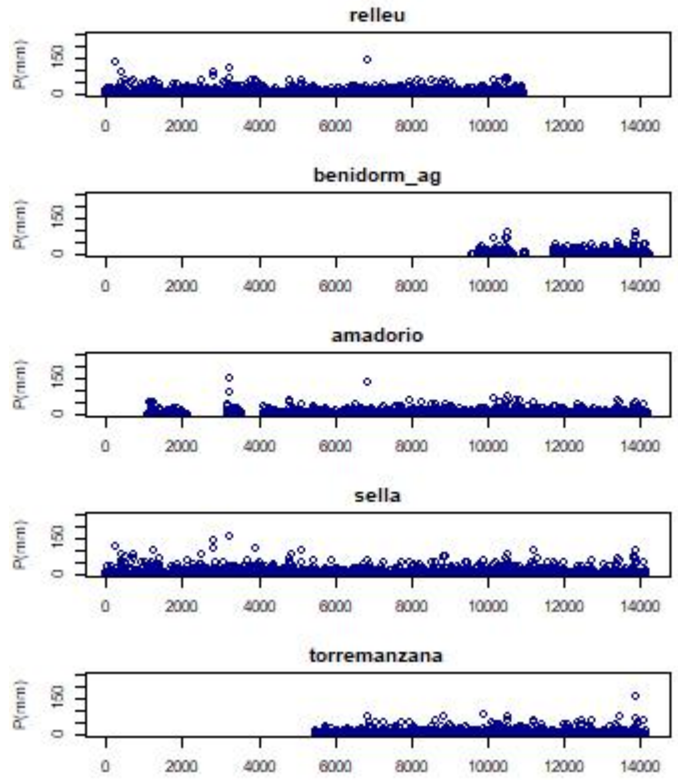
Pearson correlation coefficient

#benimantell_aemet 0.880763303
#torremanzanas_aemet 0.879761235
#relleu_pa_aemet 0.859979367
#sella_aemet 0.838425315

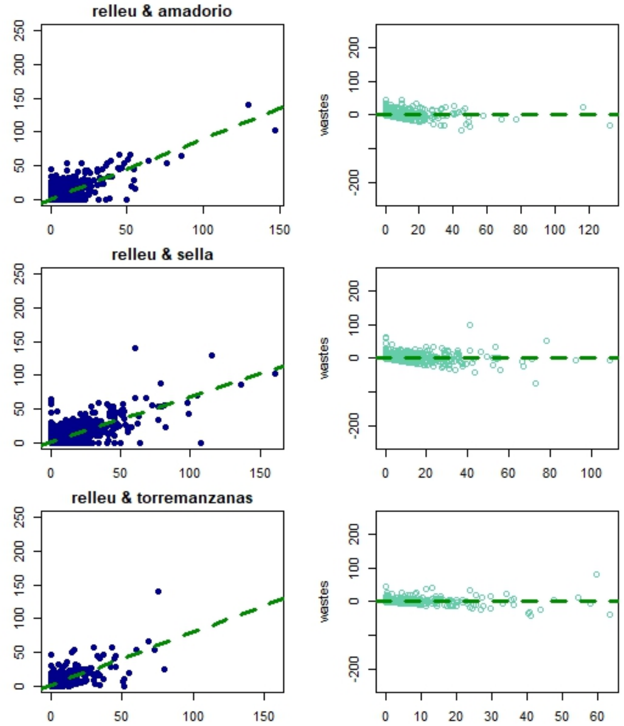
#1° benimantell y=0+x0.62317 R2 0.7844
#2° torremanzanas y=0+x1.014114 R2 0.7807
#3° sella y=0+x0.948272 R2 0.7133

RELLEU

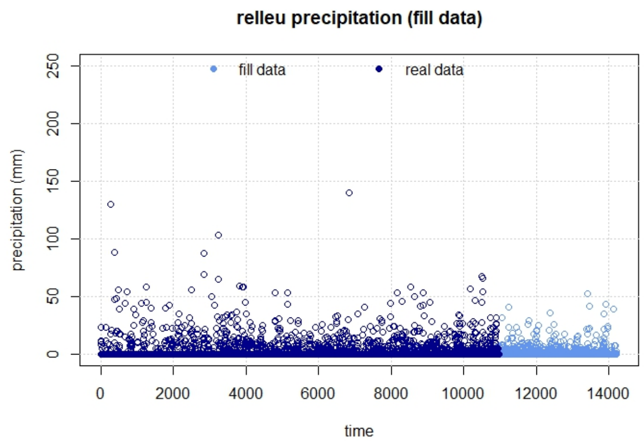
Used stations



Regressions



Results



Error MAE

0.64

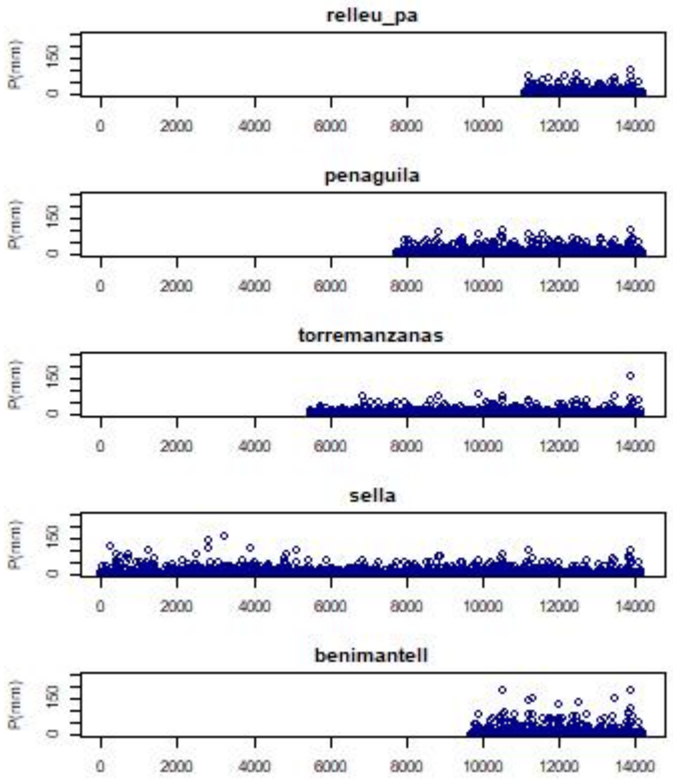
Pearson correlation coefficient

#benidorm_ag_aemet 0.849911312
#amadorio_aemet 0.813039324
#sella_aemet 0.778945573
#torremanzanas_aemet 0.769209498

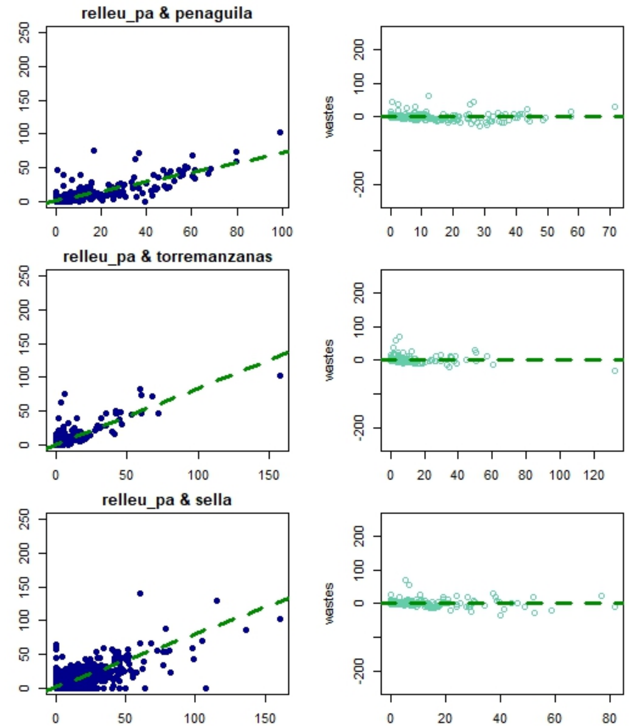
#1° amadorio y=0+x0.899064 R2 0.6715
#2° sella y=0+x0.679042 R2 0.6185
#3° torremanzana y=0+x0.793072 R2 0.6035

RELLEU_PA

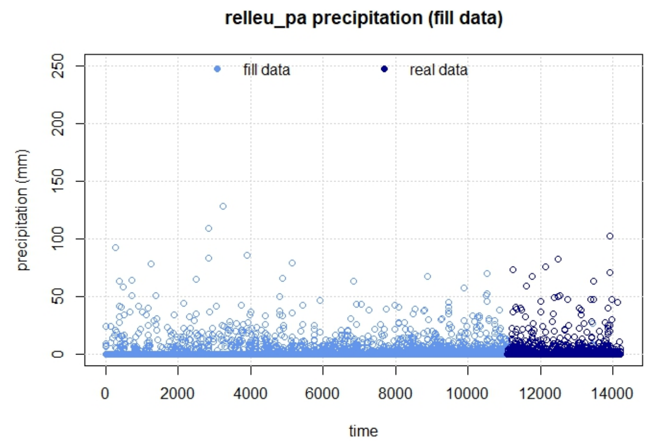
Used stations



Regressions



Results



Error MAE

0.58

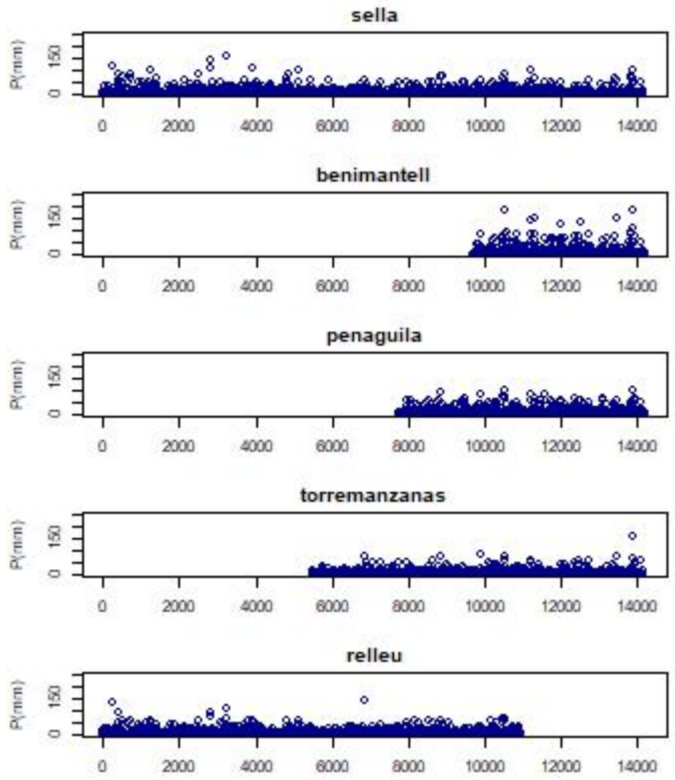
Pearson correlation coefficient

#penaguila_aemet 0.859979367
#torremanzanas_aemet 0.856326234
#sella_aemet 0.845436759
#benimantell_aemet 0.796816069

