Drought Challenges in the Tagus River Basin: Transboundary Water Management through Climate Change Adaptation and Cooperation Strategies

Msc Thesis

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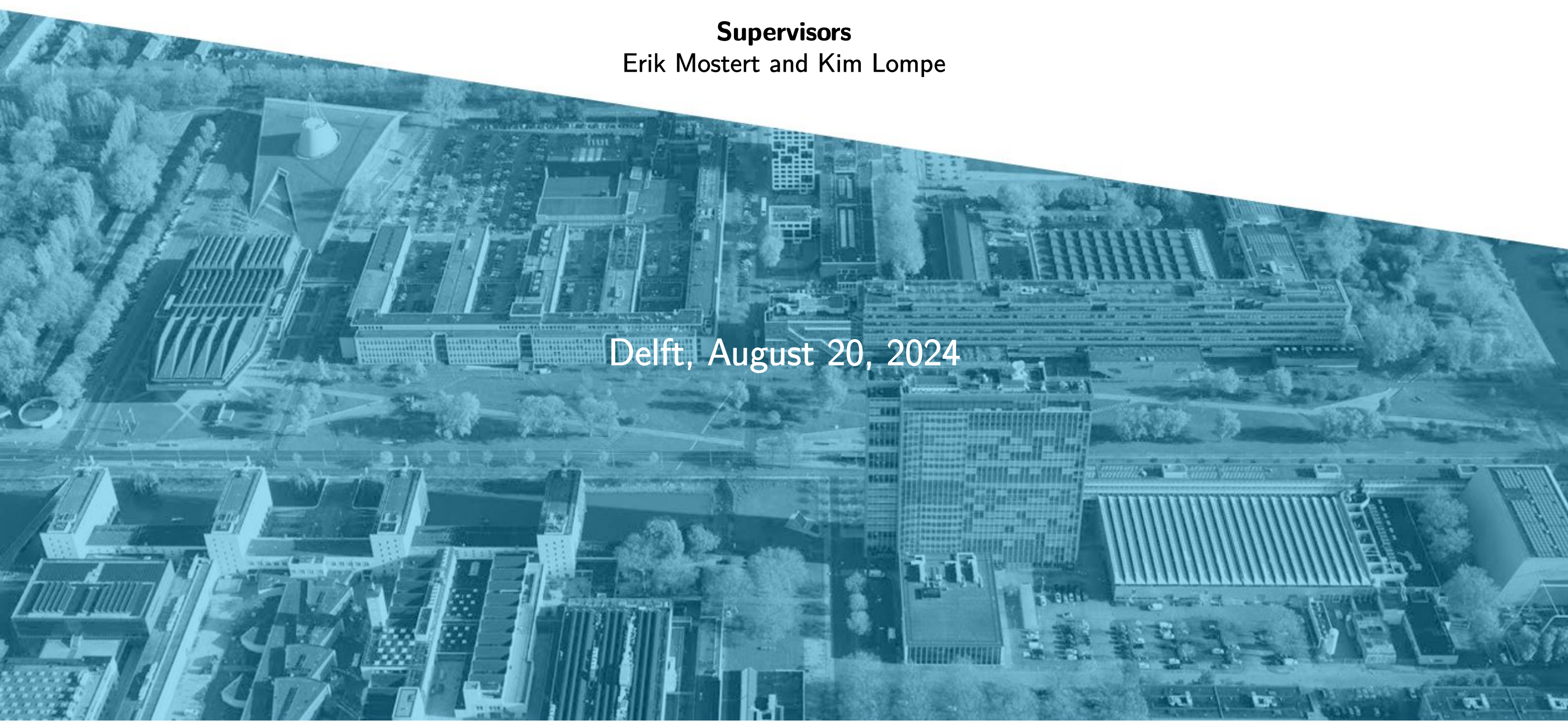

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Contents

List of Tables

List of Figures

Acronyms

AC Albufeira Convention

AIWM Adaptive Integrated Water Management

APA Portuguese Environmental Agency

APRH Associação Portuguesa dos Recursos Hídricos

ARHTejo Administração de Região Hidrográfica do Tejo

CADC Commission for the Application and Development of the Convention

CHT Confederacion Hidrografica del Tajo

CoP Conference of Parties

STP Permanent Technical Secretariat

WFD Water Framework Directive

WEI+ Water Exploitation Index Plus

WWTP Wastewater Treatment Plant

1 | Introduction

Water resources in the Tagus River Basin, which spans across Portugal and Spain, have long been a matter of concern due to a history of water stress and the shared nature of this transboundary water basin. The interdependence of Portuguese and Spanish water resources underscores the need for coordinated conservation policies and water resource planning. Approximately half of the water resources available in Portugal originate from basins that are shared with Spain, with only 22% of their area being in Portugal (Zucco & Costa, 2013).

To address this intertwined water resource scenario, the AC (AC) was initiated in 1998. However, the Convention's inception was somewhat unilateral, as it was instigated following Spain's water planning cycle, including the publication of its water law and National Hydrological Plan, which included plans for inter-basin water transfer, with limited prior consultation with Portugal (Henriques, 2018).

In response to a severe drought that affected Spain and Portugal in 2005 and led to a significant reduction in the discharge of the Tagus River at the border, the AC was subsequently modified in 2008. The current management strategy for flow regulation in the Tagus River Basin involves winter water storage and summer release to mitigate the basin's considerable intra-annual discharge variability. Potential changes in discharge, especially during the winter months, which are higher than in summer, present a pressing challenge to management and adaptive strategies (Lobanova et al., 2016).

A fundamental impediment to the development of effective water management policies in the Iberian transboundary basins is the scarcity of comprehensive, shared knowledge about available water resources and a thorough understanding of how multipurpose reservoirs regulate stream flows and the impact of existing pressures on the water system. Researches show that in the current situation, the water demand in the Tagus River basin is not fully satisfied. The problem is expected to be more critical in the future, with the increase in water demand and decrease in river discharge. (Sondermann & Proença de Oliveira, 2021).

Recent climate projections for the Iberian Peninsula predict a general decrease in precipitation and an increase in air temperature. Kilsby et al. (2007) even anticipate a 50% yearly reduction in Tagus River discharge, primarily attributed to the rising potential evapotranspiration (PET) and a year-round decrease in rainfall. These projections raise concerns about the viability of existing bilateral water agreements. Spain failed to meet the discharge requirements agreed upon with Portugal under the AC due to extreme drought events.

The challenges and risks associated with quantity and quality in the Tagus River basin are intricately linked and stand to escalate with the impacts of climate change. Portugal's dependence on Spain for water quantity is marked, yet the quality of water from Spain often faces degradation, coupled with diminishing tributary flows, making the Tagus Basin stand out as particularly risky due to the combination of water scarcity and fluctuating flows, intensifying pollution concerns. Despite the advanced AC, the absence of a clear definition for "good water status" complicates the situation. The Tagus-Segura transfer, an inter-basin water transfer that diverges water from the Middle Tagus basin to the Segura Basin in Spain is another topic of conflict between the countries, as it is a big transfer that changes significantly the natural flow of the Tagus River. Also, specialists claim that the establishment of a consistent ecological flow in the Tagus River is necessary at the crossing from Spain to Portugal to align with the Water Framework Directive, however, it is currently only implemented on the Spanish side (Palermo et al., 2022).

In light of these challenges and to avert conflicts over water resources and the associated drought and scarcity impacts, it is imperative that both Portugal and Spain align their planning and management approaches. However, current disparities in their stages of development, with Portugal having their national drought plan approved in 2017 while Spain has one since 2007, as highlighted by Maia et al. (2022), make it clear that harmonizing these efforts will require integrating adaptive and precautionary management procedures into their respective planning systems and cooperation structures (Do Ó, 2012).

1.1 | Problem Statement

The objective of this study is to analyze the current water management policies and recommend strategies for addressing drought adaptation in the face of climate change within the context of transboundary water management in the Tagus River basin.

1.2 | Research Questions

In light of the contextual factors and considerations explained earlier, the research questions have been formulated. These are organized into four main inquiries, each with accompanying sub-questions to delve deeper into the problem at hand.

1. What are the water management challenges caused by current drought events in the region?
    - What are the current impacts of water scarcity on the population and environment in the region?
    - Are there already noticeable impacts on drinking water availability, environmental flow, crop production, and water quality within the affected area?
    - What implications for the future of this region can be inferred from the various climate change scenarios?
2. Is the existing agreement between the countries and the management approach that is currently being employed in the Tagus River Basin effective?
    - What is the current agreement between the countries?
    - How is the basin management being done currently, domestically and transboundary?
    - What are the identified gaps in the current approach?
3. Which combinations of technical adaptation measures could be explored for the Tagus River Basin?
    - Can adjustments to reservoir management (increased storage capacity or change in operation), desalination, restoration of natural systems (ecological flow), wastewater reuse, or improvements in irrigation efficiency be viable measures for this specific river basin?
    - How can the most suitable adaptation measure be selected to address the current situation?
    - Is there currently available information on the river basin sufficient to develop an effective solution plan for addressing the situation?
    - What potential advantages can be identified for both countries concerning the measures that may be implemented?
4. What are the key strategies and cooperation mechanisms that can be implemented to effectively address climate change adaptation in the Tagus River Basin while bridging the current gaps adaptively and collaboratively?

- What does it mean to have an Adaptive Water Management and is it feasible to be implemented in this case? and if so, should it be done? How?
- Can stakeholders, including governments, local communities, and environmental organizations, be actively involved in shaping and implementing adaptive water management strategies in the Tagus Basin? If yes, how?
- Can these strategies be seamlessly integrated into the existing management framework? If yes, how? If not, how should the framework be changed?

2 | Methodology

This chapter will outline the methodologies adopted for this research. The research for this thesis was conducted as a comprehensive case study focusing on the Tagus River Basin, with a specific emphasis on transboundary water management and the challenges posed by climate change and drought in the region. The approach focused mostly on literature study, to first better understand the current situation in the basin, drawing insights from policies and climate change adaptation approaches to inform recommendations and strategies for the Tagus River Basin. Alongside the literature study, a document analysis was employed, to examine both national policies and the agreements between the countries. The goal was to combine the literature study with the existing documents and policy frameworks to gain a comprehensive understanding of the scope to answer the research questions that were proposed.

Following the initial methodologies, interviews were prepared by organizing relevant questions and identifying ideal interviewees. The aim was to interview specialists in the subject and individuals closely connected to the topic to gather diverse perspectives and comprehensive information. Subsequently, the interviews were conducted. Below, Table 2.1 shows the research questions and the methodologies chosen to answer them.

Table 2.1: Methods Used for Each Research Question

	Literature Study	Document Analysis	Interview
Research Question 1	×	×	×
Research Question 2	×	×	×
Research Question 3	×		×
Research Question 4	×		×

2.1 | Document Analysis

For the document analysis, official sources such as laws, directives, and national plans were reviewed. Table 2.2 lists the specific documents examined.

2.2 | Literature Review

For the literature review, keywords were utilized on platforms such as Google Scholar and Scopus to find relevant studies in this field. Key terms included: Transboundary water management, Climate Change, Tagus River Basin, Albufeira Convention, Adaptive water management, Adaptation measures, Drought, Water transfer, Spain, and Portugal. The literature review also served to complement the document analysis, as some studies analyzed some of the important documents found in Table 2.2.

2.3 | Interview

To conduct the interviews, a preliminary list of potential interviewees was made, divided by specialization and country of residence to ensure diversity and coverage of topics pertinent to this study. Subsequently,

Legal Instruments	Applicable Region
Water Framework Directive	EU
Albufeira Convention	PT/ES
Lei da Água (Water Law)	Portugal
Plano Nacional da Água (National Water Plan)	Portugal
Programa Nacional para o Uso Eficiente da Água (National Program for the Efficient Use of Water)	Portugal
Comissão para Seca (Drought Commission)	Portugal
Plano de Gestão de Bacia Hidrográfica (River Basin Management Plan)	Tagus Basin - Portugal
Plano de Prevenção, Monitorização e Contingência para Situações de Seca (Prevention, Monitoring and Contingency Plan for Drought Situations)	Portugal
Guia Metodológico para a Definição de Regimes de Caudais Ecológicos em Aproveitamentos Hidráulicos de Portugal Continental (Methodological Guide for Definition of Schemes of Ecological Flows in Uses Hydraulics from Portugal Continental)	Portugal
Estratégia Nacional de Adaptação às Alterações Climáticas (National Climate Change Adaptation Strategy)	Portugal
Plan Hidrológico Nacional (Hydrological National Plan)	Spain
Plan Nacional de Depuración, Saneamiento, Eficiencia, Ahorro y Reutilización (National Plan for Purification, Sanitation, Efficiency, Savings and Reuse)	Spain
Plan Especial de Sequía (Special Drought Plan)	Tagus Basin - Spain
Plan Hidrológico de la parte española de la Demarcación Hidrográfica del Tajo (Hydrological Plan of the Spanish part of the Tajo Hydrographic Demarcation)	Tagus Basin - Spain

Table 2.2: Documents and Policies analyzed in the study

candidates were contacted, resulting in the scheduling of 10 interviews, conducted both in person and online. Confidentiality of the participants' identities was agreed upon request, and before each interview, consent was obtained from all interviewees for audio recording.

The interviews followed a semi-structured and open-ended format aiming to obtain the interviewee's perspective on the main issues facing the Tagus River Basin and explore potential solutions. Each interview started with the question, 'What do you perceive as the main challenge currently facing the Tagus River Basin?' and was then adapted based on the interviewee's initial insights and area of specialization. The topics that were selected as a guideline for the interview were aligned with the four main research questions and can be found in Table 2.3.

Interviewees included four women and six men, evenly split between Spain and Portugal. Specializations varied, encompassing water quality, governance, water policy, environmental law, ecology, hydrology, and civil and environmental engineering. Their affiliations with the Tagus River Basin were also diverse, with some of them currently doing research on the topic at Portuguese and Spanish universities. Three were associated with NGOs dedicated to maintaining the basin's ecological health. Additionally, two interviewees were former presidents of the Portuguese Association of Water Resources (Associação Portuguesa dos Recursos Hídricos - APRH), and one had contributed to the development of Spain's first Tagus Basin management plan.

The analysis of the interviews focused on identifying the key challenges mentioned by the interviewees and quantifying the frequency with which each challenge was raised. Additionally, the analysis was conducted on a topic-by-topic basis to extract the most valuable insights from each interviewee on specific subjects.

Topic	Subtopics
Main challenges	Free answer from the interviewee
Transboundary River Basin Management	Albufeira Convention Minimum Flow Coordination and Monitoring
Segura-Tagus Water Transfer	Solutions
Ecological Integrity of the River	Ecological Status Ecological flow
Pollution	Sources Problem
Reservoir Management	Possible Changes
Possible Technical Solutions	Water Quality Water Supply/Demand

Table 2.3: Topics of Discussion

3 | Conceptual Framework

This chapter introduces key concepts that form the foundation of this study, particularly about research questions 3 and 4. To address research question 3, we will explore various adaptation measures discussed in the literature. We will also define and explore the principles of Adaptive and AIWM, which are crucial for understanding the strategies and frameworks applied in addressing water-related challenges. These concepts are essential for providing a comprehensive response to research question 4 and will be revisited in Chapter 6.

3.1 | Drought Management from Literature

The European Commission emphasizes the necessity for adaptation measures in water policies to tackle water scarcity and drought. According to Sondermann and Proença de Oliveira (2022), designing an adaptation plan demands innovative thinking to develop a comprehensive strategy that minimizes society's vulnerability to climate change and allows for flexibility in handling uncertainties, having each potential adaptation measure in the strategy being carefully evaluated regarding its environmental and socio-economic impacts and weighing cost-benefit relationships. Also, the final adaptation strategy must consider the opportunities and limitations of each measure based on the hydrological and geological characteristics of the river basin system, as well as the complexity and operational objectives of the reservoir network. For (Kumar et al., 2016), water allocation considers objectives beyond economic efficiency, including equity and environmental protection. Efficient allocation systems involve stakeholders in decision-making and prioritize users for alternative water resources to prevent conflicts, addressing diverse stakeholder concerns as well as utilizing scenario planning and multi-criteria decision-making to guide the development of various future water demand and supply projections and make management more efficient, reducing conflicts and cultivating synergy and innovation for sustainable practices.

Adaptive measures include both demand and supply-side approaches (Pulwarty & Maia, 2014). Supply-side measures aim to boost fresh water supply by expanding hydraulic infrastructures, constructing reservoirs or water transfer systems, exploiting groundwater resources, and implementing alternative water sources like seawater desalination plants, wastewater reuse, and rainwater harvesting (Iglesias et al., 2018). On the other hand, demand-side approaches focus on minimizing water consumption and enhancing water-use efficiency, including minimizing physical losses and waste, upgrading irrigation systems, and altering cropping patterns and planting schedules in the agricultural sector (Sordo-Ward et al., 2019). When dealing with adapting to climate change in rivers and watersheds, the best way to tackle it is to have a proactive approach, taking actions beforehand to maintain or enhance river resilience. Proactive strategies involve anticipating change and adjusting river management accordingly. Building adaptive capacity at the watershed level includes integrating various activities and ensuring minimum environmental flows. In regions facing droughts, planting drought-tolerant plant varieties along riverbanks can help prevent erosion, and increasing the genetic diversity and population size of plants and fish through planting or stocking can improve their ability to adapt. In some cases, restoring floodplains by adjusting levees helps store water during droughts. (Palmer et al., 2009)

3.1.1 | Reservoir management

Collaborative efforts between dam managers and stakeholders in regulated rivers offer significant potential to secure beneficial flows. This can involve adjusting reservoir release schedules or implementing structures for temporary floodwater storage before reaching reservoirs. In regions with high evaporation rates, there may be considerations for removing dams linked to shallow, high-surface-area reservoirs, necessitating alternative water storage strategies, or accessing groundwater. Otherwise, if dams are not removed, an option would be to elevate the outlet that releases water to the downstream river. Moreover, adjustments to dam outlet heights may be required to maintain water quality in downstream river reaches amidst large reservoir level fluctuations. (Palmer et al., 2009)

Another approach that many countries have been taking in the last year, mainly for the objective of river restoration, is the removal of dams that may be obsolete. Typically, dams go through regular inspections to assess risks, which leads to the identification of deficient structures that may be suitable candidates for removal. In the decision-making process, social and economic considerations are crucial, particularly regarding the benefits the dam provides to the local population. Other important factors include the technical challenges, cost, and timeline of the removal project; the dam's purpose and size; the level of reservoir sedimentation; the ecological status of the river; downstream infrastructure; and a thorough understanding of river hydrology. When it comes to the process, dam removal can be executed either partially or fully. In cases of full removal, the process can be instantaneous, where the dam is demolished in a single event and the debris is mechanically removed, or it can be staged, taking place over several months or years. The staged approach is especially important for large dams with significant sediment accumulation, as it helps mitigate environmental and infrastructure risks downstream by controlling the release of sediments. (Duda & Bellmore, 2021)

Recent studies indicate that the ecosystem's physical responses to dam removal are typically rapid but vary significantly between upstream and downstream areas, highlighting the need for localized studies to better understand these dynamics. However, existing research has consistently shown that dam removal quickly reestablishes connectivity, restoring the natural movement of materials and organisms between upstream and downstream sections of the river. (Poff et al., 2018) Figure 3.1 shows the removed barriers by 2023 in European countries.

