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Transboundary Water Management under Climate Change – The Tagus River Basin

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Resumen

La relación entre el agua y el clima es muy importante. Es probable que el cambio climático tenga efectos relevantes sobre los recursos hídricos. Una gran parte de los recursos de agua dulce del mundo se encuentra en las cuencas fluviales. Como se espera que el cambio climático afecte los caudales de los ríos y las demandas de agua, un primer acercamiento para la comprensión de sus efectos potenciales, y de las posibilidades de adaptación resulta esencial, sobre todo cuando países vecinos comparten los recursos hídricos.

Se ha elegido la parte española de la cuenca del Tajo como estudio del caso. El objeto de este estudio es evaluar los efectos del cambio climático sobre la disponibilidad de agua en la cuenca del Tajo y sobre los acuerdos de las aguas transfronterizas entre España y Portugal. El estudio adopta un enfoque de modelización de asignación del agua, a partir de un modelo de la cuenca creado mediante el programa WEAP. El desempeño de la cuenca se evalúa para la línea de base (1940 - 1996), y en las condiciones climáticas proyectadas según el escenario de emisiones A2 en el corto plazo (2025), mediano plazo (2055) y a largo plazo (2085).

Los resultados muestran que la cuenca es sensible al cambio climático, y que el desempeño de la cuenca cambia de forma significativa en el largo plazo. Actualmente el área de estudio tiende a experimentar problemas de escasez de agua especialmente en los sitios de demanda agrícola. En relación con el cambio climático el déficit de agua en la cuenca se incrementaría y la fiabilidad de satisfacer el caudal mínimo para Portugal se reduciría. El desempeño de la cuenca es más sensible a la demanda de agua para agricultura que a la demanda de agua urbana. La reducción de la demanda de agua para la agricultura mediante la implementación de varias medidas podría disminuir considerablemente los efectos del cambio climático. De hecho, una reducción de un 20-30% en la demanda de agua para la agricultura podría reducir significativamente los impactos del cambio climático.

Abstract

The relationship between water and climate is a significant one. Climate change is likely to have major effects on water resources. A large part of the world's freshwater resources is contained in river basins. As climate change is expected to affect the river flows and water demands, an early understanding of its potential impacts and possible adaptation pathways becomes more essential especially when neighboring countries share water resources.

The Spanish part of the Tagus River Basin is chosen as the case study. The purpose of this study is to assess the impacts of climate change on water availability in the Tagus river basin and on the longstanding trans-boundary water agreement between Spain and Portugal. The study adopts a hydrological and water allocation modelling approach. This approach depends on creating a river basin model using the WEAP tool. The performance of the basin is evaluated under the current baseline (1940 – 1996), and under the potential climatic conditions according to the A2 emission scenario in the short term (2025), mid-term (2055) and long term (2085).

The results show that the basin is sensitive to climate change, and the performance of the basin would change significantly in the long term. The study area currently tends to experience water scarcity problems especially in the agricultural demand sites. Under climate change the water deficit in the basin would increase and the reliability of satisfying the agreed minimum flow to Portugal would decrease. The performance of the basin is more sensitive to the agricultural than to the urban water demand. Reducing the agricultural water demand by adopting several measures could significantly decrease the impacts of climate change. Indeed, a reduction of only 20-30% in the agricultural water demand could significantly reduce the impacts of climate change.

Résumé

La relation qui existe entre l'eau et le climat est de nature considérable. Il est probable que les changements climatiques aient des impacts sur les ressources en eau. Les bassins de rivière concentrent une part importante de l'eau douce dans le monde. Alors que l'on prévoit avec les changements climatiques des effets sur l'écoulement des rivières ainsi que la demande en eau, une compréhension anticipée de ses impacts potentiels et des stratégies d'adaptation possibles devient cruciale d'autant plus lorsque les pays voisins se partagent les ressources en eau.

La zone espagnole du bassin fluvial Tage a été choisie pour ce cas d'étude. Cette étude a pour but d'évaluer les impacts des changements climatiques sur la disponibilité en eau dans le bassin fluvial Tage et sur l'accord des eaux transfrontalières entre l'Espagne et le Portugal établi depuis longtemps. L'étude se base sur une méthode de modélisations hydrologiques et de répartition de l'eau. Cette méthode se base sur la création d'un modèle de bassin hydrographique utilisant l'outil WEAP. Les comportements du bassin sont évalués suivant la base référentielle actuelle (1940-1996), et les conditions climatiques potentielles selon le scenario d'émission A2, sur le court terme (2025), le moyen terme (2055) et le long terme (2085).

Les résultats montrent que le bassin est sensible aux changements climatiques, et le comportement du bassin est plus sensible à l'agriculture qu'à la demande urbaine d'eau. Réduire les besoins en eau agricole en adoptant différentes mesures pourrait diminuer de manière significative les impacts des changements climatiques. En effet, une réduction de seulement 20 à 30 % des besoins en eau pour l'agriculture réduit les impacts des changements climatiques.

ملخص

إن العلاقة بين المياه والمناخ هي علاقة هامة. من المرجح أن التغير المناخي سيكون له تأثيرات كبيرة على موارد المياه. جزء كبير من موارد المياه العذبة في العالم توجد في أحواض الأنهار. و بما أنه من المتوقع أن يؤثر التغير المناخي على تدفق الأنهار والحاجة الى المياه، فأن الفهم المبكر للآثار المحتملة وسبل التكيف الممكنة معها يصبح اكثر ضرورة خاصة للدول المجاورة التي تتقاسم موارد المياه.

تم اختيار الجزء الإسباني من حوض نهر التاجة "كدراسة حالة" في هذا البحث. الغرض من هذه الدراسة تقييم آثار تغير المناخ على توافر المياه في حوض نهر التاجة وعلى اتفاق المياه العابرة للحدود بين إسبانيا والبرتغال. تعتمد الدراسة على منهج النمذجة الهيدرولوجية و تخصيص الموارد المائية. ويعتمد هذا النهج على إنشاء نموذج حوض النهر باستخدام أداة نظام تخطيط وتقييم الموارد المائية *"WEAP"*. تم تقييم أداء الحوض تحت الظروف المناخية التاريخية (1940 – 1996)، وتحت الظروف المناخية المحتملة وفقاً لسيناريو الانبعاثات *A2* وذلك على المدى القصير (2025)، و المدى المتوسط (2055) والمدى الطويل(2085).

تظهر النتائج أن الحوض يتأثر بتغير المناخ، و أن أداء الحوض سيتغير إلى حد كبير و ملحوظ على المدى الطويل. منطقة الدراسة تميل حاليا الى المعاناة من مشاكل ندرة االموارد المائية خاصة في مواقع الطلب الزراعي. تحت إطار التغير المناخي سيزداد عجز المياه في الحوض وسيؤدي هذا إلى انخفاض إمكانية تلبية الحد الأدنى للتدفق المتفق عليه للبرتغال. أداء الحوض يعد أكثر تأثيراً تجاه الحاجة الزراعية من الحاجة الحضرية. تخفيض الطلب على المياه للأغراض الزراعية من خلال اعتماد عدة تدابير، يمكن أن يقلل من آثار التغير المناخي إلى حد كبير. في الواقع، الحد فقط من 20–30 في المائة من الطلب على المياه للأغراض الزراعية ستحد بشكل ملحوظ من آثار تغير المناخ.

Table of Contents

List of Figures

List of Tables

List of Maps

List of Abbreviations

AEMET	Agencia Estatal de Meteorología State Agency of Meteorology
AR4	IPCC Fourth Assessment Report
AR5	IPCC Fifth Assessment Report
ARH	La Administración de la Región Hidrográfica del Tajo Tagus Hydrographic Region Administration
BASE	Bottom-Up Climate Adaptation Strategies for a Sustainable Europe EU FP7
BOE	Official State Bulletin
CADC	Commission for the Application and Development of the Convention
CHT	Confederación Hidrográfica del Tajo Tagus Hydrographic Confederation
CLC	Corine Land Cover
COP	Conference of the Parties
DGA	Dirección General del Agua Directorate General of Water
DSSS	Decision Support System Shell
EE	Elementary Effect
GHGs	Green House Gases
HPR	Hydrological Planning Regulation
HPT	Hydrological Plan of the Spanish part of the Tagus Basin
IPCC	Intergovernmental Panel on Climate Change
MARM	Ministry of Agriculture and Marine Affairs
MAS	Mancomunidad de Aguas del Sorbe Sorbe River Water Community
MMA	Ministerio del Medio Ambiente Ministry of the Environment
OECC	Oficina Española de Cambio Climático Spanish Office for Climate Change
RDL	Royal Decree Law
SEI	Stockholm Environment Institute
SIMPA	Sistema Integrado para la Modelación del proceso Precipitación Aportación Integrated System of Contribution Precipitation Simulation
SWAT	Soil and Water Assessment Tool
WEAP	Water Evaluation and Planning
WFD	European Union Water Framework Directive
WG	Work Group

CHAPTER 1

INTRODUCTION

1 INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Water resources shortage has become an increasingly important issue during the last decades. It is one of the most important challenges that the world is going to face in the future, especially for those countries that are already experiencing severe water related problems.

The Mediterranean region is already suffering the adverse effects of water scarcity, and the indicators point to an increase in water scarcity problems due to the rapid social and environmental changes. The pressures on water resources underline the challenge of managing the water resources in the region (Iglesias et al. 2006).

The world's freshwater resources are contained largely in the river basins. Rivers flow naturally and cross borders. A sustainable management of shared water resources will be more complicated when the rivers cross political boundaries (Cooley, Christian-Smith, and Gleick 2009). Transboundary water management is governed by agreements and requires coordination over different political, legal and institutional settings within the countries (Timmerman and Bernardini 2009).

There are over 276 international river basins worldwide covering almost half of the world's total land surface (TFDD 2014; Duncan et al. 2012). Shared water can be a source of conflict but also can be source of cooperation between neighboring countries. In many international river basins there have been political disputes, but there also has been an amazing amount of cooperation (Wolf, Yoffe, and Giordano 2003).

The climate change affects water through a number of mechanisms, as the water is involved in all components of the climate system (atmosphere, hydrosphere, cryosphere, land surface and biosphere) (Bates et al. 2008). Climate change will increase water scarcity and lead to a potential increase in water conflicts between countries that share water (Timmerman and Bernardini 2009). Integrated water resources management in the international basin becomes more essential to reduce the impact of climate change.

For the Mediterranean area annual precipitation and the annual number of precipitation events are very likely to decrease (IPCC 2014a). This trend of decreasing precipitation together with the trend of increasing temperatures will increase the problem of water shortage.

The case of this study is the international Spanish-Portuguese Tagus River Basin. It is located in the central area of the Iberian Peninsula, and it occupies an area of 80,600 km^2 of which 69% is in Spain and 31% in Portugal. It supplies water to the cities of Madrid and Lisbon with approximately 7 million habitants. Spain and Portugal share five river basins. The cooperation between Spain and Portugal for the shared river basins relies on the “Albufeira Convention” (BOE 2000). This agreement defines the framework of cooperation between the two countries, and it seeks to balance environmental protection with sustainable use of the water resources within the framework of International and EU Law.

The Tagus River Basin is already experiencing severe impacts of drought; during 2011-12, there was a period of 7 months without rain and the reservoirs that provide urban water were below critical levels. The region of the basin has multiple vulnerabilities under climate change due to its size and economic activities. Climate change could affect the ability of the basin to satisfy the water demands of the basin and to meet the Albufeira convention commitments. In this context, this study is conducted in order to estimate the impacts of climate change on the availability of water resources in the Spanish part of the basin and on the flow regime from Spain to Portugal.

This study is embedded within the EU research project "Bottom-Up Climate Adaptation Strategies for a Sustainable Europe" (BASE). BASE supports action for sustainable climate change adaptation in Europe. BASE makes experiential and scientific information on adaptation meaningful, transferable and easily accessible to decision-makers at all levels.

Climate Change: a growing challenge for rural development

Rural areas account for almost half the world’s population, and about 70% of the developing world’s poor people. Climate change in rural areas will take place in the context of many important economic-, social- and land-use changes. Its major impact will be felt through water supply, food security and agricultural income (IPCC 2014a).

Households in the rural areas depend greatly on natural resources for their livelihood. These natural resources, such as water resources and agricultural land, are very sensitive to climate variability. Climate change can reduce the availability of these natural resources, and limit the economic activities of the households from their which may harm the development of the rural areas. Planned adaptation to climate change in rural areas would help the households and the ecosystem in reduce their vulnerability to the impact of climate change (Båge 2007).

1.2 OBJECTIVES OF THE STUDY

The overall objective of the study is "Assessing the impact of climate change on the longstanding trans-boundary water agreements between Spain and Portugal". The specified objectives are as following:

1. Characterize the Tagus river basin system.
2. Create a river basin model for the Tagus river basin using the Water Evaluation and Planning (WEAP) tool to assess the current situation.
3. Use the model to assess how changes in the runoff (using climate change projections) impact the Tagus river basin and the water agreements between the two countries.
4. Assess adaptation measures for the management of Tagus river basin.

1.3 SCOPE OF WORK

This study focusses in assessing the impact of climate change on the water resources in the Tagus river basin. For this purpose, a river basin model is built using the WEAP tool and the year 2005 is set as a reference. The reference system is assessed under the historic climate (1940 – 1996) and under the future climate variability with a reduction of the runoff by 8, 19 and 35%. Then, the variables that can impact the performance of the system are studied and the most promising ones are considered for adaptation. This study is built on some premises:

- The model of the Tagus basin is a highly simplified description of the actual complex basin.
- The study does purposely not consider the evolution of the system itself (very complex, many uncertainties, unfeasible forecasting over long time horizon)
- With respect to climate change the analysis currently considers changes in runoff quantity but not changes in variability.

1.4 STRUCTURE OF THE REPORT

This thesis is structured into six chapters. A brief summary of each chapter is given below:

Chapter 1: Introduction: This chapter provides a general introduction comprising background, research objectives and study approach.

Chapter 2: Literature review: It contains a description of the literature relevant to the impacts of climate change on water resources and the choice of climate change scenarios.

Chapter 3: General description of the study area: This chapter provides an overview of the physical characteristics, climate, land use and water resources of the study area. Moreover, it describes the institutional and cooperative framework of the study area.

Chapter 4: Methods and Materials: It provides the methodological approach of the study and a description of the data used in the study.

Chapter 5: The Tagus river basin model: It describes the Tagus river basin model and provides the data that is used in building the model.

Chapter 6: Performance of the system under historical climate: It covers the analysis of the performance of the system under historical data.

Chapter 7: Performance of the system under climate change scenario: It covers the analysis of the performance of the system under climate change.

Chapter 8: Sensitivity of the system to changes in variables: It assesses how changing various variables (e.g. agricultural water demand, environmental flow priority, etc.) impact the performance of the system.

Chapter 9: Implications for adaptation planning: Based on the results from chapter 7 promising adaptation options are suggested and their implications for the study area are discussed.

Chapter 10: Conclusions: It provides the final conclusions and recommendations of the study.

This will be followed by a list of references and appendices.

CHAPTER 2

LITERATURE REVIEW

2 LITERATURE REVIEW

2.1 CLIMATE CHANGE

In the last decades thousands of studies on the scientific evidence and possible future scenarios of climate change were published. The current knowledge on climate change is reflected in the publications of the Group of Intergovernmental Panel on Climate Change (IPCC). The IPCC defines the climate change as "a change in the state of the climate that can be identified by changes in the mean and/or the variability of its characteristics, and that persists for an extended period, typically decades or longer" (IPCC 2007a; IPCC 2014a).

Long-term climate change has been observed at continental, regional, and ocean basin scales, due to increasing concentration of greenhouse gases (GHGs) particularly carbon dioxide (CO_2). These include changes in precipitation amounts and timings, arctic temperatures, wind patterns, and aspects of extreme weather like heavy precipitation, drought, and heat waves (IPCC 2007a).

There is a scientific consensus that the global mean temperature has increased more than 0.7º C over the past 100 years, and this has not been a gradual processes, as the five warmest years have occurred over the last ten years. New atmospheric temperature measurements in the Fifth Assessment Report (AR5) of the IPCC show an estimated warming of 0.85 º C since the year 1880 with the fastest rate of warming in the Arctic. The AR5 estimated the average warming across the globe over the past century (1906-2005) was 0.74º C (IPCC 2014b).

Observed climate trends and future climate projections show regionally varying changes in temperature and rainfall in Europe with projected increases in temperature throughout Europe and increasing precipitation in Northern Europe and decreasing precipitation in Southern Europe. The semi-arid areas such as Mediterranean region is expected to become warmer and drier (IPCC 2007b; IPCC 2014a).

2.2 IMPACT OF CLIMATE CHANGE ON WATER RESOURCES

Almost 80% of the global population in the world is facing serious threats to its water security, as measured by indicators including water availability, water demand and pollution (Vörösmarty, McIntyre, and Gessner 2010). Climate change will affect water availability, and mainly the amount of runoff and recharge (Figure 2.1), which in turn determines the water resources available for human- and ecosystem uses. Runoff depends on precipitation, temperature, humidity, solar intensity, vegetation, wind speed, and soil moisture. Under climate change, the runoff is expected to increase in some regions and decrease in others (Stahl and Hisdal 2010). According to the IPCC Fourth Assessment Report (AR4), there is high confidence that the semi-arid areas such as Mediterranean region will suffer from decrease in water sources due to climate change (Figure 2.1).

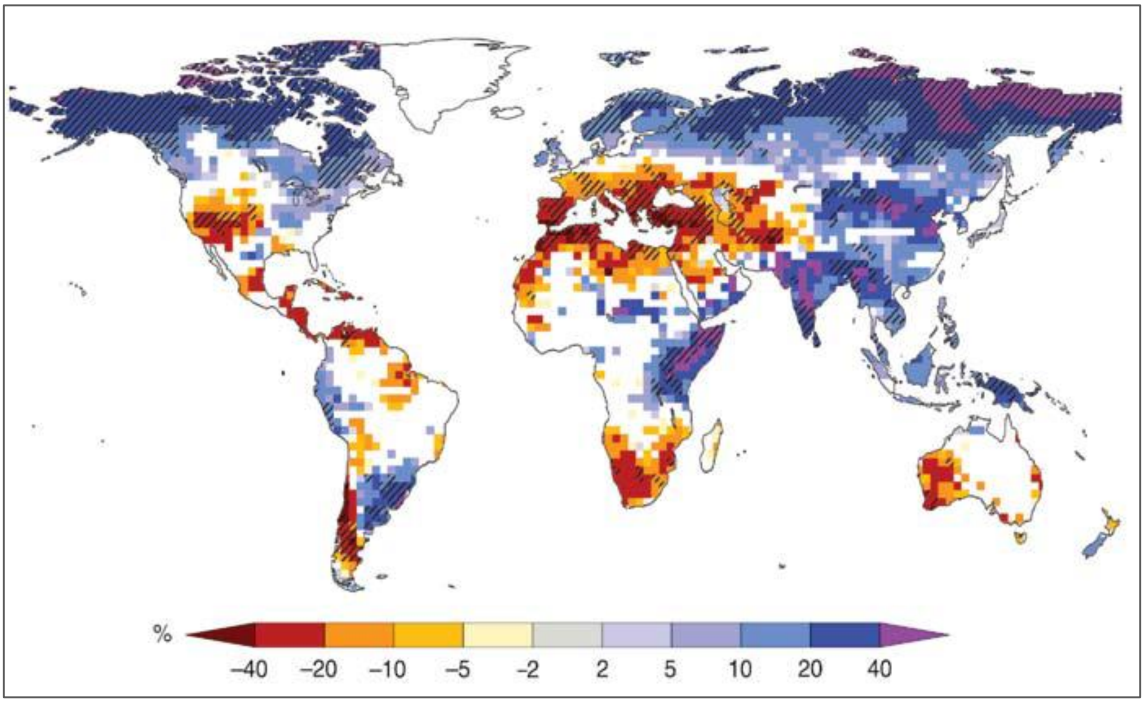


Figure 2.1: Large-scale relative changes in annual runoff for the period 2090–2099, relative to 1980–1999. Source :(IPCC 2007a)

There are many studies related to the impact of climate change on the water resources in Spain, such as the "The general preliminary evaluation of the climate change impacts in Spain" which was developed by the Ministry of Environment " Ministerio del Medio Ambiente (MMA)" (MMA 2005), which includes a chapter about the impact on water resources. Another recent study is "The impact of climate change on water resources in natural regime in Spain" (CEDEX 2011), which results are used in this study and explained in the following sections.

2.2.1 Impact of climate change on water resources in natural regime in Spain

An assessment of climate change on water resources in natural regimes in Spain (CEDEX 2011) was developed by the Centre for Studies and Experimentation of Public Works " Centro de Estudios y Experimentación de Obras Públicas (CEDEX)" by the Directorate General of Water "Dirección General del Agua (DGA)" with the participation of the Spanish Office for Climate Change "Oficina Española de Cambio Climático (OECC)". The objective of the cited study is to assess the impact of climate change on water resources in natural regime in different Spanish basins and along the 21st century. The hydrological model used was the Integrated System of Contribution Precipitation Simulation "Sistema Integrado para la Modelación del proceso Precipitación Aportación (SIMPA)", using 12 climate change projections for the 21st century, provided by the State Agency of Meteorology "Agencia Estatal de Meteorología (AEMET)" (Brunet et al. 2009) and the OECC. They give estimates of precipitation and maximum and minimum daily temperatures during the control period (1961-1990) and three future periods (2011-2040, 2041-2070 and 2071-2100) in which the impact was evaluated. This study covered two scenarios of IPCC scenario groups; A2 "The Heterogeneous World Scenarios" and B2 "The Local Sustainability Scenarios" (Nakicenovic and Swart 2000), also different types of models and methods were used.

The study estimates the impact of climate change on the variables influencing the hydrological cycle (Evapotranspiration, runoff, soil moisture and recharge). More than 200,000 maps of 1 km^2 resolution have been generated covering the whole of Spain in a monthly basis. The impact of climate change on water resources is presented as percentage deviations of runoff in each future period of the 21th century with respect to the control period. The results for the Tagus basin are shown in (Table 2.1) and the results for all basins in Spain are shown in the Annex 1.

Table 2.1: Percent change in annual runoff for the Tagus basin compared to the control period (1961 – 1990)

Period	**Average of all models of Scenario A2**	**Average of all models of Scenario B2**
2011 – 2040	- 8	-8
2041 – 2070	-19	-9
2071 – 2100	-35	-15

Source: (CEDEX 2011)

2.3 CLIMATE CHANGE SCENARIOS

Based on the Special Report on Emission Scenarios (Nakicenovic and Swart 2000), the IPCC developed four qualitative storylines which produced four set of scenarios called "families": A1, A2, B1 and B2. From these four families 40 SRES scenarios have been developed by six modeling teams (Figure 2.2).

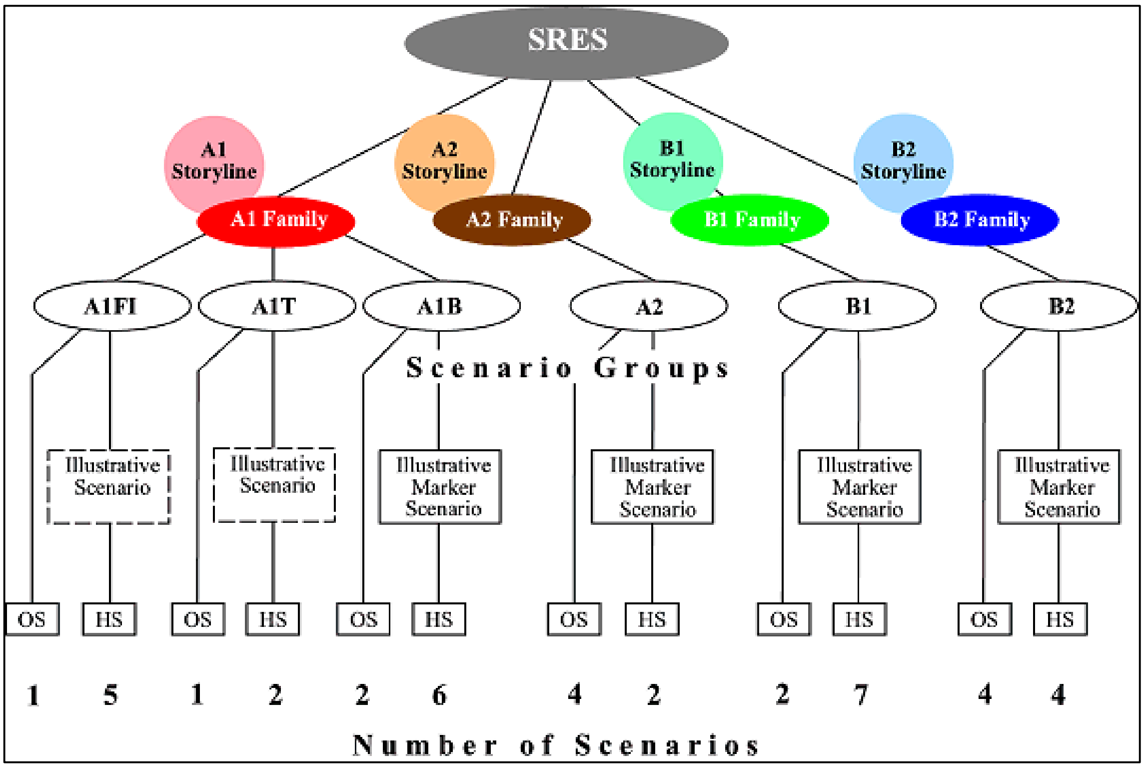


Figure 2.2: The main characteristics of the four SRES storylines and scenario families. Source: (IPCC 2000)

The storylines describe the relationships between emission driving forces and their evolution and add context for the scenario quantification. Each storyline represents different demographic, social, economic, technological, and environmental developments. The four storylines are described in the Annex 2.

2.4 HYDROLOGICAL AND WATER MANAGEMENT MODELS

The need to have a tool to support decision making on planning and management of water resources has led to the development of mathematical models.

A river basin model is a mathematical model that represents the relevant processes in a river basin and can predict the behaviour of the basin under different conditions or management scenarios (Dinar et al. 2013).

These models are used to simulate water resources system behavior based on a set of rules governing water allocations and infrastructure operation, also they are used to optimize water resource system behavior based on an objective function and accompanying constraints. Regarding transboundary river basins, models are needed by negotiators, planners, and managers of water resource systems, as well as other stakeholders who may be concerned about the economic or environmental uses of shared water resources (Dinar et al. 2013).

There are various modelling frameworks and software packages available, such as: SWAT, AQUATOOL, and WEAP. SWAT is the “Soil and Water Assessment Tool” and it is used for simulation of the effects on water management on sediments and nutrients. AQUATOOL is a Decision Support System Shell (DSSS) for planning and management of basins and water systems. It is used widely in Spain to support decision processes in many complex systems such as the Tagus basin. It was developed by the Technical University of Valencia (UPV 2014). For the purposes of our study WEAP is used which is described in the following section.

2.4.1 Water Evaluation and Planning system (WEAP)

The Water Evaluation and Planning (WEAP) software was developed by the Stockholm Environment Institute (SEI). It is designed to support integrated water resources management and planning, and it is mainly destined for decision makers in evaluating water policies and developing sustainable water resource management plans. WEAP operates on basic principles pf water balance accounting and links water supplies from rivers, reservoirs and aquifers with water demands in an integrated system.