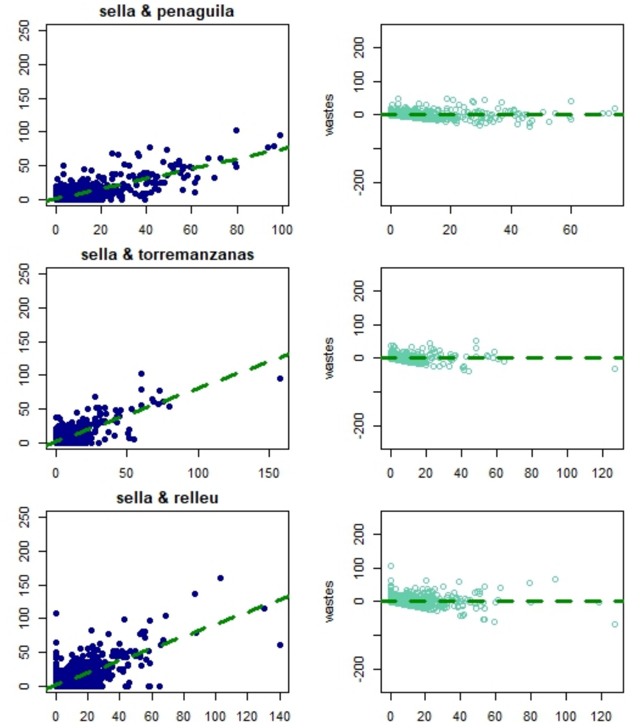
#1° penaguila y=0+x0.722982 R2 0.75
#2° torremanzanas y=0+x0.836932 R2 0.7394
#3° sella y=0+x0.799427 R2 0.7232

SELLA

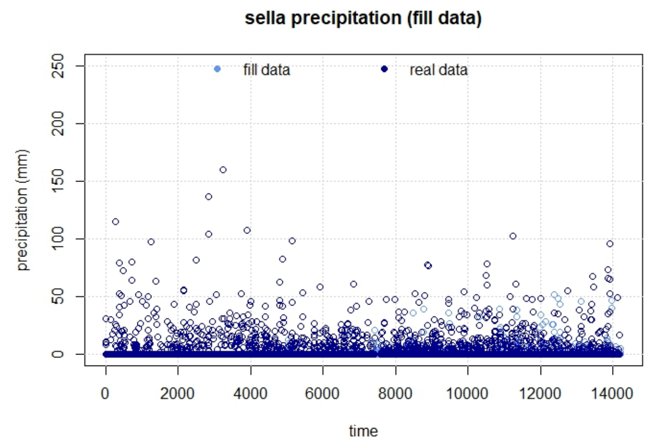
Used stations



Regressions



Results



Error MAE

0.69

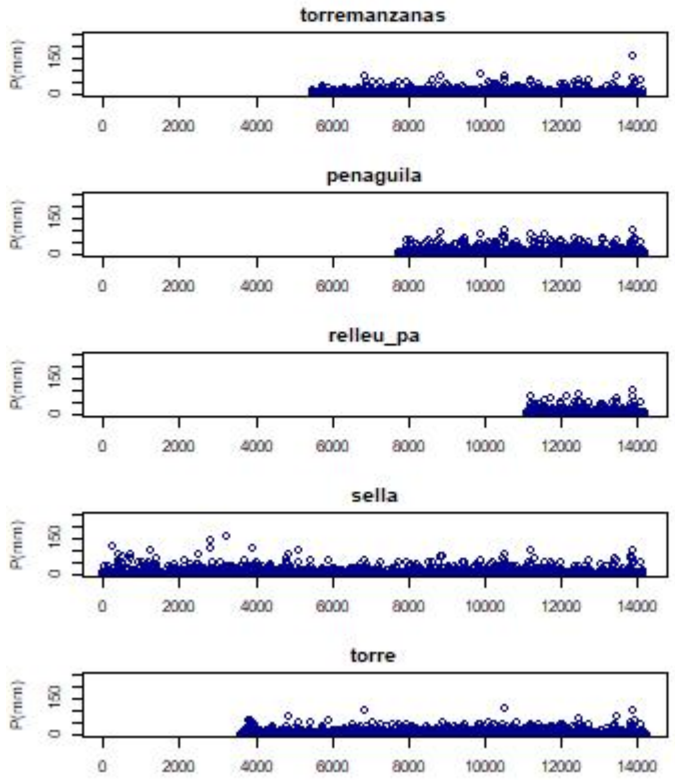
Pearson correlation coefficient

#benimantell_aemet 0.870329855
#penaguila_aemet 0.838425315
#torremanzanas_aemet 0.826939938
#relleu_aemet 0.778945573

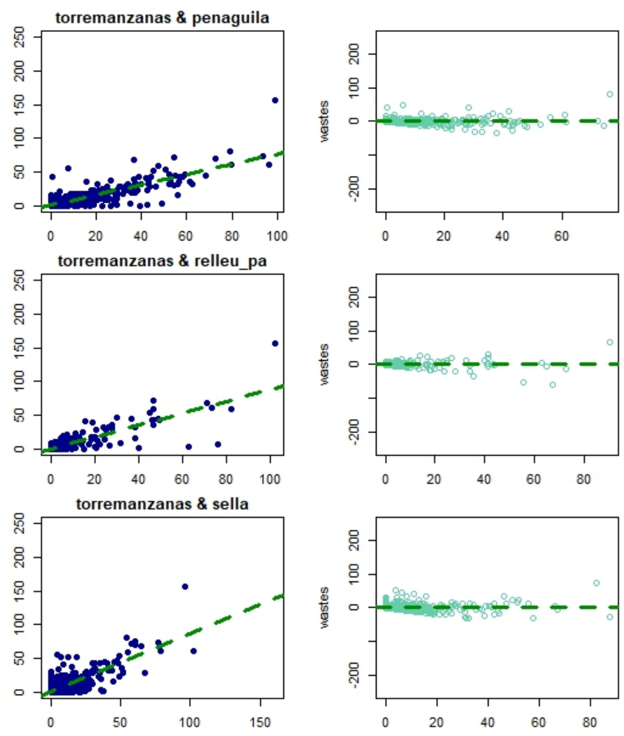
#1° penaguila y=0+x0.752292 R2 0.7133
#2° torremanzanas y=0+x0.8049084 R2 0.6916
#3° relleu y=0+x0.91087 R2 0.6185

TORREMANZANAS

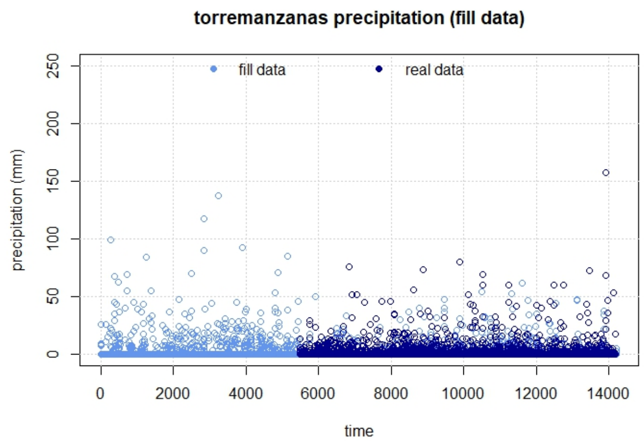
Used stations



Regressions



Results



Error MAR

0.43

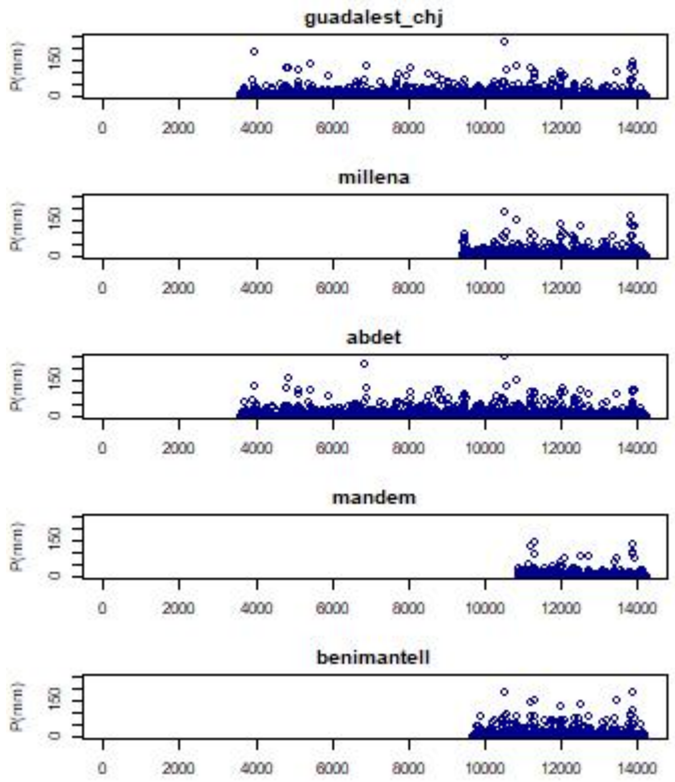
Pearson correlation coefficient

#benimantell_aemet 0.870329855
#penaguila_aemet 0.838425315
#torremanzanas_aemet 0.826939938
#relleu_aemet 0.778945573