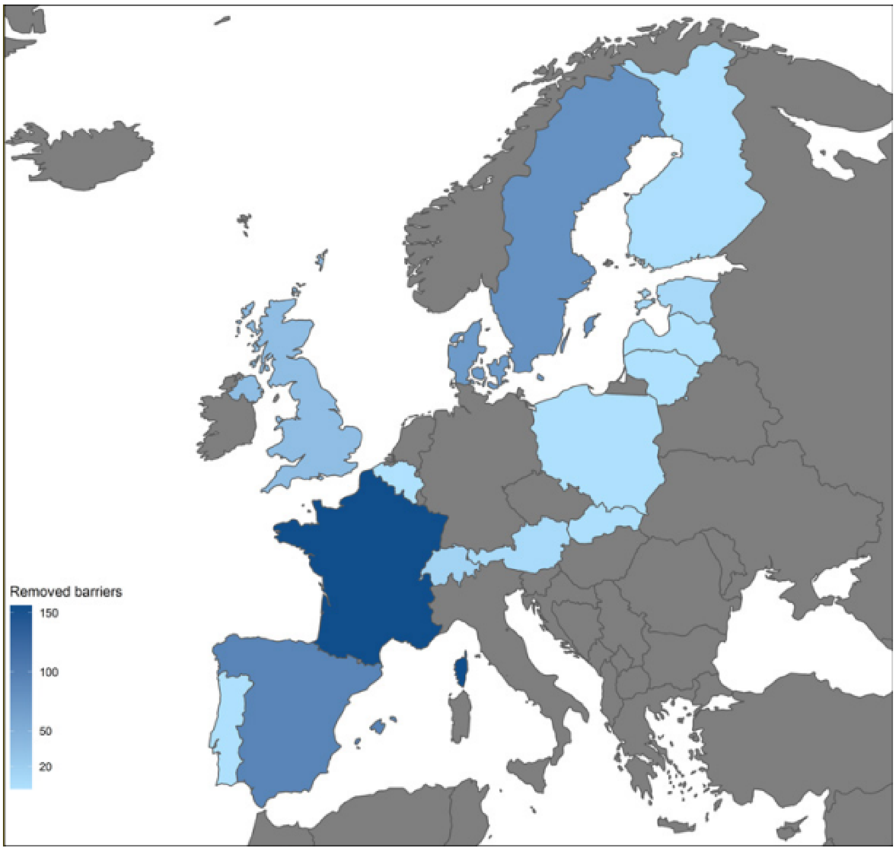


Figure 3.1: Dam removal across Europe (Dam Removal Europe, 2023)

3.1.2 | Ecosystem restoration

Dam removal can be a starting point for ecosystem restoration, but there are also other approaches to consider for restoring an ecosystem. According to Palmer et al. (2009), efforts to prioritize river restoration should target the most vulnerable segments, balancing proactive protection of existing resources with remedial projects to address climate change impacts. Key actions include reconnecting floodplains and riparian corridors to enhance flood mitigation and water storage capabilities while addressing threats such as invasive species and degraded habitats through comprehensive management strategies. Ensuring fish passage and rehabilitating river channels are critical reactive measures, particularly for migratory species facing habitat fragmentation. Special attention must be given to protecting diverse habitat types and species of ecological significance, replicating habitats across multiple locations to mitigate extinction risks. Monitoring and managing species through biological assessments enables early intervention and potential translocation efforts to support vulnerable populations under changing environmental conditions.

Aldous et al. (2011) studied the drought and water scarcity in a region in the USA and found that a restoration agreement resolved water disputes by securing irrigation water, retiring water rights, and protecting fish habitats and ecosystems, while also removing four hydroelectric dams. Additionally, protecting groundwater recharge zones is crucial due to potential future decreases in recharge rates.

3.1.3 | Adaptation in Irrigation Systems

Typically, agriculture is a significant part of water demand in a basin. Therefore, it is essential to investigate adaptation measures related to water use in irrigation. Adamson et al. (2017) conducted a literature review on adaptation responses to increasing drought frequency, particularly focusing on irrigation solutions. One common approach identified was to enhance irrigation efficiency both on-farm, through shifts from flood to drip irrigation methods, and off-farm, by lining irrigation supply channels. This means increasing the ratio of water that is beneficially used in the field to the total volume of irrigation water applied. However, it was noted that while increasing irrigation efficiency is a prevalent strategy, it doesn't necessarily lead to an increase in water availability. One explanation is that the water that was previously lost would often return to the watershed and be recovered, as runoff, for example. (Jaramillo & Destouni, 2018)

In many cases, managing soil water may offer more advantages than investing solely in infrastructure. Another perspective on producers' adaptation involves both intensive and extensive approaches, such as adjusting applied water rates and diversifying crops and irrigated areas. In the Australian context, Adamson et al. (2017) highlighted the significant advantage of the country's historic production mix, which incorporates both annual and perennial production systems. This diversified approach has enabled a considerable degree of risk minimization during droughts. According to Adhikari (2018) as a component of climate-smart agricultural practices, diversifying crops, adopting organic farming, and implementing agroforestry techniques serve the dual purpose of ensuring food security and supporting livelihoods, all while conserving soil and water resources. These initiatives open new opportunities to enhance crop diversity, increase productivity, diversify income sources, and promote environmental improvement. However, there is a significant risk of losing traditional crop varieties.

3.1.4 | Water recycling/reuse

According to the EU, water reuse is an effective solution to address the increasing droughts affecting European countries by recycling water from urban wastewater treatment plants. This approach provides a safe and reliable water source, reduces pressure on natural water bodies, and enhances the region's adaptability to climate change by extending the water's life cycle. However, despite its advantages, water reuse remains underutilized due to limited awareness of its potential benefits and the absence of a supportive and coherent framework to promote its widespread adoption. Since June 2023, the EU Water Reuse Regulation has been in effect, providing a clear set of rules to ensure that water reuse practices are safe and efficient. This regulation makes it easier for countries to implement water reuse by offering a standardized framework that promotes its adoption across Europe. (European Commission, 2023)

Recycled water serves various non-domestic purposes like agricultural irrigation, industrial needs, and other urban uses. In Tarragona, Spain, the Water Reclamation Project aims to combat regional water scarcity by reclaiming water and involves two wastewater treatment plants that supply reclaimed water to an industrial area, substituting water from the Ebro River, showing then an opportunity for expanding the practice in Spain. (Kumar et al., 2016)

3.1.5 | Desalinization

The process of desalinating salts from brackish and seawater has emerged as a rapidly growing alternative to reservoirs and inter-basin transfers, particularly in coastal regions of the Mediterranean. Currently, Barcelona has 24% of the city's water consumption coming from desalination. According to Kumar et al. (2016) desalination is primarily considered for domestic and industrial sectors, as the decentralized nature of water use in agriculture and the associated distribution costs render desalination economically unfeasible for this sector and it is assumed that desalinated water can supply up to 25% of domestic needs and a maximum of 20% for industrial purposes.

Although desalinated water may not be viable for some sectors, such as agriculture, due to the high cost, it can be used as a temporary water supply solution. That is the case for the Southeast region of Spain, where desalination plants have been supplying an average of 20.2% to the total water resources used in the region between 2004 and 2013, depending annually on the availability of other water resources. Notably, seawater desalination has been crucial in securing water supplies for the Alicante and Murcia regions, especially during periods of water scarcity. (Hernández-Sánchez et al., 2017) Therefore, desalination offers a potential long-term alternative for reducing the Segura Basin's dependence on the Tagus-Segura Transfer. (Morote et al., 2017) Currently, in Portugal, there are no major desalination plants but there are plans for construction in the Algarve region, with studies being made for it to have a renewable energy supply, such as solar, to reduce costs.

3.2 | Adaptive and Integrated Water Management

Adaptive and Integrated Water Management (AIWM) is an innovative response to climate-related challenges in water management, integrating climate adaptation into plans, and continuously learning and adjusting strategies for better responsiveness to changing conditions compared to traditional approaches. AIWM acknowledges four dimensions essential for sustainable water governance. These include the natural dimension, hydrological cycle, and water quality; the human dimension, addressing economic interests and stakeholders; spatial considerations, spanning various scales from local to international basins; and the temporal dimension, managing variability in water availability and demand over time (Savenije & Van der Zaag, 2008). Therefore, it requires new skills like stakeholder collaboration, linking science with policy, participatory learning, managing uncertainty, social learning, and assessing diverse measures and scenarios. Huntjens et al. (2010) research showed that in the cases in which a higher level of AIWM was seen, there were also higher levels of learning in terms of its physical Interventions. (Komakech et al., 2007) evaluated many transboundary river basin authorities and institutions and concluded that their efficiency and effectiveness depend on seven critical factors, including an adaptable management structure and the principle of integrated planning.

According to (Pahl-Wostl et al., 2007), the governance structure plays a fundamental role in this scenario, which also has to be adaptive, to increase the adaptive capacity of river basins at different scales by changing the entire water management system. An active learning from all stakeholders, emphasizing the importance of drawing lessons from implemented policies necessary. Raadgever et al. (2008) highlights five central regime elements on transboundary water management: actor networks, water law, water policy, information management, and financing systems, which can be used to analyze how integrated and adapted the water management is.

Actor Networks

Transboundary water management often centers around national governments, taken as unitary actors, but in addition, cooperation is needed between different government sectors and government levels, between government authorities, NGOs, and individual citizens, and between all these and the experts. All these actors have different resources that are necessary for transboundary river basin management, such as information, expertise, funds, and legal competencies. To improve the legitimacy and efficacy of management, the views of all relevant stakeholders should be taken into account.

Legal Framework

Developing comprehensive and clear water laws is crucial to allow stakeholders to voice concerns, contribute to management, and regulate environmental use while fostering innovation. Crafting such legislation requires adept balancing of interests. An effective legal framework should encompass public participation, information management, financing, planning, and operational management, including permitting. Regular policy reviews and adaptability are essential. The legislative process should be efficient, and water rights should be subject to periodic review to accommodate evolving circumstances and knowledge.

Policy Makers

Adaptive management, recognizing inherent uncertainty in policymaking, advocates for robust and flexible policies. This involves considering a full range of measures and assessing them across various scenarios, such as different climate change and economic growth levels. Policies should keep options open and be adaptable to new evidence. This approach is necessary because it's challenging to identify measures effective in all scenarios and impossible to anticipate all future developments. Additionally, our knowledge of ecological and social systems is limited. Conducting small-scale policy experiments is recommended. Long-term perspectives are crucial, and stakeholder involvement in policy development is essential for successful implementation.

Information Management

Active learning involving all stakeholders is crucial for adaptive management, particularly in information management. Stakeholders should express their needs, direct information production, and exchange viewpoints to build a shared knowledge base. This base should integrate various knowledge types and reflect stakeholder perceptions to inform decision-making. Experts should communicate uncertainties transparently. Effective information transfer between levels is essential for policy implementation.

Financing System

Transboundary river basin management financing faces challenges in securing adequate funds, avoiding perverse incentives, and maximizing learning opportunities while maintaining acceptable costs. Investing in participatory approaches and outcome monitoring can prevent costly delays and unnecessary infrastructure. Robust financing systems rely on diverse funding sources, including cost recovery mechanisms like water pricing. Consolidating decision-making, financing, and beneficiary roles enhances effectiveness without becoming overly complex. Authorities should have access to loans and depreciation options for long-term investment and asset replacement.

4 | Transboundary Water Management in the Tagus River Basin

The Convention on the Protection and Use of Transboundary Watercourses and International Lakes (UNECE 1992) defines "transboundary waters" as surface or groundwater that flows across or is located on boundaries between two or more states. This chapter will provide a comprehensive examination of the study area, focusing on its unique characteristics and complexities as a transboundary basin. First, we will examine the study area, focusing on its geographic and meteorological characteristics, reservoir regime, and water quality. The chapter will then analyze the impact of climate change on the region and then, how is basin management done. Special attention will be given to the complexities arising from cross-border management, where political and geographical boundaries intersect, presenting significant challenges for sustainable water management.

4.1 | Study Area - Tagus River Basin

The Tagus River, situated in the central region of Peninsular Spain, serves as a vital water source for over 10 million inhabitants, encompassing two European capitals, Lisbon and Madrid. It stands as the largest river in the Iberian Peninsula, stretching across a total length of 1092 km and draining an area exceeding 80,000 km^2 (Lobanova et al., 2016; Senent-Aparicio et al., 2021). Within Portugal, the Tagus river basin covers 28% of the territory, spanning 94 municipalities, while in Spain, it traverses five autonomous communities and 12 provinces, making it the most densely populated basin in the country (Ribeiro et al., 2019). Flowing westward from its origins in central Spain to its estuary in Lisbon, Portugal, the Tagus River acts as a natural divider of the Iberian Plateau into northern and southern regions (San-Martín et al., 2020). Spanning the total area, 69% belongs to Spain, with the remaining 31% falling within Portuguese borders. The Spanish segment of the basin is demarcated by the Central System to the north, the Iberian System to the east, and the Montes de Toledo to the south, resulting in a diverse landscape characterized by varying elevations, climates, and geological formations (Valerio et al., 2020).

The rainfall regime in the basin is influenced by both Mediterranean and Atlantic climates, leading to pronounced inter-annual and inter-seasonal variability in flows. High flows are typically observed in winter, from November to March, constituting around 75% of the mean annual flow, while low flows occur from June to September, accounting for approximately 7% of the mean annual flow (Sondermann & Proença de Oliveira, 2022). The mean annual precipitation in the Tagus River basin is 689 mm, with Spain receiving 618 mm and Portugal 770 mm (del Tajo O.A., 2022; do Ambiente (APA), 2022). However, exhibiting significant variability across seasons and elevations. This variability is reflected in the asymmetrical network of tributaries, with right tributaries displaying abundant discharge and shorter watercourses compared to their left counterparts (Valerio et al., 2020). The climate in the region is characterized by distinct wet (October to April) and dry (May to September) seasons, resulting in unsaturated soil for much of the year and limited aquifer recharge.(Kilsby et al., 2007) Headwaters receive approximately 1100 mm/year and middle reaches in the south receive only 450 mm/year. The upper regions of tributaries originating from the northern and western sectors of the basin (specifically, from the Central Ranges in Spain) contribute over 1500 mm of annual rainfall. Portuguese tributaries play a substantial role in the river's water supply, exhibiting a relatively consistent seasonal pattern influenced by the Atlantic, with pronounced peak flows typically occurring during winter months. (López-Moreno et al., 2009) Under natural conditions, the mean annual streamflow at Lisbon amounts to around 17,150 hm^3, with Spanish sub-basins contributing 10,250 hm^3 and Portuguese sub-basins, including the Sorraia tributary, discharging directly into the estuary, contributing 6,900 hm^3.(Sondermann & Proença de Oliveira, 2021). Table 4.1 shows precipitation, evapotranspiration, and area data from the Tagus River Basin.

Table 4.1: Area, Precipitation, and Real Evapotranspiration of the Basin

Data	**Spain**	**Portugal**
Area (km²)	55,780	25,016
Precipitation (mm/year)	618	770
Real Evapotranspiration (mm/year)	442	500

The Tagus River Basin is one of the most regulated basins in Europe, having many large multi-purpose reservoirs, with a total storage capacity of almost 14,000 hm^3. (EEA 2019) This is due to the high water-stress condition in the region, as it has a water exploitation index plus (WEI+), which is an index of water use against renewable freshwater resources, of 78% in the summer and 49% in the spring. (Sondermann & Proença de Oliveira, 2021) Due to the climate, Spain suffers more from the hydric stress, which together with the increased usage and transfers, impact also the health of downstream aquifers, often within Portuguese territory. While the water availability in Spain depends mostly on the climate, in Portugal, it depends not only on the climate but also on the Spanish water management practices, as 50% of your water resources come from Spain. (Ferreira, 2017) Figure 4.1 gives an overview of the entire basin.

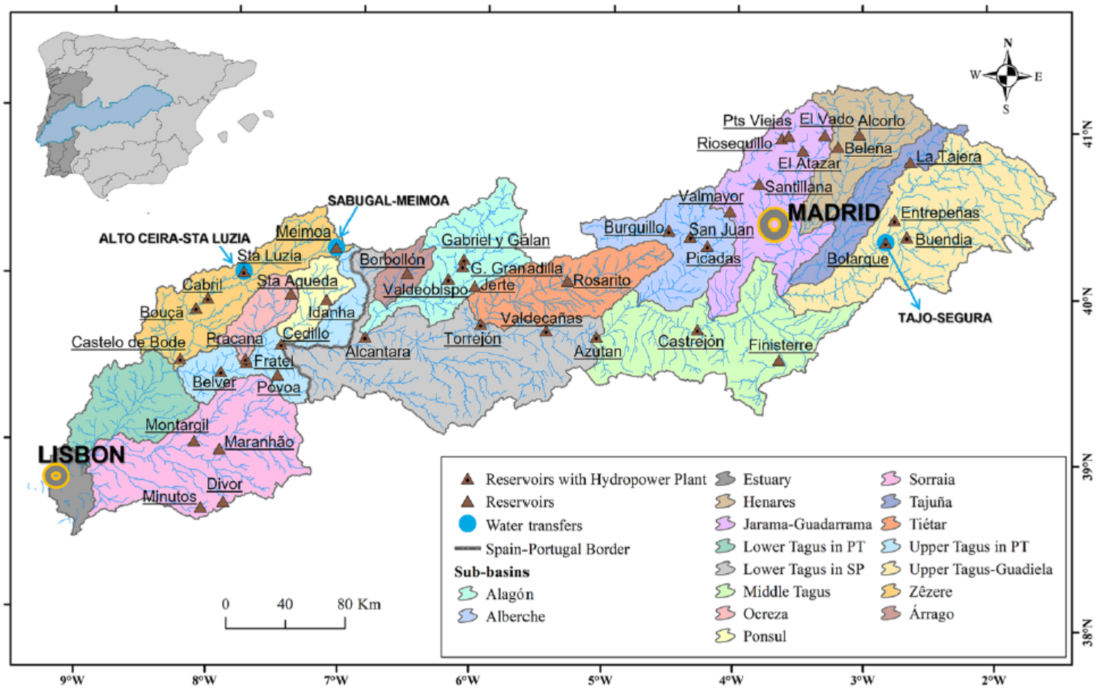


Figure 4.1: Tagus River basin, including locations of the reservoirs and main hydropower plants (Sondermann & Proença de Oliveira, 2021)

To better understand the system's functioning, a basic balance model was developed incorporating key variables: precipitation, evapotranspiration, cross-border water transfer from Spain to Portugal, water discharge to the sea, and the Segura-Tagus transfer. Data for these variables were sourced from the most recent basin management plans of both countries. Figure 4.2 shows the model.

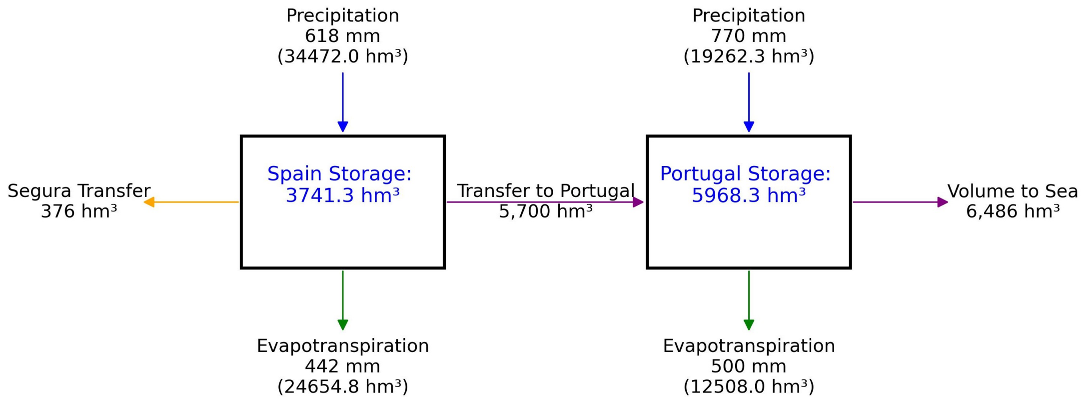


Figure 4.2: Basic Balance Model for the Tagus River Basin

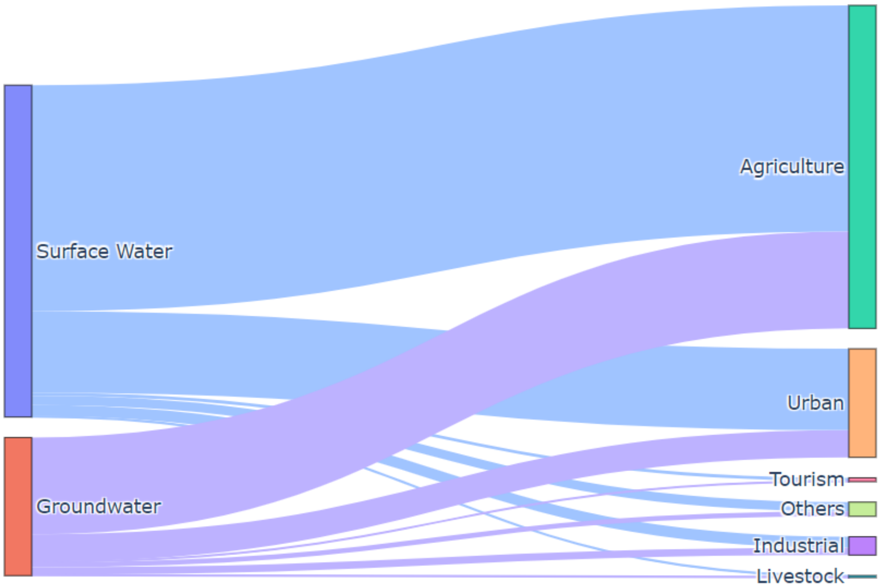
The Tagus River serves diverse purposes, including urban supply, as in Madrid and Lisbon, irrigation of vast agricultural areas (230,000 ha), and industrial uses (e.g., cooling of nuclear and thermal plants). Additionally, a significant fishing industry in the Tagus estuary and adjacent coastal regions relies on freshwater flow levels (López-Moreno et al., 2009). Urban supply and irrigation constitute the largest withdrawals from surface sources, with groundwater directly exploited at a lower rate than the national average, with it being explored more in Portugal than in Spain, where both surface and groundwater in the basin are the main sources of drinking water supply. (Sondermann & Proença de Oliveira, 2021) Table 4.2 presents the total consumptive use of water withdrawn in both the Portuguese and Spanish sides of the basin, based on the most recent basin management plans. Figure 4.3 illustrates the percentage of water withdrawals sourced from groundwater and surface water for each sector in both countries. The volume of groundwater directly exploited is lower than the national average. Aquifers are predominantly regarded as critical water sources, especially during severe droughts or for fulfilling local water requirements. They play a crucial role in sustaining the base flow of rivers. (Valerio et al., 2020)