Moreover, WEAP can address a wide range of issues including sectoral demand analyses, water conservation, water rights and allocation priorities, streamflow simulation, reservoir operation, ecosystem requirements and project cost-benefit analyses (Sieber and Purkey 2011).

WEAP applications generally include following steps (Sieber and Purkey 2011):

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

The design of WEAP is guided by a number of methodological considerations: an integrated and comprehensive planning framework; use of scenario analyses in understanding the effects of different development choices; Demand-management capability; Environmental assessment capability; and Ease-of-use (Sieber and Purkey 2011).

2.5 THE HYDROLOGICAL PLAN OF THE TAGUS BASIN

The current (2010 – 2015) Hydrological Plan of the Spanish part of the Tagus (HPT) basin was approved by Royal Decree 1664/1998 (BOE 1998). This Plan forms a hydrological framework where management of water uses in the area of the basin is set.

The new cycle of the HPT is characterized by incorporating the traditional approach of satisfying the demands and achieving a good ecological status of all water bodies in the basin.

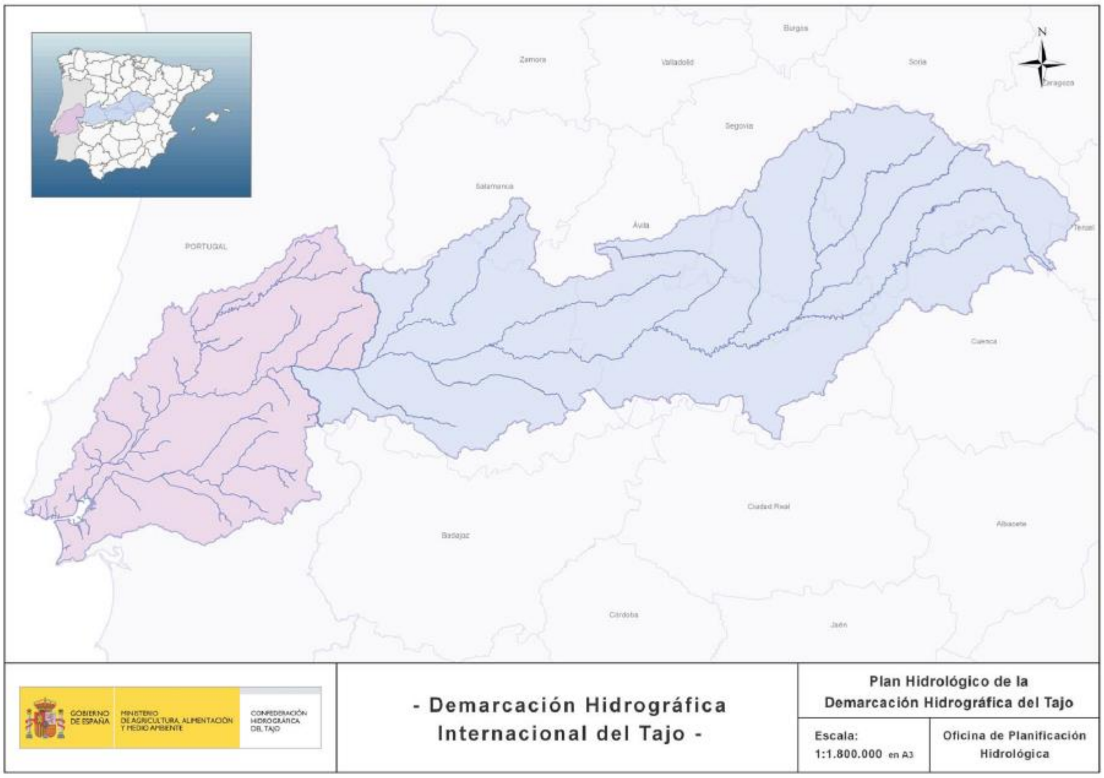
CHAPTER 3

GENERAL DESCRIPTION OF THE STUDY AREA

3 GENERAL DESCRIPTION OF THE STUDY AREA

3.1 PHYSICAL FEATURES OF THE BASIN

The Spanish-Portuguese International Tagus River Basin is located in the central area of the Iberian Peninsula and is oriented from East to West (Map 3.1). It occupies an area of 80,600 km2, which is distributed in 69.2% in the Spanish territories and 30.8% in the Portuguese territories (CHT 2014).



Map 3.1: Location of the International Tagus river basin. Source:(CHT 2013a)

It is the third largest basin in the Iberian Peninsula after the Duero and Ebro basins. Moreover, it has the highest population occupation of Spain and the Iberian Peninsula. The basin borders the Central System[1] to the north, the Mountains of Toledo and Mountains of Montánchez to the south, the Iberian System[2] to the east, and the Atlantic Ocean to the west.

[1] Sistema Central: is one of the main systems of mountain ranges in the Iberian Peninsula.

[2] Sistema Ibérico: is one of the main systems of mountain ranges in Spain.

The Tagus River flows from its source at the Sierra de Albarracin (Teruel) crossing the Spanish and the Portuguese territories and discharging in the Atlantic Ocean. It is the longest river of the Iberian Peninsula, it is 1,100 km long, 863 km in the Spanish part, 43 km along the border between Portugal and Spain and 194 km in the Portuguese part (Garrido et al. 2010). The main tributaries of the Tagus River in the Spanish part are: Jarama, Alberche, Tiétar, Álagon, Guadelia, Almonte and Salor, and in the Portuguese part: Erges, Ponsul, Zezere, and Sorraia.

This study focuses on the Spanish part of the basin which is bordered by the Duero basin to the north, by the Ebro and Júcar basins to the east, by Guadiana basin to the south, by the Portuguese part of the basin (Tejo e Riberas do Oeste) to the west (CHT 2013b).

It extends into five Autonomous Communities: Extremadura, Madrid, Castilla y León, Aragón and Castilla-La Mancha, including 12 provinces: Ávila, Badajoz, Cáceres (Image 3.1), Ciudad Real, Cuenca, Guadalajara, Madrid, Salamanca, Segovia, Soria, Teruel and Toledo. The Autonomous Community which occupies largest area in the basin is Castilla-La Mancha, followed by Extremadura, while all of Madrid is almost within the basin (CHT 2013b).

Image 3.1: Tagus river in the Monfragüe National Park in Cáceres.

Source: www.spain.info

3.2 DEMOGRAPHY

The population in the basin has increased from 6,096,942 inhabitants according to Census of 1991 to 7,879,123 inhabitants in 2011, representing a growth of 29.2% in the past twenty years, equivalent to 1.46% per year. Table 3.1 shows the provincial distribution of the population in the basin as well as the density of the population in each province. It is noted that the population density in the total area of the basin is 141 inhabitant/ km².

Table 3.1: Provincial distribution of the population in the Tagus river basin

Province	**Area**		**Population**		**Density**
	km^2	%	hab	%	hab/ km^2
Aragón	243	0.43	1,120	0.01	5
Castilla- La Mancha	26.865	48.16	902,337	11.45	34
Castilla y León	3.987	7.15	94,039	1.19	24
Extremadura	16.676	29.89	391,947	4.97	24
Madrid	8.011	14.36	6,489,680	82.37	810
Total	55.781	100	7,879,123	100	141

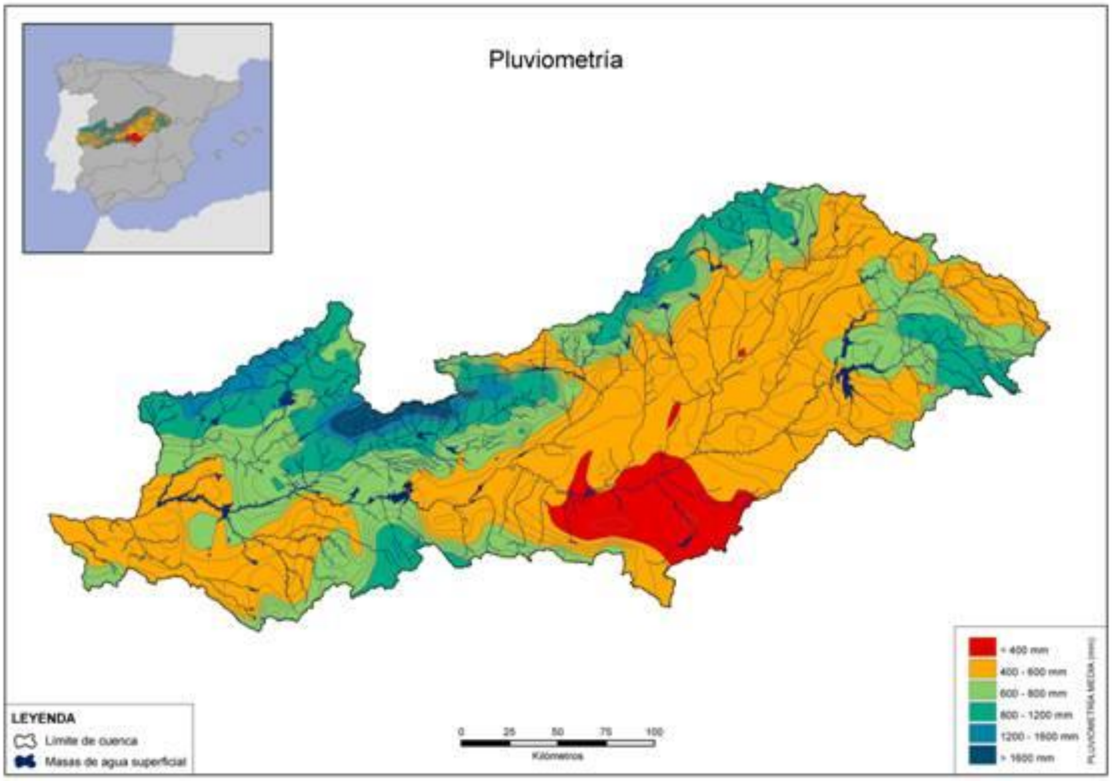
Source: (CHT 2014)

3.3 CLIMATE

The climate of the basin varies from Mediterranean with strong continental influences in eastern areas to Atlantic conditions in western areas, particularly in the Portuguese part of the basin (López-Moreno et al. 2009). It is characterized by a dry season and very distinct temperature fluctuations, leading to low rainfall and high summer temperatures causing droughts.

Temperatures within the basin exhibit strong seasonal variation; hot and dry summers and cold winters. The range of average annual temperature is between (8° - 10°) C in the mountains of Guadarrama and Gredos, which present the coldest zones and between (13° - 17°) C in the eastern and western parts which represent the warmest zones (CHT 2014).

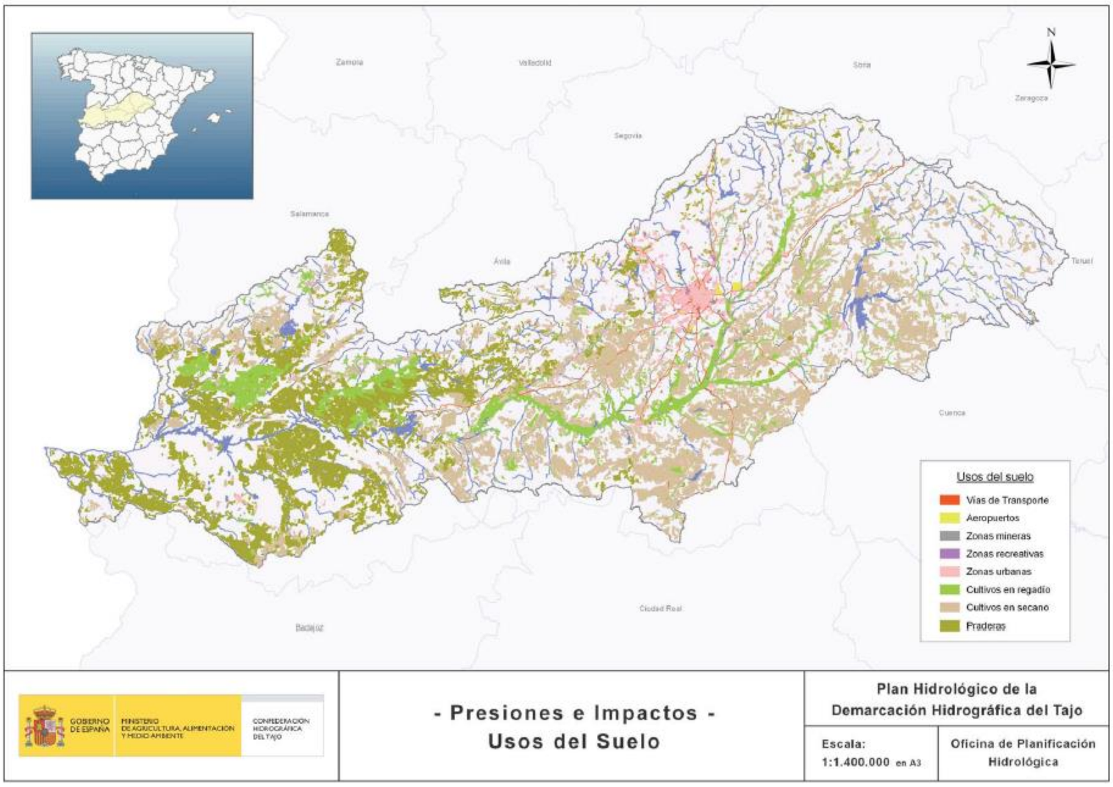
The average annual precipitation varies significantly within the basin in response to the altitude (Map 3.2). It ranges from 450 mm in the middle reaches to 870 mm in the Portuguese part of the basin to 1,500 mm in the central ranges in Spain (López-Moreno et al. 2009). The annual rainfall, considering the 1940-2006 series, is 623 mm (CHT 2013b).



Map 3.2: Average precipitation rate (mm). Source: (CHT 2013a)

3.4 LAND USE

The different land uses in the basin are shown in the following map (Map 3.3). It is noted that irrigated lands are concentrated in the lower basin system (Árrago, Tiétar, Alagón and Bajo Tajo). The previous decades witnessed an increase of the urban areas in the basin. A process of abandonment of the marginal lands for agricultural and pastures has been observed in the headwaters of the Tagus basin. New irrigated areas have been developed in the valleys of major tributaries (Beguería et al. 2008).



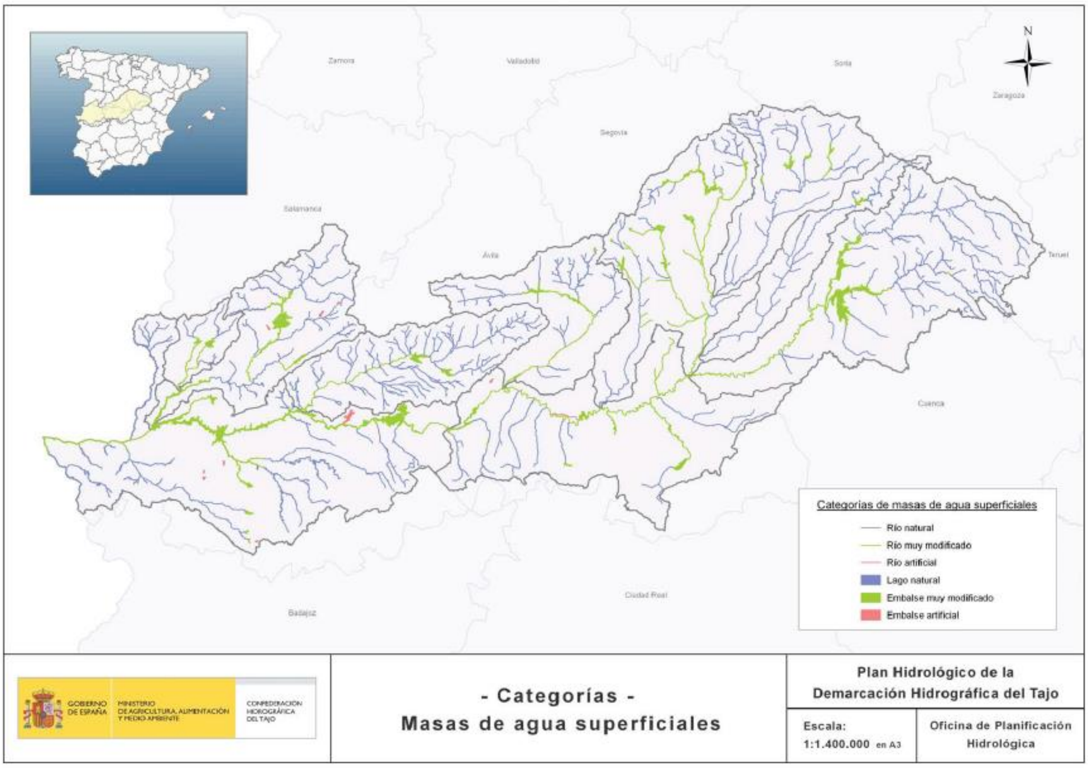
Map 3.3: Tagus river basin land cover. Source: (CHT 2013a)

3.5 WATER RESOURCES

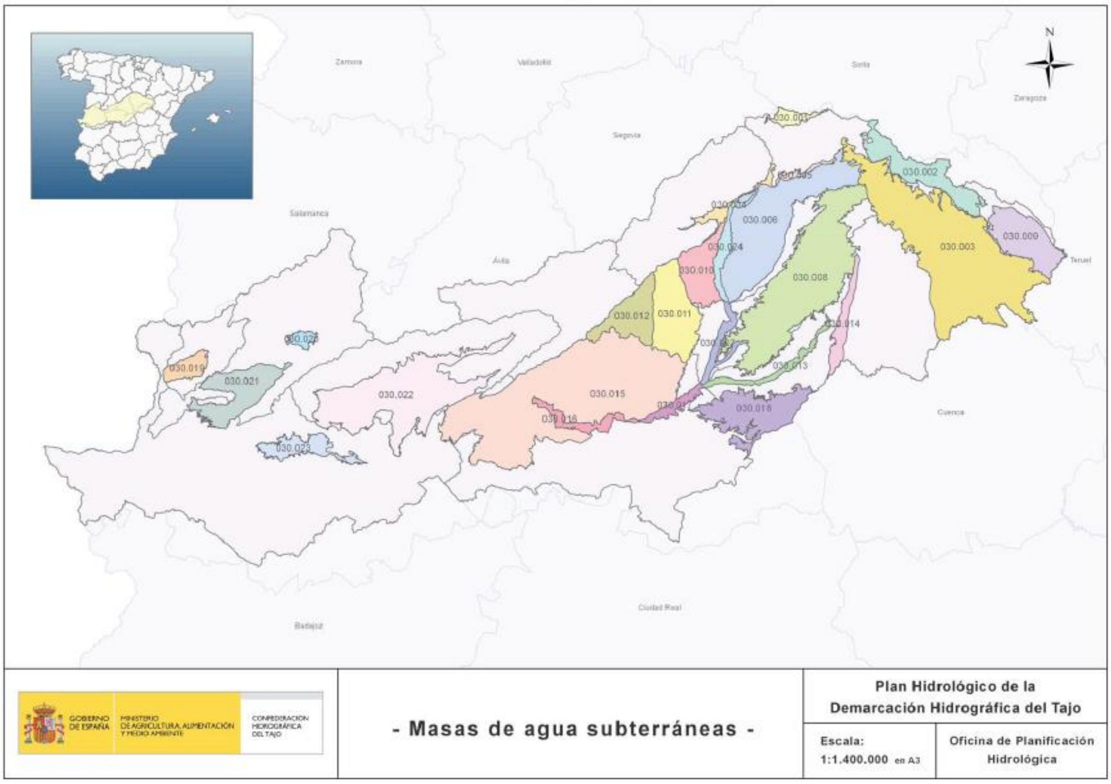
The river network is asymmetric, with high flow tributaries on the right bank (Jarama, Alberche Tiétar and Alagón), which collect rainfall from the central system (Guadarrama, Gredos and Gata). Nevertheless, on the left bank the river Guadiela is with high flow. In the period 1940 – 2006 the total average annual inflow into the Tagus basin, including the total inflow from transboundary water bodies, is 10,210 hm^3.

According to the Tagus Hydrographic Confederation (CHT), in the Tagus River basin there are 324 surface water bodies, these were defined and classified according to the "system B" that has been established in the DMA (CHT 2013b). The surface water bodies were classified based into 58 reservoirs, 16 lagoons and 250 rivers. The Map 3.4 shows the distribution of the surface water bodies in the basin classified by category.

In the Tagus basin there are 24 groundwater bodies (CHT 2013b). Map 3.5 shows the groundwater bodies in the basin. The volume of available groundwater resources is 1070 hm^3/year. 237 hm^3 is the current volume of water extracted.



Map 3.4: Surface water bodies of the Basin. Source: (CHT 2013a)



Map 3.5: Ground water bodies of the Basin. Source: (CHT 2013a)

3.6 WATER USES AND DEMANDS

In the year 2005 (CHT 2013c), the total demand of water in the Spanish part of the basin was 2,893 hm^3. The agricultural sector is the main user of water in the basin, where in the same year; the agricultural demand represented 68% of the total demand. The rest of the demand in the basin is distributed between the domestic demand, industrial demand and energy use demands. Table 3.2 illustrates the water demands in the basin by type of demand and type of water source (superficial or groundwater). The value of the demand in the table is the gross demand except for the energy use as it is the net demand (consumptive use). The gross demand for energy production is shown in (Table 3.4).

Table 3.2: Water demands in the Tagus river basin

Type of demand	Demand	
	hm^3	%
Domestic	550	19
Industrial connected to the water network	188	7
Institutional and Municipal	49	2
Total Urban Demand	**787**	**27**
Public Irrigation	1,290	45
Private surface irrigation	507	18
Private groundwater irrigation	135	5
Livestock	26	1
Total Agricultural Demand	**1,958**	**68**
From superficial source	8	0
From groundwater source	55	2
Total Industrial demand not connected to the water network	**63**	**2**
Energy use	84	3
TOTAL	**2,892**	**100**

Source: (CHT 2013b)

The urban demand corresponds to population of 7,273,871 habitants, 80% of them are concentrated in the community of Madrid. The rapid growth in the population over the last decades has increased the pressure on water resources in the basin especially during drought periods. Moreover, the concentration of the population and the economic activities in the Community of Madrid and in the neighboring area of Toledo and

Guadalajara generate a large quantity of wastewater which cause significant problems of water quality in the rivers and reservoirs that are located in the lower reaches of the basin.

With regard to the agricultural demand, the area of the irrigated land was estimated to be 237,000 ha in the basin.

The industrial demand is 250 hm^3/ year approximately. It is distributed between the industrial demand sites that are connected to the water network which represent 75% of the total industrial demand, and the industrial demand sites that are not connected to the water network.

In relation to power generation, the Tagus basin has an installed capacity of 7,288 MW (Table 3.3) that corresponds to 39% hydropower production, 20% to thermal production and 41% from a nuclear origin (CHT 2013b).

Table 3.3: Installed power capacity in the basin

Type	Potential (MW)
Hydropower plants	2,839
Thermal Plants	1,427
Nuclear Plants	3,022
Total	**7,288**

Source: (CHT 2013b)

There are 114 power plants with an installed capacity of 2,839 MW that are located mainly on the rivers of Tagus, Alberche and Alagón. Regarding the thermal and nuclear plants, there is one thermal plant in Aceca with an installed capacity of 1,427 MW, and two nuclear plants located in Trillo and Almaraz and have a capacity of 3,022 MW (Table 3.4).

Table 3.4: Characteristics of the nuclear and thermal power stations and their water demand for refrigeration

Plant	Type	Potential (MW)	Demand (hm^3/year)	Consumptive use (hm^3/year)	Return (hm^3/year)
Aceca	Thermal	1,427	551,88	17,4	534,48
Trillo	Nuclear	1,066	37,8	20,5	17,3
Almaraz	Nuclear	1,956	436,9	46,3	390,6
Total		**4,449**	**1026,58**	**84,2**	**942,38**

Source: (CHT 2013c)

3.7 INFRASTRUCTURE

3.7.1 Regulation infrastructure

The surface water resources in the basin are regulated by a high number of reservoirs with an overall storage capacity of 11,140 hm^3. According to their use, the reservoirs can be classified into reservoirs for water supply, irrigation, industrial, or/and hydropower. It is noted that there are both single- and mulitple- use reservoirs. The Annex 3 shows a table that contains the reservoirs of the basin and some of their important characteristics. The Image 3.2 shows the reservoir of Alcántara (Jose Maria Oriol) which is the second largest reservoir in Europe with a volume of 3,162 hm^3 and located on the Tagus river.

Image 3.2: Alcántara reservoir (Jose Mª Oriol)

3.7.2 Tajo – Segura aqueduct

The Tajo – Segura aqueduct (Image 3.3) came into operation in the year 1981 in order to solve the shortage of water resources in the Southeast of Spain. It has a capacity of 33 m^3/sec and starts from the reservoirs of Buendía and Entrepeñas which have capacity storage of 2,443 hm^3, and ends in the Talave reservoir in the Segura basin (CHT 2014).

The Entrepeñas reservoir was built in the year 1956 over the Tagus River with a capacity of 804 hm^3 and the Buendía reservoir was built in the year 1957 over the Guadiela River with a capacity of 1639 hm^3 (CHT 2014).

This aqueduct permits a transfer of water of 600 hm^3 per year, 155 hm^3 for urban use and 455 hm^3 for irrigation. In the last thirty years the transferred volume was on average 350 hm^3/year, and the maximum volume was 605 hm^3 in the hydrological year 1999/2000 (Garrido et al. 2010; CHT 2013b).

The CHT is responsible for the technical and financial management of the aqueduct in the part corresponding to pipe line from the intake on the Tagus river to the outlet in the Talave reservoir.

Image 3.3: Tajo - Segura aqueduct. Source:(Soria and Barajas 2010)

3.8 ENVIRONMENTAL FLOWS

The environmental flow regime of the rivers is defined in the article 18 of the Hydrological Planning Regulation (HPR). According to the article 17 "Priority and Compatibility of uses" of the HPR, the environmental flows or environmental demands should not be used, and should be considered as a restriction imposed generally to the operating systems (BOE 2007).

Twenty points of control are located on strategic stretches throughout the basin to monitor the minimum flow requirements. The criteria that have been taken into consideration in the locations of control points are: the location of the main river, the existence of upstream reservoirs, the existence of protected areas and the ability of making measurements to control the flow (CHT 2013b). The temporal distribution of the minimum flows for each stretch is show in the Table 3.5.