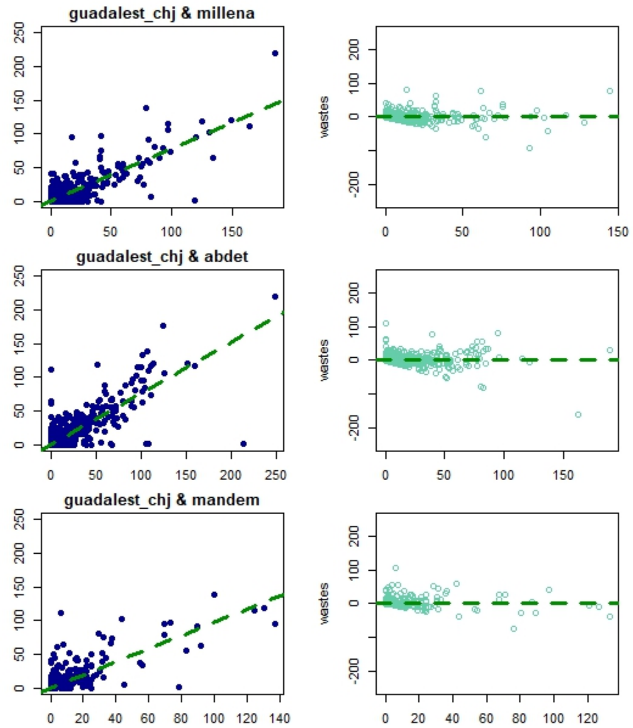
#1º penaguila y=0+x0.752292 R2 0.7133
#2º torremanzanas y=0+x0.8049084 R2 0.6916
#3º relleu y=0+x0.91087 R2 0.6185

GUADALEST_CHJ

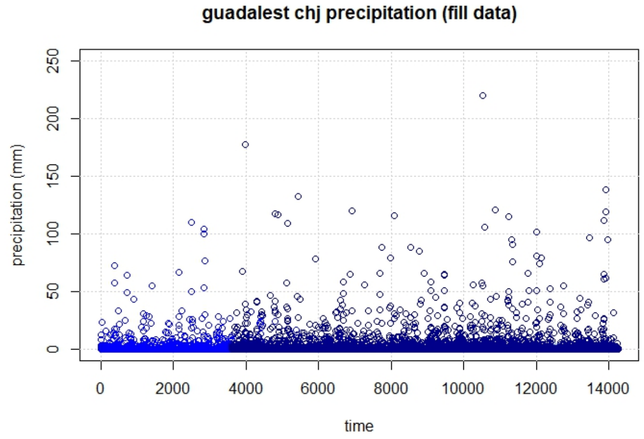
Used stations



Regressions



Results



Error MAE

0.78

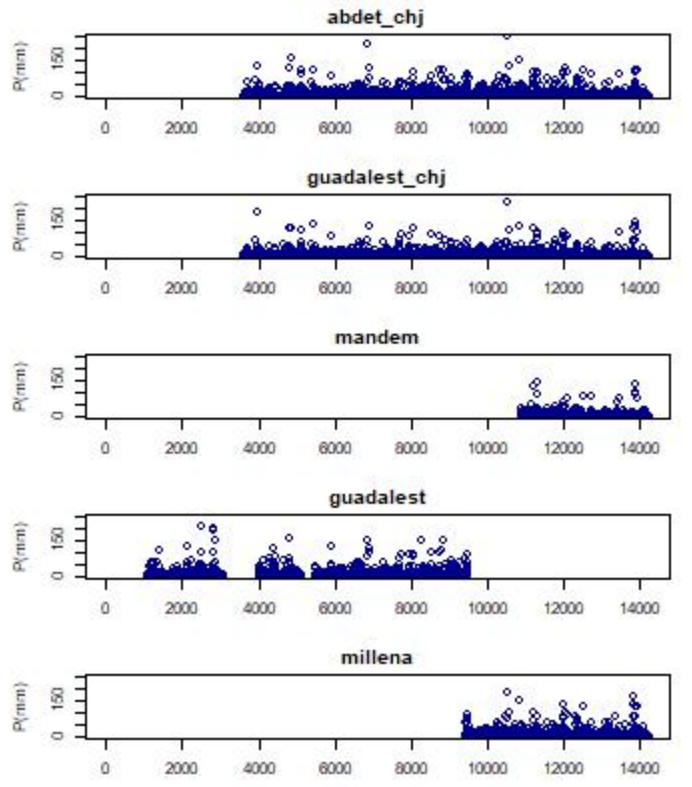
Pearson correlation coefficient

#millena_chj 0.86432308
#abdet_chj 0.862016807
#mandem_chj 0.805535885
#guadalest 0.74583824

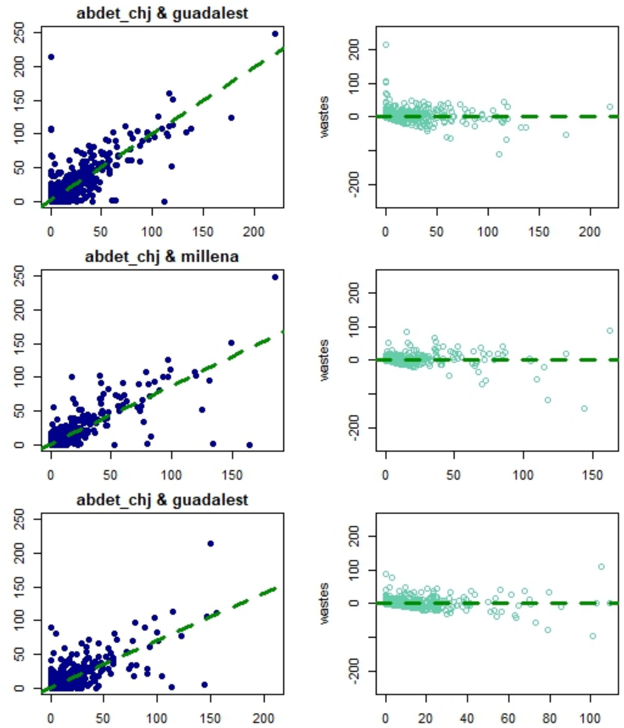
#1° millena y=0+x0.780528 1 R2 0.7554
#2° abdet y=0+x0.757954 R2 0.7516
#3° mandem y=0+x0.97056 R2 0.658

ABDET_CHJ

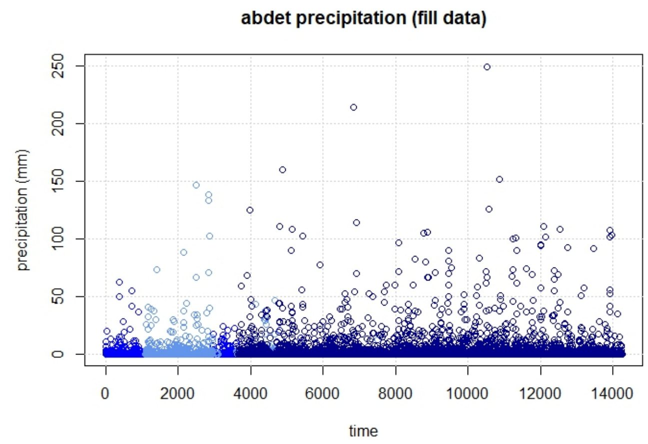
Used stations



Regressions



Results



Error MAE

0.8

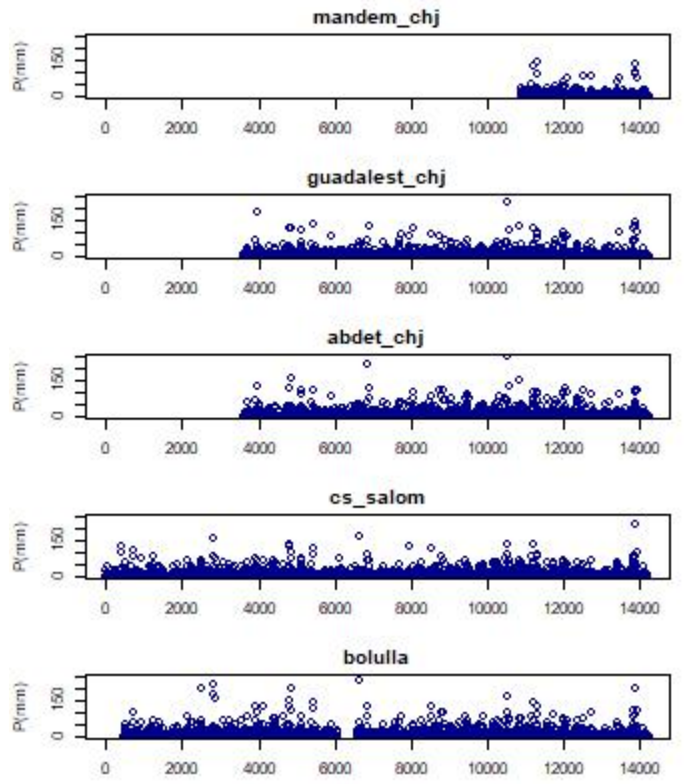
Pearson correlation coefficient

#guadalest_chj 0.862016807
#millena_chj 0.847955524
#mandem_chj 0.794711299
#guadalestaemet 0.781561323