Use	**Portugal**		**Spain**	
	Quantity (hm^3)	**Percentage (%)**	**Quantity (hm^3)**	**Percentage (%)**
Agriculture	1.173	69%	1.993	72%
Industrial	67	4%	52	2%
Urban	394	23%	707	25%
Others	73	4%	27	1%
Total Consumptive Use	**1.707**	**100%**	**2.779**	**100%**

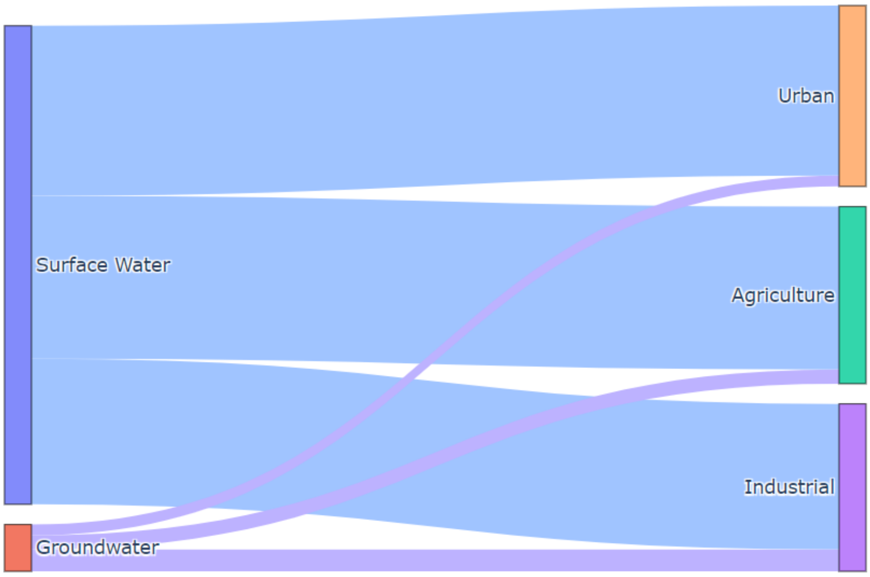
Table 4.2: Total Consumptive Use of Water Withdrawn in Portugal and Spain

4.1.1 | Reservoir management and changes in the river

During the latter part of the 20th century, an increase in water and electricity demand prompted an extensive dam construction initiative in the Tagus River basin. That led to a storage capacity of 11.150 hm3 in Spain, with more than 40 large dams, being the river with the largest total and hydroelectric



(a)



(b)

Figure 4.3: Percentage of water withdrawals sourced from groundwater and surface water in 4.3a Portugal and 4.3b Spain

reservoir capacity (5268 hm3) in Spain, and 2.850 hm3 in Portugal, with 34 water plants. (Ministerio para la Transición Ecológica, 2019) Urban water demands in both countries are predominantly met by large reservoirs situated in the Jarama-Guadarrama (Spain) and Tagus Valley (Portugal) sub-basins, where the metropolitan areas of Madrid and Lisbon are located, respectively. For the agricultural sector, which is the primary water user, with irrigation centers spread throughout the entire Tagus River basin, the Alagón and Tagus Valley sub-basins are the main suppliers. The Alagón sub-basin in Spain relies mainly on reservoir regulation for it, while in the Tagus Valley sub-basin groundwater from the Tagus-Sado aquifers serves as the primary source. (Sondermann & Proença de Oliveira, 2022)

Besides basin usage, a potential transfer of up to 650 hm3 per year from the Bolarque reservoir to the Guadiana, Jucar, and Segura River basins for irrigation and urban supply is feasible. However, these transfers are contingent upon the water levels of the Entrepeñas and Buendia reservoirs. From 1986 to 2013, an average of 375 hm3 per year was transferred. (Centro de Estudios y Experimentación de Obras Públicas, 2018; Sondermann & Proença de Oliveira, 2021) Besides that, in Portugal, the Tagus receives water from the Douro (up to 82 hm^3/year) and Mondego (up to 44 hm^3/year) river basins.(Sondermann & Proença de Oliveira, 2022) The study by Sondermann and Proença de Oliveira (2021) found significant reductions in mean annual flow within the Tagus main channel when compared to the natural conditions. Values range from 25% to 57%, with the most substantial decreases observed downstream of the Tagus-Segura aqueduct. Similar reductions in stream flow, ranging from 11% to 38%, were observed in tributaries of the Tagus River in both Spain and Portugal. The extensive regulation of flow has significantly altered the morphology of the river over the past five decades, resulting in the accumulation of large volumes of sediment within the reservoirs (Lobanova et al., 2016). The area downstream of the Entrepeñas and Buendía reservoirs is also another factor of concern. It has four protected areas of the Natura 2000 Network, with eight Community-interest habitats linked to water. With the changes in the river flow, the protected areas had a reduction in their conservation status of some of their natural values, as in fish populations. (Baeza et al., 2023)

According to Lorenzo-Lacruz et al. (2010), this regulation of reservoirs and water transfers has been causing uncertainty about future water resource availability in the Tagus River basin, as it disrupts the climate-hydrology relationship. Despite the more frequent and severe drought, maintaining the natural flow of the river is not a priority. The current strategy relies on the resilience of the Entrepeñas-Buendía reservoir system to mitigate short-term drought impacts. However, sustained droughts since the 1990s have challenged this approach. In 2005 and 2006, the reservoir system failed to meet demand during prolonged drought, necessitating a reduction in flow to both the Tagus River and the Mediterranean basin transfer system, leading to conflicts and political ramifications at the national level.

In the upper-middle course of the river, the natural flow dynamics are disrupted by withdrawals for the Tagus-Segura transfer. This leads to a reduction in headwater flows, effectively preventing the establishment of a genuine environmental flow regime with seasonal variability. Table 4.3 shows the daily average and minimum flow of the Tagus River in Aranjuez, Toledo, and Talavera after the Segura-Transfer was added, showing that the reduction in the daily average and minimum flow is around 50-60% in this region. Therefore, the flow pattern persists at consistently low levels throughout much of the year, experiencing a temporary increase only during reservoir water releases for irrigation or other designated purposes, before promptly reverting to the original minimum level (San-Martín et al., 2020). According to "Plan Hidrológico de la parte española de la Demarcación Hidrográfica del Tajo. Memoria. Plan hidrológico de cuenca [2015-2021]. Diciembre de 2015" (2015) minimum flow requirements are applied in these three cities in the Tagus River.

As a result, the middle section of the river experiences significant challenges, including the consequences of water transfers, the presence of dam cascades upstream of the Tagus's entry into Portugal, the absence of natural river dynamics, and the discharge of effluents from Madrid.(San-Martín et al.,

Table 4.3: Average and minimum flow in the Tagus river downstream the Segura-Transfer, before and after. Adapted from (San-Martín et al., 2020)

City	Daily Average Flow (m^3/s)		Daily Minimum Flow (m^3/s)	
	Before	Now	Before	Now
Aranjuez	35	8.5	9.2	5.2
Toledo	74.6	36	31.5	13.7
Talavera	115	46	21	9.3

2020) All of that leads to a reduction in the daily average flow of around 27% at the border, with flow rates increasing notably just after crossing the border, largely due to the contribution of Portuguese tributaries, which helps mitigate flow reductions originating from Spain. (R. Rodrigues, 2007; Sondermann & Proença de Oliveira, 2021)

The low flow before the Portuguese border can be explained also by the segment of the Tagus River, extending from Talavera de la Reina in Castile-La Mancha to the Portuguese border in Extremadura, which is marked by a succession of dams spanning nearly 300 km, including the significant Alcántara reservoir, the second-largest in Spain. (San-Martín et al., 2020) The downstream drought characteristics of the Tagus River have undergone significant changes since the construction of the Alcántara dam in 1969. Before 1969, droughts were longer and more severe in the upstream sector compared to the downstream sector during the period from 1943 to 1969. However, post-1970, the Portuguese sector has experienced more severe droughts in terms of duration and magnitude than the Spanish sector. These changes are attributed to management practices at the Alcántara reservoir. Fortunately, the impact of the Alcántara reservoir in exacerbating droughts is partially offset by the inflow of tributaries into the Tagus River downstream of the reservoir, particularly between the Alcántara reservoir and the gauging station at Santarém. Drought severity in these tributaries is considerably less than that experienced in the Tagus River, particularly in recent times. (López-Moreno et al., 2009)

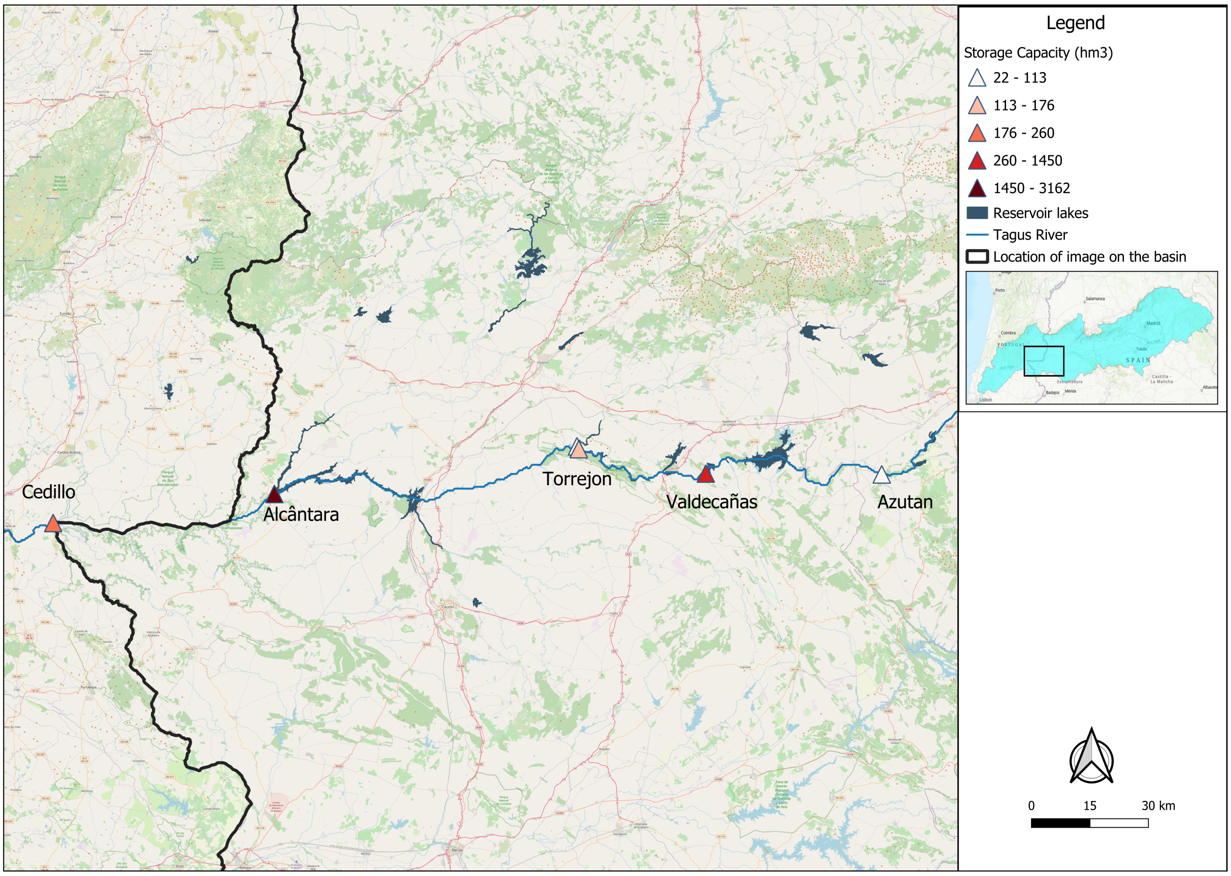


Figure 4.4: Segment of the Tagus River with five consecutive dams

Uses of the main dams in Spanish Extremadura							
Dam	**Urban Water Supply**	**Irrigation**	**Hydro power**	**Industry**	**Fishing**	**Navigation**	**Bathing**
Azutan		X	X		X		X
Valdecañas	X		X				
Torrejon	X		X				
Alcântara			X				
Cedillo			X				

Table 4.4: Uses of the main dams in Spanish Extremadura.
Source: www.embalses.net; Ministry of Environment.

The other reservoirs are the Cedillo, Azutan, Valdecanas, and Torrejon dams, and can be seen in Figure 4.4. Collectively, these five reservoirs have a capacity exceeding 5000 hm^3. However, in the Extremadura region, encompassing a stretch of 200 km from east to west, the Tagus River enjoys only 30 km of free flow, confined between the Azután dam and the tail end of the Valdecañas. Downstream from the Azután reservoir, the tributaries of the Tagus River contribute an additional 1500 hm^3 in capacity ("La cuenca del Tajo en cifras", 2002). Nonetheless, their primary function is power generation, accounting for nearly 70% of the installed hydropower capacity in the basin ("Plan hidrológico de cuenca [2015-2021]. Anejo 3 de la memoria. Usos y demandas de agua. Parte española de la Demarcación Hidrográfica del Tajo", 2015). Also, a minimum flow of 10 m^3/s was established upstream from the Azután dam, which corresponds to a minimum flow of 16 m^3/s in the water section. (Henriques, 2018)

The Cedillo dam is a very important one, as is the one by the border between both countries, and even though is technically on the Portuguese side of the border, it is operated by Spain. This dam drains 58.000 km^2 of the basin. According to Henriques (2018), it is evident that, although generally meeting the minimum values determined, for a good part of the time, the flow out of the Cedillo dam is zero, while the rest of the mandatory flow is concentrated in a short period, only a few hours per week. This is done because the Cedillo dam is operated to produce electricity in periods of bigger consumption. The weekly flow established in the agreement between the countries is 7 hm^3 and is satisfied usually between four to eight hours of operation of the hydroelectric plant at full or half power, respectively. Therefore, Henriques (2018) concluded the operating time was only 27.2%, leaving the flow of the Tagus River entering Portugal zero for 72.6% of the time during the 2016/2017 hydrological year, with the flow being zero at least 20 hours per week. Downstream from Cedillo is the Fratel dam, which also serves as a power generator facility Between 2010 and 2017, the tributary flows to the Fratel dam were consistently low, averaging less than 10 m^3/s for approximately 14 days each year. Despite this, the daily mean flow stands at a relatively high 184 m^3/s. Also, Henriques (2018) highlights that the flows that are reported by Spain in Cedillo are considerably higher than the ones recorded in Fratel, while no consumption between them would justify the difference in value.

The fluctuations in water flow in the final segment of the Spanish Tagus River due to irregular and frequent releases triggered by energy price fluctuations have well-documented environmental consequences. This includes habitat destruction, reduced biodiversity, and the displacement of native species by more adaptable generalist species capable of withstanding frequent and substantial flow fluctuations. San-Martín et al. (2020) highlights sustainability concerns linked to the management of these five reservoirs, all under the control of Iberdrola. Historical incidents, such as one in 2019, in which farmers found themselves unable to irrigate their land, while residents in Berrocalejo faced a shortage of drinking water, exemplify the repercussions of this centralized management. In that case, Iberdrola decided to release excess water to farmers, leading to the water pumps in the reservoir being exposed above the water level, to meet obligations under the AC. (Fernández & Marcos, 2019) This selective prioritization of hydroelectric power generation, as observed in the cascading dams, accentuates the absence of consideration for the externalities affecting other stakeholders along the Tagus River. The management practices near the Portuguese border, governed by the AC, lack multi-scalar governance and inclusive participation, thereby privileging only the interests of major stakeholders like Portugal and Iberdrola, the Spanish energy company responsible for the dams with hydropower generation (del Moral & Do Ó, 2014).

Both Spain and Portugal are working on implementing environmental flow requirements to protect aquatic and plant life and improve water quality. In Spain, discussions are ongoing regarding minimum flow requirements for all water bodies, while in Portugal, regulations are in effect for only a few reservoirs, including Castelo de Bode, Pracana, and Minutos. Sondermann and Proença de Oliveira (2021) made a model that indicates that the current system is insufficient to meet demands, with future water supply failures expected to worsen, especially in areas with increasing water demand. Implementing new environmental flow requirements will further constrain water availability for consumptive uses at basin headwaters. While additional releases from upstream reservoirs and natural flows help satisfy downstream water demands while maintaining environmental flows, reducing water transfers through the Tagus-Segura aqueduct is crucial for the Tagus River basin's sustainability, despite potential negative economic impacts in recipient basins. Recent Spanish government decisions to reduce maximum water transfers align with this goal. However, remediation measures in recipient basins are necessary to mitigate economic impacts. While new environmental flow requirements will help some water bodies, further measures may be needed, especially in Spanish upstream sub-basins and near the Cedillo dam on the lower Tagus. This could worsen water demand satisfaction, particularly affecting non-priority agricultural uses.

4.1.2 | Tagus-Segura water transfer

The Tagus-Segura transfer is the most significant water transfer in operation in Spain. This water transfer project, documented as the largest and longest in Spain according to MITECO (2018b), was intended to be a pioneering hydraulic endeavor independent of state subsidies. (San-Martín et al., 2020) The transfer can be seen in Figure 4.5 and 4.6.

Figure 4.5: Segment of the Segura Water Transfer (elDiario.es, 2015)

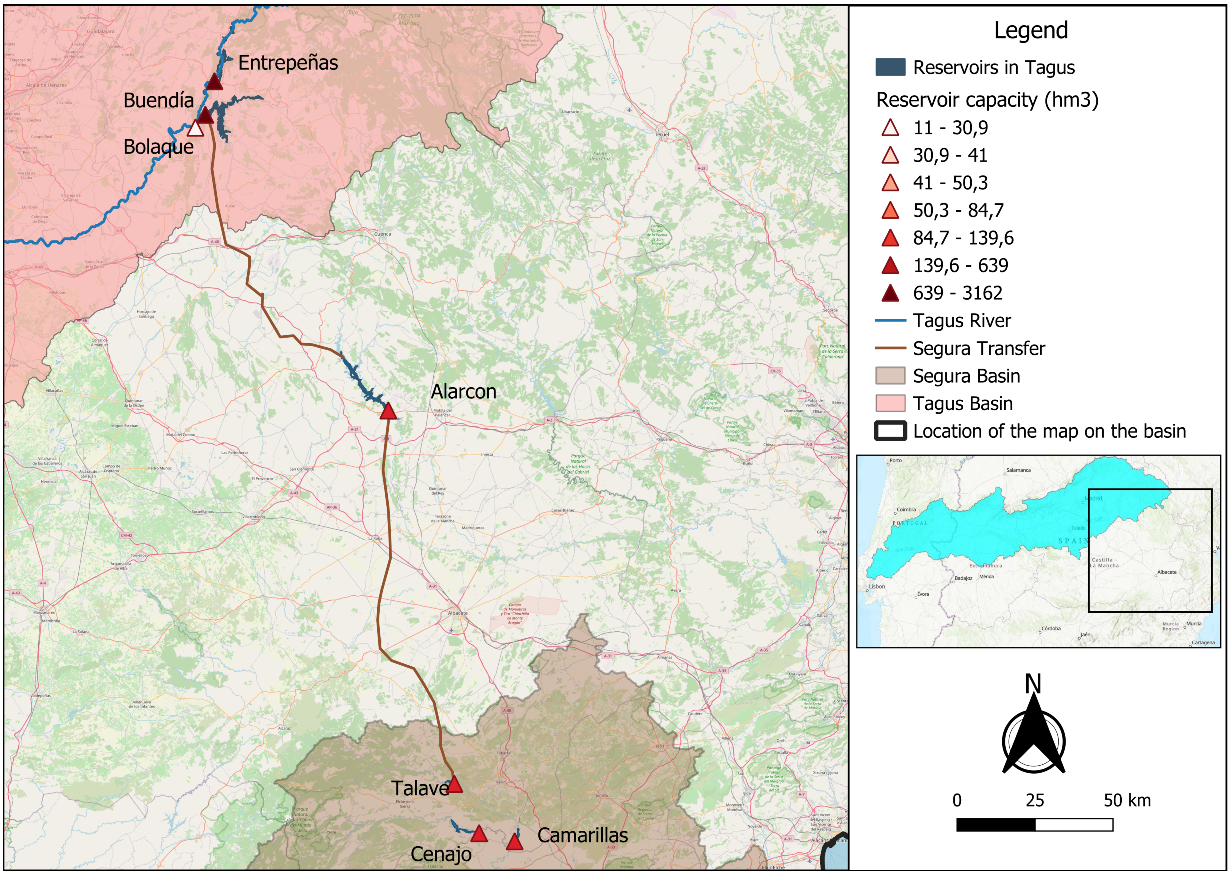


Figure 4.6: Map of the Segura-Tagus Water Transfer

The Tagus-Segura water transfer started operating in 1979, having the upper Tagus river basin as the source of water for the southeast of Spain, being an important actor in the region's socioeconomic development. The transfer comprises a 286 km-long channel with a flow rate of 33 m^3/s, commencing at the Bolarque reservoir downstream of Entrepeñas and Bundía reservoirs. Water is pumped from Bolarque to the Bujeda reservoir, then directed towards the Alarcón reservoir on the Júcar River. From there, it flows to the Talave reservoir on the Mundo River or the principal tributary of the Segura River. (Melgarejo et al., 2018) Ever since the operations started, natural inflows to the Entrepeñas and Buendía reservoir system have decreased by more than 47% (San-Martín et al., 2020), with the yearly average of water transfer being 350 hm^3, and that water is being used for urban supply and agriculture. (Lorenzo-Lacruz et al., 2010) The average volume is smaller than the actual authorized maximum volume for the transfer, which is 600 hm^3 of water per year, with a maximum monthly flow reaching 68 m^3, due to the availability of resources. Throughout a hydrological year, the transfer's maximum volume stands at 650 hm^3. However, monthly flow limitations are enforced based on the stored volume in the Entrepeñas and Buendía reservoirs at the month's onset and the cumulative flow volume into these reservoirs over the preceding 12 months. (Pellicer-Martínez & Martínez-Paz, 2018)

In addition to the significant volume of water transferred from the Tagus River, the water transfer project has faced criticism for its disproportionate distribution of costs and benefits. The basin from which the water is extracted bears the brunt of the costs, while the advantages are predominantly realized in the receiving basin. Notable costs include environmental repercussions, such as reduced river flow, as well as socio-economic impacts like diminished revenue from tourism and other leisure activities in the affected region. According to the 2013 PwC report, the Tagus-Segura transfer has created more than 100.000 jobs, especially in the Segura basin, and contributes €2.364 million to the national gross domestic product each year. (Senent-Aparicio et al., 2021) Further controversies surrounding the transfer include its construction during the dictatorship, the redistribution of water from economically disadvantaged to affluent regions, and its primary focus on irrigation. (San-Martín et al., 2020)

4.1.3 | Agriculture

A dedicated section on agriculture within the basin was deemed essential because, besides the nonconsumptive use of water in both countries due to industrial cooling and hydropower, the sector with the highest water demand in both countries, hence demanding extra attention when it comes to water allocation. When the agriculture practice is intensive, not only there is a high water demand, but also causes diffuse pollution, due to pesticides and fertilizers, affecting the good status of the water bodies.