Table 3.5: Values of Environmental Flows in the Tagus River Basin (m³/sec)

Control point	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Average
Alagón (Valdeobispo)	1.83	1.83	1.83	1.83	1.83
Alberche (San Juan)	1.21	1.21	1.21	1.21	1.21
Árrago (Borbollón)	0.30	0.30	0.30	0.30	0.30
Bornova (Alcorlo)	0.19	0.19	0.19	0.19	0.19
Cañamares (Pálmaces)	0.08	0.08	0.08	0.08	0.08
Jarama (El Vado)	0.30	0.30	0.30	0.30	0.30
Jerte (Jerte – Plasencia)	1.15	1.15	1.15	1.15	1.15
Lozoya (El Atazar)	0.88	0.88	0.88	0.88	0.88
Manzanares (El Pardo)	0.99	0.99	0.99	0.99	0.99
Rivera de Gata (Rivera de Gata)	0.12	0.12	0.12	0.12	0.12
Sorbe (Beleña)	0.29	0.29	0.29	0.29	0.29
Tajo (Aranjuez)	6.00	6.00	6.00	6.00	6.00
Tajo (Toledo)	10.00	10.00	10.00	10.00	10.00
Tajuña (La Tajera)	0.50	0.50	0.50	0.50	0.50
Tiétar (Rosarito)	0.54	0.54	0.54	0.54	0.54
Tiétar (Navalcán)	0.03	0.03	0.03	0.03	0.03
Tiétar (Pajarero)	0.00	0.00	0.00	0.00	0.00
Guadiloba (Guadiloba)	0.07	0.07	0.07	0.07	0.07
Salor (Salor)	0.02	0.02	0.02	0.02	0.02

Source: (CHT 2013b)

3.9 INSTITUTIONAL FRAMEWORK

The water resources in the Tagus basin are managed by the Tagus Hydrographic Confederation (CHT) in Spain and by the Tagus Hydrographic Region Administration (ARH) in Portugal. The CHT was created in the year 1953. The CHT has the following functions within the basin (CHT 2014):

- The preparation of the Hydrological Plan for the catchment area as well as the monitoring and review thereof.
- The administration and control of publicly-owned water resources.
- The administration and control of the exploitations of general interest or which involve more than one autonomous community.

- The planning, construction and operation of the works built and charged to the Organization's own funds and those that are entrusted to it by the State.
- Those that derive from agreements with the Autonomous Communities, local Corporations and other public and private entities or those signed with private individuals.

Moreover, there are other administrative offices which share the management of the water resources of the basin with the CHT, such as the water utility Canal Isabel II Office, and the regional governments of Madrid Community, Castilla La Mancha and Extremadura, as well as other municipalities.

3.10 COOPERATIVE FRAMEWORK

3.10.1 Albufeira Convection

The river basins shared by Portugal may serve as a good example of the evolution of a case of bilateral management of shared water resources. The Albufeira Convention, the Convention on Co-operation for Portuguese-Spanish River Basins Protection and Sustainable Use, was signed in 1998 in the town of Albufeira in Portugal and approved later on January 2000 (Barreira 2007). The objective of this convention, according to its article 2, is to define a framework for the cooperation between Portugal and Spain, in order to protect the surface and ground water and to promote the sustainable use of the water resources in the shared river basins. More information about the cooperation between Spain and Portugal is in Annex 4

3.10.1.1 The flow regime

The Convention established a provisional flow regime for each river considered. It is regulated in the Article 16 and in the Additional Protocol. In the year 2008, a new flow regime were proposed by the CADC in the second COP at Madrid and were approved and published in the year 2010 at the Revision Protocol of the Convention (BOE 2010). Probably this is the most important part of the agreement, as the flow regime is essential to the sustainable use of the water resources in the shared basins. It imposes to ensure a minimum flows in the control points.

The flow regime for the Tagus river basin is detailed in the Table 3.6. In order to ensure the minimum flow in the Tagus basin, two gauging stations were chosen; one of them in the Spanish part of the basin and located on the exit of Cedillo reservoir and the other is in the Portuguese part and located in Ponte de Muge. Spain has to guarantee annual, quarterly and weekly minimum flow in the exit of the Cedillo reservoir except in the normal hydrological conditions. The annual minimum flow is 2,700 hm^3. This flow regime is not applicable in the periods that verify one of the following circumstances:

For the annual flow: The accumulated reference precipitation in the basin from the beginning of the hydrological year (1st of October) until the 1st of April is lower than 60% of the average accumulated precipitation in the Basin in the same period.

The accumulated reference precipitation in the basin from the beginning of the hydrological year (1st of October) until the 1st of April is lower than 70% of the average accumulated precipitation in the basin in the same period and the accumulated reference precipitation in the previous hydrological year had been lower than 80% of the annual average.

For the quarterly flow: The accumulated reference precipitation in a period of six months until the first day of the third month of the trimester is lower than 60% of the average accumulated precipitation in the same period in the basin.

For the weekly flow: In the period of exception referred in the previous paragraph.

The reference precipitation is calculated according to the precipitations values of the pluviometric stations of Cáceras and Madrid (Retiro), impacted by a weighting coefficient equal to 50%. The average values are calculated according to records of the period 1945/46 to 2006/07 and will be updated every 5 years (BOE 2010).

Table 3.6: Flow regime of the Tagus basin

	Period	**Gauging Station**	
		Salto de Cedillo	Ponte de Muge
Minimum Flow (hm^3)	**Annual**	2,700	1,300
	Quarterly		
	1st Oct – 31th Dec	295	150
	1st Jan – 31th Mar	350	180
	1st Apr – 30th Jun	220	110
	1st Jul – 30th Sep	130	60
	Weekly	7	3

CHAPTER 4

METHODS AND MATERIALS

4 METHODS AND MATERIALS

4.1 THE METHODOLOGICAL FRAMEWORK

The general approach adopted in the study is the hydrological and water allocation modelling to evaluate the current performance of the Tagus river water system and the effects of climate change scenarios on the basin in order to recommend water management scenarios to potentially mitigate the impacts.

The study consists of five main phases, the first one is data processing and building the water balance model for the Tagus river basin in WEAP, the second assesses the performance of the current system under historical data using the WEAP model, the third assesses the impact of climate change on the performance of the system, the fourth assesses the sensitivity of the system to adaptation actions and the fifth proposes some measures to be adopted in the future.

The general methodology adopted in this study is shown in (Figure 4.1) and is described in steps as follows:

4.1.1 Data collection and data processing

In a first step data was collected and processed to characterize the Tagus River Basin system as well for developing the model of the basin. The required data for the development of the study is obtained from different resources but mainly from the website of the CHT and the Water Information System "Sistema de Información del Agua (SIA)". All the collected data is prepared in Excel and converted to the CSV format in order to be introduced into the software WEAP.

4.1.2 Building the Tagus River Basin using the software of WEAP

In order to conduct the analysis, a river basin model is created using the "Water Evaluation and Planning" software version WEAP21. WEAP has been used in climate change studies for many regions in the world, and its design is ideal to be used to simulate various climate change and adaptation scenarios for river basin systems. The Tagus river basin with all its elements is implemented in WEAP for further analysis. All processes, methods and data that have been used for building the model are presented in detail in section 4.2 "Water Evaluation and Planning (WEAP)" and chapter five "The Tagus river basin model"

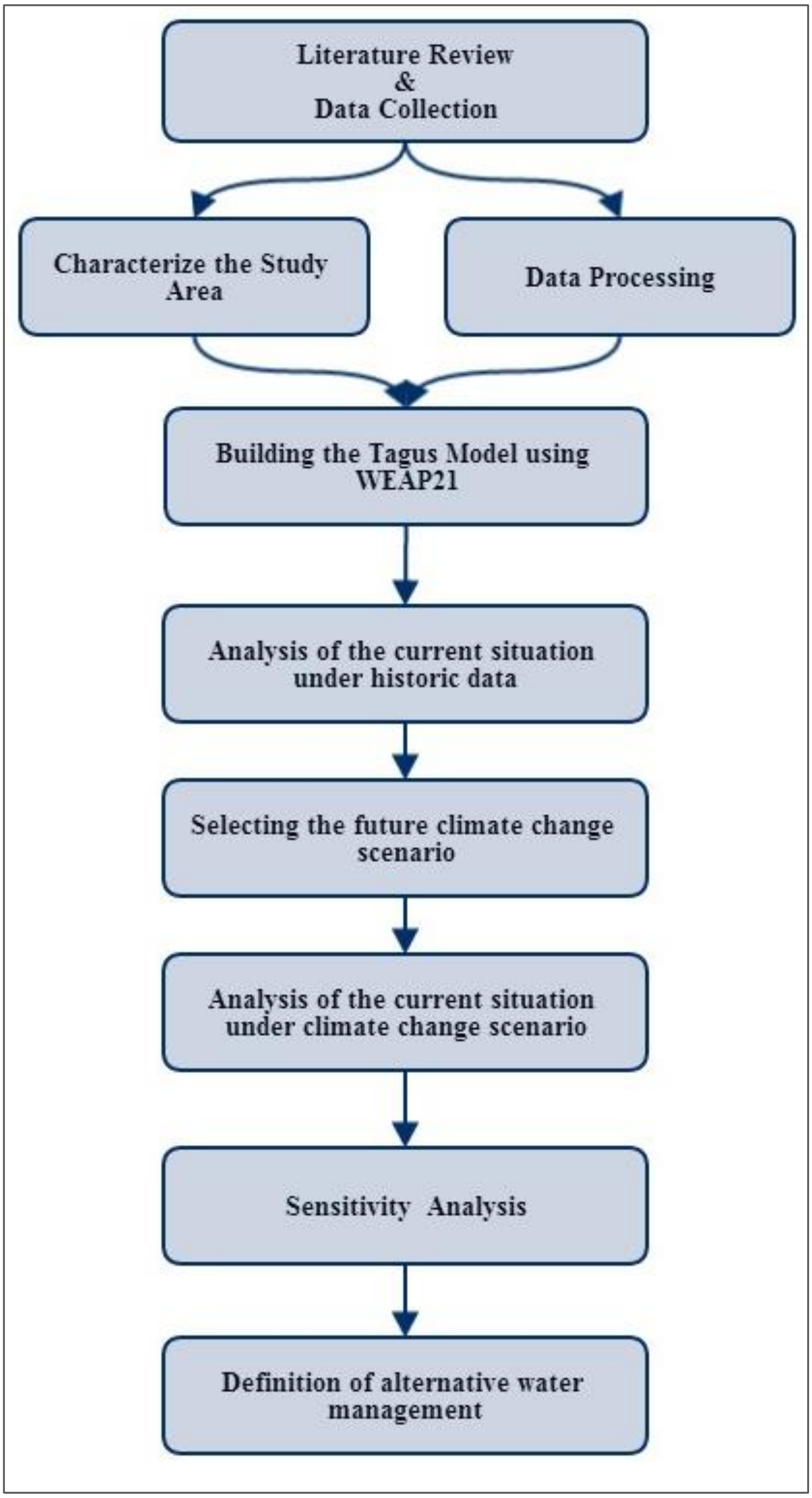


Figure 4.1: Methodology of the study

4.1.3 Analysis of the current situation under historic data

After developing the Tagus basin using the WEAP tool, an assessment for the performance of the current system under the historic climate data is conducted.

To study the performance of the current situation under the historic data, the model was set up for a baseline water demand (2005) and run for the 56 years (1940 – 1996) of historic hydrological data. This means that no changes were imposed in the baseline scenario; water demands, water system conditions and land use do not change over time. This approach will allow us to test how the current system fares under historic climate conditions.

The unmet demand in the basin and the reliability of satisfying demands and/or flows requirements have been selected as principle performance criteria to assess the ability of the basin to satisfy the required demand in the system.

4.1.4 Selecting the future climate change scenarios

The Climate Change Scenarios were selected from the study "Impact Assessment of Climate Change on Water Resources in Natural Regime"(CEDEX 2011) as it is the only source to obtain data related to climate change impact on water resources for a basin scale in Spain. In this study, the A2 emission scenario has been adopted to assess the impact of climate change on the Tagus river basin. The average of the change in the runoff for the three periods is used to assess the impact of the climate change in the short term (2025), mid-term (2055) and long term (2085) (Table 4.1). The A2 scenario is a high emission scenario. It is important to point out that the results of the simulation can also be used to assess the impacts of other scenarios. For example, the predicted reduction in annual runoff for the B2 scenario at the end of the century is equivalent to the reduction in annual runoff for A2 in mid-term.

Table 4.1: Average of change in annual runoff for the A2 emission scenario for the Tagus basin

Period	**Average of the change in runoff (%)**
Short term (2025)	- 8
Mid-term (2055)	-19
Long term (2085)	-35

4.1.5 Analysis of the current situation under climate change scenarios

The three climate change scenarios are introduced into WEAP. Each of them has the same configuration as the baseline scenario. The corresponding runoff reductions (Table 4.1) are applied to the 56 year inflow time-series used in the baseline scenario. In this way, the current system is assessed under the predicted future reduced water availability.

4.1.6 Sensitivity analysis

The principle objective of this phase is to determine the variables that have the greatest impact on the performance of the system. For this aim, sensitivity analysis is conducted as a previous step to identify the adaptation actions. Sensitivity analysis can be defined as the study of how the variation in the output of a model can be apportioned (qualitatively or quantitatively), to different sources of input variations (King and Perera 2007).

Two methods are adopted to do the analysis, the first method is One-at-a-time (OAT) which depends on changing one variable at a time and keeping other variables as in the baseline scenario and see how this will affect the output variables, and the second method is Morris Screening to assess the overall importance and the interaction among the variables.

In order to conduct the analysis a set of input variables with different ranges was defined as well as a set of output variables. The input variables are: 1) Inflow, 2) Urban water demand, 3) Agricultural water demand 4) Environmental flows priority. The ranges for the input variables were chosen in a way to cover both effects of socioeconomic changes (e.g. deindustrialization or population growth) as well as effects of planned adaptation actions (e.g. increase in water efficiency). Figure 4.2 and Table 4.2 show the levels considered for all the variables.

Table 4.2: Description of the input variables

Variables	**Range**
Inflow (*X1*)	(0.65 – 1.0) of historic data
Urban water demand (*X2*)	(0.25 – 1.5) of 2005 urban water demand
Agricultural water demand (*X3*)	(0 – 1.5) of 2005 agricultural demand

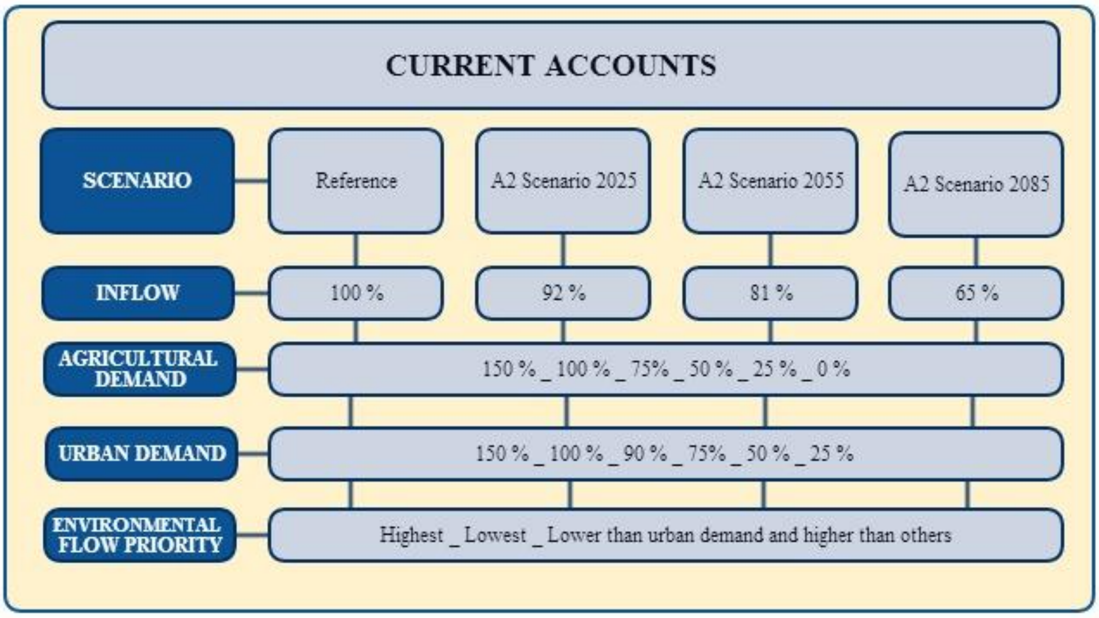


Figure 4.2: Main variables and their values for the sensitivity analysis

The selected output variables are:

- Average unmet demand (hm^3/year)
- Maximum unmet demand (hm^3/year)
- Albufeira Flow requirement reliability (%)

One-at-a-time (OAT) sensitivity analysis:

In each simulation we change just the value of one variable. For example, to test the sensitivity of the system to changes in the agricultural water demand, we give the agricultural water demand each time a value of 0%, 25%, 50%, 75%, 100% or 150% and keep the other variables as in the baseline scenario. Simulating the system with progressive reduction of the agricultural demand will let us test how the performance improves as demand is being changed and to find the demand reduction required to restore performance to current levels.

Morris Screening

The second analysis applies the Morris Screening method. The origins of this method lie in Experimental Design and it has proved to be an efficient and reliable technique to identify and rank important variables (M. Morris 1991; King and Perera 2007). Compared to the One-at-a-Time (OAT) analysis is looking how the performance is impacted by changes in one variable while the other variables are not at their baseline values (Table 4.3). It can capture possible interactions between variables.

It provides an overview of the influence of input variables on a model's output with a limited number of model simulations. At first the ranges are partitioned into p=5 levels and an increment delta=3 levels is chosen. In a first step the model is evaluated at a randomly selected starting point from the partitioned variable space (No. sample 1 in Table 4.3). In the next run only one input variable is given a new value (e.g. in Table 4.3 in sample no.2 *X3* is changed by delta) and the elementary effect EE_3 is calculated:

$$EEi(x) = \frac{\left[f(X1,......, Xi-1, Xi+\Delta, Xi+1,.....Xn) - f(X1,...., Xi-1, Xi,...., Xn) \right]}{\Delta}$$

In the next run another variable is changed (in Table 4.3 sample no.3 *X1*) and the EE calculated for this variable, this goes on until all variables are changed. Then a new starting point is selected and the same procedure is repeated. Each loop provides a value of EE for each variable. Repeating the loop 5 times provides 5 values of EE for each variable.

This method finally condenses the information in two sensitivity measures (M. Morris 1991) for each variable:

- The measure μ (mean of the EEs for each variable) assessing the overall importance of an input factor on the model output.
- The measure σ (standard deviation of the set of EEs for each variable) describing non-linear effects and interactions.

A revised measure μ* was proposed by Campolongo et al. (2007), this measure is the mean of the absolute EE's. The use of μ* solves the problem of the effects of opposite signs which occurs when the model is non-monotonic. The results are summarized in a scatter with μ* as a measure of importance and σ as a measure of nonlinearity and interactions. The values of the input variables for the 20 samples are presented in Table 4.3. These samples designed to run two times: first when the eenvironmental flow has the highest priority, and second when environmental flow has the lowest priority.

Table 4.3: Input variables for the Morris Screening

No. of Sample	*X1*	*X2*	*X3*
1	0.65	1.125	1.1875
2	0.65	1.125	0.25
3	0.9125	1.125	0.25
4	0.9125	0	0.25
5	0.65	1.5	0.5625
6	0.9125	1.5	0.5625
7	0.9125	1.5	1.5
8	0.9125	0.375	1.5
9	0.9125	0.375	0.25
10	0.9125	0.375	1.1875
11	0.9125	1.5	1.1875
12	0.65	1.5	1.1875
13	0.7375	0.375	0.5625
14	1	0.375	0.5625
15	1	1.5	0.5625
16	1	1.5	1.5
17	0.7375	1.125	1.5
18	1	1.125	1.5
19	1	1.125	0.5625
20	1	0	0.5625

4.1.7 Definition of alternative water management

By analysing the results of the sensitivity analysis, adaptation actions for the future climate change are identified and discussed. At this phase potential water management in the basin are discussed in order to keep a good performance of the system in the future.

4.2 WATER EVALUATION AND PLANNING (WEAP)

4.2.1 Building a model using WEAP

Creating the Tagus river basin model using WEAP involves mainly the following steps:

- **Creating an area and setting its boundary:**

An "area" in WEAP is defined as a self-contained set of data and assumptions. Its geographical extent is typically a river basin (Sieber and Purkey 2011). In order to refine the Basin boundaries and build the system, a GIS based vector map for the boundary of the basin was added in WEAP as a background.

- **Definition of general parameters:** such as timeframe and resolution, unit's type, and timestep.
- **Creating elements into the schematic view:**

This means creating the topology of the basin. The topology is an arrangement of various elements, nodes and lines. In WEAP, a node represents a physical component such as a demand site, wastewater treatment plant, groundwater aquifer, reservoir or special location along a river. Nodes are linked by lines that represent the natural or man-made water conduits such as river channels, canals and pipelines. These lines include rivers, diversions, transmission links and return flow links. A river reach is defined as the section of a river or diversion between two river nodes, or following the last river node (Sieber and Purkey 2011).

Depending on the background layers the rivers network was drawn and then, demand sites, reservoirs, flow requirements, transmission links, return flow links and ground water reservoirs were created. The elements that have been used in the model are described in the following:

<u>Demand sites:</u> A demand site is best defined as a set of water users that share a physical distribution system, that are all within a defined region, or that share an important withdrawal supply point (Sieber and Purkey 2011). Demands can be defined as groups such as, municipal, agricultural, industrial, energy production and etc. Each demand site needs a transmission link from its source, and where applicable, a return link either directly to a river or other location.

<u>Rivers, Diversions and River Nodes:</u> Both rivers and diversions in WEAP are made up of river nodes connected by river reaches. Other rivers may flow in (tributaries) or out (diversions) of a river. The river nodes used in the model are:

1- Reservoir nodes, which represent reservoir sites on a river.
2- Flow requirement nodes, which defines the minimum instream flow required at a point on a river.
3- Withdrawal nodes, which represent points where any number of demand sites receive water directly from a river.
4- Tributary nodes define points where one river joins another.

5- Return flow nodes, which represent return flows from demand sites and wastewater treatment plants

A groundwater supply node: which can be linked to any number of demand sites.

Transmission links: deliver water from surface water (reservoir nodes, and withdrawal nodes), groundwater and other supplies to satisfy final demand at demand sites.

Return Flows links: deliver return flows from demand sites to wastewater treatment plants, groundwater, and/or rivers.

- **Entering related data:**

Entering all data for the current accounts and the future scenarios. The Current Accounts represent the basic definition of the water system as it currently exists.

- **Run the Model:**

Running the model to see and check all the results.

4.2.2 Methods and calculation algorithms

In this section the methods used in the model for this study and the calculation processes are presented. The calculation process in WEAP is based on a mass balance of water for every node and link and is subject to demand priorities, supply preferences, and water requirements. As it is described in the user guide of WEAP, calculation starts from the first month of the Current Account year to the last month of the last scenario. Each month is independent of the previous month, except for reservoir and aquifer storage. Thus, all of the water entering the system in a month is either stored in an aquifer, reservoir or catchment, or leaves the system by the end of the month (e.g., outflow from end of river, demand site consumption, reservoir or river reach evaporation, transmission and return flow link losses). Because the time scale is relatively long (monthly), all flows are assumed to occur instantaneously. Thus, a demand site can withdraw water from the river, consume some, return the rest to a wastewater treatment plant that treats it and returns it to the river. This return flow is available for use in the same month by downstream demands (Sieber and Purkey 2011).

4.2.2.1 Hydrologic inflow simulation

WEAP can simulate and project water surface hydrology using four methods: the Water Year Method, Expressions, Catchments Runoff and Infiltration, and the Read FromFile Method.

In this study “Read FromFile” method is used. The Read FromFile Method allows to model the system using the available data of inflows. The required file formats for these data files are given in ASCII Data File Format for Monthly Inflows.

4.2.2.2 Priorities for water allocation

Two user-defined priority systems are used to determine allocations from supplies to demands sites, for instream flow requirements, and for filling reservoirs (Sieber and Purkey 2011):

- Demand priority: It is attached to the demand site, reservoir (priority for filling), or flow requirement. Priorities can range from 1 to 99, with 1 being the highest priority and 99 the lowest. The demands with higher priorities are satisfied as fully as possible before demands with lower priorities. Many demands can have the same priority, in this case WEAP tries to satisfy all demands to the same percentage of their demands.
- Supply preference: If a demand site has more than one supply source, then by using the supply preference it is possible to rank its choices. It is attached to the transmission link that connects the demand site with the source.

4.2.2.3 Demand calculation

Several options exist to input and calculate demand within WEAP, in this study the “Annual Demand with Monthly Variation” method is used. The monthly variation used to vary the demand on the annual level.

The demand for a month (*m*) equals that month's fraction of the adjusted annual demand.

$$MonthlyDemand_{DS,m} = MonthlyVariationFraction_{DS,m} \times AdjustedAnnualDemand_{DS}$$

A linear program (LP) is used to maximize satisfaction of requirements for demand sites and subject to demand priorities, supply preferences, mass balance and other constraints (David Yates et al. 2005).

4.2.2.4 Reservoir calculation

4.2.2.4.1 Reservoir Initial and Total Storage Capacity

The Storage Capacity represents the total capacity of the reservoir, while the Initial Storage is the amount of water initially stored there at the beginning of the first month of the "Current Accounts". WEAP maintains a mass balance of monthly inflows and outflows in order to track the monthly storage volume.

4.2.2.4.2 Evaporation

Calculating the amount of evaporation from the reservoirs depends on two input variables, the monthly evaporation rate and water surface of the reservoir which can be calculated using the Volume-Elevation Curve of the reservoir. Since the evaporation rate is specified as a change in elevation, the storage level must be converted from a volume to an elevation. This is done by a simple linear interpretation between adjacent points on the volume-elevation curve.

4.2.2.4.3 Reservoir operation

WEAP allows the modelling of advanced reservoir operation through the definition of several zones (Figure 4.3), each zone has a different operational constraint.

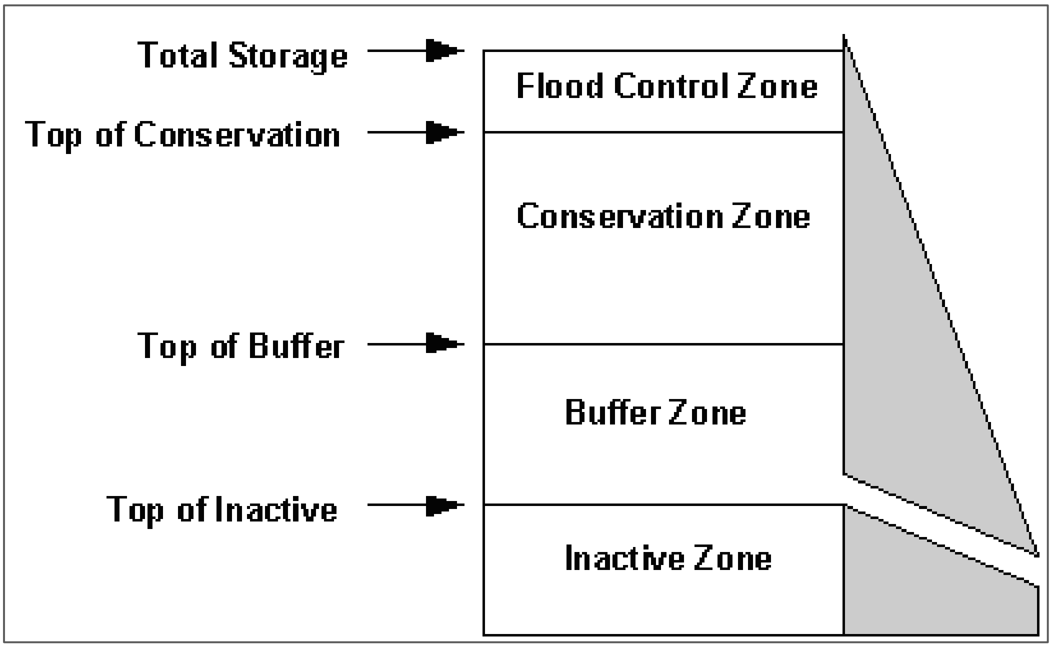


Figure 4.3: Reservoir Zones in WEAP. Source:(David Yates et al. 2005)

Defining the reservoir’s zones is a way to regulate water releases when the water level in the reservoir is within the buffer zone. As when the storage level drops into the buffer zone the release will be restricted according to the buffer coefficient. The buffer coefficient determines how much of the water that is in the buffer zone at the beginning of the timestep is available for release during this timestep.