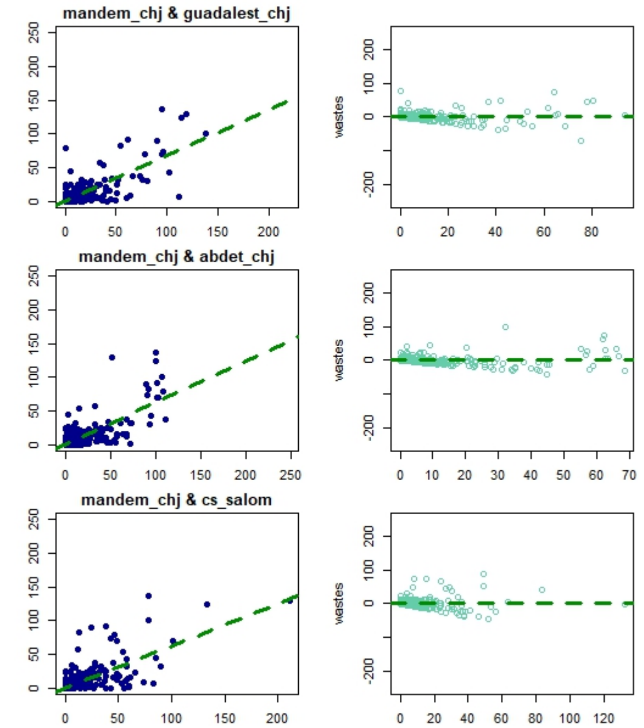
#1° guadalest y=0+x0.991705 R2 0.7516
#2° millena y=0+x0.875114 R2 0.7288
#3° guadalest y=0+x0.699942 R2 0.6247

MANDEM_CHJ

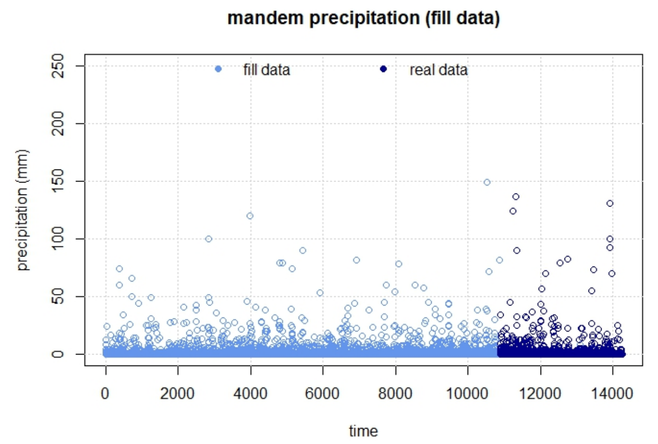
Used stations



Regressions



Results



Error MAE

0.78

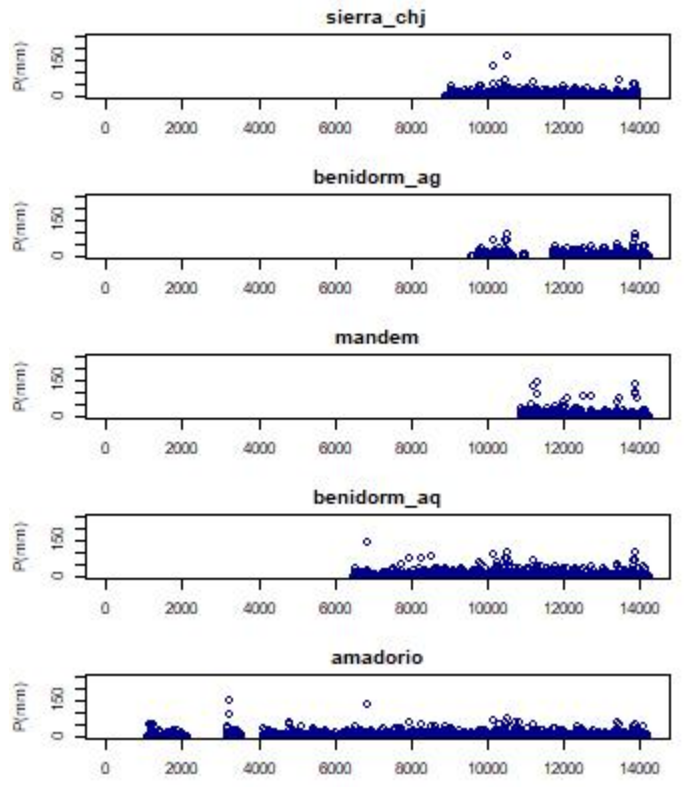
Pearson correlation coefficient

#guadalest_chj 0.805535885
#abdet_chj 0.794711299
#cs_salom_aemet 0.751404337
#cs_algar_aemet 0.748175032

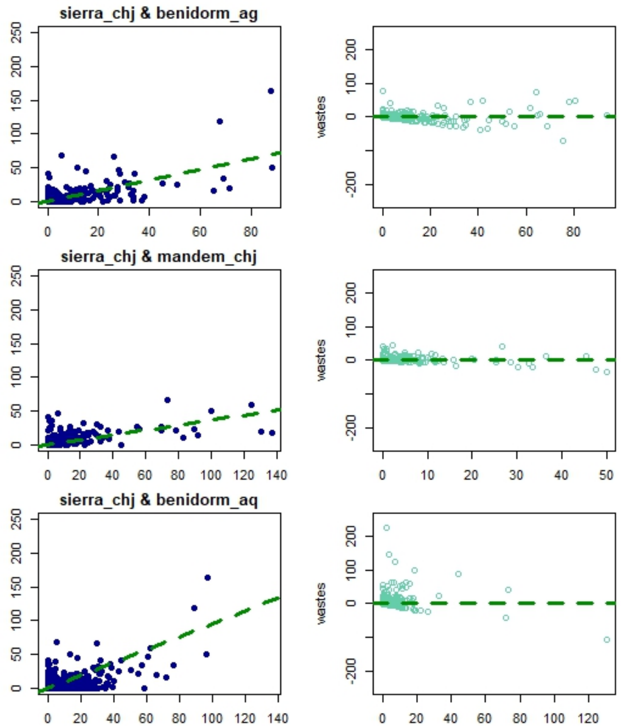
#1° guadalest_chj y=0+x0.678018 R2 0.658
#2° abdet y=0+x0.617926 R2 0.6413
#3° cs_salom y=0+x0.625330 R2 0.5756

SIERRA_CHJ

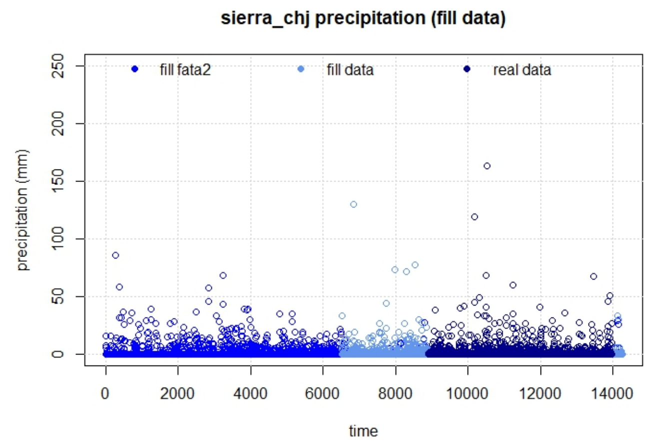
Used stations



Regressions



Results



Error MAE

0.63

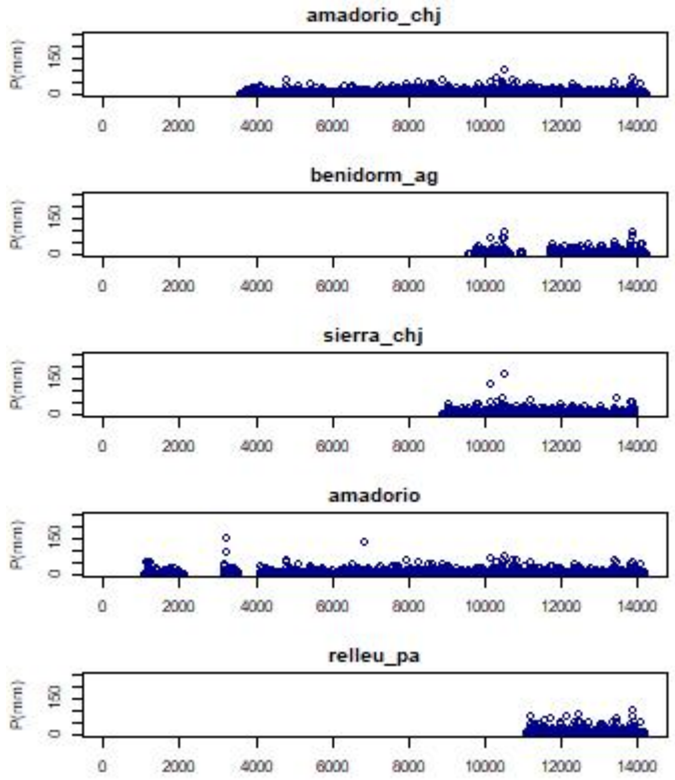
Pearson correlation coefficient

#benidorm_ag_aemet 0.709770404
#mandem_chj 0.684425104
#benidorm_aq_aemet 0.67153708
#amadorio_aemet 0.640815624