Due to the highly regulated nature of the Tagus Basin, 45% to 90% of the water withdrawn for irrigation is centrally served by surface irrigation systems, depending on the region. While the remaining agriculture areas are irrigated by sprinkler systems (up to 35%) and localized systems (up to 15%). Spanish farms have been acknowledged to be over-irrigated, with high degrees of nitrate pollution and other effluents. Recently, awareness of these factors has led to an increase in sprinkler and drip irrigation leading to water saving and reduction in pollution. (Striver, 2006)

Both countries have similar efficiency. The global efficiency for those extracting surface water is 0.6, considering a return rate of 22% and 324.34 hm^3/year lost. In the management plan, they estimate 2027 with an improved global efficiency of 0.65, but a reduced return rate of only 16% and a loss of 334.04 hm^3/year. Regarding groundwater, the efficiency remains at 0.9 for both 2022 and 2027, with losses also amounting to 15.14 hm^3/year. Table 4.5 shows the potential of improvement per sector according to calculations found in Tejo (2017).

Overall, in the region, cereals, vineyards, and olive trees are the main cultures cultivated due to the dry weather. Cereals complete their growth cycle just as the hot, dry season begins, while vineyards and olive trees have deep roots that help them withstand prolonged droughts. (Striver, 2006) In Portugal, the predominant permanent crops are vineyards, olive groves, nuts (such as almonds and walnuts), and some fresh fruits, primarily apple and pear trees, but also including peach, plum, and cherry trees. (*Recenseamento Agrícola 2019*, 2021) While in the Spanish Tagus, the most exploited crops are grains, fallow lands, fallow fields, vineyards, olive groves, and non-citrus fruits.(del Tajo O.A., 2022) With these data, a calculation was performed to determine the water requirements based on the crop types in both countries and the average water demand per hectare for those crops. When comparing the total water needed for irrigation according to the crops used and the actual total water used for irrigation in the basin, a 42% discrepancy was identified, as shown in the Table 4.6, which aligns with the figures calculated in Table 4.5.

Recently a Rural Development Program was made to improve irrigation systems for farmers in Portugal, and some improvements were seen in the south of the Tagus River. The program encouraged the adoption of advanced irrigation technologies, to enhance productivity and contribute to water conservation. (Observador, 2022) According to Iglesias et al. (2018), the increase in irrigation efficiency is necessary but not enough, and adaptation options such as improvement of drainage systems and small-scale water reservoirs should be considered.

Sectors	**Volume of Water Used (VWU) (a)**	**Water Savings Potential (WSP)**		
		Water Waste (W) (b)	**Water Resources Efficiency (WE) (c)**	**Total (d)**
Agricultura	75%	37,5%	30%	42%
Urbano	20%	25,0%	30%	19%
Industrial	5%	22,5%	30%	2%
Total Use	**100%**		**Total Potential**	**54%**

Table 4.5: Water Use and Savings Potential by Sector

Notes:
(a) National Water Plan 2015; (b) National Water Plan 2010 (preliminary version).
(c) In the urban sector, concerning buildings, both nationally and within the European Union, a water savings potential of 30% is estimated with the adoption of water efficiency measures - from the Aqua eXperience Guide - ANQIP, ADENE, and EPAL. In the absence of data for the agricultural and industrial sectors, identical levels of water efficiency were assumed.
(d) Water Savings Potential = Volume of Water Used x Waste + Water Consumption x Water Efficiency, thus, WSP = VWU x W + (VWU - VWU x W x WE).
Sources:
a) PNUEA - Programa Nacional para o Uso Eficiente da Água
b) Guia Aqua eXperience - ANQIP, ADENE e EPAL

Table 4.6: Comparison of Water Usage in Agriculture

Total water used according to the crops per ha (hm^3)	**Total water used in agriculture (hm^3)**	**Difference**
684	1173	42%

4.1.4 | Water Quality

The Water Framework Directive (WFD) introduced a comprehensive approach to water management, emphasizing the importance of achieving a good status for water ecosystems. This defines the wastewater treatment plant (WWTP) effluent limits to ensure the positive condition of receiving waters, however, the preamble of the WFD states that "it may be unfeasible or unreasonably expensive to achieve good status, less stringent environmental objectives may be set" and that was utilized in the Spanish legislation to set less stringent environmental objectives around the city of Madrid. The Urban Waste Water Treatment Directive (UWWTD - 01/271/EC) sets pollutant concentration limits and connects to the WFD by stating that more "stringent requirements" can be applied to guarantee the satisfaction of any other relevant directive. The parameters defined by the UWWTD can be found in Table **??** and are, since 2021, also the ones utilized by the Tagus River Basin Authority.

Despite nearly two decades of implementation of the WFD, however, only 38% of surface water bodies in the European Union are currently classified as being in good status, and the Tagus River is not found in this percentage. (Bolinches et al., 2020a) The surface waters in both countries fail to meet the requirements of the WFD. According to the latest basin management plans for both countries, 39% and 51% of water bodies in the basin were assessed as being in bad status, for Spain and Portugal,

Table 4.7: Urban Waste Water Treatment Directive (UWWTD - 91/271/EEC) Parameters for WWTPs Effluent

Parameter	**Maximum Value**
TSS (Total Suspended Solids)	35 mg/L
BOD_5 (Biochemical Oxygen Demand)	25 mg/L
Phosphorus	1 mg/L
COD (Chemical Oxygen Demand)	125 mg/L
Total N (Total Nitrogen)	10 mg/L

respectively. However, it is important to note that, because these are separate management plans, the data collection and monitoring techniques and procedures differ between the two countries. An issue arising from the decrease in flow caused by the increasing droughts and the Tagus-Segura transfer is the deterioration of the water quality. With a diminished and steady water flow, the result is the lack of hydraulic connection between the river and the floodplain. This reduction in connectivity diminishes the floodplain's ability to enhance water quality. (San-Martín et al., 2020) According to (Bodoque et al., 2016), the natural processes of surface water purification are impeded due to the absence of fluctuation between low-water and high-water phases, as well as the lack of seasonal or intermittent flooding. Therefore, with less volume, there is a reduction in the dilution of the pollution discharged into the river.

In the "Plan Hidrológico de la parte española de la Demarcación Hidrográfica del Tajo [2009-2015]. Memoria" (2014), the middle section of the Tagus River has been designated as a heavily altered water body, and some portions of it are not expected to reach the environmental goal of achieving good ecological status until 2027, being classified as having poor biological, physicochemical, and hydromorphological indicators, reflecting the overall poor ecological condition of the area. In the MITECO (2018a) report, it was shown that the percentage of bodies of water considered to be in good condition in the Tagus River changed from 56% in 2014 to 42% in 2018. However, there is a controversy in these numbers as the Tagus River Basin Authority says the difference in number is due to a change in the method used to measure the quality of the water. For San-Martín et al. (2020) that means that in the 2014 data, the proportion of bodies of water in good condition was overestimated. According to the basin authority, the chemical status of the water is poor, as hazardous substances such as lindane and simazine were identified in the Jarama sub-basin. Moreover, elevated levels of chemical oxygen demand, ammonia, nitrate, and phosphorus exceeding legal limits have been detected in the Tagus River following its confluence with the Jarama. Figures 4.7 and 4.8 show the evolution of the status of the water masses in Portugal and Spain's different planning cycles.

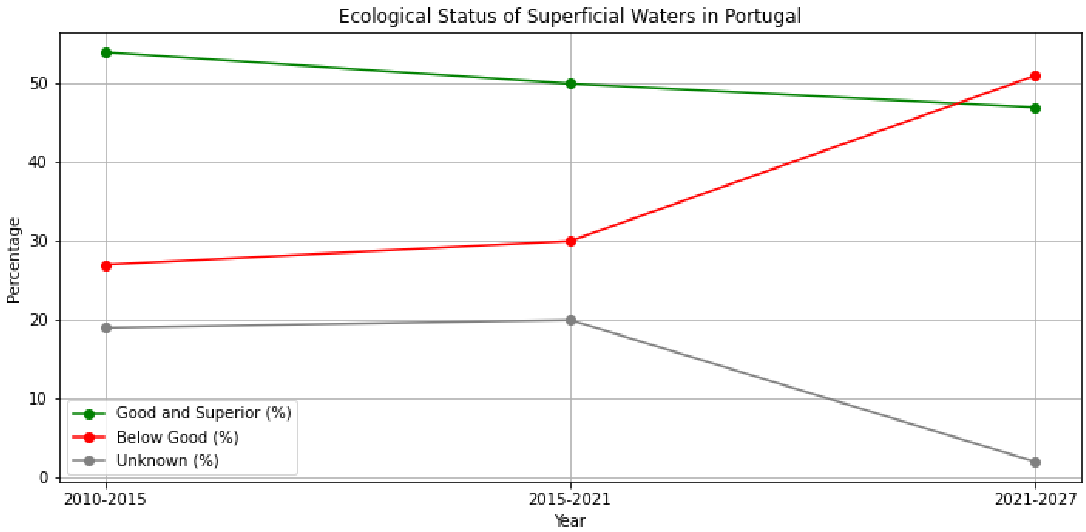


Figure 4.7: Ecological Status of Superficial Waters in Portugal across the years

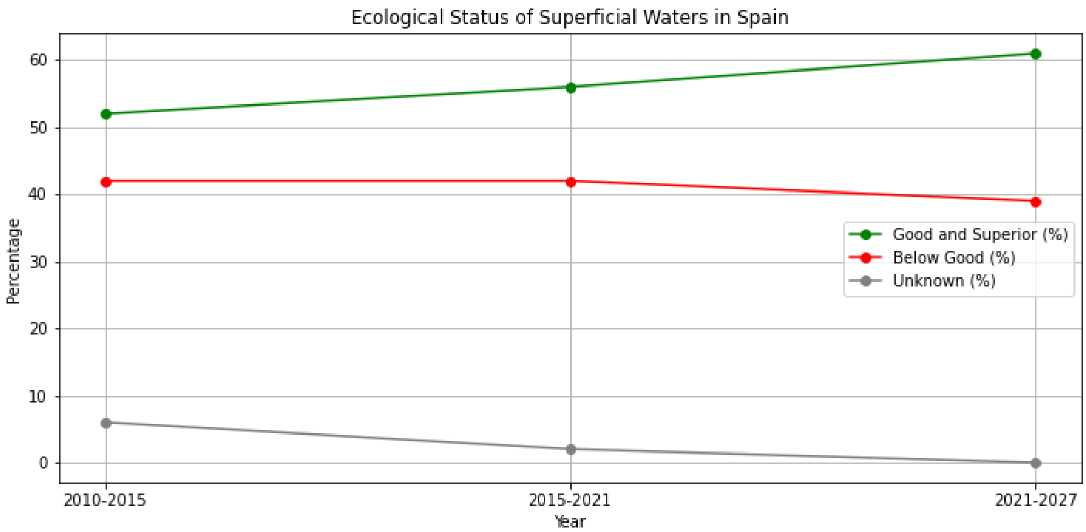


Figure 4.8: Ecological Status of Superficial Waters in Spain across the years

The pollution found in the middle section of the Tagus, especially between Aranjuez, Toledo, and Talavera de la Reina, can be explained by two factors. First, the discharge of the Jarama River, which is one of the rivers that carry the insufficiently treated wastewater of the Madrid metropolitan region (Bolinches et al., 2020b; Gonzalez Alonso et al., 2009) and second, the low streamflow of the Tagus River downstream of the Tagus-Segura transfer, having a lower flow than the Jarama river. Therefore, the quality of the Jarama River will have a big influence on the Tagus River's water quality. (San-Martín et al., 2020).

According to Cátedra (2022) almost all of the water from the Jarama that flows into the Tagus in Aranjuez originates from urban or industrial wastewater discharges, as it was found that this river contributes up to 15.86 m^3/s of wastewater to the Tagus, according to data obtained from the Authorized Discharge Census of the Tagus Hydrographic Confederation (Censo de Vertidos Autorizados de la CHT, 2021), while considering that the average flow of the Jarama River at the Titulcia bridge station is 17.9 m^3/s (Centro de Estudios y Experimentación de Obras Públicas, 2018). The Jarama River has a nitrate concentration five times higher than that of the Tagus, a phosphate concentration seven times higher, and an ammonia concentration over 100 times higher, on average. (Cátedra, 2022) Also, Rico et al. (2019) conducted a study of the Jarama, Manzanares, and Henares that found toxic effects of heavy metals on freshwater organisms in the upper Tagus River. An image of the Tagus River meeting the Jarama River can be seen in Figure 4.9 and it shows the clear water of the Tagus River turning into the brown water of the Jarama River.

Besides those factors, the high number of dams in the basin, the water abstraction done to supply water to the Madrid region ("Plan Hidrológico de la parte española de la Demarcación Hidrográfica del Tajo. Memoria. Plan hidrológico de cuenca [2015-2021]. Diciembre de 2015", 2015) and the diffuse pollution from fertilized irrigated land, as both groundwater and surface water bodies receive the excess nutrients from fertilizers applied to 200.000 hectares of agricultural land in the region are the main pressures in the river basin that are hindering the river from having a good ecological status. (Bolinches et al., 2020b)

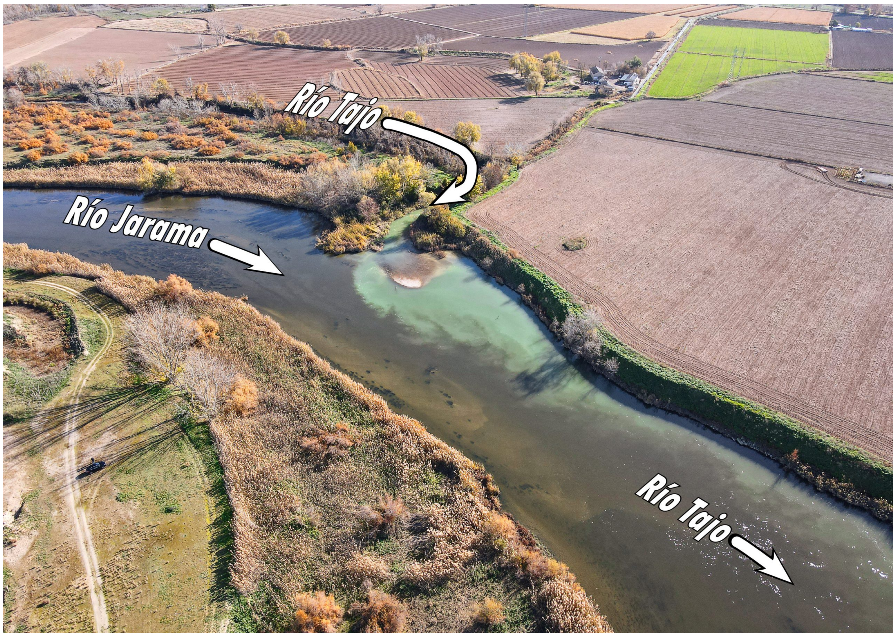
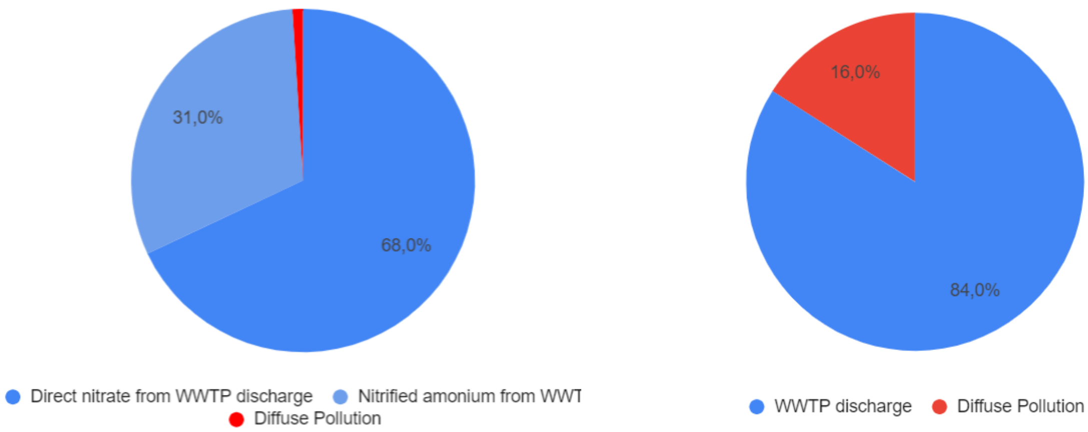


Figure 4.9: The encounter of the Jarama and Tagus river (Cátedra, 2022)

Bolinches et al. (2020b) conducted a study to determine the additional reduction in nutrients necessary to achieve environmental improvement in the area. This was prompted by the inconsistent performance of WWTPs in the region regarding nutrient reduction. The findings indicate that WWTPs account for over 95% of nitrogen pollution and over 80% of phosphorus pollution. Figure 4.10 shows the sources of nitrate and phosphorus pollution in the Middle Tagus. The study also looked into the diffuse load and found a result of up to 4.8 kg/ha per year loads for nitrate and up to 3.6 kg/ha per year for phosphate. It was also found that the surface water in this area does not comply with the standards as both ammonia and phosphate concentrations are above the legal values in the Jarama and the Tagus between Aranjuez and Toledo, at any value of water transfer. Nevertheless, he also saw that if the transferred volume is higher (from 10 to 30 hm3 per month), those concentrations will rise by 30%. Therefore, Bolinches et al. (2020a) recommends upgrading the WWTPs in Madrid to meet legal standards as imperative (Table 4.8), even in the absence of the water transfer. The new recommended standards can be found in Table 4.9. Also, monthly water transfer volumes should consider these limits to ensure the preservation of water quality.



(a) (b)

Figure 4.10: Sources of nitrate and phosphorus in the Middle Tagus river (Bolinches et al., 2020b)

Table 4.8: Limits for Ammonia, Phosphate, and Nitrate in the Tagus River

Component	**Limit (mg/L)**
Ammonia (NH_3)	1 mg/L
Phosphate (PO_4)	*0.4* mg/L
Nitrate (NO_3)	25 mg/L

Table 4.9: Proposed Concentration for Receiving River to Achieve Good Status (Bolinches et al., 2020b)

WWTP	**NH_4 (mg/L)**	**NO_3 (mg/L)**	**PO_4 (mg/L)**
Henares	4.00	60	0.65
Manzanares	0.65	30	0.55
Jarama upstream of Henares confluence	1.00	50	0.55
Jarama downstream of Henares confluence	8.00	60	1.00

According to Bolinches and De Stefano (2018), the standards defined on the UWWTD are insufficient to achieve the good status defined in the WFD in the Tagus River since the WWTPs effluents contribute to 90% of the Manzanares flow, and those values would be sufficient only for a river that receives a small percentage of WWTPs effluents. Bolinches et al. (2020a) studied the impact of WWTP effluents on the Manzanares River downstream of Madrid. They aimed to establish discharge limits compatible with maintaining the river's good status, as it affects not only the local ecosystem but also the Tagus River. The study found that the existing BOD5 requirement (25 mg O2/L) for plant effluent does not align with the BOD objective for receiving water.