When the water level is in the conservation zone, WEAP allows the reservoir to freely release water to fully meet downstream requirements. Water in the inactive zone is not available for allocation.

CHAPTER 5

THE TAGUS RIVER BASIN MODEL

5 THE TAGUS RIVER BASIN MODEL

5.1 MODEL DESCRIPTION

Building the model of the Tagus river basin in WEAP is a challenging process. It requires reflection of the system and its management. Getting the model to behave correctly or in a way close to the reality required a lot of steps in making assumptions, trying many operational options and most important to understand how the system is functioning in the real world. A system such as the Tagus basin with a complex network of large reservoirs and canals that ensure the water supply for a lot of demand sites makes the basin heavily managed and the system very complicated. Hence, for being able to build such a model strategies have been adopted to simplify the complicated system.

The first and most important step in simplifying the model is considering only the major and main rivers network in the basin and considering only the reaches where data for their streamflow is available. Another strategy is to aggregate some reservoirs that are located along the same river. Moreover, the number of the demand sites are reduced by aggregating all demand sites of the same use and within the same sub-catchment.

5.2 MODEL VALIDATION

Validation is defined as the demonstration of the accuracy of a model in representing the true system (Hassan 2006). In most studies, the conventional approach is to calibrate and then validate. Then the performance of the model is assessed and compared with the validation results. If the comparison is good then the model predicts the process well (Haji 2011).

In this study the model is validated through assessing the accuracy of the results of the model. This was done by comparing the results of the model in this study with the results of the model that was developed by the HPT (CHT 2013d). As a first step, and after entering all the elements into WEAP and running the model for the first time, the results of unmet demand for each demand sites in this study were compared with the results of the unmet demand of the HPT model. From the comparison, it was noticed that there are unacceptable deficits in some demand sites. In order to find the reason, a water balance analysis for each sub-catchment in the basin was conducted. This step helped the researcher to understand how WEAP is functioning and how the water is distributed between the demand sites. Moreover, the behavior of the majority of the reservoirs in supplying water for the demand sites was studied. From this analysis, it was noticed that there are some reservoirs that release water downstream when it is not needed by local demands or by other demands. In some cases this situation was acceptable, as the amount is very small and did not affect the reliability of the local demand sites. It was concluded from these studies, that it is important to define some management parameters in the model in order to obtain a better performance of the system. One of these parameters is "Supply Preference" which allows defining which water source should be used in priority to supply water to the same demand site, the other one is the "Buffer Coefficient" which provides a way to regulate water releases when the water level in the reservoir is within the buffer zone (D. Yates et al. 2005). The values of these factors have been identified by trial and error, until an acceptable behavior of the system was achieved.

5.3 DATA OF THE MODEL

In this section, the data that is introduced in the model for the baseline scenario is presented.

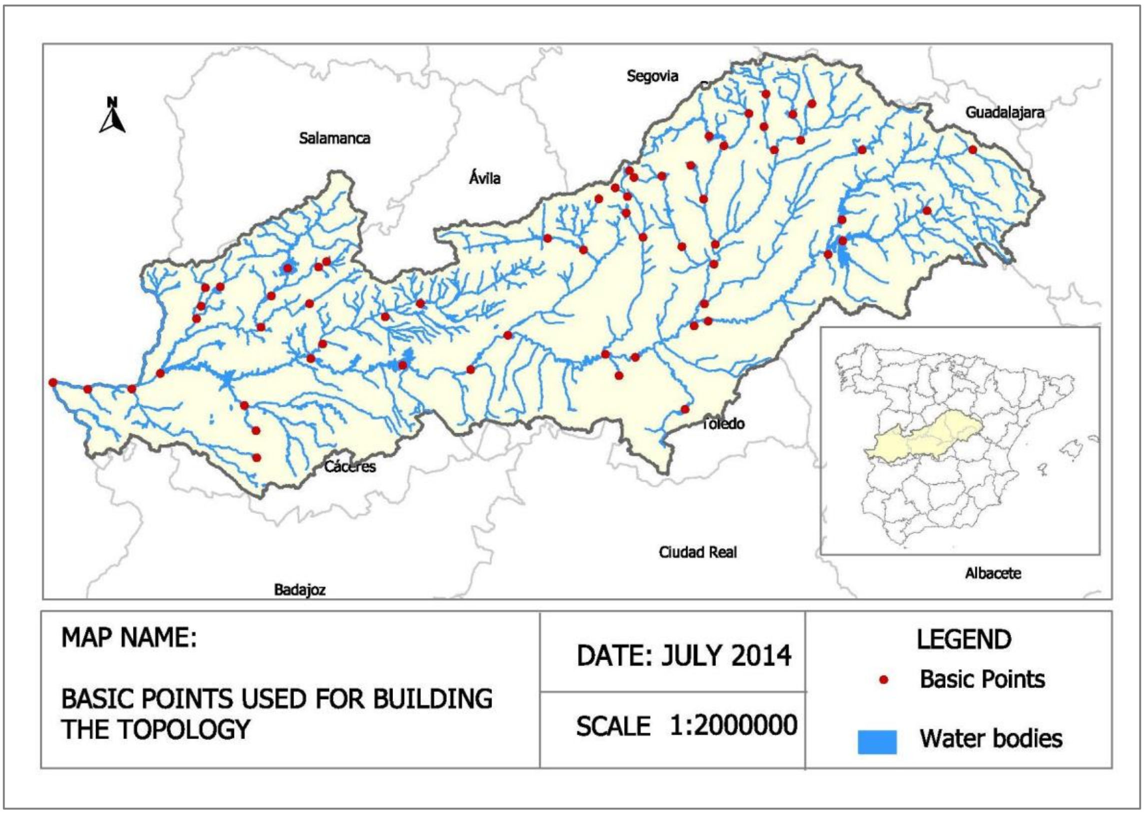
5.3.1 General parameters

The Current Accounts data forms the baseline Scenario "Reference Scenario" from year 1940 – 1996. The timesteps per year is set to be 12 and the timestep boundary to "Based on Calendar Month", starting with the month of October.

5.3.2 Basin topology

Two previous topologies of the Tagus River Basin have been used as a base in order to build the topology in WEAP: one based on the "National Hydrological Plan" (see Annex 5) (MARM 2000) and the other based on the "Project Proposal Hydrological Plan of the Spanish part of Tagus River Basin" (CHT 2013b).

The vector layers that used in the model in order to draw the topology are: *river network* layer, *boundary of the sub-catchments* layer, *reservoirs* layer and a layer that contains the *basic points* that present the location of reservoirs, streamflow inputs, withdrawal nodes and return flow nodes. The following map (Map 5.1) shows the distribution of these points in the Tagus Basin.



Map 5.1: Basic points used for building the model

Figure 5.1 shows the topology of the Tagus river basin that is built in WEAP.

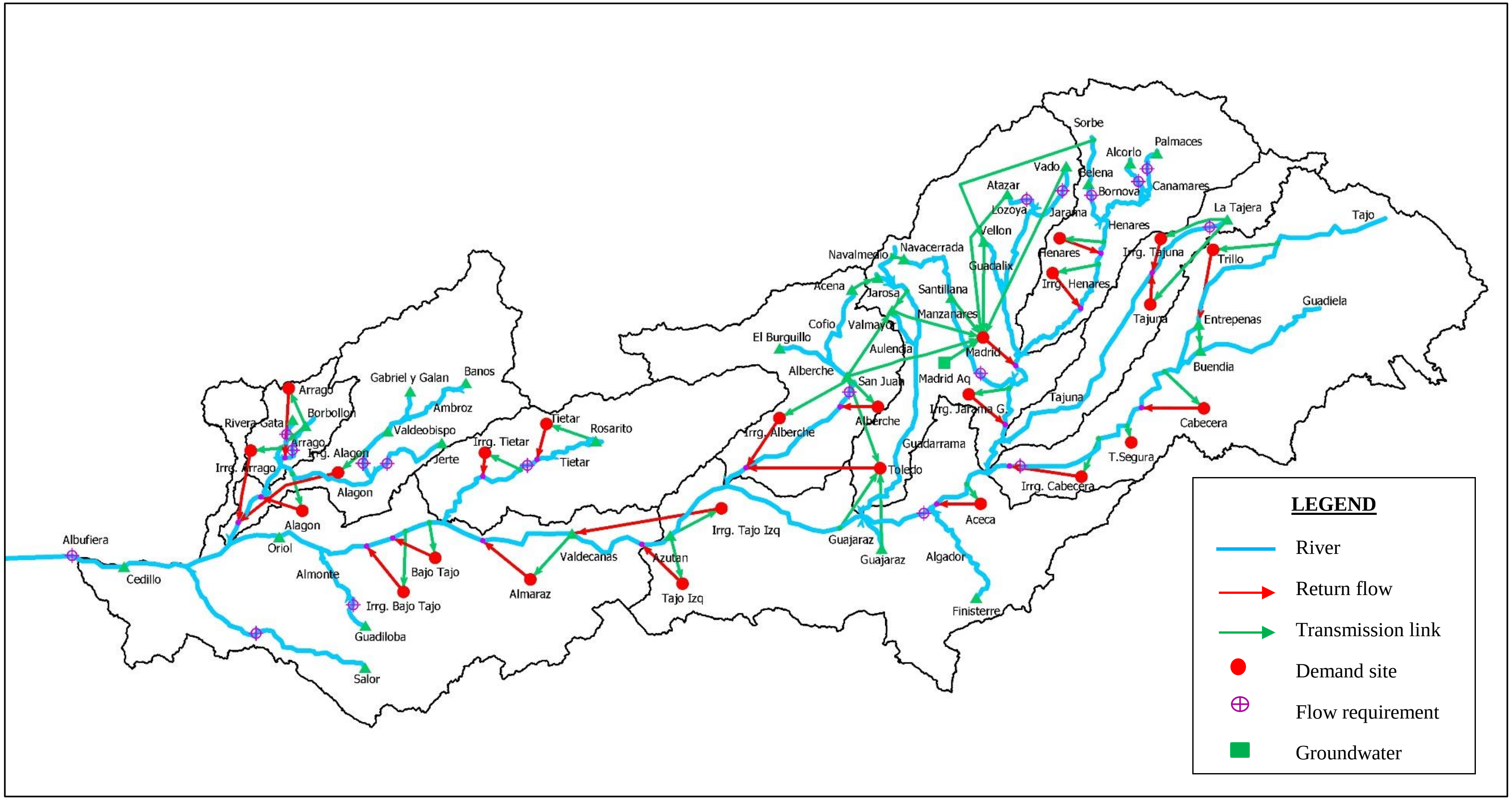


Figure 5.1: Tagus River Basin Topology in WEAP

5.3.3 Streamflow

The streamflow data were obtained from SIMPA model. The results of the SIMPA model are published in the webpage of SIA (MARM 2011). They consist of time series of monthly flow from the year 1940 to 1996. The flow data are entered in 39 points on the river network.

The annual average streamflows are shown in the following table (Table 5.1).

Table 5.1: The average annual and accumulated annual streamflow considered in the study

River	Inflow Point	Annual (hm^3/year)
Alagón	Alagón in Gabriel and Galán reservoir	893
	Alagón below Ambroz river inflow	158
Alberche	Alberche in Burguillo reservoir	428
	Alberche below Cofio river inflow	169
Algador	Algador in Finistrre reservoir	26
Árrago	Árrago in Borbollón reservoir	148
Aulencia	Aulencia in Valmayor reservoir	26
Baños	Baños in Baños reservoir	52
Bornova	Bornova in Alcorlo reservoir	67
Cañamares	Cañamares in Pálmaces	34
Cofio	Cofio in Aceña reservoir	13
Guajaraz	Guajaraz in Guajaraz reservoir	36
Guadiela	Guadiela headflow	481
Guadiloba	Guadiloba in Guadiloba reservoir	15
Guadalix	Guadalix in Vellon reservoir	47
Guadarrama	Guadarrama below Jarosa and Navalmedio rivers inflow	72
	Guadarrama below Aulencia river inflow	53
Jarama	Jarama in Vado reservoir	120
	Jarama below Lozoya river inflow	48
	Jarama below Henares river inflow	395

River	Inflow Point	Annual (hm^3/year)
Jerte	Jerte in Jerte reservoir	305
Jarosa	Jarosa in Jarosa reservoir	5
Lozoya	Lozoya in Atazar reservoir	228
Manzanares	Manzanares in Santillana reservoir	67
Navalmedio	Navalmedio in Navalmedio reservoir	15
Navacerrada	Navacerrada in Navacerrada reservoir	12
Rivera de Gata	Rivera de Gata in Rivera de Gata reservoir	112
Salor	Salor in Salor reservoir	21
Sorbe	Sorbe headflow / before Beleña reservoir	124
Tajo	Tajo headflow / before Entrepeñas reservoir	566
	Tajo below Jarama river inflow	452
	Tajo below Algador river inflow	96
	Tajo below Alberche river inflow	679
	Tajo below Azutan reservoir	302
	Tajo below Alagón river inflow	1,607
	Tajo below Salor river inflow	534
Tiétar	Tiétar in Rosarito reservoir	922
	Tiétar in Jaranda	916
Tajuña	Tajuña in Tajera reservoir	103
Total		**10,400**

5.3.4 Ground water aquifer

In the study one groundwater aquifer was taken into consideration that supplies water to Madrid with a maximum withdrawal 90 hm^3/year (CHT 2013d).

5.3.5 Water using activities

The water demands adopted in this study are obtained from “Hydrological Plan of the Tagus Basin” (CHT 2013c). Urban, Irrigation and industrial demands were considered as well as the transferred water from the Tagus Basin to the Segura Basin. As mentioned previously, the demands reflect the conditions of 2005, and were estimated in accordance with real data on withdrawals and the consumption (CHT 2013b). Multiple sources of information were used to obtain the demand data, including the Statistical Yearbook of Madrid Community for the years 1985-2007, the Water Commonwealth of Sorbe, and different Agricultural County offices (Comarcas).

Urban demand: it includes the domestic demand, the demand of local and institutional public services and water demand for commercial and industrial sites connected to the water network. The total yearly urban demand equals to 787 hm^3; of which 188 hm^3 are industrial demands.

Agricultural demand: it includes irrigation, forestry and livestock demand. For agricultural use, the estimates are based on gauging networks, and remote sensing studies. Actual consumption data for livestock and forestry is not available. The total yearly water demand for irrigation is about 1,826 hm^3.

Energy production: the Aceca thermal plants and Trillo and Almaraz nuclear plants were taken into consideration in the study. The total water demand for energy production is about 1,027 hm^3/ year.

Water Transfer: the water demand of the Tajo – Segura aqueduct that has been considered in the model is equal to the average transferred volume in the last 30 years, and it is 350 hm^3.

The (Table 5.2) shows the values of the urban, agricultural, energy production demand in each sub-catchment. The demands in this table are gross demands.

Table 5.2: Water demands considered in the Study (hm^3/year)

Sub - Catchment	Urban	Agricultural	Energy Production	Total
Cabecera	25.63	180.13	37.8	243.56
Tajuña	6.42	34.39	0	40.81
Henares	48.81	116.88	0	165.69
Jarama Guadarrama	597.67	214.19	0	811.86
Alberche	27.8	113.26	0	141.06
Tajo Izquierda	29.49	216.3	551.88	797.67
Tiétar	14.34	234.78	0	249.12
Alagón	11.81	522.27	0	534.08
Árrago	2.48	90.37	0	92.85
Bajo Tajo	22.2	103.82	436.9	562.92
Total	**786.65**	**1826.39**	**1026.58**	**3639.62**

Source: (CHT 2013b)

The monthly variation for water demand is shown in the figure below (Figure 5.2).

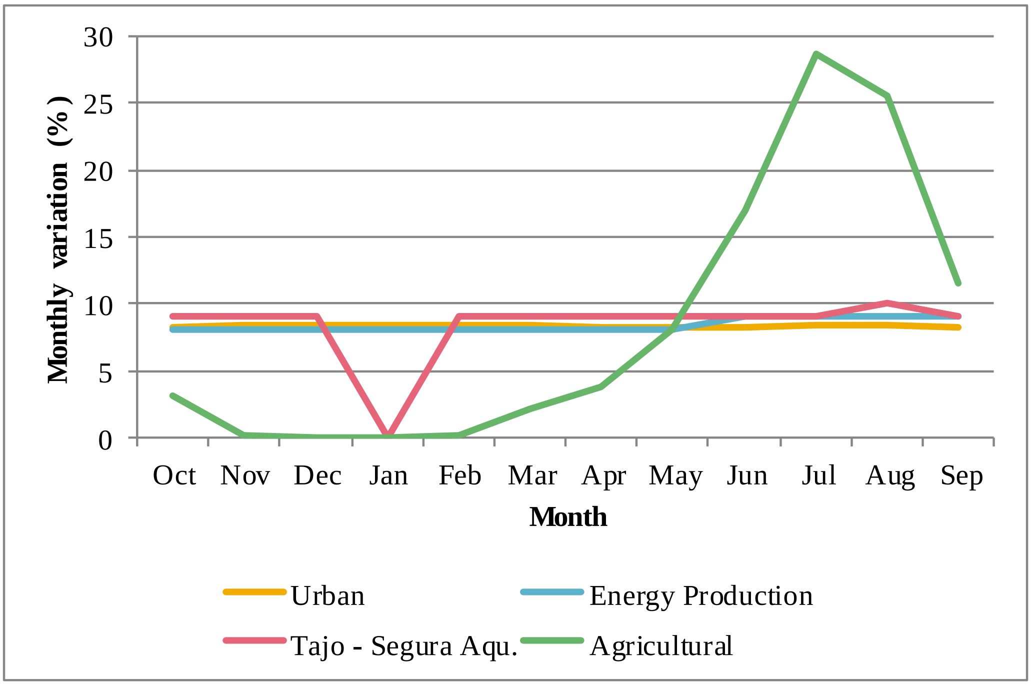


Figure 5.2: Monthly variation of water demand

5.3.6 Water demand priority

As shown earlier, demand has been classified into four different types: urban demand, agricultural demand, energy production demand and water transfer demand. The urban demand holds the highest priority for water supply in the system, agricultural demand holds the second priority, energy production demand holds the third priority, and the water transfer demand is the fourth in the supply priority order.

5.3.7 Transmission links

The transmission links are used in the model to connect between demand site and its supply sources. Some of the demand sites are connected to more than one supply resource, a demand site's preference for each source of water can be assigned. The Supply Preference is attached to the transmission links. In the baseline scenario almost all demand sites that have more than one water supply resource have no preference. Therefore the supply preference is set to 1 in all their transmission links. This is not the case in Madrid demand site which is located in Jarama Guadarrama sub-catchment and is supplied from many resources, the supply preference is defined for each source of water depending on the reservoir storage (if the source is reservoir) and on the number of sites that are supplied from the same source.

5.3.8 Return flow

The return flow is an important component in the water balance in the basin. The percentage of the return flow for urban, agricultural and energy production demand sites is shown in Table 5.3.

Table 5.3: return flow as percentage of gross demands by type of demand and sub-catchment [%]

Sub - Catchment	Agricultural	Urban	Energy Production
Cabecera	14	80	45
Tajuña	9	80	
Henares	15	80	
Jarama Guadarrama	17	80	
Alberche	16	80	
Tajo Izquierda	11	80	97
Tiétar	14	80	
Alagón	19	80	
Árrago	19	80	
Bajo Tajo	8	80	90

Source: (CHT 2013c)

5.3.9 Reservoirs

As mentioned before, the most representative reservoirs in the basin were included in the model. Some of the parallel reservoirs were aggregated into one reservoir. The aim of this strategy is just for simplification of the model and does not affect the study result.

The following table (Table 5.4) shows the reservoirs that have been considered in the study with their storage capacity. The initial storage was considered to be 50% of the capacity storage of the reservoir. The reservoir filling was given the lowest priority; it means that it will fill only after all other demands have been satisfied.

As mentioned before, calculating the net evaporation from the reservoirs depends on the monthly net evaporation rate and the Volume – Elevation Curve. The monthly net evaporation rate for each reservoir is shown in Annex 6.

Table 5.4: Reservoirs considered in the Study

Reservoir	Sub-catchment	River	Capacity (hm^3)
Entrepeñas	Cabacera	Tajo	684
Buendía		Guadiela	1,557
La Tajera	Tajuña	Tajuña	65
Palmaces	Henares	Cañamares	30
Alcorlo		Bornova	171
Beleña		Sorbe	48
El Vado	Jarama Guadarrama	Jarama	53
El Atazar		Lozoya	554
El Vellon		Guadalix	39
Navacerrada		Navacerrada	10
Santillana		Manzanares	86
La Jarosa		Jarosa	7
Valmayor		Aulencia	118
El Burguillo	Alberche	Alberche	185
La Aceña		Cofio	23
San Juan		Alberche	156
Finisterre	Tajo Izquirda	Algodor	126
Guajaraz		Guajaraz	25
Azutan		Tajo	107
Rosarito	Tiétar	Tiétar	113
Valdeobispo	Alagón	Alagón	50
Baños		Baños	39
Gabriel y Galan		Alagón	878
Jerte		Jerte	54
Rivera de Gata	Árrago	Rivera de Gata	46
Borbollon		Árrago	81
Oriol	Bajo Tajo	Tajo	3,000
Cedillo		Tajo	247
Guadiloba		Guadiloba	19
Salor		Salor	13
Valdecañas		Tajo	1,374

5.3.10 Artificial aqueducts

The following table (Table 5.5) summarizes the artificial water aqueducts that have been considered in the study with their maximum flow volume.

Table 5.5: Artificial water aqueducts considered in the Study

Water aqueducts Name	**Q_{max} (hm³/month)**
Aceña – Jarosa	26
Atazar	36
Borbollon – Rivera Gata	24
Entrepeñas– Buendía	436
Impulsion Picadas	10
Impulsion San Juan	17
Isabel II canal	61
Jarama canal	20
Navalmedio – Navacerrada	15
Nieves - Valmayor	78
Santillana canal	10
Sorbe canal	8
Valmayor canal	15
Vellon canal	21
Picadas – Toledo	2.6

5.3.11 Albufeira minimum flow

The Albufeira agreement that regulates how much water Spain needs to release to Portugal has been considered in the model as a flow requirement after Cedillo reservoir with a minimum flow of 2,700 hm^3/ year. The flow requirement for the Albufeira agreement was given a priority lower than the priority of all demand sites.

5.3.12 Environmental flows

The values of the minimum flows in the Tagus river basin is show in the Table 5.6.

Table 5.6: Values of Environmental Flows in the Tagus river basin (m³/sec)

Control point	Average
Alagón (Valdeobispo)	1.83
Alberche (San Juan)	1.21
Árrago (Borbollón)	0.30
Bornova (Alcorlo)	0.19
Cañamares (Pálmaces)	0.08
Jarama (El Vado)	0.30
Jerte (Jerte – Plasencia)	1.15
Lozoya (El Atazar)	0.88
Manzanares (El Pardo)	0.99
Rivera de Gata (Rivera de Gata)	0.12
Sorbe (Beleña)	0.29
Tajo (Aranjuez)	6.00
Tajo (Toledo)	10.00
Tajuña (La Tajera)	0.50
Tiétar (Rosarito)	0.54
Tiétar (Navalcán)	0.03
Tiétar (Pajarero)	0.00
Guadiloba (Guadiloba)	0.07
Salor (Salor)	0.02

Source: (CHT 2013b)

CHAPTER 6

Performance of the System under Historical Climate

6 PERFORMANCE OF THE SYSTEM UNDER HISTORICAL CLIMATE

In this chapter, the results of the baseline scenario will be presented and discussed. As it is mentioned before, the baseline scenario is established by computing the model with the 2005 water demands for the 56 years of historical inflow data available.

6.1 STREAM FLOW

The natural streamflow (mean annual inflow entering the hydrological system) in the basin has an average value of 10,400 hm^3, with a maximum of 26,143 hm^3 in the year 1940/1941 and a minimum of 2,216 hm^3 in the year 1991/1992 (Figure 6.1). As a result of the human activities and water demands in the basin the average yearly streamflow is reduced to 7,855[3] hm^3/ year. The Figure 6.1 compares the yearly natural streamflow of the whole basin with the yearly accumulated streamflow in the Cedillo reservoir which corresponds to the flow that can be transferred to Portugal (Figure 5.1).

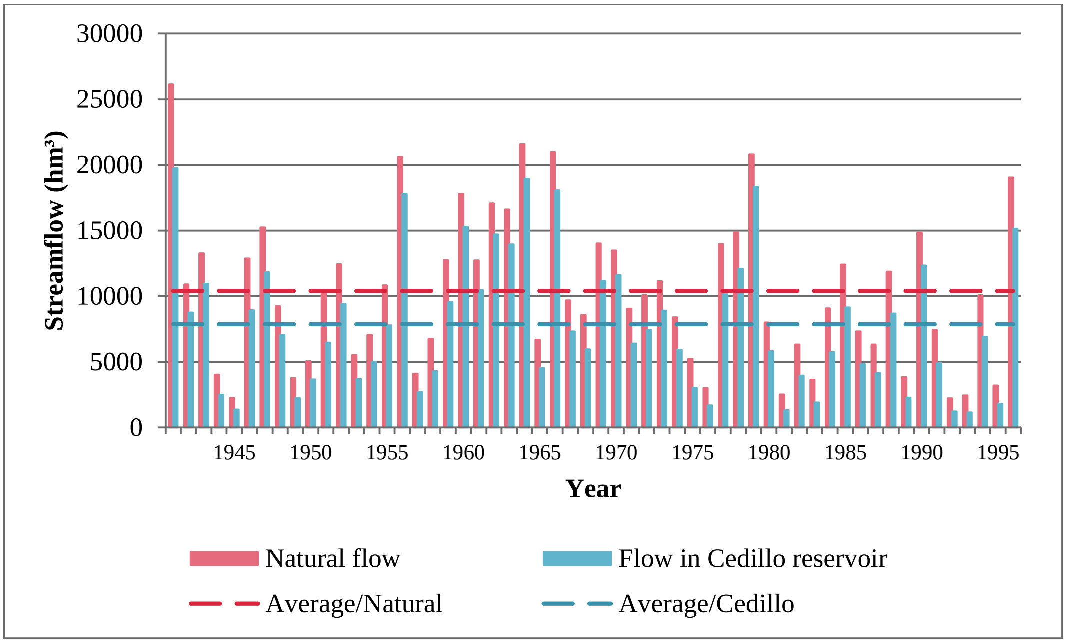


Figure 6.1: Yearly average streamflow in Tagus river basin.

Natural flow corresponds to the streamflow entering the river network and the flow in the Cedillo reservoir corresponds to the flow that can be transferred to Portugal.

[3] Total inflow - (gross demand – return flow) – evaporation

The Table 6.1 shows the annual contribution by each sub-catchment to the total inflow in the Tagus river basin. It's noticed that the Bajo Tajo sub-catchment has the higher contribution in the basin with a percentage of 24%, followed by the sub-catchments of Tietár and Alagón.