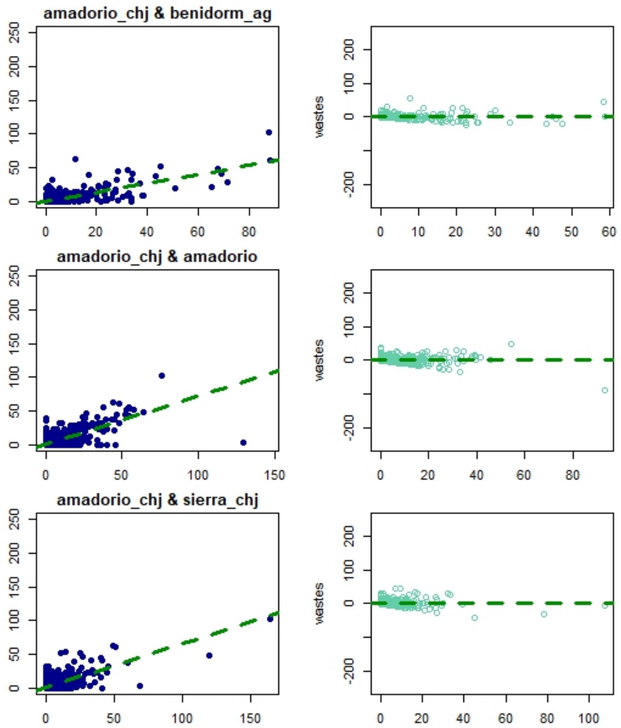
#1° benidorm_ag y=0+x0.77424 R2 0.515
#2° mandem y=0+x0.363754 R2 0.4825
#3° benidorm_aq y=0+x0.95484 R2 0.1785

AMADORIO_CHJ

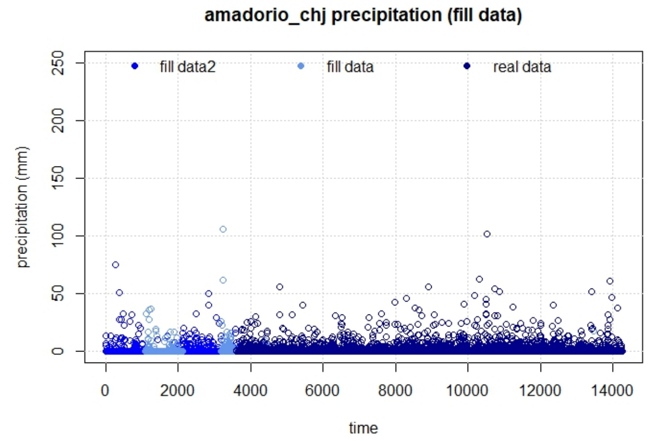
Used stations



Regressions



Results



Error MAE

0.52

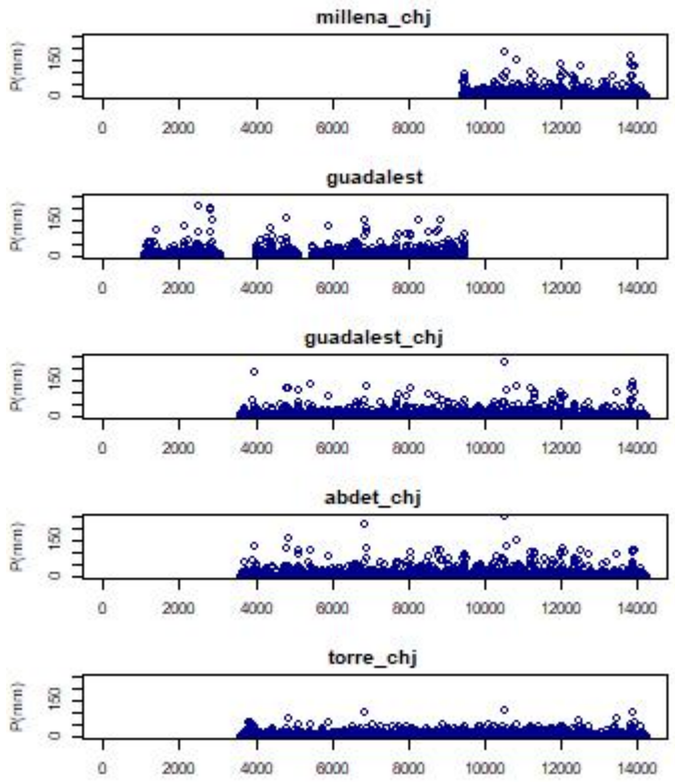
Pearson correlation coefficient

#benidorm_ag_aemet 0.786402911
#amadorio_aemet 0.775439985
#sierra_chj 0.763314511
#relleu_pa_aemet 0.738554772

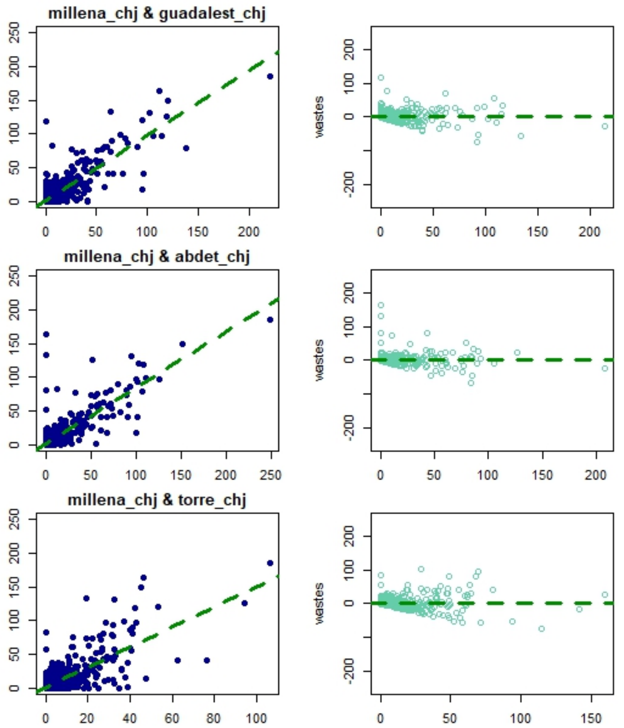
#1º benidorm_ag y=0+x0.666931 R2 0.6295
#2º amadorio y=0+x0.717634 R2 0.6147
#3º sierra_chj y=0+x0.655626 R2 0.5951

MILLENA_CHJ

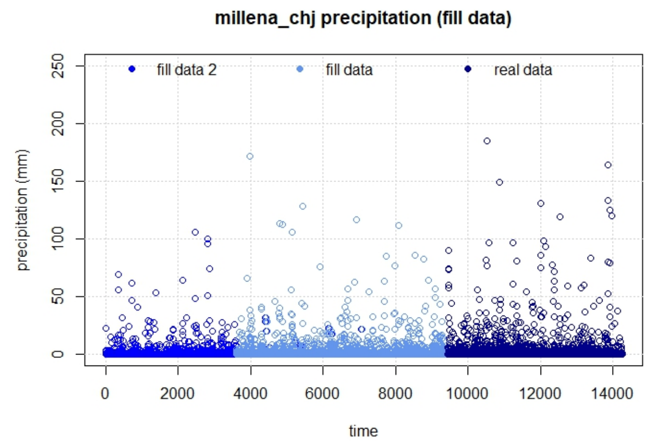
Used stations



Regressions



Results



Error MAE

1.03

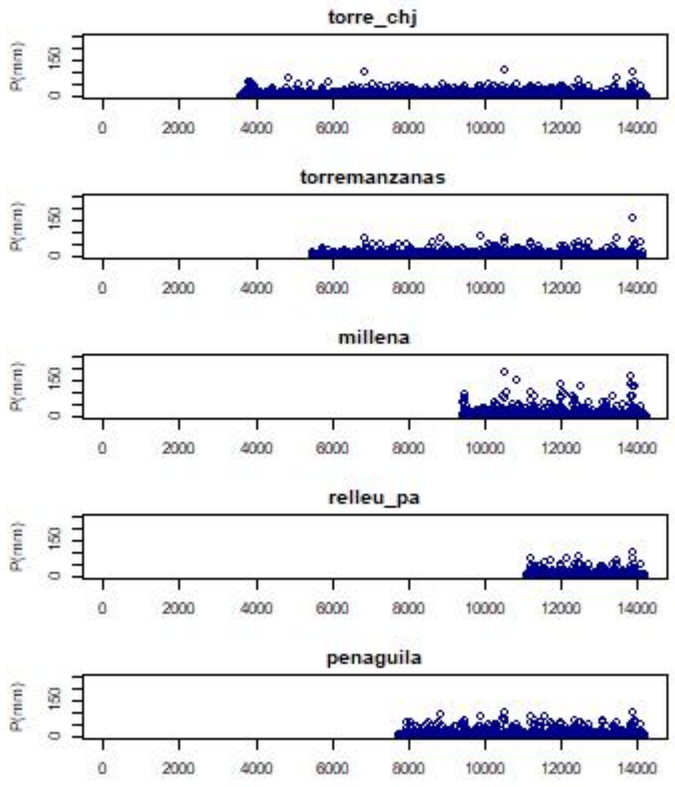
Pearson correlation coefficient

#guadalestaemet 0.880872128
#guadalest_chj 0.86432308
#abdet_chj 0.847955524
#torre_chj 0.789142458

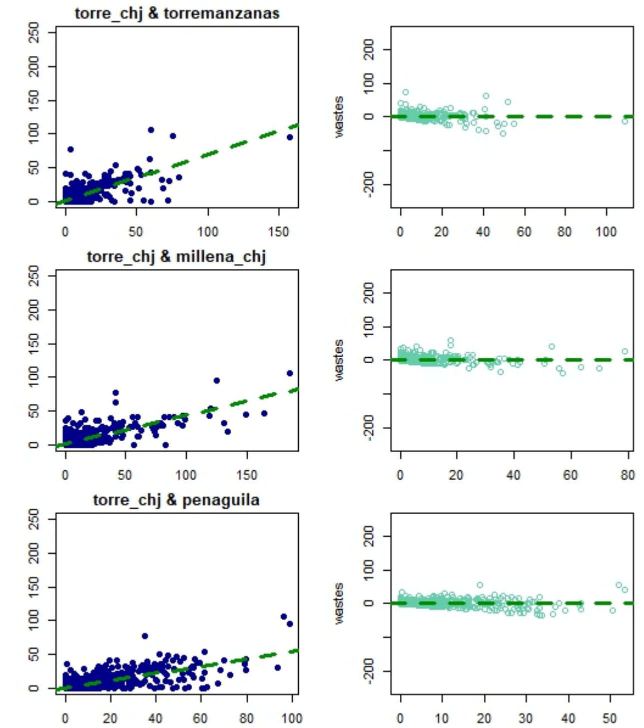
#1° guadales_chj y=0+x0.967834 R2 0.7554
#2° abdet_chj y=0+x0.832913 R2 0.7288
#3° torre_chj y=0+x1.49882 R2 0.6367