Valerio et al. (2020) made a study aimed to quantify the ecosystem response to stressors in the Spanish part of the Tagus River basin revealing the significant relevance of land use variables. It highlighted the importance of nutrients, with agricultural land cover serving as a proxy for diffuse pollution in the form of nutrients, urban areas and the number of urban wastewater discharges representing point pollution, and forested lands acting as proxies for processes that aid in filtering water pollutants. The study concluded that current nutrient thresholds in Spain are inadequate to ensure values of biological indices consistent with good ecological status across all water bodies in the Tagus basin. To address this, the study proposed coupling more stringent nutrient thresholds with measures to enhance riparian habitat quality. This integrated approach was identified as a priority mitigation measure for restoring the status of freshwater ecosystems in the basin, potentially leading to a significant improvement, with up to 85% of water bodies achieving good status in biological indices.

The poor water quality is not a problem only in the upper Tagus. In January 2018, a pollution incident caused by the Celtejo paper paste factory between the Cedillo and Fratel dams exposed the water quality issues in this river stretch. Henriques (2018) highlighted that the volume defined in the Additional Protocol of the AC for the Cedillo dam is insufficient to ensure water quality. This happens due to the periods of zero or little flow from the Cedillo dam, where even if water quality at the Portugal entrance is satisfactory, any discharge can degrade it. The Fratel stations recorded poor dissolved oxygen values, indicating that BOD5 and COD discharges surpass the reservoir's capacity, causing extreme conditions of anoxia during low or zero flow rates. High total suspended solids were also found in the discharges, around 1 ton per day, and are deposited at the reservoir bottom, needing dredging, which was undertaken after the 2018 pollution incident. Current discharge conditions set by Celtejo's water resource license exceed the water body's capacity to receive pollutants without deteriorating its quality and existing uses. Adapting discharges to maintain water body condition and reviewing the license accordingly is imperative. According to Henriques (2018), this incident showcases that licenses should only be granted if companies demonstrate compliance with discharge conditions upfront. This approach, known as the combined approach principle, shifts the burden of verifying compliance from authorities to the company. The current system, transferring environmental responsibility to authorities even with inadequate license conditions, is critiqued based on the precautionary principle.

Environmental flow

Water resource developments like dams, diversion structures, interbasin transfers, direct river water extraction, and aquifer utilization, although essential, have caused significant impacts on the river ecosystems due to the changes in the natural flow patterns of the rivers. Therefore, over the years, numerous scientists, including Rosenberg et al. (2000), have advocated for maintaining the natural flow of rivers. This concept entails ensuring that the flow regime of a river includes five critical components: variability, magnitude, frequency, duration, timing, and rate of change. These elements are essential for sustaining ecosystem integrity and biodiversity.

An Environmental Flow Assessment is the science that evaluates how much of the original flow pattern of a river should be maintained to preserve specific ecosystem features on both the river and its floodplains and was developed to ensure the water resource development and management while keeping the ecosystem integrity. (King et al., 2000) According to the Brisbane Declaration (2007), environmental flow is the quantity, timing, and quality of the water flows that are necessary to maintain freshwater and estuarine ecosystems and, at the same time, beings that depend on this ecosystem. Due to an increase in water demand worldwide, it's a topic that is being addressed by many governments, water management policies, and river basin management plans, including water supply and reservoir management, to protect biodiversity, ecosystem services, and other activities such as tourism and hydropower generation. (Postel & Richter, 2003). In resume, the Environmental Flow Requirements are the requirements of total flux volumes, spatiotemporal patterns, and water quality that need to be followed to maintain the structures and environmental functions of these ecosystems, achieving a fair or good ecological status. (Gerten et al., 2013) According to Paredes-Arquiola et al. (2014), defining an environmental flow is an important step in the water allocation process as well.

In 2001 it was approved in Spain the Law 10/2001 that requires the establishment of environmental flows as part of the River Basin Management Plans (RBMPs) and since 2008 it has been applied to the planning documents. (Baeza et al., 2023) However, according to Baeza Sanz and Matías (2023) the numbers defined for the Tagus River are inadequate and insufficient, as the methodology was not uniformly applied and misinterpreted. (Baeza et al., 2023) analyzed the area of the Tagus River downstream of the Entrepañas and Bundía reservoir and found the proposed environmental flow for the section is no longer sufficient and showed it is significantly lower than the natural flow of the river. There is also no current monitoring to evaluate the effectiveness of the environmental flow regimes ("Memoria 2018", 2019)

Salt intrusion

Estuaries, particularly vulnerable to droughts, experience significant impacts on water quality and dynamics due to the interaction between saltwater and freshwater, affecting the water quality. Salinity fluctuations during low river discharge periods exacerbate stress on estuary ecosystems and economic sectors like public health, fishing industries, and aquifers found near estuaries. (Conrads & Darby, 2016) Therefore, with the increase in drought events, the Tagus River has also suffered from salt intrusion, having as a main driver the combined effect of tides and low river flow. Also, the problem increases with the sea level rise (M. Rodrigues & Fortunato, 2017)

In the Tagus River, close to the Tagus Estuary, there is an area called Lezíria Grande in the municipality of Vila Franca de Xira. The public irrigation perimeter of Lezíria Grande has as water supply the Tagus River, more specifically an area very close to the limit of the salinity intrusion in the Tagus estuary. Also, the area rests within low-lying terrain and has protection dikes all around. According to a risk identification report (Freitas et al., 2017) In the recent droughts of 2005 and 2012, agricultural operations in this region suffered, prompting the implementation of emergency measures to mitigate the adverse effects of the drought, having as a consequence significant losses in crops. At the time, the high salinity made the water inappropriate for irrigation and as a solution, a temporary weir was built to supply freshwater.

(M. Rodrigues et al., 2019) used a model to predict how the saline intrusion can affect the region. In the scenario where the mean Tagus river flow is 44 m3/s, in the station closest to the estuary, at high tide, salinity can exceed 1 psu, which would be above the limit for irrigation water. For the scenario considering the worst recent drought, with the river flow at 22 m3/s, the values at the same station can reach 2.5 psu at high tide, going up to 10 psu after a period. For the minimum flow in the

AC, after 10 days the salinity is already in 5 psu and goes to 15 psu at the end. The results showed that the salinity intrusion will depend on the river flow and the duration of the droughts. Therefore, in these drought scenarios, the water abstraction should only happen at low tide.

4.2 | Climate Change in the Tagus River Basin

Future climate forecasts for the Iberian Peninsula and the Mediterranean region indicate a widespread decline in precipitation alongside rising air temperatures. ("Plan Hidrológico de la parte española de la Demarcación Hidrográfica del Tajo. Memoria. Plan hidrológico de cuenca [2015-2021]. Diciembre de 2015", 2015) Therefore, this section goes through several studies that aimed at quantifying the climate change effects in the Tagus River Basin.

Guerreiro et al. (2014) analyzed the precipitation patterns for the last years in the Tagus River Basin and came to the conclusion that the precipitation decreased in February, March, and June, but increased in October. Lorenzo-Lacruz et al. (2013) pointed out that the severity, extent, and duration of droughts in the Iberian Peninsula have escalated between 1945 and 2005, accompanied by a notable decline in river discharges, including those within the Tagus River basin. While the Basin Hydrological Plan (2015-2021) for the Tagus River basin anticipated a 7% reduction in contributions when estimating resources and allocating demands by 2033, Roca and del Moral (2021) discovered that comparing resource levels from 1980-2015 to those in the control period outlined in the basin hydrological plan revealed decreases of up to 25%. Furthermore, the study's findings suggest that climate change projections, when considering current water usage patterns, indicate an increase in the number of days where Mediterranean river contributions dip below critical levels. When it comes to the flow in the Tagus River Basin, many studies aimed to find the reductions due to climate change. In the latest Spanish Basin Hydrological Plan (2021 - 2027), it was stated that the average flow in the headwaters of the Tagus River went from 716 hm^3/year from 1940 to 1980 to 483 hm^3/year from 1980 to 2018, showing a reduction of 32%.

Kilsby et al. (2007) found reductions in flow varying from 20 to 49% in Tagus river by the year 2100. According to climate change modeling projections by Guerreiro et al. (2017), there could be reductions of up to 71% in autumn flows within the Tagus basin. Notably, autumn and winter jointly accounted for 75% of the total flow accumulation in the Tagus basin from 1980 to 2011, as reported by "Plan Hidrológico de la parte española de la Demarcación Hidrográfica del Tajo. Memoria. Plan hidrológico de cuenca [2015-2021]. Diciembre de 2015" (2015).Lorenzo-Lacruz et al. (2010) assessed the effects of climatic droughts in the Central Spain region along the Tagus River, revealing that drought occurrences have escalated in the Tagus River's upper reaches since the 1970s. Water resources in the Tagus basin have decreased by nearly 26%, with an average reduction of approximately 17%. (Terrero, 2016) In Sondermann and Proença de Oliveira (2022) study, it was revealed that the average annual natural stream flow and the average natural stream flow in the dry months are expected to decrease between 9.3 and 36.6% and between 19.3% 50.5%, respectively. Nortes Martinez (2014) compared the discharge in the headwaters of the Tagus River, observing a decrease of 47% from 1980 to 2005 compared to the period from 1960 to 1980. Nevertheless, conclusive evidence is lacking regarding whether this trend can be solely attributed to recent changes in climatic conditions or to alterations in land use and widespread water management practices in the region. Lobanova et al. (2016) also found a decrease in discharge of about 30% to 60& by the end of the century, for the RCP 4.5 and 8.5 scenario, respectively.

According to Senent-Aparicio et al. (2021), the precipitation in the Upper Tagus River Basin could decrease by 13% to 26% under the RCP 4.5 and RCP 8.5 scenarios, respectively. Additionally, the study forecasts a substantial rise in temperatures, with an average increase of up to 6.3°C by the century's end. Consequently, the Entrepeñas and Buendía reservoirs face significant reductions in inflows, with total decreases ranging from 20% to 50% under the RCP 4.5 and RCP 8.5 scenarios, respectively. Looking to a closer future (2040–2069), these numbers are expected to diminish to 10% and 31%, respectively. Moreover, the decline in water availability at the Entrepeñas and Buendía dams in the headwaters of the Tagus has reached 47%, nearly double the basin's average reduction. Given that the Tagus-Segura transfer originates from this region, the associated consequences are expected to exacerbate. Interestingly, the volume of water transferred has remained unchanged (Lorenzo-Lacruz et al., 2010). Lobanova et al. (2016) contends that the failure to address the environmental requirements downstream of the Entrepeñas and Buendía reservoirs in the Tagus headwaters might increase the likelihood of a hydrological system collapse in response to climate change-induced alterations.

(Pellicer-Martínez & Martínez-Paz, 2018) conducted simulations of the discharge in the Tagus River basin, revealing a depletion of its natural water resources by 39.7% in the most favorable scenario and 46.6% in the least favorable one. These losses were attributed to decreased precipitation (15% and 20% for each scenario, respectively) and increased potential evapotranspiration, corresponding to temperature rises of 2.2°C and 3.4°C, respectively. Regarding the snowfall in the mountains in the headwater of the Tagus River, it was a decrease of up to 70 or 90%, for best and worst scenario, for the years between 2070 and 2100. For the aquifer recharge, it was found a decline bigger than 50%, with October, November, and December being the most affected ones. On an annual basis, these changes would lead to increased variability in surface flows within the basin, characterized by greater relative differences between maximum and minimum flows during spring and summer, respectively. Ultimately, these alterations will reduce the natural capacity of the river basin to regulate its water resources. The study also found this will not only affect the Tagus River Basin but also decrease around 70-79% the available volume of water for the Tagus-Segura water transfer, which would mean a loss of over 380 million euros per year. When analyzing the possibilities with the Tagus-Segura transfer, Sondermann and Proença de Oliveira (2022) concluded that if the assigned volume is reduced by 30%, it is possible to maintain the current levels of water scarcity in the region. While if is reduced by 60%, it is possible to achieve current water supply reliability levels under the best scenario. However, for the worst scenario, bigger reductions would be necessary. Also, Pellicer-Martínez and Martínez-Paz (2018) suggest average decreases around 70–79% in water transfer to alleviate losses in available water resources within the Tagus River headwaters, and Lobanova et al. (2016) suggested a reduction of 20 to 40% in water transfers when environmental flows are defined as a priority over the Tagus-Segura aqueduct.

Sondermann and Proença de Oliveira (2022) study showed it is anticipated that the Spanish territory will experience a greater decrease in agricultural reliability compared to Portugal. This discrepancy can be attributed to Spain's heavier reliance on river regulation and dam operations to meet water demands, particularly through surface water withdrawals. In contrast, Portugal partially satisfies its water demands by tapping into aquifers, notably in the Tagus Valley and Sorraia sub-basins, where the Tagus-Sado aquifer is located. Sub-basins situated on the right bank of the Tagus River in Spain, which are major centers of agricultural activity, are expected to endure the most substantial decrease in water availability. The consequences of all these predictions are very concerning. With the reduction in precipitation, there is also a reduction in aquifer recharge, significantly diminishing the long-term water resources accessible to society. There is also the challenge of maintaining environmental flows. Especially in overexploited regions, various factors worsen water source degradation, including reduced water table levels, increased extraction costs, and environmental impacts like saltwater intrusion and ecosystem degradation. Higher temperatures intensify evapotranspiration, reducing runoff, as it can be seen in the Centro de Estudios y Experimentación de Obras Públicas (2018), which shows an increase above 10% for the Potential Evapotranspiration in the headwaters of the Tagus River and a decrease in runoff of around 25% for the Tagus river basin. Also, according to Miranda and Santos (2006) the decline in runoff coupled with the rise in evapotranspiration could result in a 10% rise in the water volume required per irrigated hectare by 2060. Diminished precipitation and increased evapotranspiration further reduce river flows and aquifer infiltration, necessitating scenarios with reduced water availability. The main challenge of climate change for water management is preserving ecosystems to prevent irreversible changes and loss of services, requiring increased environmental flows. This, alongside a general reduction in flowing volumes, demands a reassessment of resources and resizing water uses to align with new availabilities. (Roca & del Moral, 2021)

(Sondermann & Proença de Oliveira, 2022) evaluated potential demand-side adaptation strategies to manage water abstractions and prevent future increases, or even achieve reductions and concluded that reducing irrigation water consumption by 25% to 40% would notably enhance the performance of the Tagus River transboundary system, which would help sustain the current conditions in the face of projected climate change scenarios. According to Álvarez Arcá (2019), the desertification of the Iberian Peninsula caused mainly by climate change requires that the management of water resources is made according to the supply and not the demand, which has to adapt to the existing water availability. (Álvarez Arcá, 2019) Figure 4.11 shows the annual flow reduction for the main studies analyzed.

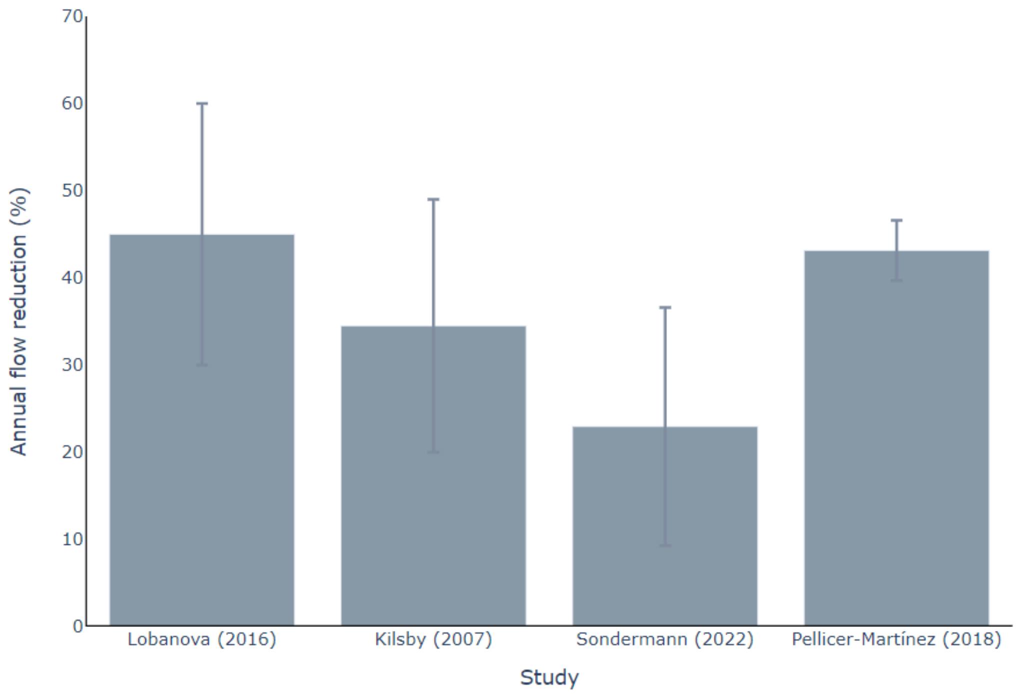


Figure 4.11: Annual flow reduction predicted in the main studies analyzed

4.3 | Water management in the Tagus River Basin

The water management in the Tagus River basin is managed by two different agencies, the Confederación Hidrográfica del Tajo (CHT), in Spain, and the Administração de Região Hidrográfica do Tejo (ARH Tejo) in Portugal, which belongs to the Portuguese Environment Agency (Agência Portuguesa do Ambiente - APA). (Sondermann & Proença de Oliveira, 2022).

In Portugal, the National Water Plan was formulated in 2001, followed by the Watershed Plan in 2002. Subsequently, the government enacted the Water Law of 2005 to align water administration with the requirements for coordinated management based on hydrographic basins, as mandated by the European WFD of 2000. It s Under this law, the National Institute of Water (INAG) assumed authority and responsibilities in the national water policy, with the ARHTejo managing it at the territorial level. Additionally, it established Hydrographic Region Councils (CRH) as consultative entities for public water administration, comprising representatives from various governmental sectors, professional organizations, user groups, and environmental associations. (Bento & Rainho Bras, 2019; Bilhim, 2015)

An important change in water management in Portugal was the creation of the APA in 2007. The APA has evolved into the National Water Authority and the National Dam Safety Authority, which shows a shift into a greater integration and centralization in Portugal's water management framework. The APA now bears the responsibility for executing the national water resources policy, enforcing the Water Law, safeguarding, planning, and regulating water resources, facilitating responsible water usage and its planning, overseeing the economic and financial aspects of water resources, monitoring water resources, managing droughts and floods, resolving conflicts among water users, and fostering the development and implementation of an integrated coastal zone management strategy.(Bilhim, 2015)

The ARH Tejo plays a central role in regulating water resources in Portugal's Tagus River Basin through a range of responsibilities. It develops and oversees the implementation of river basin and water management plans, alongside specific measures to protect and enhance water resources. It coordinates the development and enforcement of public water reservoir and coastal zone management plans, as well as estuary management plans within relevant hydrographic regions. Additionally, ARH Tejo monitors and licenses water resource use manages water-related infrastructure information systems, supports water user associations, and ensures compliance with environmental regulations, including revenue generation and legal procedures related to water resource management. Under the ARH Tejo, water user associations (Associações de Utilizadores do Domínio Público Hídrico) and local municipalities may be involved in the management and operation of specific reservoirs within their jurisdictions and manage jointly their respective licenses or concessions for the use of water resources. The company EDP (Energias de Portugal) is responsible for managing the hydroelectric infrastructure on the Portuguese side of the Tagus River Basin, while some dams, reservoirs, and water supply systems in the region are managed by regional or local entities, including municipalities or regional water management bodies, and are overseen by the ARH Tejo. Águas de Portugal is a business group with exclusively public capital that manages the urban water cycle, through regional operations, such as Águas do Tejo Atlântico and EPAL. Águas do Tejo Atlântico is the main company responsible for collecting, treating, and discharging domestic and urban effluents in the Portugal side of the basin and EPAL is responsible for water supply in the Greater Lisbon.

In Spain, the first Water Law was approved in 1985 and declared that all waters must be jointly managed and administered, making hydrological planning the central piece of the law. Also, it was already defined that an annual volume of water must be reserved for ecological purposes. It defines that the planning is done through the National Hydrological Plan, with its latest version being approved in 2005, and the Basin Hydrological Plans, with the first basin plans being approved between 1998 and 2001. The NHP aims to achieve the best satisfaction of water demands and balance and harmonize regional and sectoral development, increasing resource availability, protecting its quality, economizing its use, and rationalizing its use in harmony with the environment and other natural resources and is responsible for approving the Basin Plans. (Martinez et al., 2011)

On the Spanish side, falls under the responsibilities of the CHT to conduct studies on river regimes, inspect canal and reservoir works carried out by corporations or concessions, direct the construction of canals and reservoirs funded by budgetary allocations, carry out channeling and flood defense works, and undertake water supply projects for populations. CHT is also responsible for river quality management and WWTP discharges. (Bolinches et al., 2020a) The Community of Madrid, in coordination with CHT, conducts additional work and studies besides controlling the water supply for the population, entrusted to the Canal de Isabel II, which is the company responsible for the sanitation and water supply for the Madrid region, as the management of wastewater treatment and sanitation typically falls under the responsibility of municipalities and regional water authorities.