Table 6.1: Average annual inflow in natural regime by sub-catchment

Sub-catchment	**Average Annual flow (hm³/year)**	**Sub-catchment**	**Average Annual flow (hm³/year)**
Cabecera	1,057.81	**Tajo Izquierda**	1,289.09
Tajuña	103.73	**Tietár**	1,855.14
Henares	226.81	**Alagón**	1,418.86
Jarama Guadarrama	1,094.18	**Árrago**	262.07
Alberche	614.86	**Bajo Tajo**	2,480.10
Tagus Basin	**10,402.64**		

6.2 UNMET DEMAND AND DEMAND COVERAGE

The total gross demand in the basin is 3,640 hm^3/ year approximately. In the simulation some of the water demand sites experience periods of unmet demand, even during normal years. The average annual unmet demand over the study period for the whole demand sites in the basin is about 64 hm^3 (Figure 7.2).

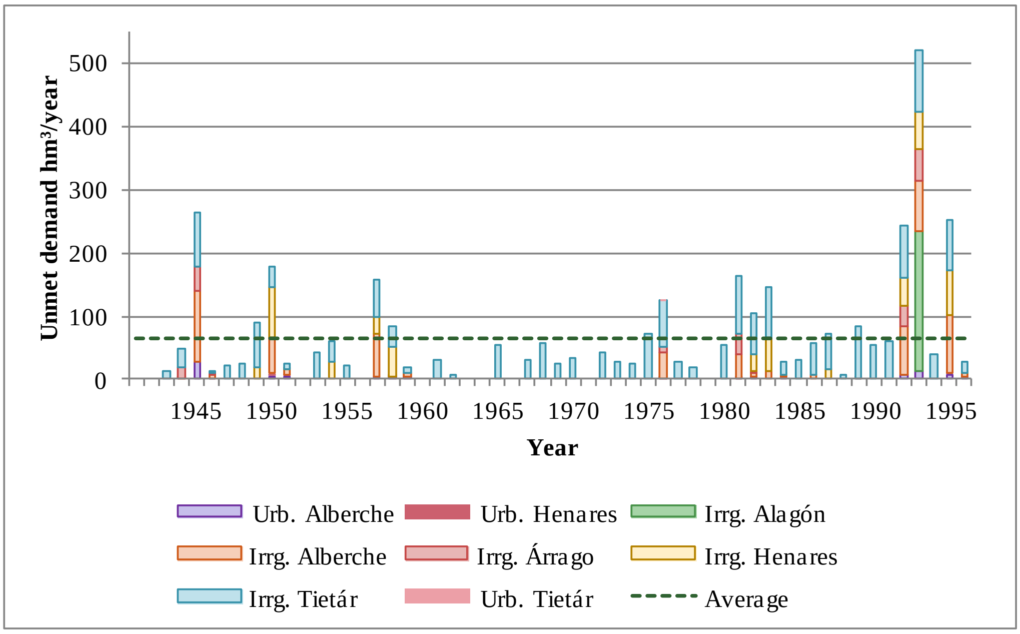


Figure 6.2: Yearly unmet demand in baseline scenario

As it is shown in (Figure 6.2) the highest unmet demand is experienced for the hydrological year 1992/1993 and is equal to 522 hm^3. By looking to (Figure 6.1) it is clear that the basin experiences a dry season, as the natural streamflow between the years 1991-1993 is very low, which explains the severe shortage in this year. In addition, there are other years where the deficit is also high, such as the years of 1945, 1950, 1992 and 1995. Furthermore, it is noted from (Figure 6.2) that there are plenty of years, especially between the years 1961-1975, where there is just deficit in Tietár agricultural demand sites.

According to the estimations that have been taken into consideration about the return flow, the yearly average return flow to the basin is about 1,842 hm^3.

6.2.1 Urban unmet demand

Regarding the urban demand sites, there are three demand sites that experience deficits: Alberche, Henares and Tietár demand sites (Figure 6.2). The Alberche demand site has the highest total deficit during the study period followed by Henares demand site and then by Tietár demand site. It is worth mentioning that the Tietár demand site experiences water shortage only in the month (November 1975), while Alberche and Henares demand sites experience deficit in several months and years.

However, according to the Spanish legislations (CHT 2013b) the urban water demand can be considered satisfied: (1) when the deficit in one month does not exceed 10% of the corresponding monthly demand, and (2) if for ten consecutive years, the sum of deficit over the ten years does not exceed 8% the annual demand. Regarding this, the water demand for the Tiétar site can be considered satisfied. However, this is not the case for the Alberche and Henares demand sites; there are several months throughout the study period where they experience deficit that is higher than 10% of the monthly water demand. The number of months where the deficit is higher than 10% is 40 months for Alberche demand site and 10 months for Henares demand site out of a total of 12*54=648.

6.2.2 Irrigation unmet demand

97% of the total unmet demand through the study period is in irrigation demand sites and the rest is in urban demand sites. There are five irrigation demand sites that experience deficit: Alagón, Alberche, Árrago, Henares, and Tietár. The table below shows the reliability in time for the agricultural demand sites that have deficit and the number of months where there is deficit (Table 6.2). The reliability refers to percentage of months in which a demand site's demand was fully satisfied.

Table 6.2: Reliability and number of months of deficit

Demand site	Reliability (%)	Nº of months of deficit
Irrg. Alagón	99.6	3
Irrg. Alberche	93.2	46
Irrg. Árrago	97.2	19
Irrg. Henares	94.0	40
Irrg. Tietár	88.4	78

According to the Spanish legislation (CHT 2013b) the irrigation water demand can be considered satisfied if: (1) the deficit in one year does not exceed 50% of corresponding demand, (2) in two consecutive years, the total deficit does not exceed 75% of annual demand, (3) for ten consecutive years, the total deficit does not exceed 100% of annual demand.

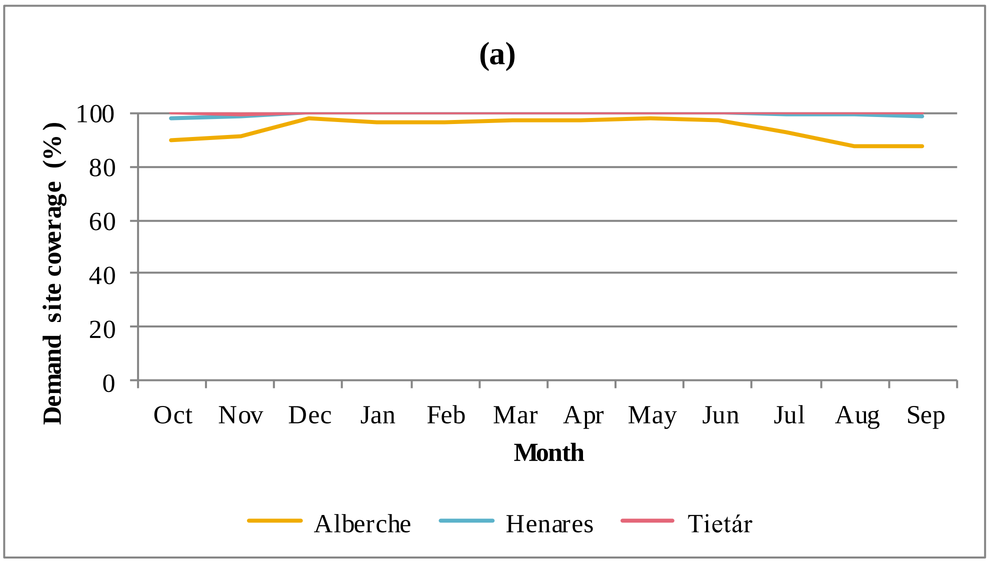
As a result, the water demand of the Alagón demand site can be considered satisfied as it complies with the three conditions; as it experiences a deficit of three months in one single year which corresponds to a reliability in time of 99.6%. The agricultural demand site of Tietár experiences deficits during almost all the years of the study period with reliability in time of 88.4%; it complies with the first and third condition in all years of study period and does not comply with the second condition just in 1992/1993. The other three demand sites do not comply with the first and second conditions in some of the years.

6.2.3 Other demands

The Aqueduct of Tajo – Segura is considered as a demand site in the model with a yearly water demand of 350 hm^3, the results of the simulation shows that it doesn't experience deficit in the entire study period.

6.2.4 Monthly variation

During the year, the months of deficit vary from one demand site to another, but in general all of them experience the deficits during the months of June to September. However, there are sites, such as the Alberche urban demand site, where in each year of deficit it experiences shortage of water in different months (Figure 6.3). Most of the agricultural demand sites have water shortage starting from the month of June until the month of November. The Figure 6.3 shows the monthly variation in the demand sites coverage[4] in percentage for both urban and agricultural demand sites.



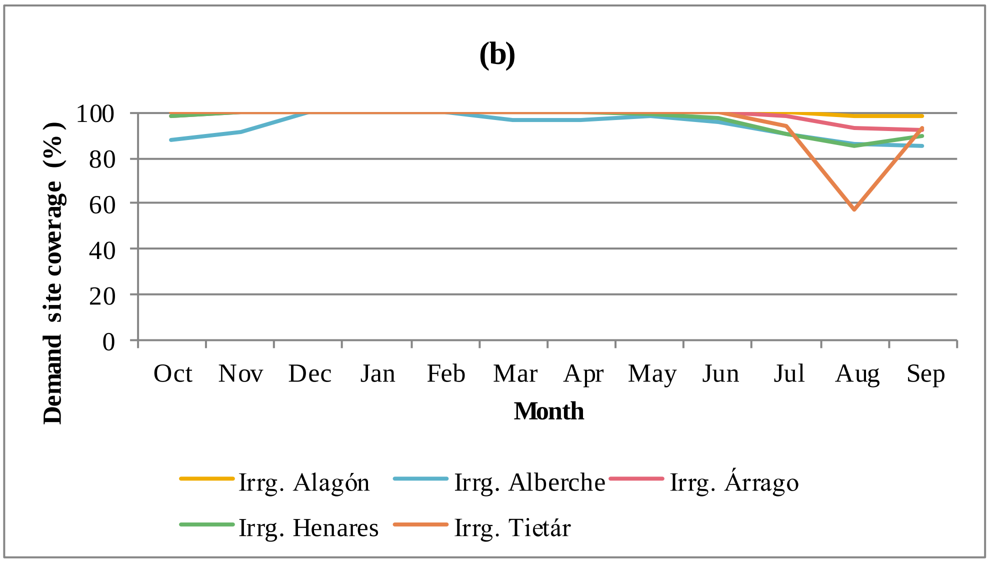


Figure 6.3: Percentage of demand site Coverage in (a) Urban demand sites, (b) Agricultural demand sites

[4] Demand site coverage is the percent of each demand site's requirement that is met. The coverage percent gives a quick assessment of how well demands are being met.

6.2.5 Principle problems

The most complicated zone in the basin is the Jarama Guadarrama sub-catchment and the sub-catchments around it due to the large urban demand of Madrid. The water demand of the Community of Madrid is being satisfied from the water resources of Jarama Guadarrama sub-catchment as well as Henares and Alberche sub-catchments, which lead to a complex water management in this area of the basin. Moreover, this situation is affecting the supply delivered to the demand sites in Alberche and Henares sub-catchments, especially the agricultural demand sites which have a lower priority than the Madrid urban demand site.

Moreover, the upper basin of the Tagus consumes water more than 60% of the total demand in the basin, while it contributes to about 40% of the water resources in the basin. In the Hydrological Plan of the Tagus, this was considered as one of the principle problems in the basin, as it causes low flow in some critical points in the river and associated water quality problems.

6.3 RESERVOIRS' STORAGE

The following figure (Figure 6.4) shows the monthly variability of storage of the modelled reservoirs during the study period. The maximum storage capacity of the reservoirs is 9,960 hm^3, this amount of storage isn't reached in any time during the study period. The average value of the reservoirs' storage is 8,800 approximately. The average value of net evaporation of the modelled reservoirs is 420 hm^3/ year.

During the study period the storage drops to a low value such as in the year 1993, when many reservoirs reach their minimum storage. In the basin there are reservoirs that have almost constant water storage during all years of the study period, while others experience a big change in the storage from one month to another in the same year. This is due to the location of the reservoir and its use. For example, the San Juan reservoir (Figure 6.5) shows high storage variability and several times it reaches zero storage. This is because it is a small reservoir supplying large users such as Madrid, Toledo, Alberche and Irrg. Alberche demand sites as well as transferring water to the Valmayor reservoir. On the other hand, the water storage in Azutan reservoir is almost constant through the different months in the study period. While in other reservoirs such as Buendía and Atazar there are years where the storage is almost constant and years where there is a big change in storage between one month and another.

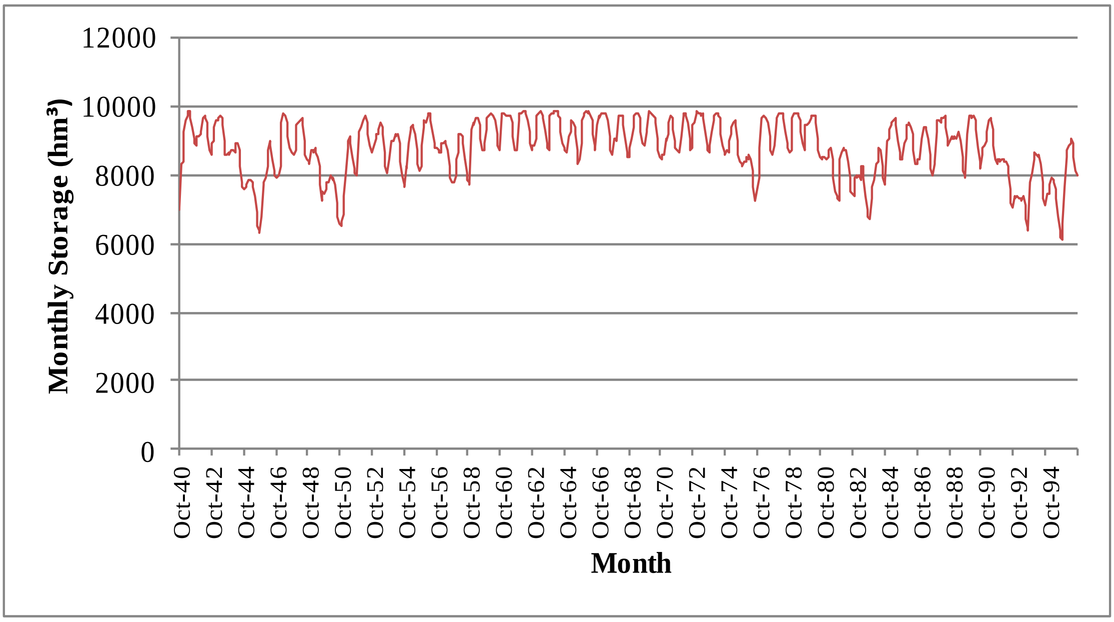


Figure 6.4: Monthly storage of the modelled reservoirs in the basin

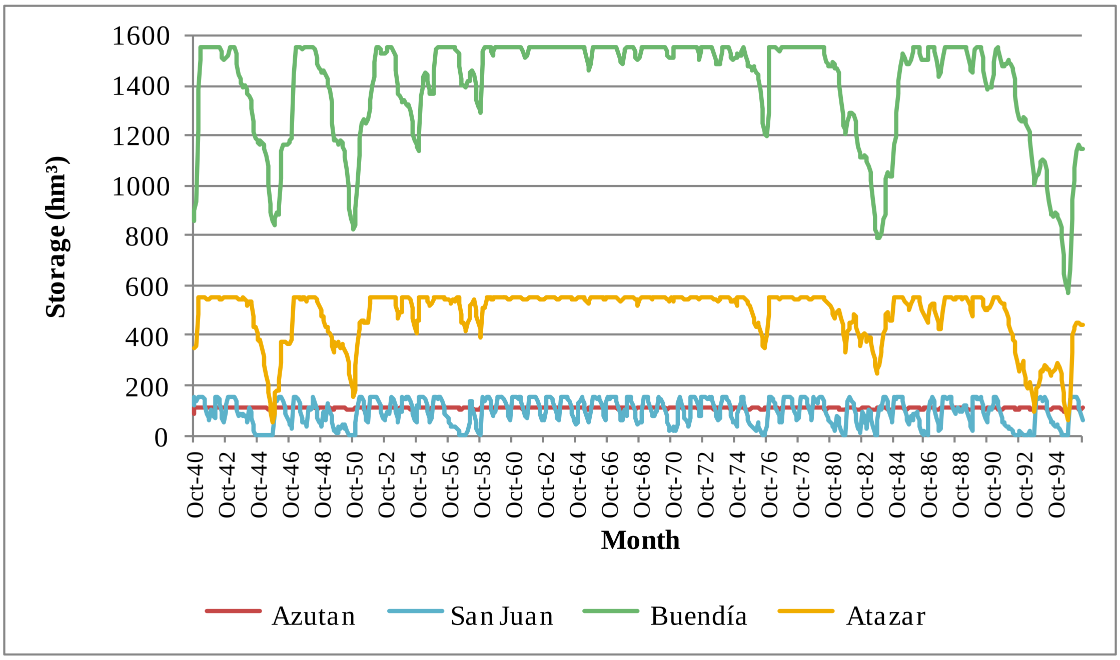


Figure 6.5: Monthly storage variability of four reservoirs in the basin

6.4 TRANSFERRED WATER

As mentioned in the previous chapter, artificial aqueducts were taken into consideration in the model topology. These aqueducts transfer water between reservoirs or between reservoirs and demand sites within the same sub-catchment or from one sub-catchment to another. Four aqueducts transfer water to the Jarama Guadarrama sub-catchment. The yearly average quantity of transferred water is about 220 hm^3, of which 185 hm^3 are transferred from Alberche sub-catchment and the rest are from Henares sub-catchment. The other artificial aqueducts transfer water within the same sub-catchment.

6.5 ALBUFEIRA CONVENTION

According to the analysis of the precipitation data for the period (1940 – 1996) of in the basin which was conducted in the "National Hydrological Plan", there are eleven years that have been considered as "Exceptional Periods" where Spain is not obliged to supply the whole quantity of water to Portugal.

In this section, the results of the simulation related to the streamflow below the Cedillo reservoir are analyzed and compared with the previous results. The Figure 6.6 and Figure 6.7 show the annual streamflow below the Cedillo reservoir in two cases; 1) the Albufeira flow requirement was given a priority lower than all demands sites and reservoirs except the Cedillo reservoir, 2) the Albufeira flow requirement was given a priority lower than all demands sites and reservoirs except the Cedillo and Oriol reservoirs. Both cases were compared with the annual minimum flow of Albufeira Convention.

In the first case, the flow below the Cedillo reservoir is lower than the minimum flow of Albufeira Convention in eleven years, while in the second case it is lower one time in the year 1992/1993. This means that the Albufeira minimum flow can be satisfied in the Exceptional periods but this will affect the water level in both reservoirs (Cedillo and Oriol), where in some months the water level reach zero.

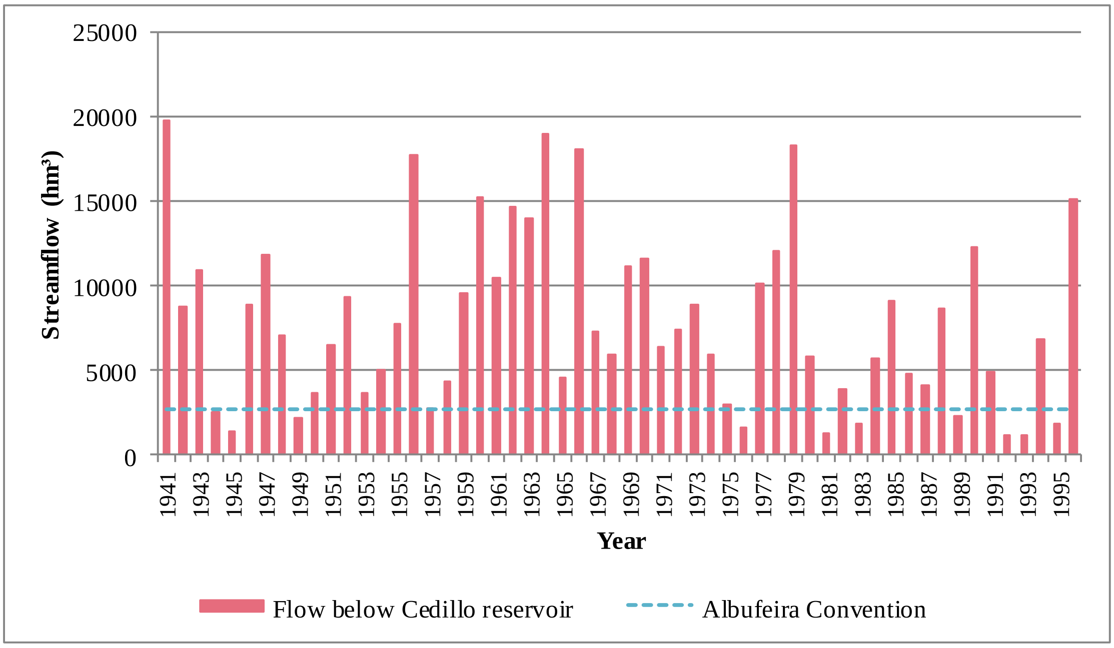


Figure 6.6: Obtaining the minimum flow regime according the Albufeira Convention, first case. Albufeira has a priority lower than all demands sites and reservoirs except the Cedillo reservoir

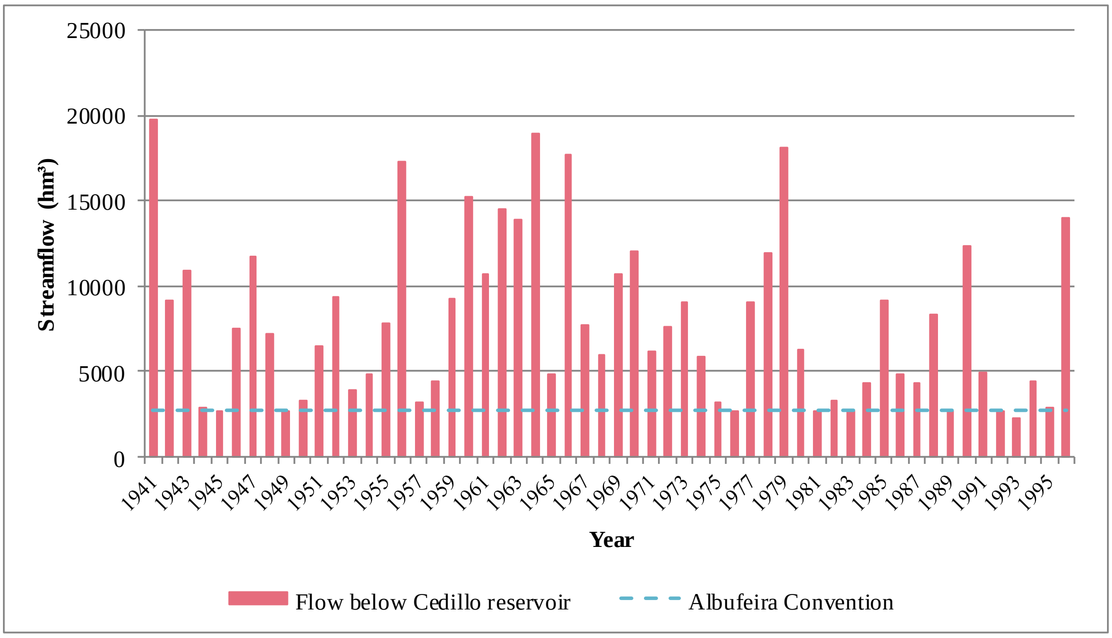


Figure 6.7: Obtaining the minimum flow regime according the Albufeira Convention, second case: Albufeira flow requirement has a priority lower than all demands sites and reservoirs except the Cedillo and Oriol reservoirs

6.6 ENVIRONMENTAL FLOWS

The reliability of the environmental flow is studied in two cases of priority, first when they have the lowest priority and then the highest priority. In the first case, the reliability of satisfying the environmental demand is high for all control points except Manzanares control point, where its reliability is less than 70%. Satisfying the environmental demand lead to an increase in the mean annual unmet demand in the basin from 64 to 170 hm^3/year.

However, in the second case the environmental flow is met only in two control point: Rosarito and Toledo. The reliability of satisfying the environmental flow in the other control points is below 70% and in some cases below 10% (e.g. Manzanares) (Figure 6.8).

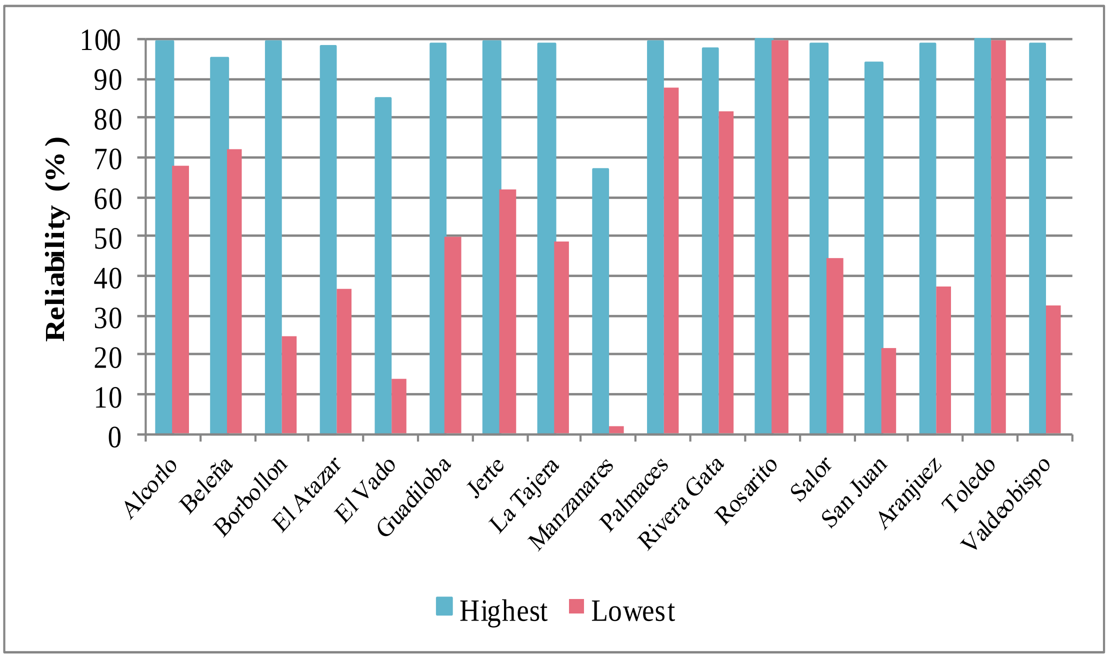


Figure 6.8: The reliability of meeting environmental flow requirement for assigning highest or lowest priority to environmental flows

A summary of the water balance in the basin: the overall inflow into the basin is about 10,400 hm^3/year. The supplied demand is equal to 3,925 hm^3/year, and 1,842 hm^3 of them return to the river network. The evaporation losses from the reservoirs equal to 420. The outflow of the basin is 7,855 hm^3.

CHAPTER 7

PERFORMANCE OF THE SYSTEM UNDER CLIMATE CHANGE SCENARIO

7 PERFORMANCE OF THE SYSTEM UNDER CLIMATE CHANGE SCENARIO

In this section, the impact of A2 climate change scenario on the water resources in the basin will be discussed for short, mid and long term horizons. The results of the simulation will give a general idea about the sensitivity of the basin to climate change in the future.