TORRE_CHJ

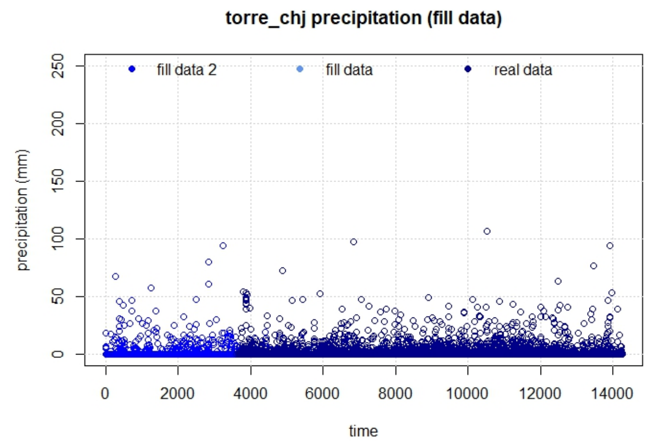
Used stations



Regressions



Results



Error MAE

0.72

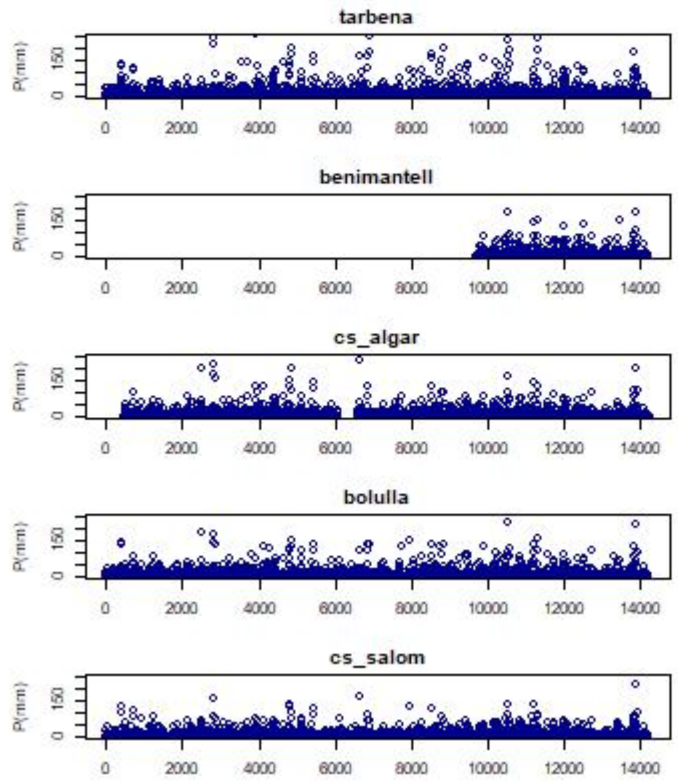
Pearson correlation coefficient

#torremanzanas_aemet 0.792739254
#millena_chj 0.789142458
#relleu_pa_aemet 0.786562869
#penaguila_aemet 0.778137553

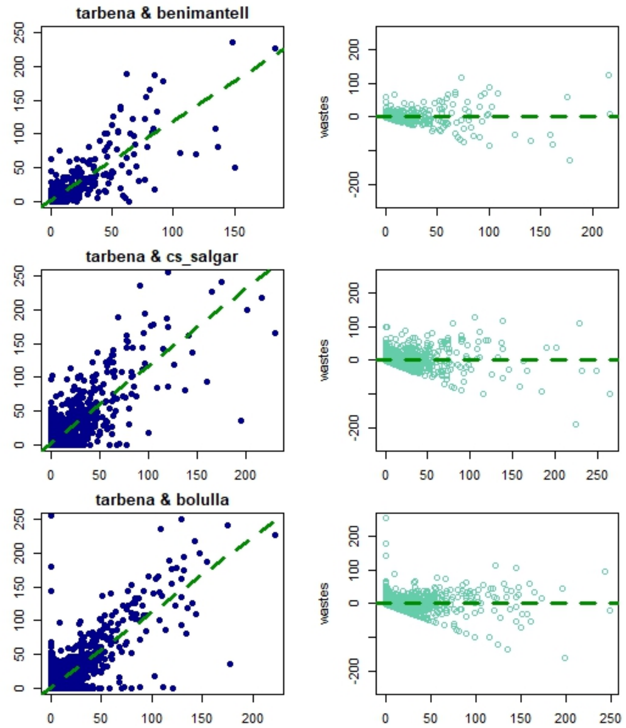
#1° torremanzanas y=0+x0.688387 R2 0.639
#2° millena y=0+x0.424830 R2 0.6367
#3° penaguila y=0+x0.539178 R2 0.6236

TARBENA

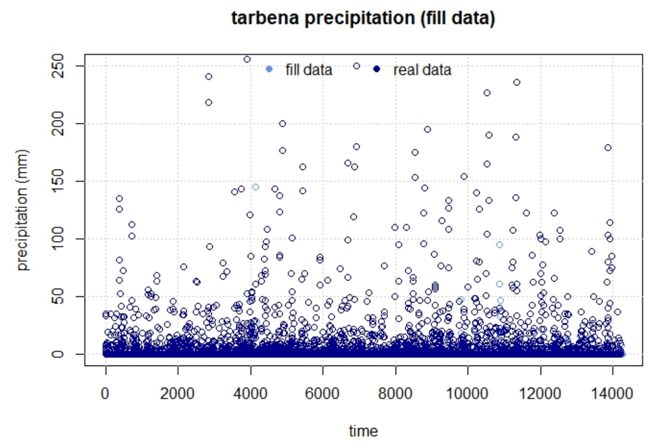
Used stations



Regressions



Results



Error MAE

1.68

Pearson correlation coefficient

#benimantell_aemet 0.85807592
#cs_algar_aemet 0.847075901
#bolulla_aemet 0.842552174
#cs_salom_aemet 0.838847891

#1° benimantell y=0+x1.18131 R2 0.7439
#2° cs_algar y=0+x1.150792 R2 0.7255
#3° bolulla y=0+x1.117259 R2 0.7184

Appendix D. Correction of temperature data

The objective of this section is to obtain current temperature series that are homogenized, outlier-free and without gaps. We've analyzed the data from 11 stations and we have calculated its temporal continuity. We need current data and with some continuity. For this reason, we have only been able to use the stations of: Benidorm (aquagest), Benimantell and Alcalali.

The homogenization and detection of outliers has been carried out by means of the SNHT test. We have so few stations we have not been able to use the most conventional methods for data filling (HOMER, CLIMATOOL, etc.). Therefore, the filling has been carried out between the stations more correlations between them and by means of statistical regressions.

Benidorm station

The results of the SNHT test were as follows:

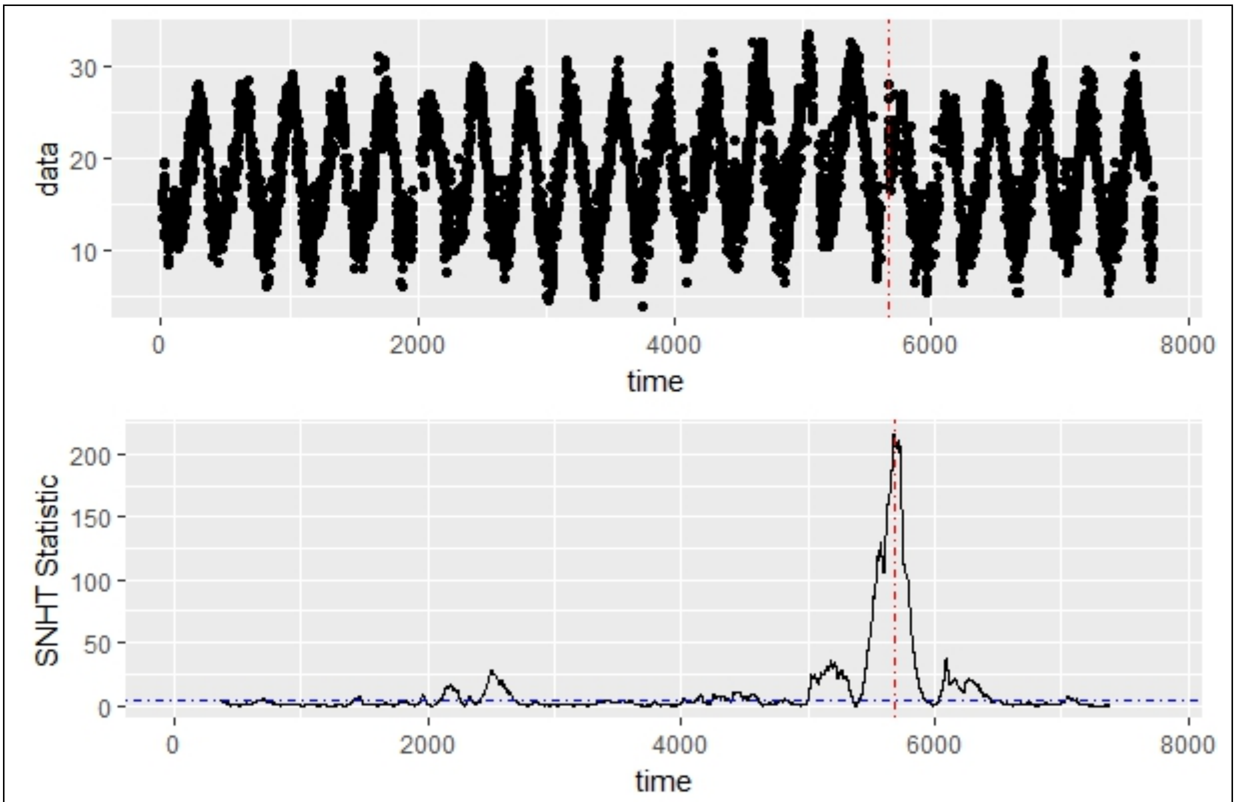


Figure. SNHT test for the Benidorm station

There is a point where the test exceeds the value of 100. Therefore, this point is considered a break and the series is not homogeneous. To homogenize the series, the arithmetic mean is calculated on each side of the break and the difference between both means has been applied to all the values of the oldest part (referring to the break division). Next we have calculated again the SHNT test