Iberdrola plays a significant role in the management of dams and reservoirs within the Tagus River basin by operating hydroelectric power plants that utilize water stored in these facilities. While Iberdrola manages the technical aspects and electricity generation, regulatory oversight and broader water management responsibilities rest with the CHT. Since most of the dams in the region are also used for hydropower, Iberdrola is responsible for operating most of it, while others belong to the Canal de Isabel II. Irrigation communities play an important role in the management of water for irrigation purposes. The Irrigation Communities of the Tagus Basin Federation (Federación de Comunidades de Regantes de la Cuenca del Tajo - FERTAJO) is the one acting on the Basis and oversees the distribution of water to irrigated lands in collaboration with the CHT.

Both countries have developed national strategies to adapt to climate change, outlining expected impacts and objectives related to water resources. These objectives include reducing hydrological pressures on water bodies, enhancing the safety and reliability of water systems, fostering risk management, promoting research and development to deepen knowledge, and increasing public awareness and technical training. (Pulwarty & Maia, 2014) Although not very effective for water and ecological protection, there were some agreements between both countries in the first half of the 20th century. The 1927 agreement, for example, had as the objective the hydroelectric exploitation of the international part of the Douro River. Later, another agreement was made in 1964, aiming to regulate the hydroelectric development on the Douro River, compassing now also its tributaries. It was only in the agreement of 1968 that other rivers were included, such as Lima, Minho, Tagus, Chança, Guadiana, and its tributaries. However, even though now water supply and irrigation were also addressed, the main focus was still the hydroelectric exploitation of those rivers. (Sereno, 2012)

Previously to the current agreement, Portugal and Spain had very distinct experiences when it came to water resources planning. While Spain already had the Spanish Hydrological National Plan (Plano Hidrologico Nacional Espanol - PHNE) in 1993, in Portugal only in 1994 was a Decrete that made the National Hydrological Plan mandatory. (Ferreira, 2017) For incorporating hydraulic infrastructure and basin transpositions, the Spain National Hydrological Plan, raised concerns for Portugal regarding Spain's water usage intentions. Despite causing tension in bilateral relations, this led both countries to acknowledge the necessity for a new agreement including water uses not addressed in previous agreements, alongside environmental protection requirements. Consequently, on November 30, 1998, the new agreement between Portugal and Spain was signed, referred to as the "Convention on Cooperation for the Protection and Sustainable Use of the Waters of the Portuguese-Spanish Hydrographic Basins," commonly known as the AC (AC) (Ribeiro et al., 2019)

Since 2000, the WFD has acted as the main law for water protection in Europe. Its objective is to ensure good quality of water resources for the European Union countries through an integrated approach while respecting the ecosystems. This framework can be applied to any inland, transitional, coastal surface water, or even groundwater and has a river basin district approach, which facilitates cooperation for rivers that can be found in different countries. The WFD determines that if a river basin is shared by different EU countries, water management should be coordinated for the entire River Basin District, to protect the water bodies and reach the environmental goals of the basin. Article 13.2 of the WFD suggests a single River Basin Management Plan for transboundary rivers, though it is not obligatory. As a result, such a plan does not exist for the Iberian Peninsula. However, Article 3.4 emphasizes the necessity of coordination, stating that "For international river basin districts, the Member States concerned shall together ensure this coordination and may, for this purpose, use existing structures stemming from international agreements." Consequently, Spain and Portugal have chosen to develop their river basin management plans independently but with coordinated management of the basin. (San-Martín et al., 2020)

For drought management, Spain has implemented detailed Drought Management Plans (DMPs) with specific indicators like the State Index (IE) and Water Scarcity Indicator (SI), while Portugal's approach has historically been more reactive (Pulwarty & Maia, 2014). Despite efforts to establish common indicators under the AC, a unified system has not yet been realized. The Spanish methodology offers a solid foundation for developing a common indicator system, which would better integrate both countries with the WFD and enhance the effectiveness of the AC. However, there are still gaps, such as the need for improved risk management strategies, including addressing climate change impacts and regional vulnerabilities. (Urquijo Reguera et al., 2022)

4.3.1 | The Albufeira Convention

The AC functions as a bilateral framework treaty integrated into the international normative structure, with rules that both states commit to following in their collaborative efforts. (Álvarez Arcá, 2019) The content of the Convention can be seen as, first, the determination of rules that guide the cooperation between the parties and the protection and sustainable utilization of the water resources, followed by exceptional situations and the institutional structure.

The objective of the AC is "to define the framework of cooperation between the Parties for the protection of surface and groundwater and the aquatic and terrestrial ecosystems directly dependent on them and for the sustainable use of water resources of the hydrographic basins specified in paragraph 1 of Article 3", which are the basins of the Minho, Lima, Douro, Tagus, and Guadiana rivers. The coordination of the Parties in the AC aims to promote and protect the good status of surface and groundwater in the Portuguese-Spanish hydrographic basins, and to achieve sustainable water management actions, as well as actions aimed at mitigating the effects of floods and situations of drought or scarcity. To achieve these objectives, it is defined in Article 4.2 that the Parties establish as a cooperation mechanism a "regular and systematic exchange of information, consultations and activities within the framework of the bodies and the adoption, either individually or jointly, of technical, legal, administrative, or other measures necessary for the application and development of the Convention.

The AC defines two cooperation bodies: The Conference of Parties (CoP) and the Commission for the Application and Development of the Convention (CADC). The CADC is a body of technical nature, both in its composition and its duties, and as seen in Article 22 of the AC, is the privileged body for resolving issues related to the interpretation and application of the Convention, aiming in cooperation and coordinating measures and actions for the protection and sustainable use of Iberic river basins. The Commission is composed of delegations appointed by each of the Parties, subject to prior agreement on the number of delegates, and may create subcommittees and working groups deemed necessary and exercises the powers provided for in the Convention, as well as those conferred by the Parties, for the pursuit of the objectives and provisions of this Convention, therefore, they may propose to the Parties measures for the development of the bilateral relationship regime. The Commission meets in ordinary session once a year and in extraordinary session whenever one of the Parties requests it. Decisions require unanimous agreement from all parties, allowing any party to veto proposals from others. If no formal request for reconsideration or referral to the CoP is made within two months, the effects of the decision will come into force.

The CoP has a political nature and as is stated in Article 21 of the AC, the Conference is composed of representatives appointed by the Governments of the Parties under the presidency of a minister from each of the States or their delegates. The CoP meetings are when the Parties decide, at the request of any of the Parties to assess and resolve issues on which they haven't reached an agreement within the CADC, translating decisions made by technical bodies into obligations, and thus far, they have convened on three occasions. If issues cannot be resolved through these meetings, Article 26 of the Convention outlines a conflict resolution process where the Parties will look for a solution through negotiation or any other diplomatic method of dispute resolution mutually accepted by them. If a resolution is not reached within a year, the dispute will be referred to an Arbitral Tribunal. Thus tribunal has three members, two of them are choices made by each party and the third is chosen in an agreement between the two previously chosen members.

Since 2008, the institutional framework has been complemented by the Permanent Technical Secretariat (STP), which is a permanently active body of the CADC, composed of delegates from both countries. The main objective of the STP is to ensure a rotating platform of technical information and documentation, the management of computer interfaces with the public and stakeholders in technical work, and systematic monitoring of work progress, without the need for an extraordinary CADC meeting. Therefore, it has goals that are very similar to the CADC, however carries out its functions continuously over time. Besides the STP, there are also four working groups in each delegation: Flow Regime, Droughts, and Emergency Situations; Information Exchange and Public Participation; Infrastructure Safety and Floods; and Water Quality.

According to both WFD and the AC, there has to be cooperation between the parties. That translates to a regular exchange of information, that is done through the CADC and the PTS. This information sharing encompasses various aspects such as water basin management, activities with potential transboundary impacts as well as any modifications. For example, anytime a party understands that a new project or activity can have a transboundary impact or anytime a transboundary impact assessment is requested, the other party has to be immediately informed through the CADC, and if not, information can be requested. Additionally, in compliance with EU regulations, the Parties have to make the necessary information available regarding any matter that concerns the AC, upon request, being open to public participation.

Besides improving the communication between the Parties, these mechanisms are also important to inform on the procedures and competent entities for the transmission of information regarding situations of alert and emergency, and contingency plans for these situations (Article 11). Also, the Parties jointly develop specific programs on the safety of hydraulic infrastructures and the assessment of risks that, in the event of a rupture or serious accident, could result in significant adverse effects on either Party, as well as the assessment of potential risks. (Article 12).

In the third part of the AC, goals for environmental protection and sustainable development are defined. The provisions outlined in the Convention primarily address ensuring good quality of the waters, by classifying the water and adopting programs and management plans to endure their good state, preventing and controlling pollution, defining and managing the water uses, and defining a flow regime for each basin, necessary to ensure the good condition of the waters, current and foreseeable uses.

The Convention has also a section dedicated to exceptional situations, including accidental pollution incidents, floods and droughts, and water scarcity. Overall, it is defined as a system of information exchange, again through CADC, to prevent or mitigate the situation. The Convention states that the parties should adopt measures aimed at preventing accidental pollution incidents and limiting their consequences, as well as exceptional mechanisms to minimize the effects of flooding, such as alarms and measures to mitigate and/or control the effects of the flood. When it comes to droughts and water scarcity, Article 19 of the Convention, states that the Parties are obligated to coordinate their efforts in preventing and managing drought situations, institute exceptional measures to alleviate their impact, and define which situation would be an exception to the general regime. The coordination between Parties includes measures to encourage the control, savings, and reduction in water consumption, norms defining the water resources used to guarantee water supply to the populations, management of the infrastructures that contain water storage, and regulations concerning wastewater discharges, water withdrawals, and diversion. Also Article 19, it is stated that the Parties must conduct joint studies on droughts and scarcity situations to define measures to mitigate their effects and establish the criteria and indicators for the exceptional regime and the measures to be taken in these situations, and these must be defined within 2 years. However, this still hasn't been done.

After the definition of the institutional structures and the final provisions, an additional protocol can be found. The Additional Protocol establishes the minimum water flow requirements. To ensure compliance with these minimum flows, multiple control stations are established within the territories of both states for monitoring purposes. Besides the Additional Protocol, there is also another document, called the Review Protocol of the Convention and The Additional Protocol, that was signed on April 4, 2008, and modifies some aspects of the convention, mainly establishing a new regime of minimal flows. The Review Protocol of the 2008 Convention amends Article 16 of the AC and establishes that within the CADC, "the Parties shall define, for each hydrographic basin, using methods that are appropriate to the characteristics of each one, the flow regime necessary to guarantee the satisfactory condition of the waters and current and future uses." According to Álvarez Arcá (2019), the level of cooperation necessary to fulfill the obligations stemming from the Convention resulted in the establishment of the STP, as the exchange of information and cooperation require continuity that was lacking before 2008.

The Additional Protocol of the AC outlines specific requirements for the Cedillo dam, situated on the border between both countries and the area where the Muge bridge, downstream in Portugal. It mandates that the flow rates must meet a minimum annual full flow of 2.700 hm^3 and 1.300 hm^3, respectively, except during periods of precipitation scarcity as defined in the same protocol. Additionally, Table 4.10 illustrates minimum quarterly and weekly full flow values that must be maintained at that location. These specified minimum values do not apply during periods of precipitation scarcity, as defined in the Convention's Protocol Review (Henriques, 2018). Compliance with these flow regulations at the Cedillo dam appears relatively manageable for Spain, given that the five reservoirs collectively hold nearly double the minimum annual flow required, primarily serving non-consumptive purposes such as hydro-power generation.(San-Martín et al., 2020)

Table 4.10: Full flow per quarter

	October 1st to December 31st	**January 1st to March 31st**	**April 1st to June 30th**	**July 1st to September 30th**	**Weekly flow**
Cedillo dam	295	350 hm^3	220 hm^3	130 hm^3	7 hm^3
Muge bridge	150	180 hm^3	110 hm^3	60 hm^3	3 hm^3

The exceptions, defined in the Additional Protocol, for the Tagus River, are when the reference precipitation in the basin, accumulated from the beginning of the hydrological year (October 1st until April 1st), is less than 60% of the average accumulated precipitation during the same period or less than 70% if the reference precipitation in the previous hydrological year was less than 80% of the annual average of the previous year. The declaration of an exceptional situation exempts the declaring State from the obligation to ensure the minimum flows stipulated in the Additional Protocol, and no other value is given instead.

There have been over the years, some conflicts regarding the fulfillment of the agreement. There were four times when Spain didn't comply with the agreement in the AC. The first two were in 2002 and 2005, both in the Douro River Basin, when the minimum flow defined in the AC was still only annual. On the first occasion, Portugal was satisfied with the justification presented by Spain, due to the extreme drought event. In the second one, with the flow being under the established in the agreement, Portugal requested, not through the official channels, that Spain declared exceptional circumstances or compensated for non-compliance, and after pressure, Spain declared there were exceptional circumstances and no economic compensation was needed. The third one was in 2009 when the minimum flow established in the Revision Protocol for the Tagus River was not followed and both countries agreed that no compensation should be imposed as it was the first year of the new flow regimes and it is considered a transitional period, therefore, it was not formally deemed a breach of obligations.Álvarez Arcá (2019) The last one was related to the nuclear power plant in Caceres, Spain, the Almaraz plant. The Almaraz plant is situated within the Tagus River basin, approximately 100 kilometers away from the Portuguese border, and works with an open circuit refrigeration system, that uses the Tagus River water. The plant was supposed to end in June 2010, however, by decision of the Spanish government, it will be in operation now until 2030. The conflict happened in 2017 when the Spanish government decided to build a nuclear waste warehouse at the plant. Since this was a decision made unilaterally, the Portuguese government asserts that Spain has failed to adhere to the principle of legality by not conducting an assessment of the cross-border impacts of such storage, thus contravening a community directive. (Ferreira, 2017) Although the breach was not formally reported, Portugal made use of European Union Law to ensure its rights and compliance by Spain, as it was also a breach of the WFD. Álvarez Arcá (2019)

4.3.2 | Challenges and issues surrounding the Albufeira Agreement

There are several positive aspects to the AC. According to Álvarez Arcá (2019), the successful institutionalization of interstate collaboration, offering stability and continuity in cooperation, insulated from political fluctuations is a big advantage. Consequently, management decisions are entrusted to a technical body guided by scientific principles. Nonetheless, the final decisions still need to be approved by the COP (Conference of the Parties), which may potentially dilute technical considerations in favor of non-technical factors, including political ones. For Ribeiro et al. (2019), choosing a single Convention for all the shared basins shows their willingness to resolve the issue at a centralized, national level, independent of regional interests. Do Ó (2012) also highlights the importance of having an agreement for cooperation and having conflict resolution mechanisms. However, Do Ó (2012) agrees that the agreement is not effective enough as it is highly political and lacks a technical operative framework. For Falkenmark and Jägerskog (2010), the agreement needs to be more proactive, incorporating social, economic, and environmental scenarios and developing opportunities.

According to San-Martín et al. (2020) the Convention's strictly national governmental institutional structure and emphasis on national interests over international river basin planning objectives have constrained the implementation of multilayered governance and meaningful public participation, as it does not change the traditional water management approach, remaining focused on satisfying the needs of their traditional national water users while aligning with national water policy priorities and objectives. Therefore, it is recommended a new institutional governance aimed at promoting public participation, so that citizens who are not traditional water users can influence management decisions. Additionally, the agreement between the countries should integrate the social dimension of the WFD, incorporating concepts such as water justice, common heritage, and hydrological territory. This study also analyzed the situation of the Tagus River in Spain and its river basin management plan and it concluded that the instrument is not very effective in guarantying the good quality of the Tagus River quality, since it is environmentally very poor due to the low flows, pollution and absence of natural river dynamics. Specifically the lack of commitment to improving the wastewater treatment in Madrid. Besides that, the Tagus-Segura transfer is managed as it is a priority demand of the Tagus basin, defining how the rest of the basin will be managed, and putting the interest of the users of other basins as a priority.

When it comes to the cooperation mechanisms, it is not defined how it should be done, leaving it open for coordination of activities or joint implementation. Therefore, there are some drawbacks, as Portugal and Spain have chosen coordination over joint implementation for the majority of actions aimed at sustainably managing international river basins. One example is the river basin management plan, which despite the WFD recommendation in elaborating a single river basin management plan, Spain and Portugal decided to have them coordinated, but separate. As a consequence, some issues arise, such as the difficulty of having a correct classification in water assessment due to different calibration systems. According to Álvarez Arcá (2019), implementing a joint basin management plan would enhance coordination, offering a multi-level approach to water resource management that integrates both bottom-up and top-down strategies. The advantages of a unified hydrological plan will lead to improved compliance with environmental regulations. These benefits will arise from the Parties' consensus on critical aspects, including water body monitoring, establishment of objectives, and implementation of measures. For Bilhim (2015) collaborative planning for the second cycle of River Basin Management Plans for shared waters is crucial. This involves updating the identification and delineation of transboundary water bodies, conducting a comprehensive assessment of their common water quality, establishing quality objectives for these shared waters, and ensuring the harmonization of measures across borders.

The current minimum flow regime values are also a point of discussion. According to Álvarez Arcá (2019) these values are insufficient as a measure, since it doesn't need to be followed in exceptional cases, and should be reviewed. Henriques (2018) agrees and considers the definition of the flow regime in more points to be a priority, which is currently done by the Spanish authorities. He also notes the lack of verification, from Portugal, of the flows that should enter the country and be guaranteed by Spain, as the flow reported by Spain in Cedillo is higher than the flow recorded in Fratel, which is downstream, even though there is no significant extractions that would explain the difference in those numbers. Therefore, the monitoring should be improved and be made continuously, hourly, not only for flow but also for water quality, since that would make it easier to identify those accountable for potential incidents.

The fact that there was never an official non-compliance of the AC, does not mean that it has never happened. The four times where the was non-compliance as mentioned before, show that the states hesitate to acknowledge the existence of exceptional circumstances and are also reluctant to report such situations through established conventional channels. According to Álvarez Arcá (2019) that shows Portugal's dependence on Spain, as it hesitates to adopt a more assertive stance in condemning breaches of the instruments to which it is bound, and also, Spain's prioritization of national interests over compliance with international obligations. Another critique is the number of meetings of the CoP, which were only three in twenty years, which is not enough, since they are dealing with issues that demand a high level of monitoring and updates due to the constantly growing information on climate change, as well as technical and scientific knowledge related to the situation.

The management of drought periods in the agreement also demands revision. As severe droughts will become more frequent, bilateral regulation in that regard is necessary. At the 20th plenary meeting of the CADC, both states agreed they should take climate change and its effects on their water resources into consideration in their efforts. Also, they assigned the Hydrological Information Working

Groups the responsibility of facilitating the assessment of methodologies for computing flows and accessing real-time flow and precipitation data. All these efforts are geared towards preempting drought occurrences, which are increasingly prevalent in shared river basins.(Álvarez Arcá, 2019) Do Ó (2012) also highlights that even though a common framework for drought and water scarcity is stated in Article 19 of the AC, it still does not exist. Besides that, it also underscored the need for improvement in cross-border public participation, as there is no shared process developed or implemented, making it challenging to identify common goals. According to Do Ó (2012), the Convention loses its main mechanisms when it is most needed, as there is a threshold for exceptional years, and once it's passed, Spain has no longer any obligation regarding minimum flow. It is also noted that there are no criteria to define the minimum flow under exceptional circumstances, nor are there defined measures and procedures to mitigate and/or prevent the consequences of droughts. Therefore, according to Pulwarty and Maia (2014), minimum volumes should be defined to guarantee downstream flow during those scenarios, as well as the reserves for water uses, including ecological needs.

5 | Interviews

This chapter presents an analysis of the interview data, organized according to the key topics discussed during the interviews, as outlined in Table **??**. The insights gathered from the interviewees provide valuable perspectives on the current and future situation of the Tagus River Basin, and this chapter systematically explores their responses across each thematic area. Although there were some divergent opinions, there is an agreement between all the interviewees that the current way of managing the basin has to change, especially when considering climate change for the future. To maintain confidentiality, each interviewee has been anonymized and will be referred to as I1, I2, I3, and so forth throughout the chapter.

5.1 | Main challenges currently in the Tagus River Basin

To better understand the situation, the first question to all of the interviewees was what is the main challenge currently, according to them, to the managing of the Tagus River Basin. The main answers and their connections can be found in 5.1.