7.1 IMPACT ON STREAMFLOW

The shape of the climate change scenario is reflected clearly in the value of the natural flow in the basin, where it is growing slowly in the beginning and very quickly at the end. The impact of the climate change scenario on the short and mid-terms is smaller than the impact on the long term. The following figure shows the impact of A2 climate change scenario on the annual value of the natural streamflow in the Tagus river basin among the study period. The average value of the natural stream flow in the basin is decreasing from 10,400 hm^3 in the reference scenario to 6,760 hm^3 in the year 2085 (long term) of A2 scenario (Figure 7.1).

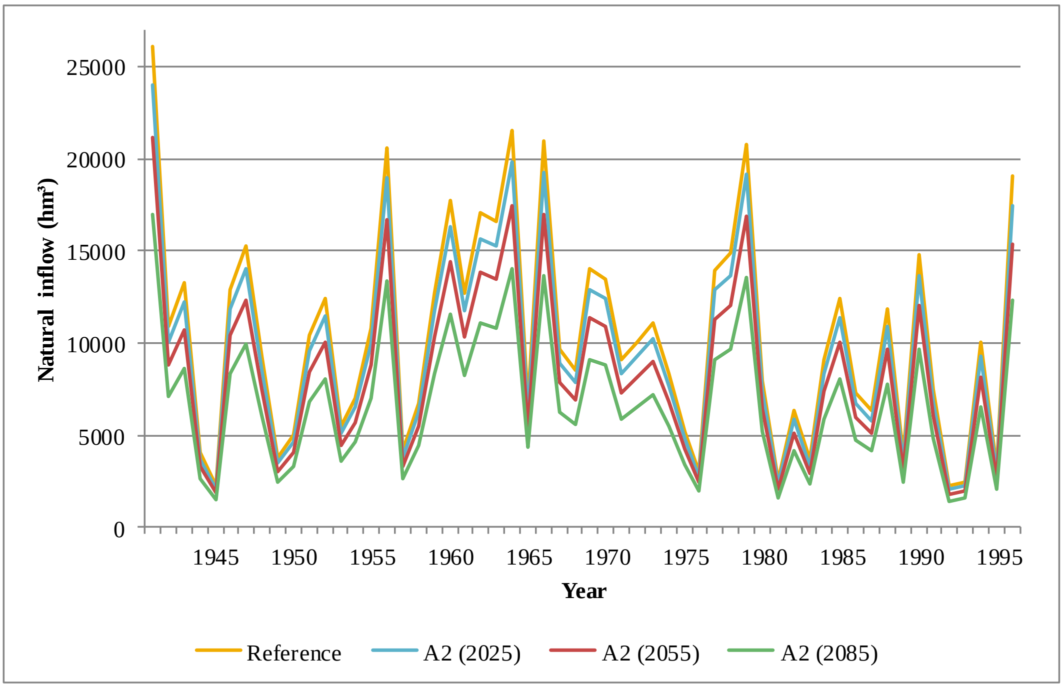


Figure 7.1: The average value of natural stream flow in the Tagus River basin for A2 scenario

7.2 IMPACT ON THE UNMET DEMAND

The results of the simulation show that the unmet demand in the basin tends to increase due to the A2 climate change scenario. The following figure (Figure 7.2) shows the annual unmet demand over the study period for the three horizons of the A2 climate change scenario. The value of the unmet demand in the basin is growing significantly by moving in time, but the difference between the value of the unmet demand in the first two scenarios (short term and mid-term) and reference scenario is minor compared to the difference between the value of the unmet demand in the third scenario (long term) and reference scenario.

This means that the nature of the problem that the basin is facing in the current situation and in the short and mid-terms scenarios is relevant, thus the type of applied water management in the basin might be similar, but moving to the long term scenario where the reduction in the unmet demand is much stronger, this exposes the basin to different problems where different types of water management need to be considered.

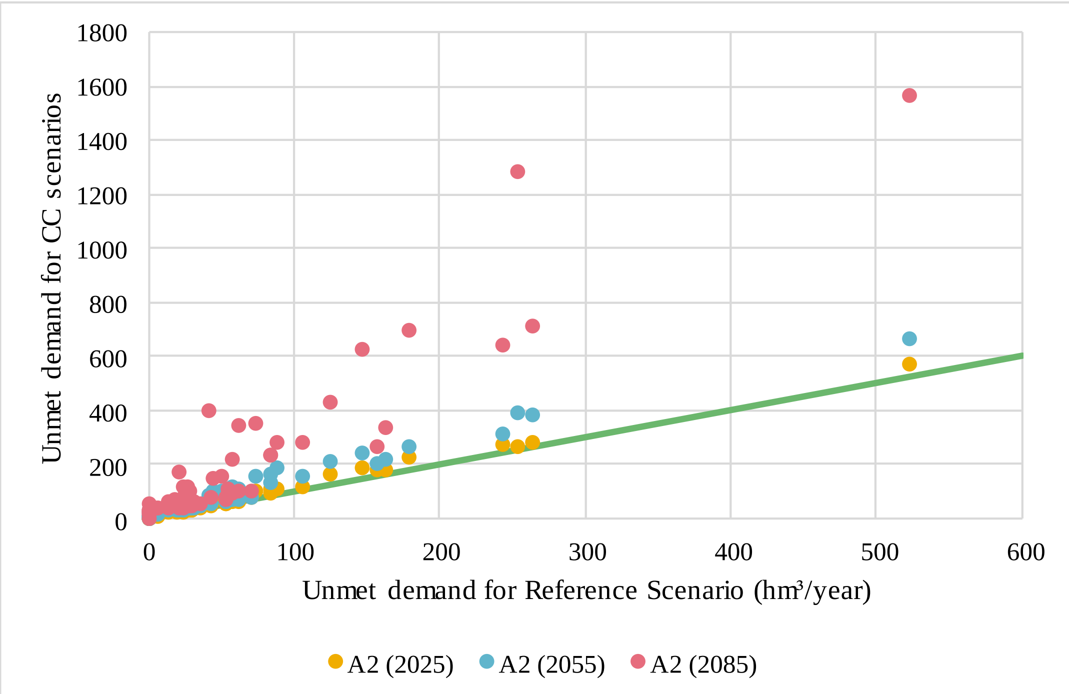


Figure 7.2: Yearly unmet demand based on A2 emission scenario

The following figure (Figure 7.3) shows the different values of the annual average unmet demand in the three cases of scenario A2 (green line). It also shows the distribution of this value by the type of the demand. This figure also supports the previously discussed idea: unmet agricultural demand in the reference scenario and in the short and mid-terms scenarios has the highest percentage of the total unmet demand, and the unmet urban demand has a small percentage. On the other hand, the total unmet demand in the long term scenario is distributed differently. The percentage of the unmet urban demand is increased and the basin experiences for the first time unmet demand for energy production sites and for transferring water to Segura Basin.

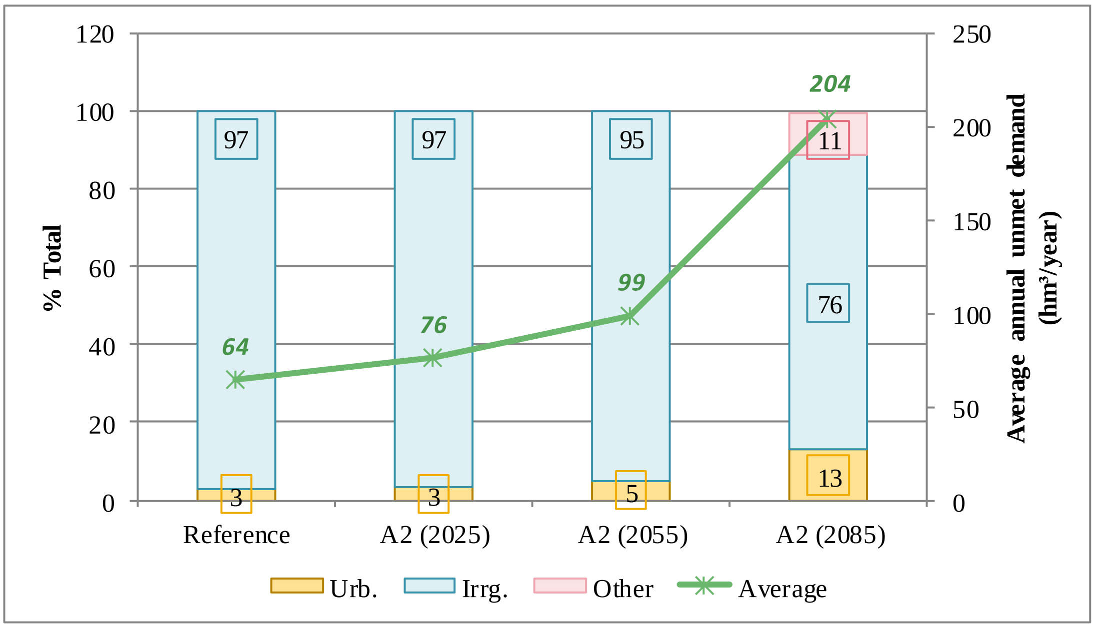


Figure 7.3: Impact of the A2 climate change scenario on the unmet demand in the basin

Figure 7.4 shows the demand sites that have a deficit in the climate change scenarios and their reliability in time.

The water deficit in the urban demand sites is not high compared to the water deficit in the agricultural demand sites. However, there are urban demand sites that do not experience deficit, such as Toledo, Bajo Tajo and Cabecera, and there are other urban demand sites that only experience deficit on the long term scenario such as Tajuña. On other hand, the unmet demand for Henares and Alberche demand sites is higher than other urban demand sites with a reliability below 90%.

The Madrid demand site starts experiencing shortage from the mid-term and the shortage grows in the long term scenario with a reliability of 96%. The water deficit in demand sites such as Madrid and Tajuña can be solved locally by transferring water from other sub-catchments in the basin or from other basins like Duero.

As it was discussed earlier in the previous section, the agricultural demand is the real problem in the basin. This result also is relevant to the performance of the basin under climate change scenarios, and the problem is getting bigger on the long term scenario. The reliability for some agricultural demand sites is lower than 90%, for example Tiétar agricultural demand site is facing a problem that is growing clearly by time, as well as Henares and Alberche demand sites, where their reliability in the long term is below 85%.

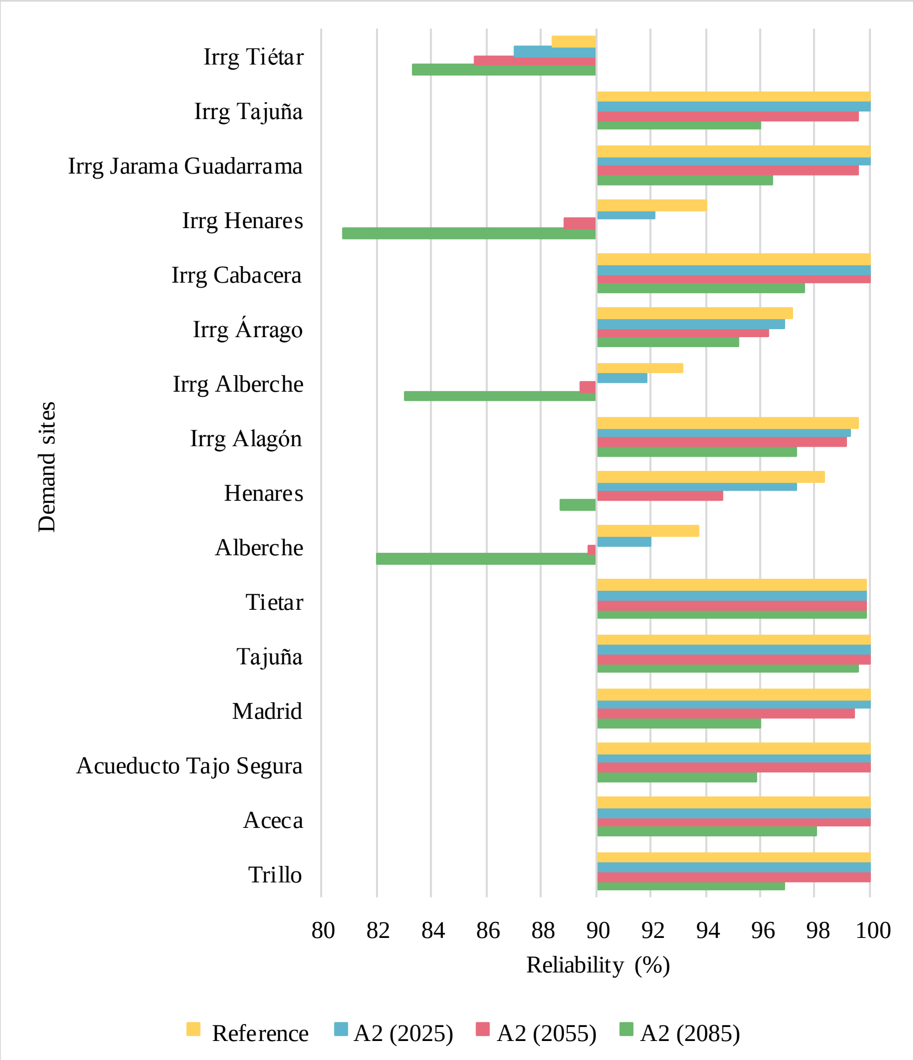


Figure 7.4: Demand sites reliability under climate change scenarios

The following table gives more details about the unmet demand for all demand sites in the basin for the reference scenario and climate change scenarios (Table 7.1).

Table 7.1: Summary of water demands and the unmet demands for all considered demand sites for the reference and climate change scenarios

Demand Site	Water Demand (hm³/year)	% of Total demand	Unmet Demand (hm³/year)			
				A2 Emission Scenario		
			Reference	2025	2055	2085
Urban Demand						
Alagón	11.81	0.30	0.00	0.00	0.00	0.00
Alberche	27.8	0.70	1.62	1.99	2.59	4.54
Árrago	2.48	0.06	0.00	0.00	0.00	0.00
Bajo Tajo	22.2	0.56	0.00	0.00	0.00	0.00
Cabecera	25.63	0.64	0.00	0.00	0.00	0.00
Henares	48.81	1.22	0.23	0.43	0.98	2.69
Madrid	597.67	14.98	0.00	0.00	1.29	19.08
Tajo Izquierda	18.51	0.46	0.00	0.00	0.00	0.00
Tajuña	6.42	0.16	0.00	0.00	0.00	0.001
Tietár	14.34	0.36	0.004	0.005	0.06	0.07
Toledo	10.98	0.28	0.00	0.00	0.00	0.00
Agricultural Demand						
Irrg Alagón	522.27	13.09	3.95	4.88	6.99	17.66
Irrg Alberche	113.26	2.84	11.22	14.24	18.76	26.76
Irrg Árrago	90.37	2.27	3.29	3.81	4.89	6.93
Irrg Bajo Tajo	103.82	2.60	0.00	0.00	0.00	0.00
Irrg Cabacera	180.13	4.51	0.00	0.00	0.00	6.12
Irrg Henares	116.88	2.93	8.37	11.55	17.25	29.69
Irrg Jarama Guadarrama	214.19	5.37	0.00	0.00	0.65	10.97
Irrg Tajo Izquierda	216.3	5.42	0.00	0.00	0.00	0.00
Irrg Tajuña	34.39	0.86	0.00	0.00	0.08	1.90
Irrg Tietár	234.78	5.88	35.43	39.03	44.97	55.07
Energy Production						
Aceca	551.88	13.83	0.00	0.00	0.00	7.89
Almaraz	436.9	10.95	0.00	0.00	0.00	0.00
Trillo	37.8	0.95	0.00	0.00	0.00	1.02
Water Transfer						
Aqueduct Tajo Segura	350	8.77	0.00	0.00	0.00	14.09
Total	**3989.62**	**100**	**64.11**	**75.93**	**98.46**	**204.42**

7.3 IMPACT ON ALBUFEIRA FLOW REQUIREMENT

The decrease of the inflow in the basin will affect the coverage and the reliability of the Albufeira flow requirement, this impact is shown in the following figure which presents the reliability of Albufeira flow requirement as well the minimum flow below Cedillo reservoir during the study period (Figure 7.5).

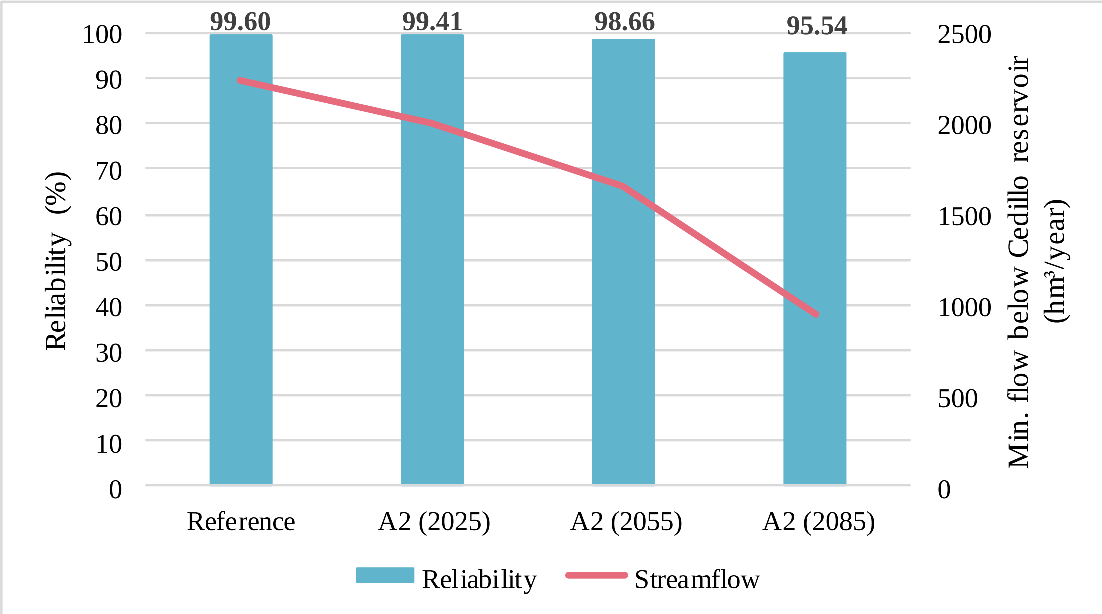


Figure 7.5: Reliability of meeting the Albufeira flow requirement and the minimum annual flow below Cedillo reservoir under climate change scenario

In the future it is clear that the number of years where Spain cannot satisfy the minimum annual flow of Albufeira convention would increase as the reliability decreases. Moreover, there are years for the long term scenario where the flow to Portugal would be less than 1000 hm^3/year.

7.4 IMPACT ON THE ENVIRONMENTAL FLOWS

As it was shown earlier, the reliability of satisfying the environmental flows is very low when they have the lowest priority in the basin, and as an expected result the reliability is getting lower in the future climate change scenarios. The Figure 7.6 shows the reliability of the environmental flows in the reference and climate change scenarios. The environmental flows have the lowest priority in this case.

Maintaining the minimum environmental flow in the river network is important to conserve their hydrological and ecological functions. In some cases the minimum flow cannot be maintained, and some river reaches are completely dry during one or several months of the year. Hence, planning of future management is a big challenge when taking into consideration the environmental flow, as it is very difficult to satisfy the needs of humans without compromising environmental demands.

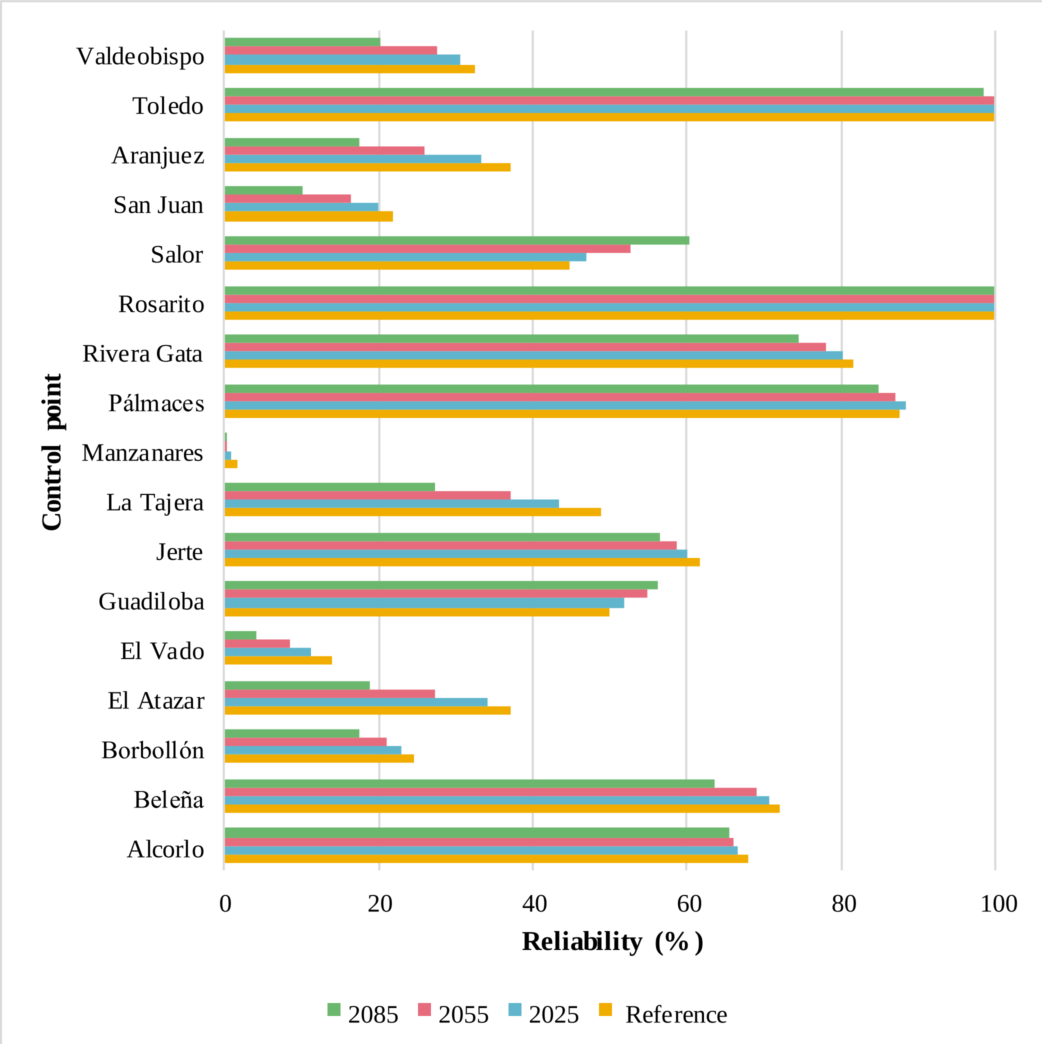


Figure 7.6: Impact of climate change scenario on the reliability of the environmental flows

CHAPTER 8

SENSITIVITY OF THE SYSTEM TO ADAPTATION ACTIONS

8 SENSITIVITY OF THE SYSTEM TO ADAPTATION ACTIONS

Understanding the relationship between the input and output variables in the model is important in the process of decision making regarding to the river basin management. Sensitivity analysis is applied to reduce the uncertainty and explore the importance of the input variables in order to facilitate the process of defining the management actions that could be adopted in varying climatic conditions in the future.

Analyzing the sensitivity of the basin to the selected variables (see Sensitivity analysis, page number 36), without defining a specific alternatives for the management, will give a general idea about how the performance of the basin would change if the agricultural/ urban demands grow or decrease or if the highest priority in the basin would be for protecting the environment or satisfying the demands.

In the following sections, the results of both selected methods are presented. The overall importance for the input variables on the output variables is assessed as well as the interactions between input variables is described.

8.1 ONE-AT-A-TIME SENSITIVITY ANALYSIS

8.1.1 The change in unmet demand

The unmet demand in the Tagus river basin is the central variable to assess the performance of the system. The unmet demand in the basin shows a high sensitivity to the value of the agricultural demand (Figure 8.1), and a low sensitivity to urban demand (Figure 8.2). This means that reducing the urban demand will not solve the problem in the basin but reducing the agricultural demand by the same percentage might solve the problem. By comparing the below figures, it is clear that the performance of the system when reducing the agricultural demand is much better than when reducing the urban demand. Reducing the agricultural demand by 25% is enough to keep the system as in the current situation, but by reducing the urban demand 75%, the system will still have a high deficit. The change in the deficit by reducing the urban demand is not relevant, but in the agricultural demand the effectiveness is much higher.