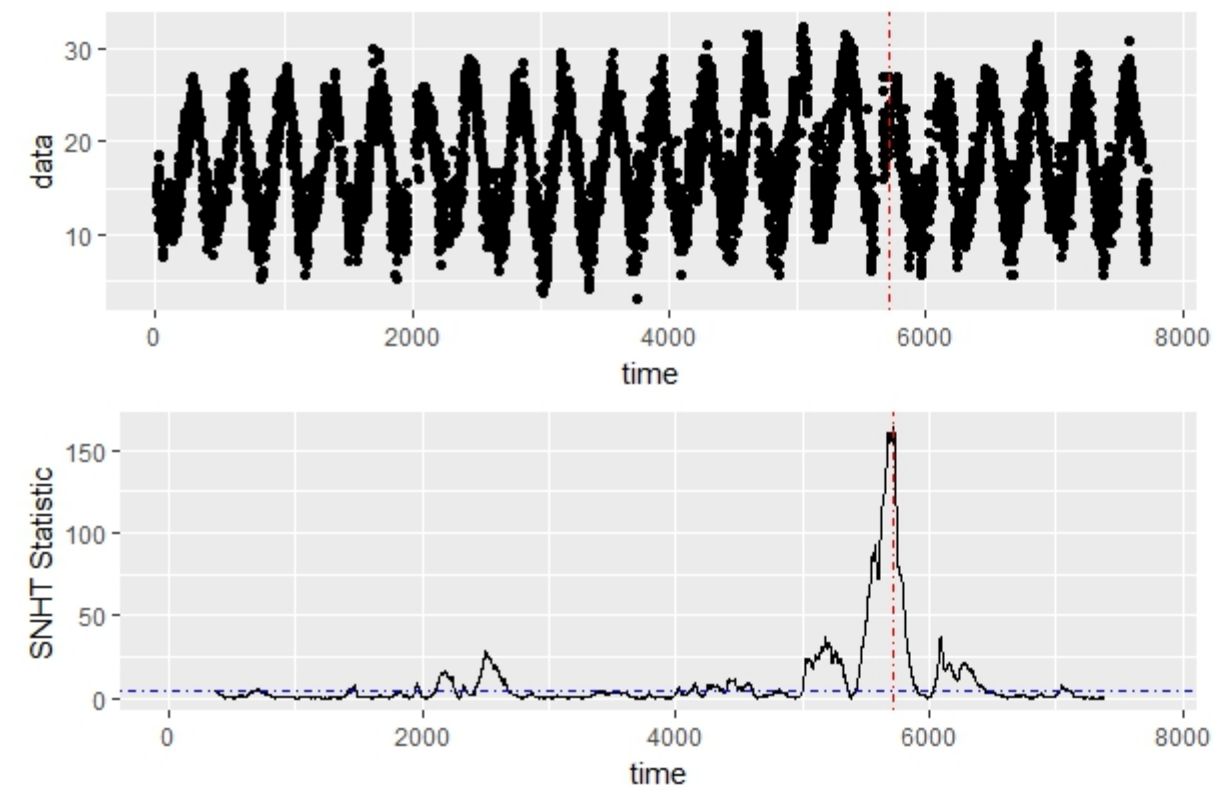


Figure. Second SNHT test for the Benidorm station

Although the test value has been reduced (from 210 to 160). The series is still not homogeneous. This fact is due to the fact that the series does not have a time jump, it has a change in the trend between 2009 and 2014. Therefore we propose: remove the data between 2009 and 2014 the series is homogeneous, work with the raw data (without equalization of means) and without data between 2009 and 2014.

The data filling has been done between the three stations giving priority to the most systematically related stations. The moving average shows a homogeneous trend.

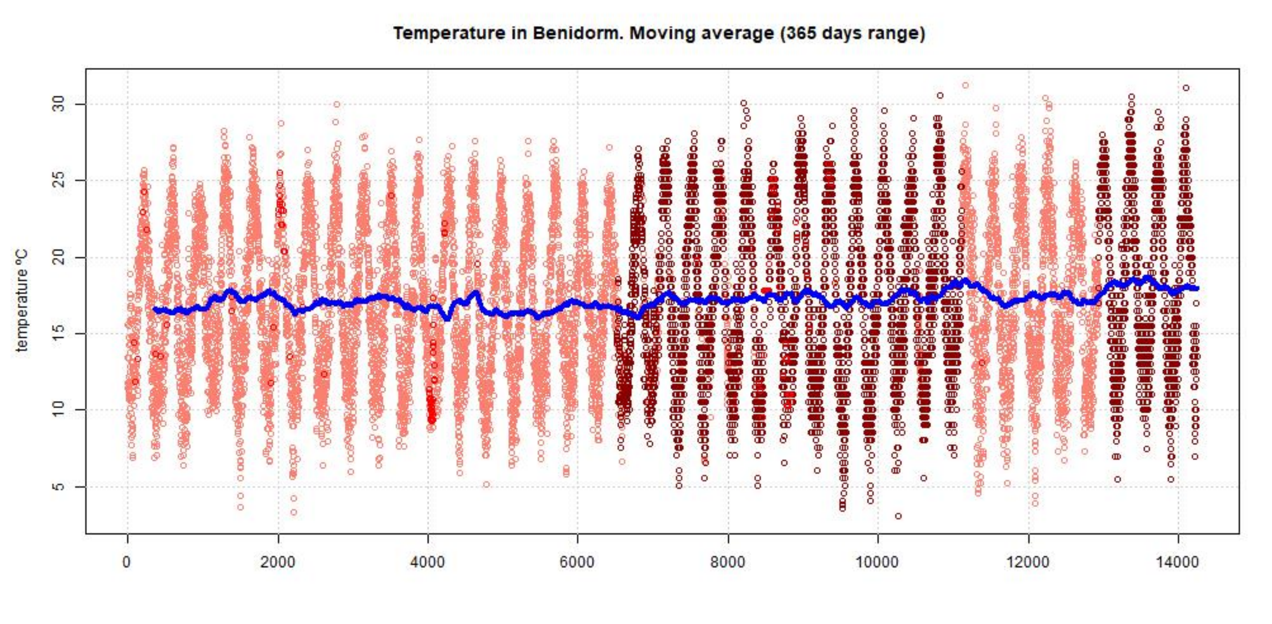


Figure. Benidorm temperature data

Benimantell station

In the data of the Station of Benimantel no homogeneities and no outliers are observed because de maximum value doesn't achieve to 20.

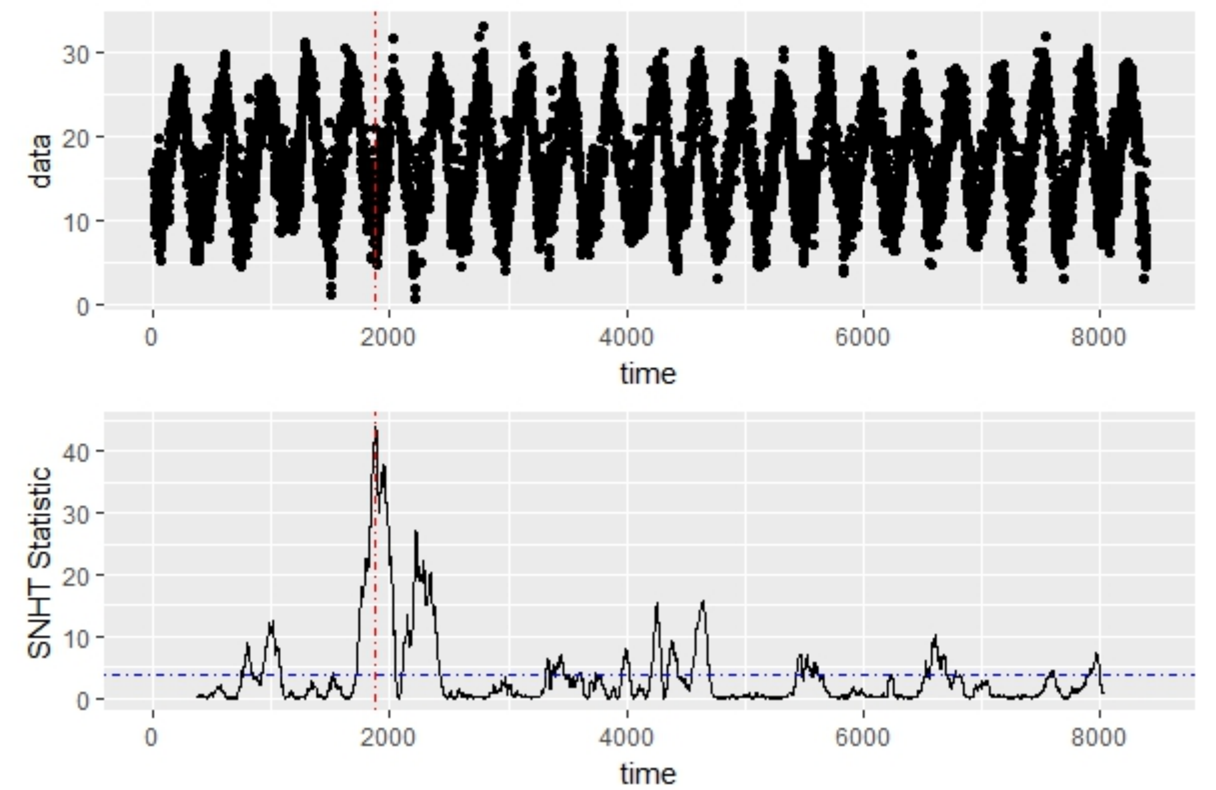


Figure. SNHT test for the Benimantell station

The data filling has been done between the three stations giving priority to the most systematically related stations. The moving average shows a homogeneous trend.