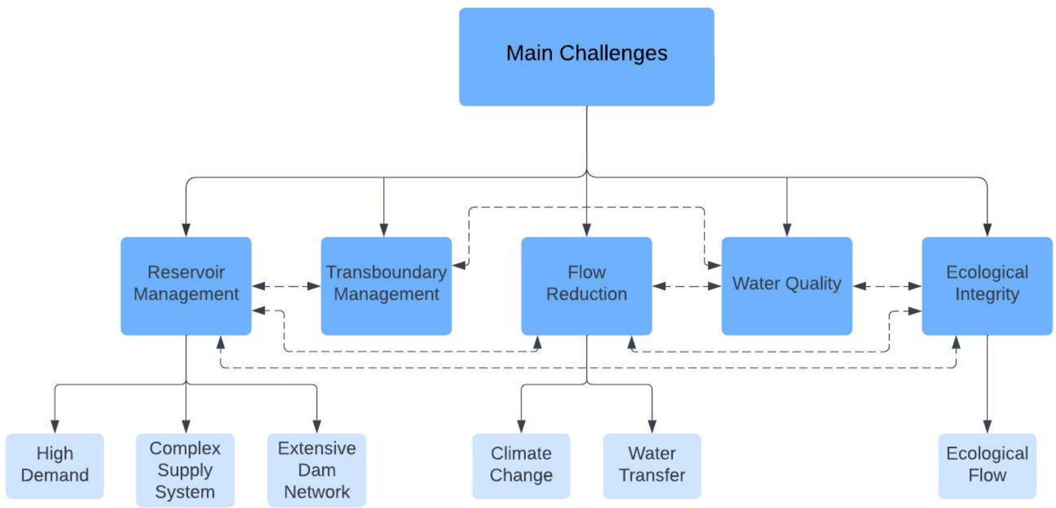


Figure 5.1: Main challenges in the Tagus Basin according to the interviewees.

The two topics that were given more attention were the flow reduction of the river, especially due to the Segura-Tagus water transfer, and the water quality in the Tagus River Basin. Both topics were mentioned by 6 out of 9 interviewees as the main challenge in the basin. It was also clear that those challenges were connected since the flow reduction creates a favorable condition for pollution in the river. The extensive dam structure and complex water supply system the Tagus River has were also mentioned by most of the interviewees as a challenge that causes not only the ecological degradation of the river but also puts high pressure on the basin. Two interviewees also believe that flow reduction was the main challenge in the basin but focused on the climate change aspect of it, of which we have less control. In the following sections, the aforementioned topics will be discussed in greater detail. In Figure 5.2 the main topics can be found according to their weight in a Sankey Diagram. Since each interviewee could identify multiple main challenges, the total number of mentions for each topic exceeds the number of interviewees. For instance, out of the 9 interviewees, 7 cited flow reduction as a primary challenge. Of these 7, 6 also identified water quality as a significant challenge. As a result, these 6 interviewees are counted in both categories, leading to an overlap in the data shown in the diagram.

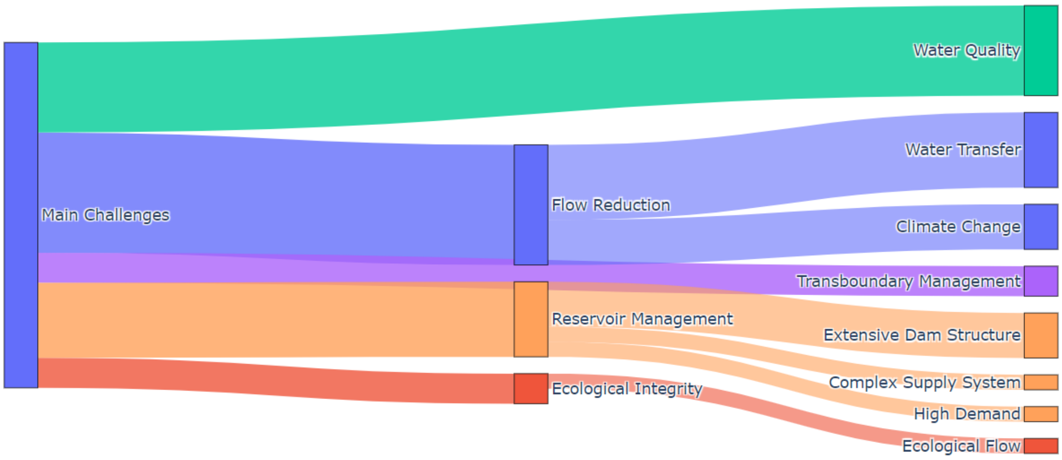


Figure 5.2: Main Challenges viewed by how many interviewees mentioned them

5.2 | Transboundary river basin management

The complexity of the transboundary management and the basin management in each country was also a topic of debate for most interviewees. When it comes to public participation, I1 noted a disconnect between the Portuguese Environment Agency's claims of constant collaboration and the actual perception of stakeholders. They believe there is a general reluctance to make concessions, particularly concerning water management in the context of climate change. Nationally, there is increasing pressure on water resources, especially from the agricultural sector, which consumes 75% of the country's water. Management efforts focus heavily on ensuring sufficient water volumes for agriculture, often resisting any reduction in water allocation to this sector. Despite the occasional easing of restrictions when reservoirs have more water, there is a persistent tendency to prioritize agricultural demands. I6 underscores the need for revising existing conventions and enhancing coordination in river basin management across borders, highlighting the importance of synchronizing indicators, thresholds, and objectives for ecological quality and quantity to achieve environmental goals effectively. Therefore, I6 advocates for adapting flow regimes to incorporate not only minimum quality flows but also weekly flows and overall environmental clarity, including parameters for water quality, stressing the importance of transparency and participation in agreements and meetings to foster collaboration and address the multifaceted challenges associated with water management. I6 also notes a growing awareness among stakeholders, including irrigators' syndicates, universities, and production companies, regarding the need for alternative approaches to sustain the production system in the face of environmental challenges.

A decline in investment for river basin water management plans over the years was brought up by I1. According to the interviewee, this trend is moving the country away from achieving the goals of the EU WFD and the gap between the number of measures planned and those implemented is widening, which does not bode well for future water management outcomes. They emphasize the need for more adaptive and genuinely collaborative water management practices to address these challenges effectively. I6 also highlights the complexity of governance structures and the challenges faced by public workers in the water administration, illustrating the nuanced dynamics shaping decision-making processes in the region.

Regarding water management plans, I3 explained that the WFD does not mandate a single, unified plan but requires coordination between countries. Some coordination has been achieved, particularly in defining water bodies and monitoring data, as well as public discussions about each country's plans. However, full integration of management plans is complex and not necessarily in the best interest of both countries. For I3, although there was some talk about a joint water management plan, it is unclear if this was ever seriously considered, as Portugal may not have a strong interest in developing joint plans, and the interviewee remains uncertain about the merits of such an approach. I1 also mentioned this intention to develop a joint management plan for the river basin that did not materialize, noticing that the Spanish management plans were subject to public consultation in Portugal, and possibly vice versa. However, there was no joint management effort. Therefore, I1 acknowledged the governance challenges but stressed the necessity of joint management to prevent each country from pursuing its interests to the detriment of environmental sustainability. I9 also believes a joint management plan is necessary between Spain and Portugal and that the implementation of multi-level governance is necessary, as the current system is overly centralized around Madrid-Lisbon and, in Portugal's case, heavily concentrated within the APA.

I3 noted that the Tagus basin, which supplies major urban areas like Madrid and Lisbon, faces considerable demand from diverse sectors, including agriculture and hydropower production. This demand is nearing the basin's water availability, creating substantial pressure. As a transboundary basin, there are further challenges in managing the water flow into Portugal, with Portuguese authorities seeking more water or better regulation of the timing and quantity of water they receive, highlighting the significant geopolitical and resource management issues at play. I4 highlights that the complex water supply system for Madrid and the water transfer in the Tagus Basin are well-managed, with significant investments ensuring the water supply is fully guaranteed. The interviewee also talks about the importance of drought management, emphasizing that there is a comprehensive drought management plan for the entire Spanish Tagus basin, including the city of Madrid. This plan, which is common to all Spanish basins, is a significant strength of the Tagus basin management and, although the plan might not be perfect due to limitations in hydrological knowledge and resilience, I4 appreciates that it includes drought indicators, thresholds, specified actions under certain conditions, and ongoing monitoring, and views these elements as crucial and positive aspects of the basin's management strategy.

5.2.1 | Adaptation to Climate Change

Regarding climate change, I9 believes better water resource management with multi-year criteria, demand control, and reduced supply is necessary due to the meteorological droughts that tend to increase. The interviewee doesn't see the Tagus River Basin management as adapted to climate change, since the state, regional, and local governments continue to insist on pursuing a culture of continuous growth. As an example, the agricultural policy of Castilla-La Mancha is intent on converting thousands of hectares of dryland into irrigated land, disregarding native species adapted to dry conditions in favor of water-dependent species and ignoring the current climate crisis we are facing. Also, administrations continue to promote a misleading modernization of irrigation systems that aims to expand irrigated areas with less water, thus consuming all available water and failing to replenish groundwater. For I9, regarding the management of the Spanish Tagus River in the face of climate change, national strategies show some initiatives, although more symbolic than effective, developed at a general level rather than specifically to each basin, except for Drought Plans. However, these plans have worst-case scenarios predicted by models that are frequently surpassed in reality, and yet the Drought Plans are based on more favorable model scenarios. Another concern is the lack of these debates at lower levels of administration in a decentralized state, to the extent that the public remains largely unaware of these discussions and ignorant of the necessary management processes to mitigate climate change impacts and enhance resilience. Basic recommendations from these debates, such as preserving riparian vegetation, soil permeabilization, reducing biocides and synthetic fertilizers, increasing native tree planting, managing floodplains more expansively, and enforcing strict penalties for debris dumping, often seem unreachable when proposed to different municipal bodies.

Meanwhile, I4 raised a critical issue regarding the integration of climate change into water management decisions, observing that while there is a mandate for climate change analysis, in practice, it often means running simulations under various climate change scenarios, revealing increased deficits compared to the current situation. However, major water allocation decisions still rely on historical data, which shows a diminishing trend. Therefore, the interviewee argues that climate change should be taken more seriously in decision-making processes, despite the challenges it poses for governance, acknowledging the difficulty in restricting user rights based on projections rather than historical data, as users may perceive such changes as manipulative. Nonetheless, I4 emphasized the necessity of incorporating climate change projections into long-term planning, which is currently lacking. For the interviewee, this gap results from the short-term focus of six-year planning cycles mandated by the WFD, leading to a missed long-term perspective essential for addressing water resources management, stressing the importance of adapting demand management to align with climate projections.

5.2.2 | Albufeira Convention

Regarding the AC, I1 expressed the view that the current minimum flow requirements could be increased, as Spain often meets or exceeds these even in dry years. They mentioned that Spain sometimes releases double the required flow in normal years and manages to comply even in extremely dry years, despite having the option to invoke exceptions. Therefore, the interviewee argued that the current minimum flows represent the absolute minimum and that higher flows should be feasible and would bring advantages for the good status of the water and believes in the need for a review of the convention, particularly the flow regime, and addressed concerns from Portugal in renegotiating and potential disadvantages due to Spain's more severe water scarcity. However, they emphasized that maintaining the current flow levels would be the worst-case scenario, and advocated for establishing daily minimum flows, similar to those in the Guadiana River Basin, to ensure more regular water releases.

For I5, the main problem is that the current minimum flow defined in the AC was initially meant to be provisional but has remained unchanged since its inception. As a result, these flows are not true ecological flows. Other river basins in Portugal, not governed by the AC, adhere to ecological flows defined according to the WFD, the National Water Plan, and European Commission recommendations. However, this is not the case for rivers under the AC, as they must follow its provisions, which do not include ecological flows. According to the interviewee, this leads to another problem, which is that the AC does not undergo public consultation or participation, whereas the basin management plans do. I5 believes that this exclusion deprives the public of a fundamental aspect of water management. I9 agrees and believes there is a need to improve Portuguese-Spanish cooperation through the AC and increase access to information for civil society and public participation.

According to I9, the AC may have been a good agreement in the past. However, since the WFD came into force, the AC is outdated because it only addresses hydrological issues. For I9 "now is the time to address the ecological state of the rivers, and in that regard, the Convention does not meet the quality requirements that the WFD expects from river management. Ideally, management and planning must comply with both the WFD and the AC, but currently, compliance with the Convention does not equate to compliance with the WFD". Therefore, although I9 considers the AC a good agreement between the countries, it should be adapted for climate change with new minimal and ecological flows.

I3 emphasizes the inadequacy of the current agreement in addressing climate change, pointing out that while there is a growing concern, the existing agreement is not equipped to handle climatic shifts. The agreement sets annual and quarterly volumes that must be met under normal conditions but lacks provisions for exceptional situations, which are expected to become more common. He argued for an agreement that adjusts water volumes based on precipitation levels, ensuring Portugal receives appropriate amounts in wet and dry years. Currently, annual and quarterly volume requirements often result in no water flow to Portugal for consecutive days, compounded by agricultural demands in both countries and the Segura basin. Therefore, I3 acknowledged the necessity of revising the AC but highlighted its political complexity. Spain claims compliance, and strong agricultural lobbies in both countries make renegotiation politically sensitive, risking criticism of any government attempting changes, thus complicating technical and political discussions across party lines.

For I5, there is no need for a new agreement between countries, but some changes could be made. The primary change should be to follow the WFD, with all technical decisions made within the basin management plan through stakeholder analysis and participation. In I5's opinion, this should be an international joint effort, given the long-standing history of agreements between the two countries, while anything related to governance and negotiation between countries should remain under the AC.

5.3 | Segura-Tagus Water Transfer

Interviewees 2, 3, 4, 6, 7, and 8 brought the water transfer as the main concern and factor to contributed to the flow reduction in the Tagus River. For I2 the upper part of the river experiences a shortage due to significant water transfers to other basins, not because of a lack of rainfall, that also exists as a 50% decrease in inflow to the Entrepeñas and Buendía reservoir can be seen since the 1980s, but mainly because half of the water that does enter these reservoirs is diverted to other basins. For the interviewee, the water transfer violates the European framework directive as basins should be managed independently. They highlighted two major issues: the definition of surplus water in the law, which says that every amount of water up to 400 hm3 in the Entrepeña and Buendía reservoirs is a surplus and the imposed limit of water transfer from certain reservoirs to the Tagus. They emphasized the need for legislative changes and stressed the importance of dialogue and understanding between stakeholders. They suggested that closing the transfer would be a drastic solution and emphasized the importance of managing water resources within the Segura basin responsibly, according to the water they have, aligning with the WFD's principles. For I8, the Segura transfer should be adjusted and progressively reduced until the transfer of water to the Segura is completed.

I3 sees the water transfer as a challenge that exacerbates the already complex water management of the basin, introducing a political complexity to it, and highlighting its political and regional tensions. He noted that the outgoing minister had proposed reducing water transfers to southern Spain, which is politically controlled by a different party, causing significant tension, therefore, the sustainability of this decision under future political leadership remains uncertain. However, according to I4, this discussion and conflict primarily affects the southeast, particularly the Segura Basin, as this transfer operates under strict rules that prioritize internal demands within the Tagus Basin, ensuring no transfer occurs if these demands are at risk of failure. For the interviewee, although there could be trouble during an unprecedentedly dry period, the current hydrological conditions indicate that the Tagus Basin's demands are fully met and the main controversy arises from the reduced flow due to water diversion, which impacts hydropower production and environmental aspects, rather than from demand satisfaction, which remains secure. I4 highlights that the decision to increase the environmental flow in the last Spanish river basin plan, from 6.5 to 8, will affect the transfer, and while the Tagus was historically seen as having surplus water, recent estimates show a significant reduction in available resources—from 1,200 million m^3 per year in the 1990s to about 800 million m^3 today, which together with an increased ecological flow requirements, has further strained the water transfer system and heightened conflicts. I5 agrees, however, believes it is something that needs to be done and the impact on the water transfer is inevitable. I6 also emphasizes that climate change will affect the entire river basin, making it necessary an increase the reservoir releases to meet environmental flow requirements, and as a consequence, there would be a natural decrease in water transfers over time and an escalation of drought-related risks.

According to I6, the inter-basin water transfer significantly influences management decisions, impacting ecological status and overshadowing other issues. I9 agrees and thinks that the existence of the Segura-Tagus Transfer conditions Tagus planning to that of the Segura, treating resources from the Tagus headwaters as part of the Segura's resources. In the best-case scenario, when Tagus planning is formulated, it is coordinated with the Segura, which ultimately modifies Tagus planning. I9 believes that what is considered now surplus in the Tagus River, to be transferred to the Segura Basin, would be much less or simply nonexistent if restoring the Tagus' fluvial dynamics and improving the water quality in the middle stretch, since it is evident that the flow from Madrid's wastewater treatment requires a higher natural flow than current levels to enable natural purification processes that restore life to all its species and ecosystems, were priorities in the managing of the river and considered as new uses and needs, that can always arise in the basin.

5.4 | Ecological Integrity of the River

The ecological integrity of the river was a theme discussed by many interviewees due to the concern about the lack of natural flow of the river and sufficient water to maintain its biodiversity and good ecological status, while an ecological flow was seen by many as not only a solution but a necessity for the basin. For I5, the main challenge for the Tagus River Basin is highlighting the importance of biodiversity and maintaining a good ecological state of the water, believing that a free and natural flow of the river is meaningful if enhances biodiversity and the ecosystem services it provides to society. On that note, I5 mentions as a concern the fluctuations in the river flow and also emphasizes that while the WFD includes physicochemical, biological, and morphological indicators, there is a shortfall in effectively monitoring biological indicators and as a result, bodies of water might be classified as being in good condition, despite inadequate monitoring of their biological health.

I2 provided a comprehensive perspective on ecological flows, distinguishing them from minimal flows and emphasizing their importance in river management, with them being necessary but not sufficient to ensure good quality of the water, saying that as they are now it is not good. The interviewee stated that while minimal flows are essential for sustaining life in the river, ecological flows encompass a broader range of factors including maximums, exchange rates, and flood flows, criticizing the current standards for ecological flows in Spain as insufficient, advocating for higher minimum levels and a comprehensive approach that considers all components throughout the year, highlighting the necessity of flood flows for simulating natural flood patterns, benefiting both agriculture and river management by replenishing groundwater. Therefore, for I2 the variability of ecological flow components and leaving sufficient water in rivers throughout the year to maintain natural flows is essential.

For I8 it is necessary a coordinate between countries so the water is brought to Portugal in a more natural format, since the water quantities may be sufficient, but not the way it is transferred, which is monthly, with the possibility of releasing a lot of water in a few days and very little the rest of the month. I1 agrees and believes that one of the main problems is that currently, Spain could in one day release all the flow for the "month" and release nothing for the rest of the days, therefore, wouldn't even be necessary to increase the annual flow requirement, but instead only a better distribution of this annual flow, suggesting that a renegotiation could ensure daily minimum ecological flows that better support ecosystems. According to I3, Portugal should focus on defining better ecological flow regimes, which Spain has established only for the headwaters of the basin, arguing that the main river sections near the border are not natural rivers and thus exempt from ecological flow requirements. Portugal disputes this, advocating for joint studies with Spain to define and implement ecological flows, while Spain currently operates on provisional values, minimum values, on the border to Portugal until these ecological flow studies are completed. I5 notes that in Spain, for example, they have ecological flows defined in their basin management plans. However, these flows are simply the ones from the AC divided by the seconds in the year, trimester, or week, which does not accurately reflect what an ecological flow should be. According to I9, current monitoring could and should improve and despite some progress, the latest Portuguese Tagus river basin management plan still fails to establish complete ecological flows in all water bodies, with these flows being politically negotiated downwards.

I5 discusses the recent developments regarding the implementation of environmental flow regimes in the River Basin management plans in Spain, acknowledging that initially, these plans lacked such regimes, but due to legal action from social movements and riparian municipalities, the authorities were compelled to include them. However, there has been a delay in the full implementation, with the maximum amount postponed until 2027, and, eventually, these flows will have to be established, potentially altering the dynamics of the transfer. On the other hand, when asked about the increase in the ecological flow in the new plan, I4 expressed uncertainty about the necessity of the increase, pointing out that there was not a comprehensive analysis justifying the change, suggesting that the decision was based on generalized formulas rather than specific studies of the Tagus Basin. Therefore, I4 emphasizes the significant economic implications of reducing the water transfer, noting that the infrastructure was built with national funds and designed to be of special interest to the nation and an investment that was meant to guarantee water availability for various uses, and the state should protect this investment, criticizing the lack of a balanced analysis of the benefits and impacts of the increased ecological flow, taking into consideration the Segura basin. The interviewee believes that defining an ecological flow is important, but questions whether the increase is justified saying that the water quality in the Tagus River has been generally good under the existing minimal flow and suggests that other measures, such as addressing pollution and barriers, could be more effective.