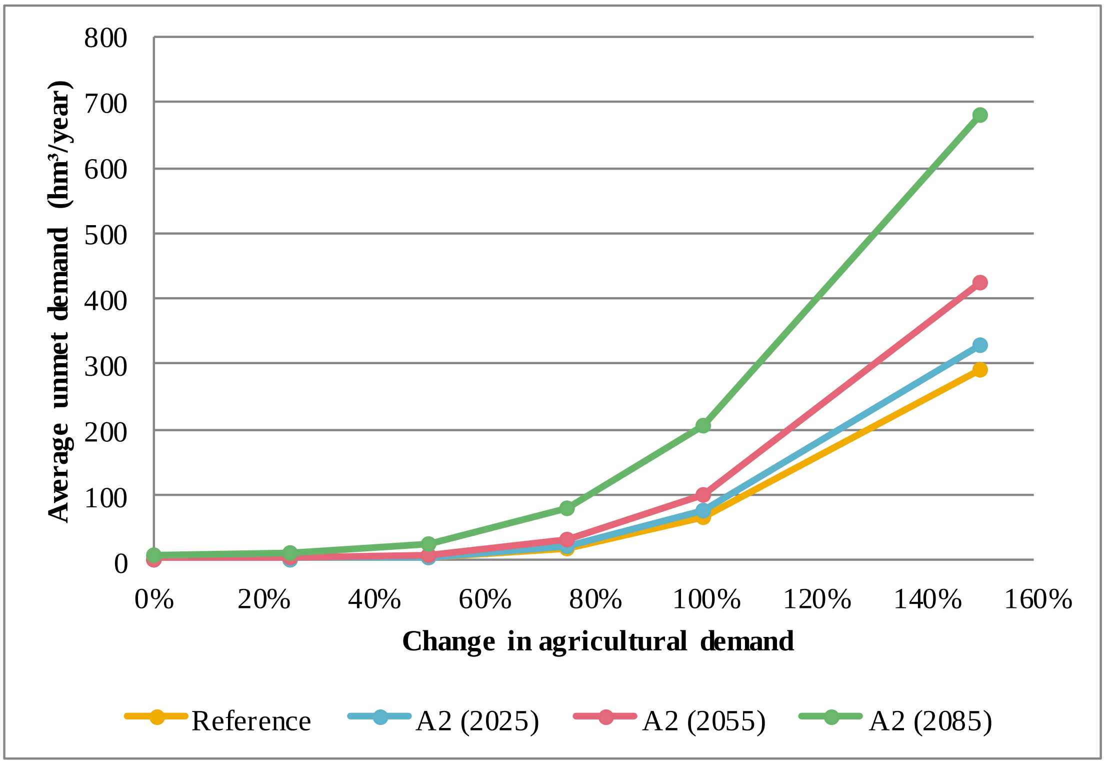


Figure 8.1: Change in the average unmet demand value due to the change in the agricultural demand (100% refers to current agricultural demand)

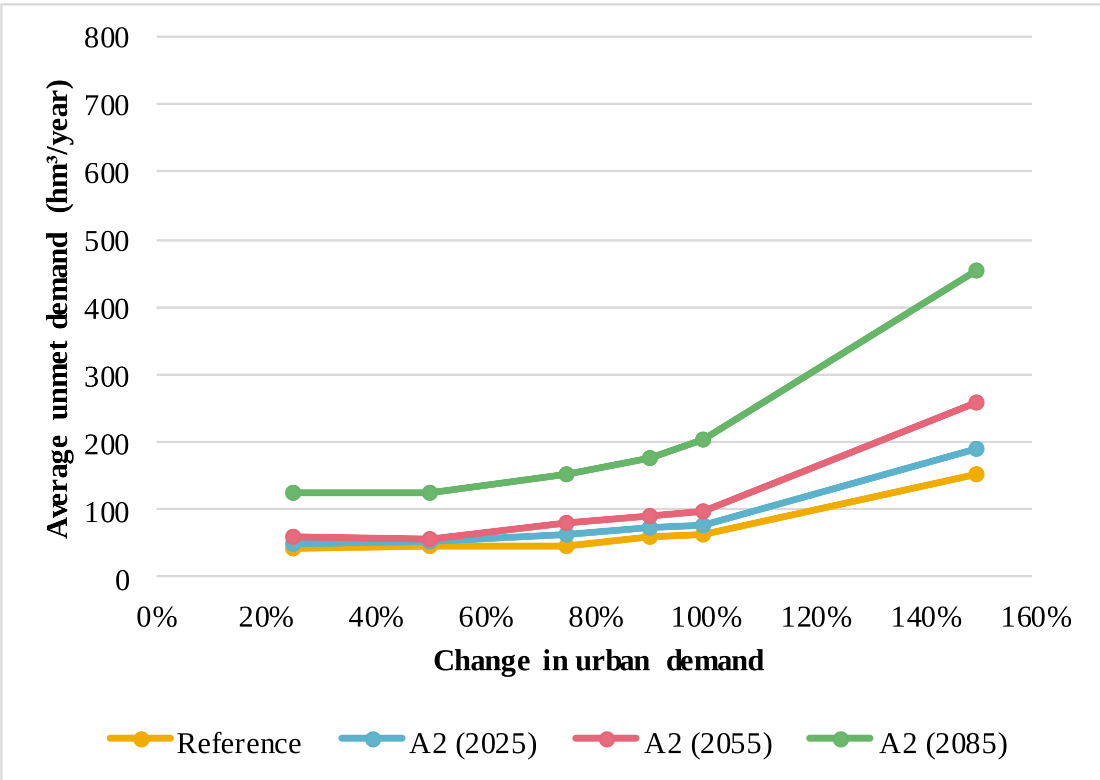


Figure 8.2: Change in the average unmet demand value due to the change in the urban demand (100% refers to current urban demand)

Moreover, the following figures illustrate the change in the value of the maximum unmet demand due to the change in the value of the agricultural demand (Figure 8.3) and urban demand (Figure 8.4).

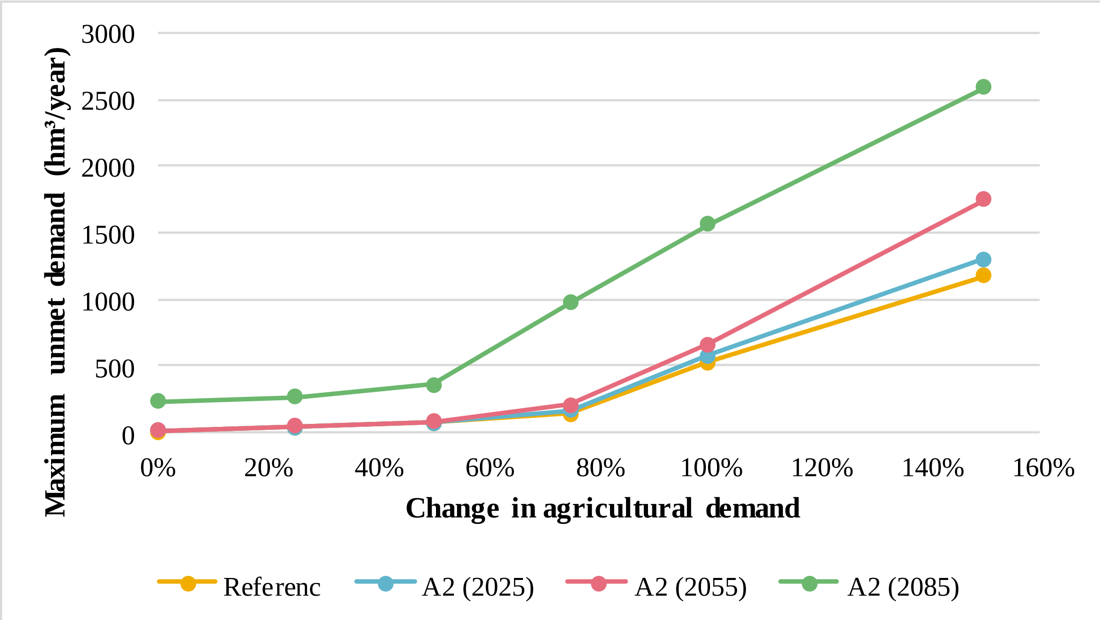


Figure 8.3: Change in the maximum unmet demand value due to change in agricultural demand (100% refers to current agricultural demand)

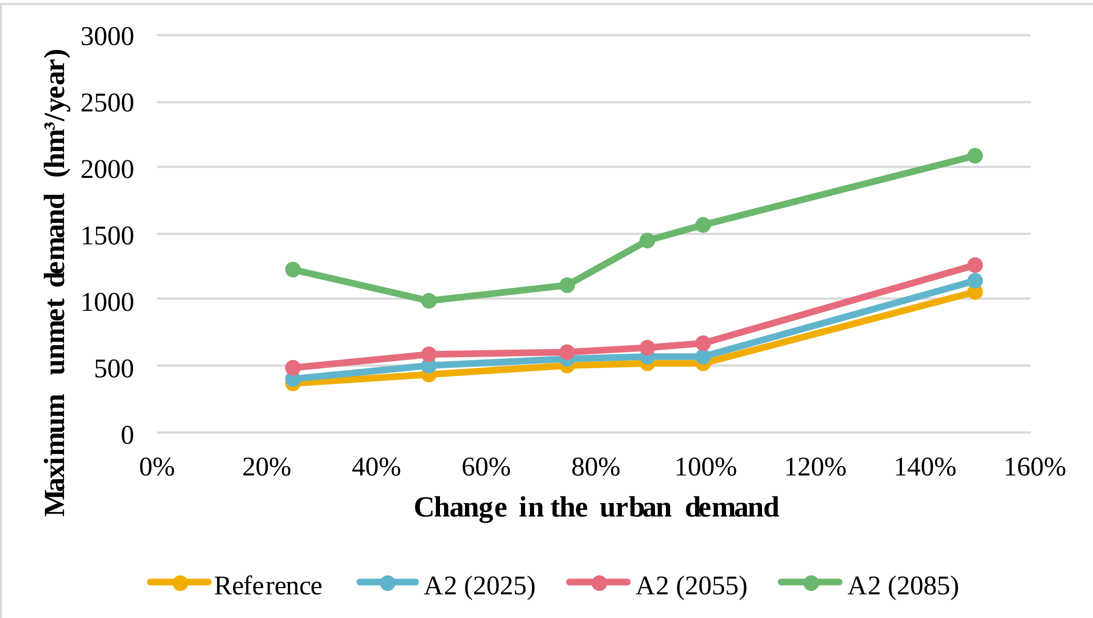


Figure 8.4: Change in the maximum unmet demand value due to the change in the urban demand (100% refers to current agricultural demand)

The other input variable that is affecting the value of the unmet demand is the priority of the environmental flow. Giving the environmental flows the highest priority in the basin will increase the unmet demand (Figure 8.5).

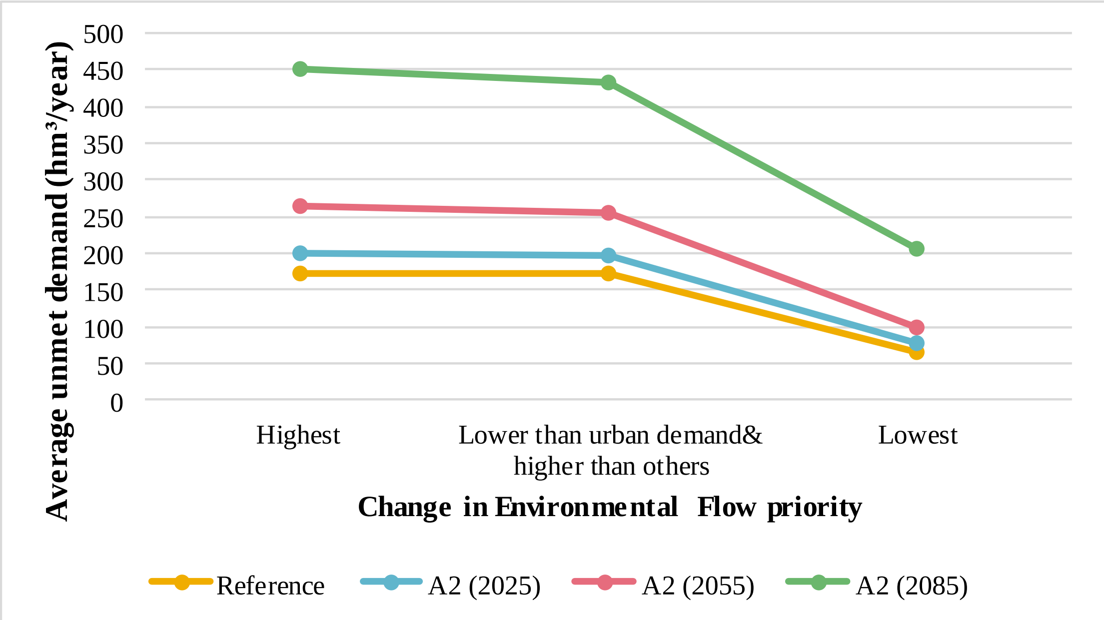


Figure 8.5: Change in unmet demand due to change in environmental flows priority

8.1.2 The change in Albufeira reliability

The reliability of meeting the Albufeira flow requirement decreases for increasing agricultural demand. Counterintuitively it increases with increasing urban demand (Figure 8.6). This is explained by the high return flow of the higher priority urban demand. 80% of the water in the urban demand goes back to the river, which leads to an increase of the downstream flow and the reliability of Albufeira as well. However, the reliability of Albufeira flow requirement shows a higher sensitivity to the agricultural demand than to the urban demand. Moreover, the reliability of Albufeira has been increased by giving the environmental flows the highest priority in the basin (Figure 8.7).

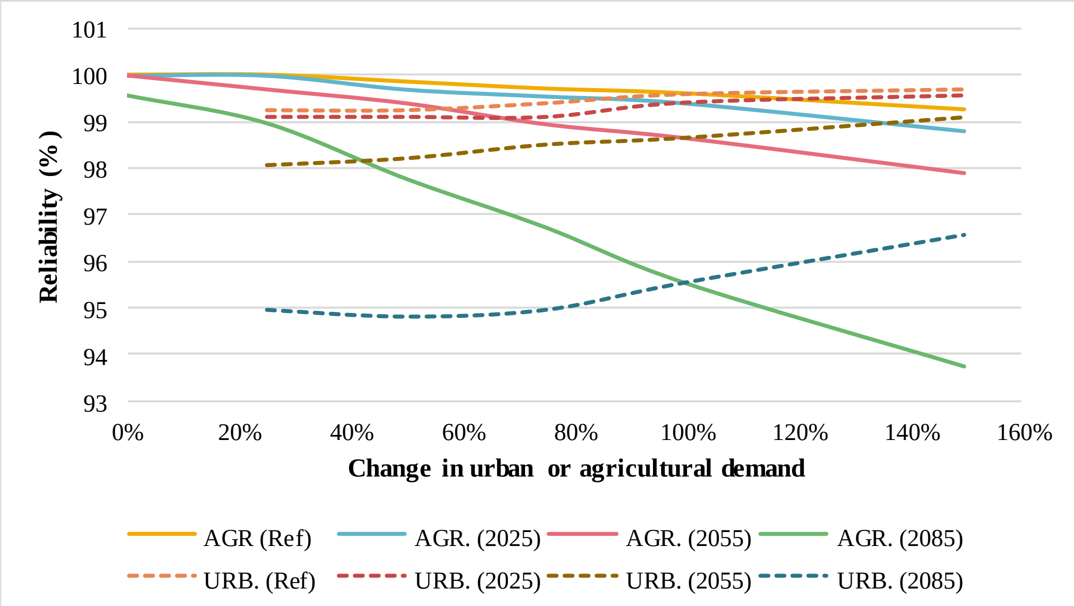


Figure 8.6: Change in the Albufeira reliability due to the change in the urban or agricultural demand

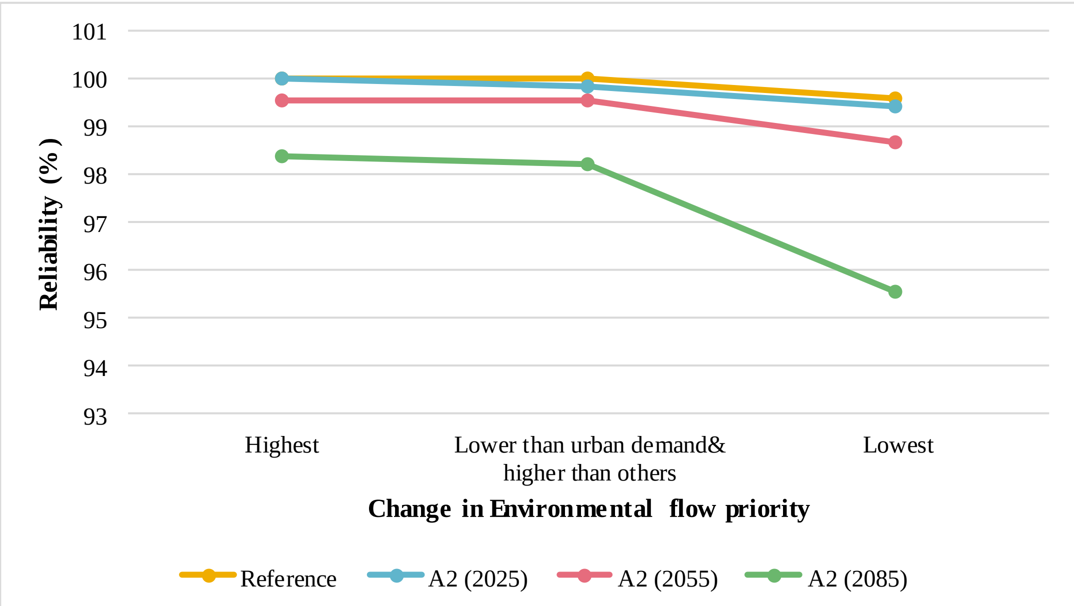


Figure 8.7: Change in Albufeira reliability due to the change in the environmental flows priority

8.2 MORRIS SCREENING

The results of the Morris Screening are presented for both cases: 1) highest priority for environmental flow and 2) lowest priority for environmental flow. Figure 8.8 shows the value of the standard deviation of EE (σ) and the mean of the absolute values of EE (μ*) for each variable. Variables with high μ* are important but variables The variables above the diagonal line in the indicate the presence of interactions or provoke non- linearity (Corominas and Neumann 2014). The diagonal line is equal to ($2.\sigma/r^{½} = 2.\sigma/5^{½} = 0.89.\sigma$) and it is defined as the standard error of μ* (M. D. Morris 1991).

For both cases, the agricultural water demand (*X2*) is the most important input variable for the maximum unmet demand and the average unmet demand because of its high value μ*. However, for the Albufeira reliability, *X1* (inflow range resulted of climate scenarios) is the most important variable because of its high value μ*. All variables are below the diagonal line except in the case of Albufeira reliability where the environmental has the lowest priority. In general, the analysis shows that the non-linearity and interactions are exist but weak.

From the results of Morris Screening we can conclude the same as the previous analysis. The performance of the system is sensitive to the change of the inflow (*X1)* resulted from the climate change. Satisfying the Albufeira flow requirement is affected mostly from the reduction of the inflow (*X1)*, and the agricultural (*X2)* and urban demand (*X3)* has almost the same importance. Moreover, the agricultural water demand (*X2)* is very important variable for the value of the unmet demand.

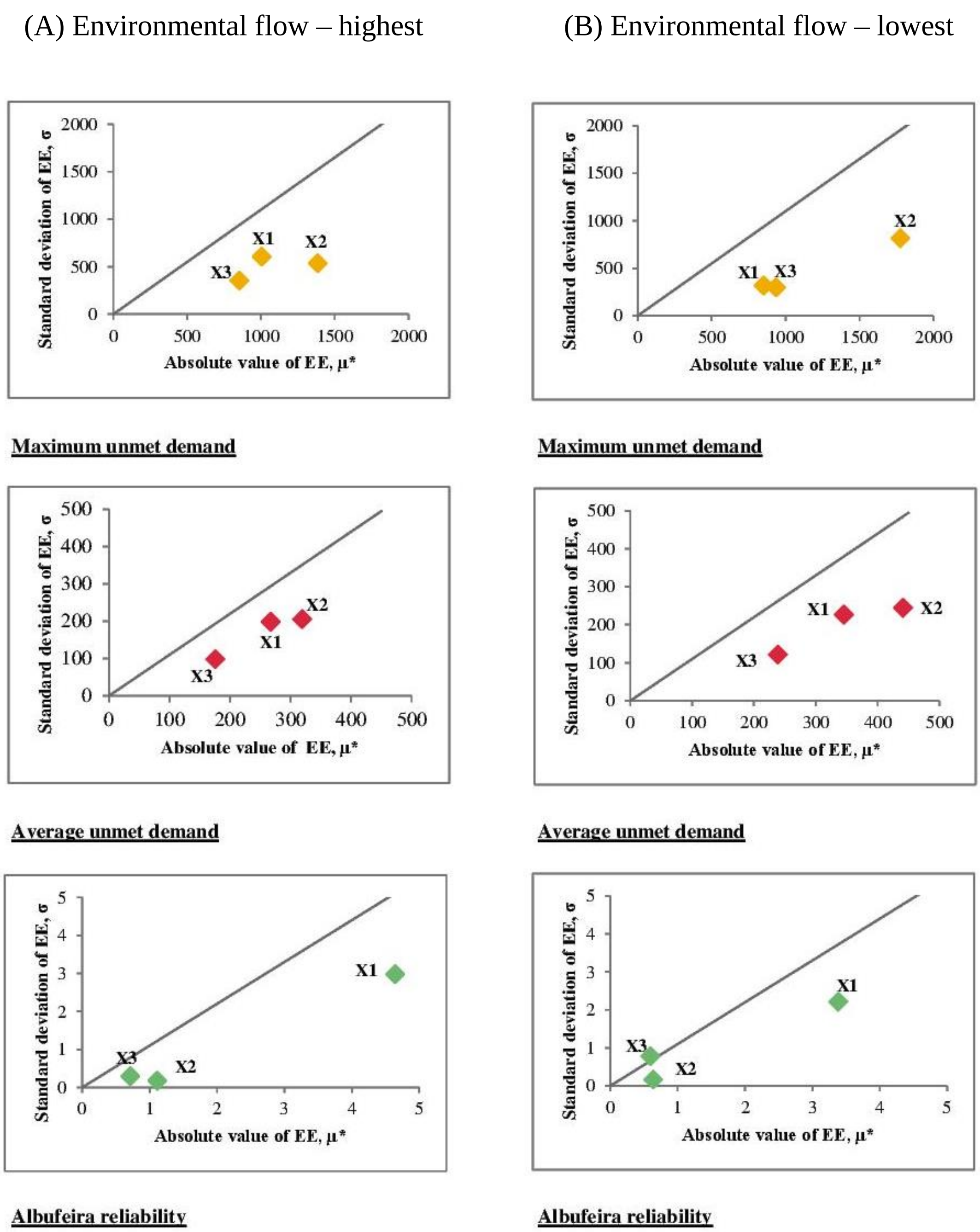


Figure 8.8: Morris screening results

X1: inflow, *X2*: agricultural demand, and *X3*: urban demand.

CHAPTER 9

IMPLICATIONS FOR ADAPTATION PLANNING

9 IMPLICATIONS FOR ADAPTATION PLANNING

9.1 AGRICULTURAL AND URBAN WATER DEMAND

The study shows that reducing the agricultural water demand is more effective than reducing urban demand. One way to do reduce agricultural demand is to increase the efficiency of irrigation by changing the type of irrigation and adopting types that do not consume so much water (e.g. drip irrigation or sprinkler irrigation). This kind of change could be particularly useful for some agricultural sites in the basin that are using surface irrigation which consumes much larger quantities of water than other types. Another measure that can be taken is to better manage the leakage in irrigation canals. This increases the efficiency of irrigation and reduces water demand. Currently, water losses in the irrigation canals are high as they are open canals. Lastly, changing the crop types with ones that do not need so much water is another adaptation measure that should be considered.

The water consumption rate in the agricultural lands in the basin varies from 5,000 to 15,000 m^3/ha/year. This difference in water consumption can be attributed to both varying types of irrigation as well as differing crop requirements, but is primarily due to the irrigation type used. The regions that consume high rates of water are mainly in the Alto Tajo sub catchment (CHT 2013c). In these areas, reducing water demand could benefit from establishing a maximum consumption rate. Assuming that a maximum consumption rate of 6500 m^3/ha/year will be defined for the long term, the agricultural demand will be reduced by 25%, and the average unmet demand will decrease from 204 hm^3/year to 79 hm^3/year. Therefore, if a reduction in the agricultural demand by 25% can be achieved within 70 years by using a maximum consumption rate of 6,500 m^3/ha/year, then the behavior of the future system would remain similar to the current situation.

This result leads to an important question: are the farmers able to pay for using new technologies in order to reduce water consumption or should the government grant subsidies? When considering this question, it is important to note that the agricultural sector in the Tagus basin is not considered highly productive mainly due to the current climatic conditions. Furthermore, the increasing impacts of climate change will continue to decrease crop production in the area. Therefore farmers may have to choose between keep working in the sector or not. If they choose to maintain their work in the agricultural sector, then they have to reduce their water demands or otherwise they have to accept low reliability of satisfying their demand. Rural tourism is a good option for those who are not able to afford adapting new technologies in order to reduce their water demands.

Another adaptation measure could be the establishment of "water rights exchange" agreements between farmers and the government to buy the water from the farmers in the dry years at a price which compensates losses.

Even though reducing the urban demand is not as effective as reducing agricultural demand, it still needs to be reduced, especially because it has the highest priority among the other demands in the basin. There are many management alternatives that could be considered. First, people should be made more aware of the shortage problem that they could face in the future due to the climate change and their roles as responsible water consumers. Innovative programs and policies to promote water conservation can be developed.

Currently the city of Madrid is already adopting new programs and policies to conserve water such as those that promote installing water saving devices in all new buildings, using treated water for cleaning streets and irrigating public parks and golf courses.

The average urban water consumption rate in the basin is 300 l/hab/day with a maximum rate of 480 l/hab/day. A reduction of 10% in the urban demand means an average rate of water consumption equal to 265 l/hab/day and a reduction of 25% means an average rate of water consumption equal to 220 l/hab/day. Establishing a maximum water consumption equal to 220 l/hab/day for the long term scenario would decrease the average unmet demand from 204 hm^3/year to 177 hm^3/year.

The following table gives an example of the value of the consumption rate by different percentages of agricultural or urban demand reduction. If it would be possible to achieve a reduction of 50% in the agricultural demand (equivalent to a reduction in the average unmet demand by 180 hm^3/year) and of 10% in the urban demand (equivalent to a reduction in the average unmet demand by 30 hm^3/year) in 70 years, the basin would not experience any deficit of water (Table 9.1).

Table 9.1: The target of consumption rate by different percentage of demand reduction

Reduction of demand	Water consumption rate for agricultural demand (m^3/ha/year)	Water consumption rate for urban demand (l/hab/day)
-10% of the demand	8,000	265
-15% of the demand	7,500	250
-25% of the demand	6,500	220
-50% of the demand	4,400	150
Note: the reduction of the demand either of the agricultural demand or of the urban demand. Not in the total demand		

"Drought Contingency Plans" are a good option for planning for both agricultural and urban demand. These plans provide different plans for different operating conditions, the normal operation of the system and the exceptional operation in drought conditions. For drought years the operation rules are changed in order to protect the urban demand and reduce the irrigation demands. This kind of operation is already applied in all basins of Spain, and has proved to be effective.

It is clear that the main action needed is to reduce the overall demand. Each of the actions that have been discussed here will eventually lead to reduction of demand, however, it has been found that social economic development would be the most effective action to reduce demand. This means that when a country is more developed, then higher reliability is expected. But this is does not mean that developed countries consume more water, as there are some socio-economic conditions make the users more conscious about using water. Establishing more favorable socio-economic conditions for the residents of a country directly or indirectly might make the farmers more resilient to drought and able to cope with water shortages and make the other users more aware and educated about conserving water. Drought insurance is an example of a service that could help to mitigate the impact of climate change and protect farmers from drought.

Another consideration that needs to be addressed is that improving the efficiency of the urban demand would be very expensive. As mentioned earlier, water losses in irrigation canals are much higher than water losses in urban water networks, this is due to the many transportation facilities that are open canals with a lot of leakage. There are regions like the mid part of the Tagus where the water losses return back to the river but in other cases the water does not return back to the source. It would be better to manage the leakage in the irrigation system than intensify the already implemented actions in the urban sector. This is true, for example, in city such as Madrid that has the highest urban demand and where improving efficiency would be more expensive since they are already following programs for reducing water demand.

So far in this section we have discussed the adaptation actions that are focusing on demand management, other types of actions to consider are those that manage supply. One way to manage supply is to build new reservoirs or increase the storage of existing ones. According to a study that is conducted in order to assess the water resources management in the under climate change in Mediterranean Europe"(Garrote et al. 2014), increasing the reservoir storage would not lead to solve the problem of the deficit in the future for the basins with a large reservoir capacity (comparable to the mean annual inflow). In the case of Tagus basin, the reservoir capacity is about 50% of the mean annual inflow, and increasing the reservoir capacity would not lead to a reduction in the unmet demand.

Moreover, this type of action has very limited scope because society rarely accepts construction of new reservoirs anymore. However, they may be accepted under certain conditions (e.g. to guarantee reliability for vital, e.g. urban uses) or if they would not have a large environmental impact. Building new reservoirs is very expensive, thus it is more feasible to consider that the irrigation demand after 70 years would decrease by 25 - 50% than considering that the reservoirs storage would be increased.

Most likely, the tendency in the future will be to emphasize the protection of the environment. To do that and to maintain the current performance of the basin an intense change in the current management is needed. All the actions that have been discussed here have the potential to be adopted in order to maintain a balance in the basin between satisfying demands and protecting the environment.

Table 9.2 summarizes the actions that would need to be adopted for the short term or long term in order to reduce the effect of the climate change in the basin.