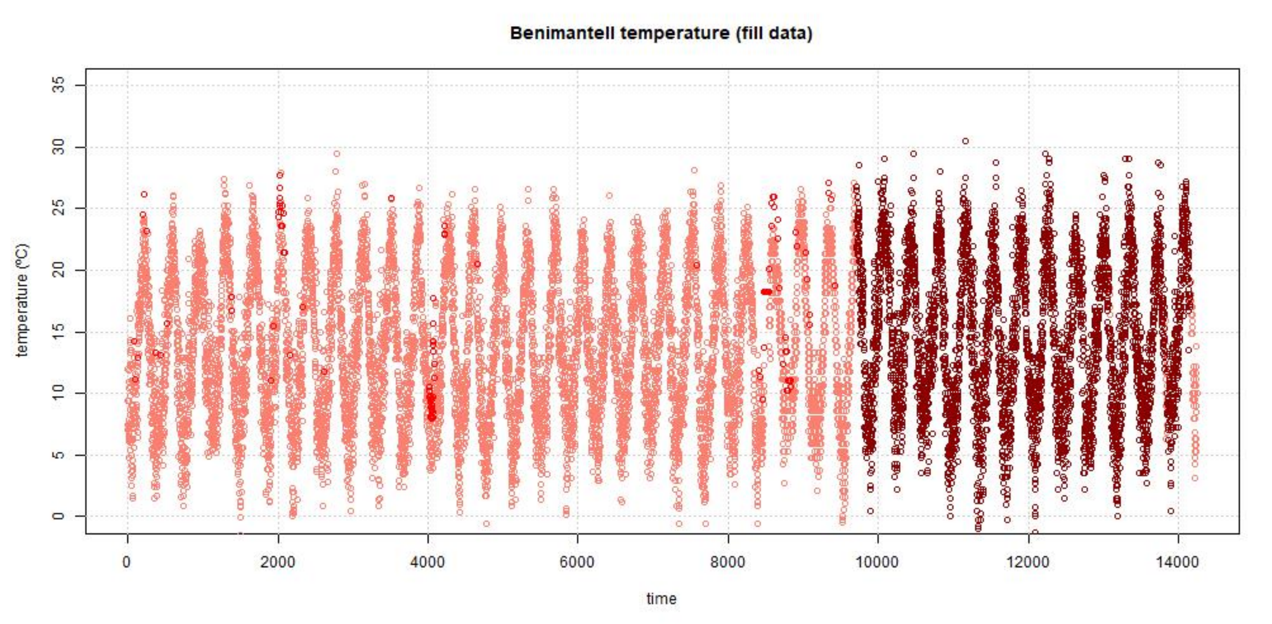


Figure. Benimantell temperature data

Alcalali station

At Alcalali station there are no outlier's data or non-homogeneous sections because the index does not exceed 100.

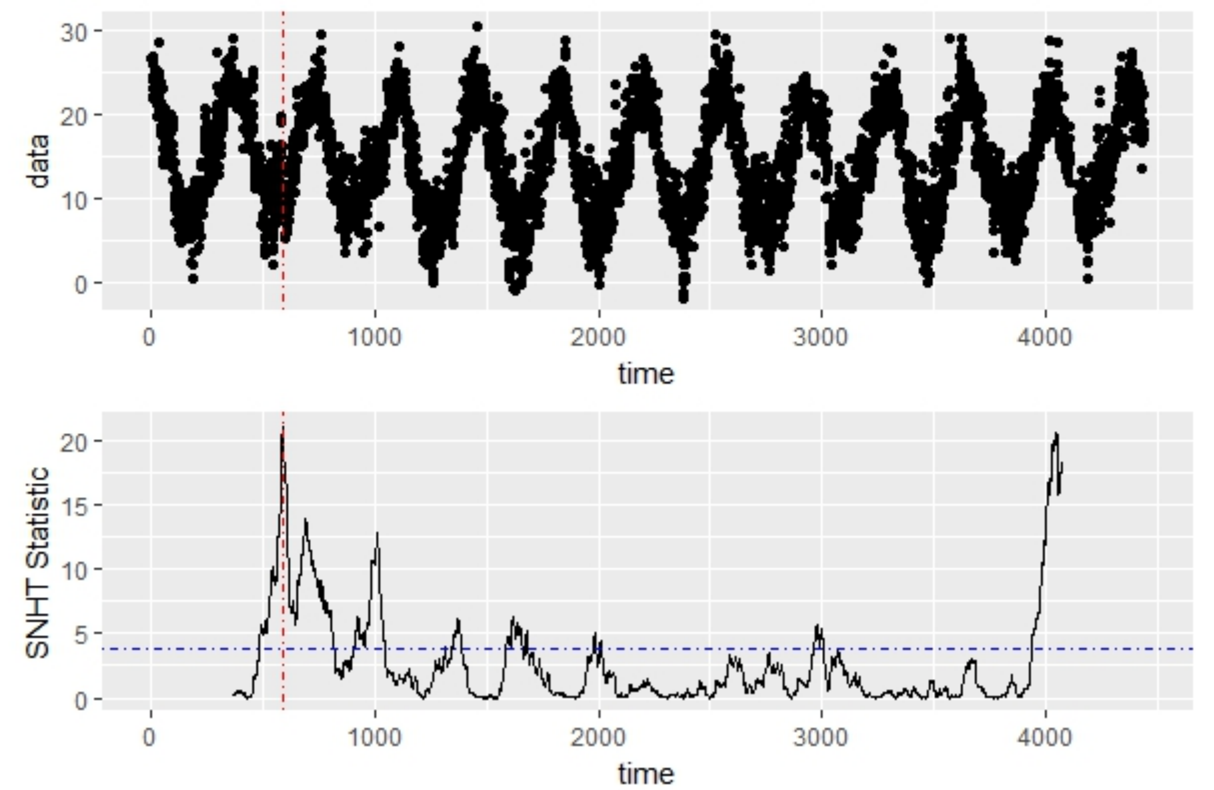


Figure. SNHT test for the Alcalali station

The data filling has been done between the three stations giving priority to the most systematically related stations. The moving average shows a homogeneous trend.

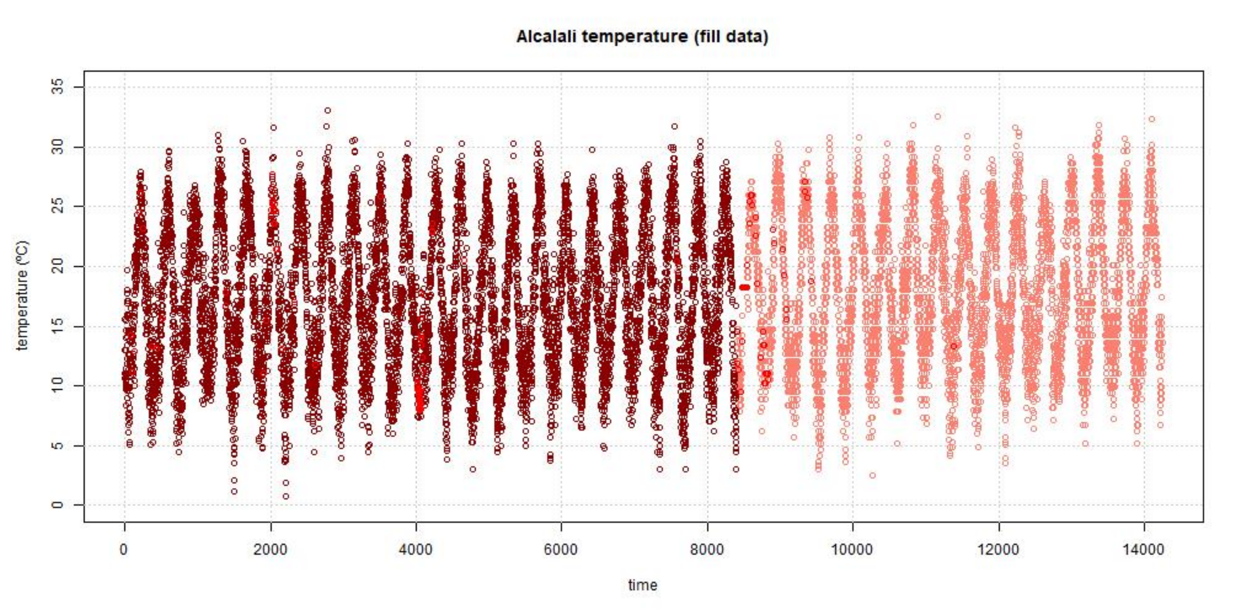


Figure. Alcalali temperature data

Appendix E. System Dynamics Model Documentation

Model Information	Number
Total Number of Variables	599
Total Number of State Variables (Level+Smooth+Delay Variables)	65 (10.9%)
Total Number of Stocks (Stocks in Level+Smooth+Delay Variables) †	66 (11%)
Total Number of Macros	0
Time Unit	Month
Initial Time	0
Final Time	23
Reported Time Interval	1
Time Step	0.0078125
Model Is Fully Formulated	Yes