Table 9.2: Adaptation actions classified by affected sector and type of action

Affected demand	Adaptation actions	Type of action	
		long term	short term
Agricultural	Changing crop type	X	
	Water rights exchange		X
	Rural tourism	X	
	Drought insurance programs	X	
	Reuse of treated water	X	
	Improving irrigation systems		X
Urban	Rehabilitation of the water network		X
	Water recycling	X	
	Policies and programs to promote water conservation		X
	Increase the ground water pumping		X
Agricultural and Urban	Water pricing		X
	Transfer water within basins		X
	Define a water consumption rate by law	X	
	Drought contingency plans		X
	Increasing reservoir storage	X	

9.2 ALBUFEIRA CONVENTION

According to Albufeira Convention, Spain is required to ensure minimum annual flow to Portugal equals to 2,700 hm^3. This convention between Spain and Portugal might change in the future as it is not known whether or not the Albufeira flow requirement would be prioritized over other demands. Considering this future scenario poses an interesting question regarding trade-offs. If the choice would be to satisfy the Albufeira flow requirement, how would this affect the demand in the system? And what would be the implications? For example, satisfying the Albufeira flow requirement in the long term climate change scenario would increase the average annual unmet demand in the basin by 6% (204 to 216 hm^3/year). However, reducing the demand in the basin by adopting some of the aforementioned actions would decrease the unmet demand in the basin and increase the reliability of Albufeira flow requirement. For instance, reducing the agricultural demand by 50% would increase the reliability of Albufeira flow requirement from 95% to 98% (Figure 8.6).

CHAPTER 10

CONCLUSIONS

10 CONCLUSIONS

The main conclusions resulting from this study are summarized here.

The simulation of the historic data using the WEAP tool has shown a behavior very close to the real behavior of the system. In general, most of sub-catchments in the basin operate efficiently in normal years. Nevertheless the system faces deficits in some sub-catchments in years of drought especially in the irrigation demand sites, as 97% of the total unmet demand is in irrigation demand sites and the rest is in urban demand sites. Some sub-catchments in the basin fail to fully satisfy the agricultural water demand in almost all years such as Tiétar.

The Tagus basin is sensitive to climatic changes which are presented in the changes of runoff in the A2 emission scenario. The impact of climate change will be stronger on those systems that are currently failing to satisfy their water demands. The impact of climate change is increasing slowly at the beginning (short term and mid-term) and very quickly at the end. In the third period (long term) of the A2 climate change scenario, the system shows a significant change of its behavior, not just in the volume of the unmet demand but also in its distribution, thus this period might need a different type of water resources management.

According to the results of the sensitivity analysis, it could be concluded that a reduction of agricultural water demands in the basin is an adequate measure to achieve a good performance of the system under current and climate change conditions. Reducing agricultural demand by just 25% could significantly improve future performance. Several actions can be adopted in order to reduce the water demand in the basin. Acting on climate change by using efficient technologies, might improve the situation in the basin.

Under the current conditions Spain is able to ensure the minimum flow of Albufeira except in some drought years. The reliability of meeting the Albufeira flow requirement has shown relatively high sensitivity to the changes in the inflow due to the climate change scenario. The number of years where Spain is not able to satisfy the minimum flow of Albufeira Convention would increase in the future climate change scenario. Moreover, in some years the streamflow to Portugal would reach to a value less than 1,000 hm^3/year. Satisfying the minimum flow of Albufeira Convention requires that the decision makers must make choices and face trade-offs in using the water resources in the Tagus river basin. Reducing the water demands in the basin would increase the reliability of Albufeira minimum flow.

It should be noted that the system characteristics may change in the future, thus the results of this study must be understood within the context of the assumption of this study. The demands in the future might change as well as the reservoirs storage and their operational rules. Moreover, always there will be an element of uncertainty in projecting the climatic conditions of the future. The projected stream flow based on the A2 climate change scenario might be higher or lower in the future. Thus, it is necessary to develop systems, approaches for management of water management and agreement from a risk management perspective.

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Annexes

Annex 1: The Δ in runoff by basins (%). Source:(CEDEX 2011)

		Escenario de Emisiones A2							Escenario de Emisiones B2						
		CGCM	ECHA	HadA	HadC	HadC	ECHA	Med	CGCM	ECHA	HadA	HadC	HadC	ECHA	Med
	2011-2040	-3	-22		-2			-8	-6	-18		1			-8
España	2041-2070	-9	-34		-8			-16	-5	-21		-8			-11
	2071-2100	-24	-37	0	-34	-28	-40	-28	-7	-28	-8	-1	-18	-22	-14
	2011-2040	-6	-20		-11			-13	-5	-15		-8			-10
Cantábrico	2041-2070	-4	-27		-17			-16	-6	-22		-19			-16
	2071-2100	-13	-40	-1	-38	-31	-44	-29	-1	-28	-12	-13	-20	-28	-17
	2011-2040	-1	-20		-1			-6	2	-13		-2			-3
Galicia-Costa	2041-2070	-4	-31		-4			-12	-5	-21		-1			-8
	2071-2100	-18	-36	11	-22	-16	-29	-19	-2	-23	4	6	-8	-9	-5
	2011-2040	-6	-18		-11			-12	-5	-14		-10			-10
CI País Vasco	2041-2070	-2	-24		-20			-16	-5	-21		-23			-16
	2071-2100	-9	-40	-8	-39	-41	-52	-30	2	-28	-20	-17	-31	-36	-20
	2011-2040	-1	-21		1			-6	0	-15		2			-3
Miño-Sil	2041-2070	-6	-34		0			-12	-4	-22		1			-7
	2071-2100	-19	-38	11	-20	-17	-34	-21	-2	-25	3	11	-8	-15	-6
	2011-2040	-3	-25		1			-8	-7	-21		5			-7
Duero	2041-2070	-13	-41		-1			-17	-7	-23		0			-9
	2071-2100	-31	-40	4	-33	-23	-47	-31	-10	-29	-2	8	-16	-24	-13
	2011-2040	-3	-31		4			-8	-11	-28		11			-8
Tajo	2041-2070	-16	-48		-1			-19	-8	-23		1			-9
	2071-2100	-39	-41	-5	-38	-32	-40	-35	-16	-32	-10	7	-22	-17	-15
	2011-2040	-7	-40		2			-12	-16	-34		16			-9
Guadiana	2041-2070	-23	-58		-11			-27	-9	-24		-4			-11
	2071-2100	-49	-48	-12	-48	-40	-25	-42	-24	-40	-15	4	-32	-16	-20
	2011-2040	-2	-36		0			-11	-21	-34		13			-13
Guadalquivir	2041-2070	-18	-55		-16			-28	-2	-25		-12			-12
	2071-2100	-48	-49	-20	-45	-44	-29	-43	-23	-43	-24	0	-33	-28	-24
	2011-2040	-1	-33		-1			-12	-16	-35		6			-16
CI Andalucia	2041-2070	-15	-50		-24			-30	-2	-26		-17			-15
	2071-2100	-43	-44	-27	-50	-42	-25	-41	-23	-40	-25	-14	-29	-30	-27
	2011-2040	-1	-25		-1			-10	-22	-24		10			-13
Segura	2041-2070	-10	-39		-11			-21	-2	-28		-11			-14
	2071-2100	-23	-39	-22	-35	-48	-21	-33	-14	-33	-22	-5	-23	-28	-21
	2011-2040	1	-11		-4			-5	-21	-17		-1			-12
Júcar	2041-2070	-11	-28		-14			-18	-5	-20		-14			-13
	2071-2100	-21	-24	-18	-46	-45	-21	-32	-16	-27	-20	-18	-34	-14	-24
	2011-2040	-2	-19		-7			-9	-7	-15		-5			-9
Ebro	2041-2070	-6	-26		-12			-14	-5	-19		-17			-13
	2071-2100	-17	-31	3	-40	-30	-46	-28	-4	-25	-9	-11	-17	-29	-16
	2011-2040	6	-4		-3			0	-9	-5		-8			-7
CI Cataluña	2041-2070	-2	-5		-6			-4	-2	-6		-19			-9
	2071-2100	-11	-3	-13	-34	-30	-29	-21	-13	-5	-18	-14	-20	-18	-16
	2011-2040	-5	-21		11			-4	-19	-31		0			-15
Islas Baleares	2041-2070	-9	-39		1			-15	-8	-31		-18			-20
	2071-2100	-20	-44	-24	-42	-22	-21	-31	-25	-39	-32	-6	-25	-13	-23
	2011-2040	-7	-37		-4			-18	-15	-34		-24			-25
Canarias	2041-2070	-16	-41		-37			-32	-11	-36		-35			-28
	2071-2100	-31	-44	-30	-57			-41	-22	-37	-29	-47			-34

ESCORRENTÍAS: Incrementos (%) de medias anuales. Títulos de columnas: A = Escenario de emisiones A2; B = Escenario de emisiones B2; C = modelo global CGCM2 y regionalización FIC; E = modelo global ECHAM4 y regionalización FIC; H = modelo global HadAM3 y regionalización FIC; S = modelo global HadCM3 y regionalización SDSM; U = modelo global HadCM3 y regionalización PROMES (PRUDENCE-UCM); P = modelo global ECHAM4 y regionalización RCAO (PRUDENCE-SMHI). Colores: verde >0%, amarillo -20% a 0%, rojo < -20%.

Annex 2: The emission scenarios of the IPCC Special Report on Emission Scenarios (SREC)

- **The A1 storyline and scenario family** describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B)
- **The A2 storyline and scenario family** describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.
- **The B1 storyline and scenario family** describes a convergent world with the same global population that peaks in midcentury and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.
- **The B2 storyline and scenario family** describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

Annex 3: Reservoirs of the Tagus river basin

Name	Year	River	Volume (hm^3)	Area (ha)	Uses
Bolarque	1910	Tajo	30.7	490.8	Irrigation and hydroelectric
Garguera	1911	Garguera	3	60	Irrigation
Burguillo	1913	Alberche	208	910	Irrigation and hydroelectric
Charco del Cura	1931	Alberche	3.47	34.5	Irrigation and hydroelectric
Puentes Viejas	1940	Lozoya	49.17	279.58	Urban
Alcántara	1946	Jartín	1.02	27.83	Urban
Hinchona	1946	Yedra	1.3	20	Irrigation
Almoguera	1947	Tajo	6.6	183	hydroelectric
Molino de Chincha	1947	Guadiela	5.8	60	hydroelectric
La Portiña	1947	La Portiña	5.2	89.74	Urban
Zorita	1947	Tajo	2.6	57	hydroelectric
Torcón	1948	Torcón	6.77	63.34	Urban
Picadas	1952	Alberche	15.2	91.7	Urban, Irrigation and hydroelectric
Borbollón	1954	Árrago	1.43	32.6	Irrigation
Borbollón	1954	Árrago	85	888	Irrigation and hydroelectric
Pálmaces	1954	Cañamares	31.36	269.6	Irrigation
El Vado	1954	Jarama	55.66	259.76	Urban
San Juan	1955	Alberche	148.3	650	Urban, Irrigation and hydroelectric
Entrepeñas	1956	Tajo	802.56	3212.88	Irrigation and hydroelectric
Riosequillo	1956	Lozoya	48.52	326	Urban
Buendía	1957	Guadiela	1638.7	8194.79	Irrigation and hydroelectric
Araya de Arriba	1958	Ayo, Ancianes	1.5	35.1	Irrigation
Rosarito	1958	Tiétar	84.7	1474.55	Irrigation, hydroelectric
Gabriel y Galán	1961	Alagón	924.2	4686	Irrigation and hydroelectric
Salor	1964	Salor	14	400	Irrigation
La Tosca	1964	Cuervo	2.5	52	hydroelectric
Valdecañas	1964	Tajo	1446	7300	Irrigation and hydroelectric
Valdeobispo	1965	Alagón	53	357	Irrigation and hydroelectric
Torrejón-Tajo	1966	Tajo	176.3	1041	hydroelectric
Castrejón	1967	Tajo	41	750	Irrigation and hydroelectric
Castrejón-El Carpio	1967	Ayo, El Carpio	1.5	4	hydroelectric
Pinilla	1967	Lozoya	37.55	480	Urban
Torrejón-Tiétar	1967	Tiétar	22	219	Energy Production

Name	Year	River	Volume (hm^3)	Area (ha)	Uses
Vellón, el	1967	Guadalix	41.23	393.09	Urban
Jarosa, la	1968	La Jarosa	7.18	61.14	Urban
Navacerrada	1968	Samburiel	11.04	92.8	Urban
Azután	1969	Tajo	113	1250	Irrigation and Energy Production
Jose Mª Oriol	1969	Tajo	3162	400	Energy Production
Santillana	1969	Manzanares	91.09	1051.9	Urban and Energy Production
Cerro Alarcón	1970	Perales	1.04	25	Recreational uses
Pardo, el	1970	Manzanares	45	550	Urban, Regulation
Guadiloba	1971	Guadiloba	20.4	281	Urban
Guajaraz	1971	Guajaraz	18.14	159.65	Urban
Atazar	1972	Lozoya	426	1069	Urban
Castro, el	1974	Algodor	7.6	98.2	Irrigation and Urban
Cedillo	1975	Tajo-Sever	260	1400	Energy Production
Valmayor	1975	Aulencia	1224	755	Urban
Arrocampo	1976	Arrocampo	34.5	776	Industrial
Bujeda, la	1976	Sin río	7	63.03	Transfer Tajo-Segura/Irrigation
Pozo de los Ramos	1976	Sorbe	1.12	14	Urban
Alcuescar	1977	Ayuela	1.04	37.5	Urban
Finisterre	1977	Algodor	133	1200	Regulation
Fresnera	1977	Fresnera	1.8	44.39	Irrigation
Fuente Guijarro	1977	Fuente Guijarro	1	1.33	Recreation
Jarilla, la	1977	Buey	1.7	42.48	Irrigation
Malpartida-Plasencia2	1977	Pilones	2.1	52	Urban
Navalcán	1977	Guadyerbas	33.9	746	Irrigation/Urban
Talavan	1977	Talaván	1.14	32	Irrigation/Urban
Alcorlo	1978	Bornoba	180	598.61	Irrigation
Membrío	1978	Membrío	1	28.36	Irrigation
Ayuela	1980	Ayuela	1.53	61.5	Irrigation
Malpartida-Plasencia3	1981	Grande	1.04	45.18	Urban
Valdefuentes	1981	Valdealcorno que	1.3	0.13	Irrigation-Urban
Beleña	1982	Sorbe	50.5	245	Urban, Irrigation
Guijon de Granadilla	1982	Alagón	13	124	Energy Production
Jerte-Plasencia	1985	Jerte	58.54	667	Irrigation-Urban
Ahigal	1986	Palomero	4.67	98.74	Irrigation

Name	Year	River	Volume (hm^3)	Area (ha)	Uses
Portaje	1986	Rivera de Fresnedosa	22.8	430	Irrigation
Morales, los	1988	Morales	2.34	32.7	Urban
Aceña, la	1989	Ayo, de la Aceña	23.7	120	Urban
Navamuño	1989	Angostura	13.8	74.5	Urban
Rivera de Gata	1990	Rivera de Gata	48.9	310.6	Irrigation
Cabeza del Torcón	1991	Torcón	1.22	23.08	Urban
Casar de Cáceres	1991	Villaluengo	4.93	102.4	Urban
Arroyo de la luz	1995	Ayo, Molano	2.2	68.93	Urban
Baños	1993	Baños	40.86	211	Irrigation
Chorrera, la		Tajo	1.4	140	Energy Production
Navalmoral de la Mata	1995	Ayo, Valdío de Torreseco	2.83	48.8	Urban
Tajera, la	1993	Tajuña	70	450	Irrigation
Torrejoncillo	1995	Fresnedosa	1.42	27.92	Urban
Valencia de Alcántara		Alpotrel	2.14	38.8	Urban
Zarza la Mayor	1995	Raposera	1.14	21.9	Urban

COOPERATIVE FRAMEWORK

Introduction

The river basins shared by Portugal may serve as a good example of the evolution of a case of bilateral management of shared water resources: until the last decade of the 20th Century, the shared water resources management was confined to the bordering stretches of those rivers; from then on, the entire river basins started to be considered.

The institutional agreement between Spain and Portugal related to the water resources management in the shared basins began in the late 19th century. The cooperation between the two countries was regulated by treaties that focused only on the use of water resources without taking into consideration the environmental aspects.

In the year 1864, both countries signed the "The Treaty of Limits" (Tratado de límites) which stipulates that boundary-spanning resources should be used for mutual benefit and without harm to the interests of the other party. This treaty was completed in the year 1906 by establishing norms for the industrial use of water on both sides of the river, assigning half of the flow for each side. Later, in 1926, a new Convention was signed "The Convention of Lisbon" to delimit the boundaries not covered by the treaty of 1864.

In the year of 1927 a new convention was signed to regulate the hydroelectric use of the international stretch of the Douro River and its tributaries. Then the cooperation extended to all shared rivers between both countries. It was followed by a new Convention in the year 1964 that regulated the use of the border stretches of Miño, Limia, Tagus, Guadiana and Chanza rivers and their tributaries. This agreement encompassed a much wider view than the convention of 1927. It aimed at ensuring a convenient exploitation of the hydropower resources along the shared rivers; moreover, it addressed the special characteristics of each river and the possibility of using their resources for other uses. Also, it referred to some aspects such as the construction of reservoirs and the maintaining of minimum flows during periods of scarcity. According to this convention, a "Spanish – Portuguese" Commission was established to regulate the use of water resources on the border stretches of the shared rivers. This commission consisted of civil servants from both governments and of the licensed companies.

THE CONVENTION OF ALBUFEIRA

Scope and Objectives

The Albufeira Convention, the Convention on Co-operation for Portuguese-Spanish River basins Protection and Sustainable Use, was signed in 1998 in the town of Albufeira in Portugal and approved later on January 2000 (Barreira 2007). The objective of this convention, according to its article 2, is to define a framework for the cooperation between Portugal and Spain, in order to protect the surface and ground water and to promote the sustainable use of the water resources in the shared river basins. The Convention of Albufeira was revised in 2008, and a trimester flow regime was added to the annual and daily flows previously established.

The convention of Albufeira was influenced by the United Nations Convention related to the use of international water recourses, as well as by the Euroepean Water Framework Directive (WFD). Several articles of the convention contain obligations stemming from WFD requirements. These include Article 4 (cooperation mechanisms to achieve good status of surface and groundwater), Article 6 (public information), Article 13 (water quality), Article 14 (pollution control and prevention), and Article 17 (incidents of accidental pollution) (Barreira 2007).

The Albufeira Convention allows Spain and Portugal to respond to the challenges posed by the impacts of climate change through the adoption of 2008 Protocol in the Article 8.

The layout of the agreement is simple and consists of a Preamble, a text with 35 articles, two annexes and an additional protocol with its annex. The articles are distributed into six parts; each part describes a practical issue in the agreement as following (De Almeida, Portela, and Machado 2009; BOE 2000):

- Part I (Arts. 1 – 4): General clauses: consists of articles about definitions, scope of application, objectives, and mechanisms of cooperation.
- Part II (Arts. 5 – 12): The Cooperation between the two parties: consists of articles about the exchange of information, information to the public, information of

commission, transboundary impact assessment, mechanism of cooperation, communication systems, and infrastructure safety.

- Part III (Arts. 13 – 16): Protection and sustainable use of water: consists of articles about water quality, pollution prevention and control, water uses and river flows.
- Part IV (Arts. 17 – 19): Exception situations: consists of articles about floods, accidental pollution and drought periods and shortage.
- Part V (Arts. 20 – 23): Institutional clauses: consists of articles about cooperation bodies from each party and the operating and decisions of the commission.
- Part VI (Arts. 24 – 35): Final clauses: consists of articles about the affected rights, force of convention, conflict resolution, force of existing convention on rivers, and mechanisms for consultation.

According to its Article 32, the Albufeira Convention is in force for seven years, and automatically renewed for three years periods (BOE 2000). Currently it is already under the third renovation period.

Institutional Framework

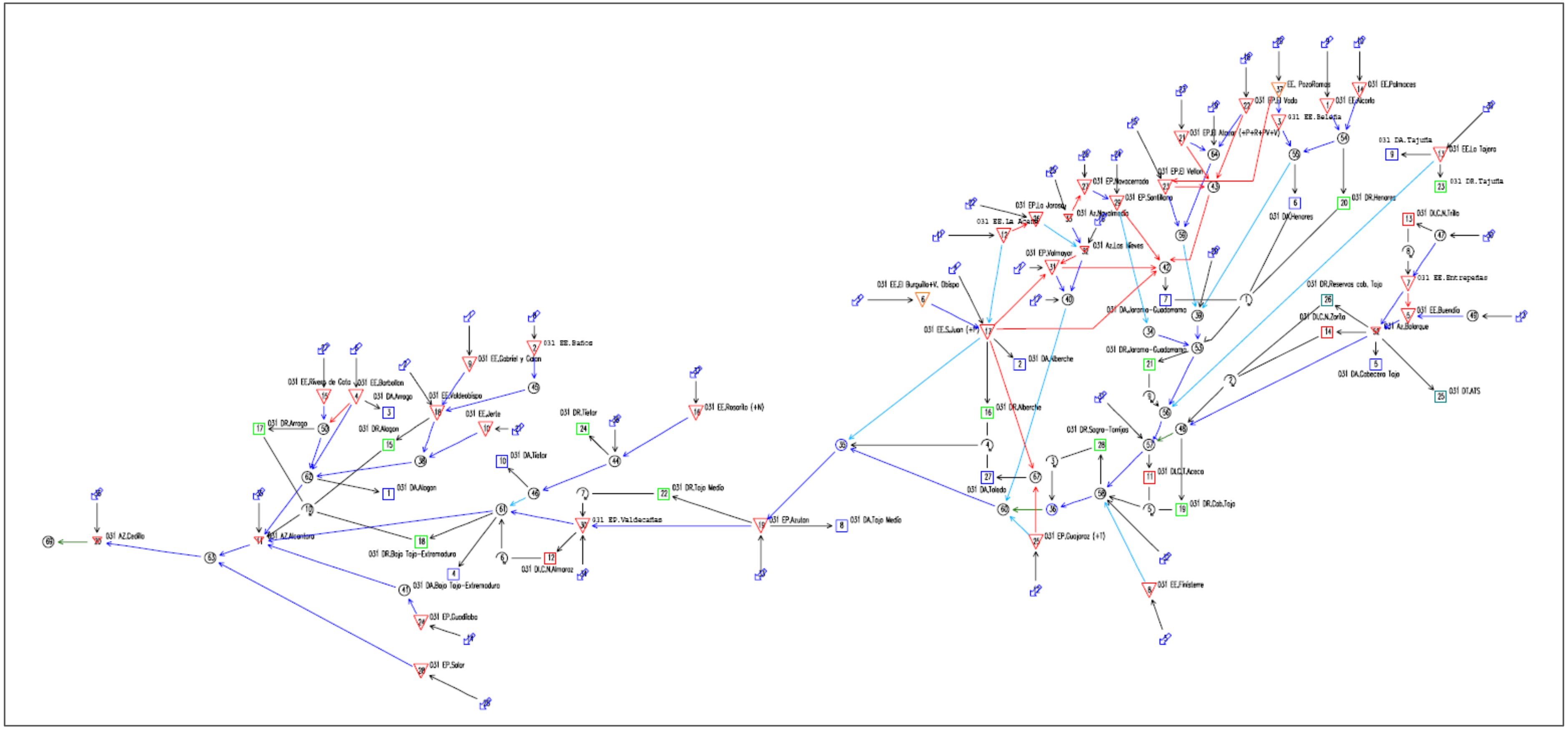
The article 20 of the convention defined two new institutional boards as the cooperation bodies, the first one is the Conference of the Parties (COP) and the second is the Commission for Convention Application and Development (CADC).

The COP is composed of a representatives determined by the both governments and headed by a Minister of each state or by delegates they appoint (BOE 2000). Until this moment two COP meetings took place, the first COP took place in Lisbon on the 27th of July 2005 and focused on the need for greater cooperation mechanisms, particularly regarding drought situations and implementation of the WFD. The second was held in Madrid on the 19th February 2008, where a new flow regime protocol based on a quarterly guarantee of minimum flow rates, with weekly minimums under certain conditions was approved.

The CADC is responsible for conducting studies related with issues involving the application of the convention (BOE 2000). In addition it responsible for information exchange, communication, for the development and maintenance of early warning and emergency systems, as well as for adopting appropriate water quality and flow measures (Maia 2008) (Almeida, Portela, and Machado 2009). According to the article 23 of the convention, the CADC shall meet in ordinary sessions at least once a year.

The CADC includes four Work Groups (WG) and sub- commission which were formed in 2006. Those WGs are active and are dedicated to: (1) Flow regime, droughts and emergency situations WG, (2) Information exchange WG, (3) Hydraulics infrastructures' safety and floods WG, and (4) Water Framework Directive (WFD) and water quality WG. And the sub-commission is dedicated to public participation (Maia 2008). Moreover, in the year 2007, a new WG on Procedures was created (Barreira 2007).

Annex 5: The Topology of the Tagus River Basin from the National Hydrological Plan



Annex 6: Monthly net evaporation rate in mm

Reservoir	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Alcorlo	42	24	16	16	29	48	76	97	128	152	133	83
Baños	56	28	20	25	37	67	89	111	147	174	159	98
Beleña	38	18	13	13	23	38	53	76	101	122	107	72
Borbollon	57	29	19	24	35	65	88	112	146	172	156	98
Buendía	38	18	9	14	23	45	61	94	111	132	116	74
El Burguillo	60	33	24	26	49	73	96	117	168	185	168	112
Entrepeñas	38	16	10	14	25	46	62	86	111	131	109	74
Finisterre	62	30	15	24	44	65	97	132	163	195	165	108
Gabriel y Galan	56	28	20	25	37	67	89	111	147	174	159	98
Jerte	58	29	16	23	35	66	88	122	158	186	170	107
Oriol	72	36	20	25	29	50	93	134	162	216	198	136
La Aceña	34	15	11	9	19	35	45	76	94	116	97	65
La Tajera	47	24	16	16	29	48	76	97	126	152	124	83
Palmaces	42	24	16	16	29	48	76	97	128	152	133	83
Rivera de Gata	67	34	24	28	41	66	89	116	154	182	165	111
Rosarito	68	33	18	26	40	71	108	147	174	208	188	127
San Juan	61	28	25	27	50	75	98	132	171	202	169	113
Valdeobispo	64	31	16	25	37	70	93	133	174	219	188	127
Azutan	65	32	23	27	48	73	97	136	174	204	185	117
Cedillo	72	36	20	25	29	50	93	134	162	216	198	136
El Atazar	39	19	14	13	24	39	63	78	104	124	108	68
El Vado	43	21	15	15	26	43	60	86	115	138	121	81
El Vellon	50	22	14	20	32	51	81	112	135	160	141	88
Guadiloba	75	35	20	30	44	69	106	135	176	202	186	129
Guajaraz	49	22	14	22	31	57	76	115	140	158	133	87
La Jarosa	34	15	11	9	19	35	45	76	94	116	97	65
Navacerrada	34	15	11	9	19	35	45	76	94	116	97	65
Salor	67	32	18	27	40	62	95	121	158	181	168	115
Santillana	50	24	17	17	30	50	81	99	133	156	138	86
Valdecañas	65	32	23	27	48	73	97	136	174	204	185	117
Valmayor	42	20	13	19	23	48	68	94	123	144	126	80