5.5 | Pollution

I1 pointed out the general degradation of water quality across the basin, and actually across the country, contrary to the goals of the EU WFD, which aims for all water bodies to achieve good status by 2027. The interviewee specified that, besides drought, diffuse pollution is the main issue affecting water quality in Portugal. This type of pollution largely comes from livestock farming and agricultural activities, particularly the use of fertilizers. In contrast to point-source pollution from industrial discharges or domestic wastewater, which has decreased due to improved treatment facilities, diffuse pollution is more challenging to control. While WWTPs exist across Portugal, their effectiveness can vary due to inadequate maintenance and equipment. In Spain, I2 states significant concerns regarding water quality in the Spanish part of the river, particularly focusing on pollution stemming from wastewater discharge, pointing out the challenge due to the large population in the area, whose wastewater ends up affecting the river's quality downstream towards Lisbon. The interviewee stressed the urgency of improving wastewater treatment, expressing dissatisfaction with the current pace of progress, citing alarming levels of pollutants such as ammonia and phosphates, far exceeding permissible limits, with ammonia of 50 mg/l, 50 times the quantity allowed and phosphates being

10 mg/l, when is only 0.4 allowed. Also, I2 attributed the formation of foams in the river, especially near Toledo, to surfactants from soaps, body gels, detergents, and certain industrial processes. For I2, the problem is that "while treatment plants may meet legal requirements of effluent release, they fail to ensure the water's "good status" of the water in the river they flow, as mandated by European law", advocating for stricter compliance standards to achieve water quality objectives. I6 agrees and suggests that addressing pollution in the Tagus River basin requires significant improvements in wastewater treatment in Madrid and that, while the city currently complies with existing laws, it falls short of the revised Water Treatment Directive's standards, necessitating tertiary treatment because, and even though most of the WWTPs achieve tertiary treatment, the concentrated contaminant load remains significant, exacerbated by untreated storm-water, and to solve this problem ecological flows are necessary to increase the river's self-cleaning capacity. Although technical challenges exist, these goals should be achievable, especially considering the substantial resources of Canal de Isabel II, the utility managing water supply and wastewater in Madrid. However, for I6, financial resources must be redirected towards infrastructure improvements instead of being distributed to municipalities. For I8, in terms of quality, there is room for improvement in the purification of water in Madrid.

According to I5, there are significant problems concerning the water quality of the Tagus River, which starts with the effluents discharged by the WWTP in Madrid and flow into the Tagus River and accumulate in the dams until they reach Portugal, a situation exacerbated by the river's extensive regulation. I5 points out that the high level of regulation has led to the accumulation of pollution in the depths of the dams over the past 20 to 30 years. This situation culminated in a recent event involving two of Spain's largest dams, Alcántara and Valdecañas. These dams were filled to 89% of their capacity, and then within two to three months, most of the water was released, reducing their levels to 40% and 21%, respectively, due to high energy prices in Spain at the time. The consequence was a drastic reduction in river water levels during those months and subsequently low water levels in the dams. Combined with the high summer temperatures, this created an algae bloom. I5 believes that the current water management practices in the dams and reservoirs, particularly regarding water release and storage, are creating conditions that deteriorate the ecological status of water bodies. The pollution accumulating at the bottom of the dams is gradually carried downstream to Portugal, leading to eutrophication, as observed in Fratel and Belver that year. As a result, the water quality in two Portuguese dams declined from reasonable to bad and from good to sufficient during the second cycle of the basin management plan. I5 sent some photos to show the situation in both reservoirs during those years and they can be seen in Figures 5.3, 5.4 and 5.5. Acknowledging the situation in the Spanish part of the river, I3 also showed concern regarding the quality of the water that enters Portugal, which is often poor, indicating a necessity of investments to improve treatment systems upon entry into Portugal, pointing out the risk of saline intrusion due to reduced flow levels, a problem that has occurred in the past. I1 also noted that similar agricultural pollution problems exist in Spain, contributing to issues such as the proliferation of cyanobacteria and algae in the Tagus River, particularly during dry periods, which is exacerbated by intensive farming practices and heavy fertilizer use. I1 also mentioned a public consultation regarding a reversible pumping project at the Alcántara Dam in Spain, which could increase the frequency of algae blooms if implemented, which has already been recurrent, particularly in dry years like 2021, 2022, and 2023.

(a) (b)

Figure 5.3: Main course of the Tagus river in Portugal in 2021 5.3a in Chamusca and 5.3b in Valada. Pictures taken by ProTEJO.

Figure 5.4: Cedillo dam, border of Spain on April 16, 2021. Photo taken by ProTejo.

Figure 5.5: Alcântara dam on September 14, 2021. Source: El Periódico Extremadura

For I9, the pollution problem has happened since the 60s with the population growth and industrialization in Madrid, and even with the current 135 treatment plants, they are insufficient to meet the quality parameters set by the WFD. For water supply, water is stored in the headwaters and the minimal flow that is left, due to the water transfer, meets the poorly treated wastewater, with uncontrolled discharges, causing pollution in the middle Tagus and preventing the natural process of diluting the pollution and improving the water quality. Therefore, for I9, meeting the water quality standards required by European directives is increasingly challenging, and eutrophication episodes are more frequent and affect a greater number of water bodies, and the low river flow does not exempt the need for improvements in wastewater treatment from Madrid and throughout the basin, as well as barrier removal to achieve better rates of change and replenishment. Also, I9 states that "it makes no sense that, while human water supply is of utmost priority, groundwater pollution issues are not addressed, prioritizing agricultural activities that are neither prioritized, sustainable, nor resilient in the face of climate change".

5.6 | Reservoir management

Three interviewees mentioned the extensive dam system of the Tagus River as one of the main challenges in the Tagus basin. I2 expressed concern over the numerous large dams along the Tagus River in Spain, primarily dedicated to hydropower generation, which even though important, leads to long stretches of the river without natural river flow, adversely affecting river ecosystems and biodiversity. For that matter, I2 proposed as a possible solution for Portugal, the managing of the Cedillo dam so it releases flow similar to natural patterns to mitigate some of the ecological impacts downstream in Portugal. However, recognition is a challenge due to the management of this dam by Iberdrola. I6 also acknowledges the challenge posed by numerous dams and hydroelectric power in the Tagus River basin, where the natural flow of the river is disrupted suggesting that due to the strategic economic importance of these facilities, removing the dams is unlikely and thinks there is a need to focus on managing the environmental impacts of these structures by regulating the release of water from hydroelectric dams to minimize harm to the river, particularly on the Portugal side of the border where significant ecological damage has occurred in the past due to excessive releases and also addressing environmental challenges in the tributaries to the Tagus River. In agreement with that, I8 says large dams may still be needed to supply the demands, but many small dams can be removed and agree that the main problem is how dams release water. I6 also showed concerns regarding the intensive regulation of hydroelectricity production in the middle basin has led to ecological and social impacts, transforming the river into a series of dams.

The variability in water release from the dams is also a significant problem for I5 in both Portugal and Spain. For example, an agreement was made with EDP in Belver for a daily average flow of 10 m^3/s. However, this flow is released in two periods of 4 hours each, leaving zero flow for the remaining 16 hours. This pattern is detrimental to the ecosystem. Thus, not only does the flow vary greatly, but it also depends on the water coming from Spain and how it is released. I9 criticizes the 280 km of hydroelectric dams at the final part of the Spanish part of the river since eliminates the natural river and shows an over-regulation in the Tagus and claims that one problem in the management of the dam is the large headwaters reservoirs being operated primarily to meet immediate demands of the Segura-Tagus Water Transfer, lacking strategies for multi-year water storage. Also, downstream reservoirs near Talavera de la Reina exemplify extensive privatization aimed at satisfying hydroelectric needs, sometimes even seeking compensation for allowing ecological flows.

I3 also discussed the ongoing debate regarding the current dam system and potential new constructions. In Portugal, a small dam in Crato village has been approved, and there's significant discussion about building a dam on the Ocreza River, a tributary of the Tagus. In Spain, while it's unclear if new dams are planned, there are significant projects for reversible systems in Alcántara and the upstream

Valdecañas dam, that would allow Spain to increase water retention and generate energy by cycling water between upstream and downstream reservoirs and most likely these structures will continue to evolve and should be evaluated for their investment value. Therefore, I3 believes that greater storage capacity in the Tagus will be necessary and, In Portugal, where geographic limitations prevent large-scale dam construction, the focus should be on transforming existing dams into multipurpose systems. Contrary to that, I1 expressed clear opposition to the construction of new dams, viewing them as additional barriers that disrupt river ecosystems and advocated for the removal of obsolete dams to restore ecological functions and enable migratory fish to reach spawning grounds, mentioning a recent discussion with the Águas de Portugal company, in which was emphasized that the current dam storage capacity is theoretically sufficient to meet Portugal's needs, however, many existing dams, some over 50 years old, have reduced storage capacity due to sediment accumulation. Therefore, as a solution, I1 suggests focusing on sediment management and proposing developing strategies to remove and re-purpose sediment, such as using organic material from sediments as fertilizer, potentially reducing Portugal's reliance on imported fertilizers. This would be done in a phased implementation across various dams with accurate volume assessments using bathymetry, and strategic planning to avoid conducting such operations during drought years when water levels are low. Even though is a long process, I1 believes it should be managed to avoid stirring up sediments that could degrade water quality, especially in dams supplying drinking water, and highlights the need for a comprehensive strategy to extend the functional lifespan of existing dams without compromising water quality or ecosystem health.

5.7 | Other solutions proposed by the interviewees

When asked about other solutions that were not mentioned or talked about throughout the interviewee, some interviewees had some topics that considered important to mention.

I5 emphasizes that while it is possible to extract water from the Tagus River for agriculture, it is crucial to ensure that sufficient water reaches the sea to complete the ecological cycle. This includes maintaining the flow of chemical substances and nutrients to support estuarine and coastal ecosystems. He suggests constructing off-river retention basins to store water during periods of drought, without fragmenting habitats or compromising biodiversity. I5 stresses the importance of combating water wastage and suggests that funds should be redirected from building new dams and water transfers to improving water distribution networks, particularly in agriculture. He notes that reducing water losses in agriculture, which accounts for 75% of water usage with 40% distribution losses, would have a significant impact. I5 argues that investing in reducing agricultural water losses yields greater benefits than similar investments in urban water systems. I3 also mentioned the importance of water conservation and improving efficiency in water usage, particularly in irrigation, as there are still significant losses in both Portugal and Spain as a key solution for addressing future water supply challenges during drought years. At the level of Irrigation Plans (carried out by the Ministry of Agriculture), I9 believes that they should undergo a Strategic Environmental Assessment, particularly to assess whether the projected water consumption and cultivated species are well adapted to the climate and water availability in the Tagus River Basin. According to I4, although irrigation is not a major economic activity in the basin, it has social implications as farmers have little motivation to invest in water-saving technologies because they believe that saved water would be transferred elsewhere, via the Segura-Tagus transfer. Despite river basin management plans targeting reduced water consumption, I4 states that there has been little action to address this issue due to the significant investment required, and unlike other regions in Spain, where public administration has supported such investments, this region lacks motivation. Besides that, the interviewee mentions that some districts in the Tagus Basin have a high water allowance, up to 12,000 cubic meters per hectare per year, significantly above the Spanish average of around 7,000.

Off-river retention basins are also mentioned by I5 as a viable solution to mitigate the impact of reduced precipitation, guaranteeing the storage of water for the dry seasons and years without interrupting the natural flow of the Tagus River. I3 recommends as possible solutions reusing treated wastewater wherever possible, desalination, which would be practical only for Lisbon, and better use of the underground water systems, noting that Portugal has three interconnected aquifers that should be managed strategically to optimize resource use, and only after these options are explored that the construction of new dams should be considered. According to I9, a significant part of the solution lies in restoring the Tagus and its rivers to their natural fluvial dynamics lost to reservoirs and transfers; the other part lies in improving wastewater treatment. However, none of this is possible without also controlling demands to ensure the absence of water stress. I8 also believes that morphological restoration work is needed in many stretches, especially in the central Tagus, as its channel has been greatly simplified, and the beneficial effects of releasing more flow are hardly noticeable.

6 | Results and discussion

This chapter will synthesize the findings from the literature review, document analysis, and interviews to provide a comprehensive discussion on the topic and explore potential solutions. First, the main challenges related to the increase of drought events and the corresponding technical solutions will be identified and discussed. Following this, the management practices in the region will be examined, with a focus on the AC, its challenges, and possible improvements—not only within the convention but also in the overall water management of the area. This will include an analysis of whether the current management can be considered adaptive, along with reflections on its effectiveness. Finally, the limitations of the research will be discussed and recommendations for future studies will be offered.

6.1 | Current and Future impact of droughts

Based on all the research, it is clear that the Tagus River Basin has a very complex water system due to the high demand from both countries. The situation gets exacerbated due to the uncertainties of climate change and the impacts it will have on this region. According to the Portuguese Tagus Basin Management Plan (Agência Portuguesa do Ambiente, 2022), water scarcity is a concern as the basin was classified as an elevated scarcity, according to the scarcity index WEI+. In every research studied it was found a decrease in average annual precipitation and an increase in average annual temperature. Hence, it was also predicted a decrease in the availability of water resources in the region. Since the 1980s it has already seen a reduction of 32% in the average flow at the headwaters of the Tagus River, a situation that, according to predictions, will be worse in the future.

Nevertheless, it seems that currently the water demands in the Tagus Basin are being met most of the years, except for recent dry years that led to a low flow in the river, causing an impact on the fishing and tourism sectors. This conclusion aligns with the basic model presented in 4.2, which indicates that both countries typically have sufficient water storage to meet their annual water demand in a normal year. However, when incorporating the projections for the Tagus basin towards the end of the century, the storage estimates change significantly. In Figure 6.1, the basic model was updated to account for the predicted decrease in precipitation, increase in evapotranspiration, and adjustments to the minimum water transfer between the two countries. The results indicate that Spain's storage would fall below the current demand, while Portugal would face a negative storage balance, which theoretically suggests reduced outflow to the sea to meet internal water demands. Therefore, it is evident that there is a pressing need to enhance current water management practices and explore alternative supply solutions, along with investments aimed at reducing water demand.

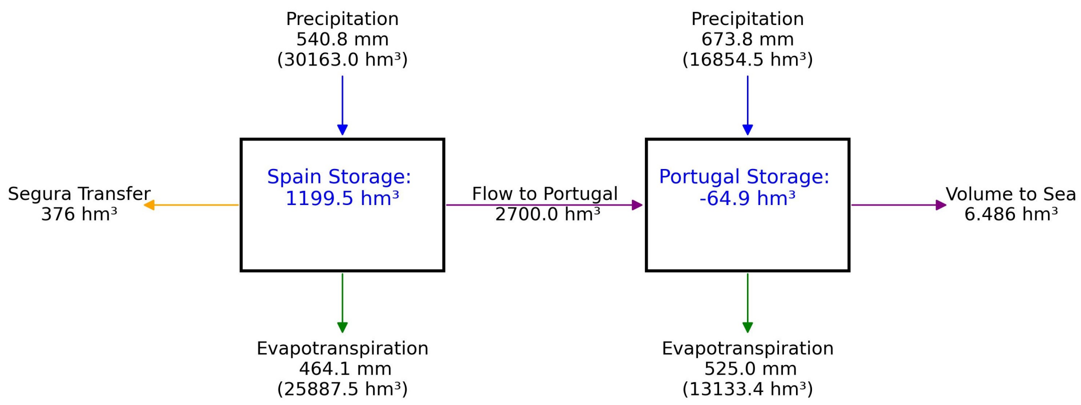


Figure 6.1: Main problems in the Tagus River Basin

Additionally, while the primary demands are currently met for most of the years, the ecological services of the river and its biodiversity are often overlooked, particularly regarding the implications of lower river flows, such as loss of biodiversity and groundwater recharge. Although climate change significantly affects the river's average flow, the management of water resources in the Tagus River Basin is also a critical factor contributing to the challenges it faces. Figure 6.2 shows a diagram resuming the main current challenges that were found and discussed throughout this study and its consequences.

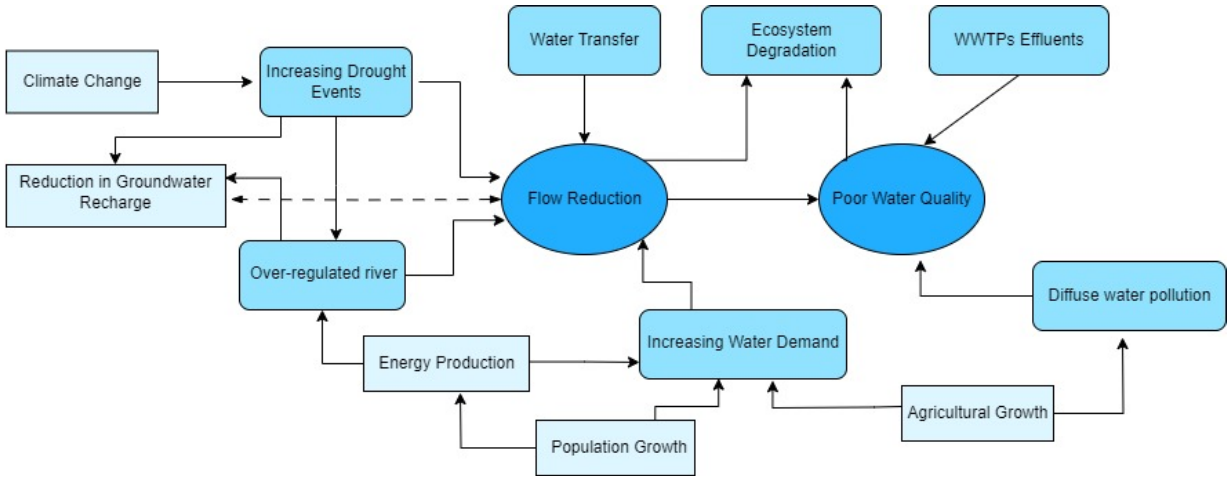


Figure 6.2: Main problems in the Tagus River Basin

As can be seen on the diagram, there are significant pressures on water quantity, including water transfers, increased frequency of droughts caused by climate change, rising water demands, and over-regulation of river systems. In response to drought events, dams have been employed across the region to store water and generate energy. However, this approach has resulted in a highly regulated river, with stretches exceeding 200 kilometers without any natural river. This not only impacts river ecosystems and biodiversity but also threatens aquifer recharge, potentially compromising future water supplies. Also, the management of these dams has drawn criticism from specialists who argue that energy generation priorities often overshadow considerations for downstream ecosystems. This issue becomes more pressing when we add the increasing water demand and the uncertainties posed by climate change scenarios.

When it comes to the water quality pressures, the situation is compounded by effluents from WWTPs, particularly in the Madrid region, as well as diffuse pollution from irrigated areas, reduced flows, caused by climate change, inadequate reservoir management, and the water transfer, reducing the river's self-cleaning capacity. Poor reservoir management also increases the pressure on water quality for being obsolete and favorable for algae bloom and eutrophication in its reservoirs due to years of sediment accumulation. Ultimately, the reduction in both flow and water quality leads to ecosystem degradation. Next, possible solutions to these challenges will be discussed and a resume can be found in Table 6.1. These solutions were specifically designed for the Tagus River Basin, according to the most significant problems identified, which means that some issues, such as diffuse pollution, are not further discussed as it is a smaller issues only in specific regions in Portugal. They were thought of as solutions that complement each other, as all of them should be implemented at some point, and were made taking into account the strategies discussed in Chapter 3, the current situation outlined in Chapter 4, the suggestions provided by interviewees in Chapter 5, and the drought adaptation strategies described by Jahangiri et al. (2023).

Table 6.1: Possible solutions and their details

Possible solutions	**Details**	**Problem solved**
Environmental flow adoption	▪ Altering reservoir releases ▪ Adopting environmental flow in many stretches of the river ▪ Adopt Environmental Flow in the AC instead of Minimum flow	▪ Irregular releases of dams harming the ecosystem downstream ▪ Low flow and pollution concentration as a consequence ▪ Guarantee the necessary flow for a good status of the river after the Water Transfer ▪ Increase the self-cleaning capacity of the river
Removal and adaptation of dams	▪ Obsolete dam removal ▪ Cleaning and sediment management ▪ Adapting dams to ensure high water quality ▪ Off-river local reservoir for irrigated areas	▪ Absence of natural river in some areas ▪ Accumulation of sediments in the dams creates a favorable environment for eutrophication
Water treatment improvement	▪ Improve tertiary operation of WTTPs	▪ High nutrient concentration especially in Middle Tagus, in Spain
Reducing water waste	▪ Climate-smart agricultural practices ▪ Increase in agriculture efficiency ▪ Public awareness and water education ▪ Water recycling and reuse	▪ Less need in building new dams to satisfy increasing demands ▪ Increasing drought events
Water Reuse	▪ Reclaim water from WTTPs	▪ Increasing water availability
Ecosystem restoration	▪ Water right permits with conditions to maintain the natural flow of the river ▪ Manage riparian corridors ▪ Reconfiguration of channels ▪ Expand protected area ▪ Ensure fish passage ▪ Enhance floodplain management ▪ Habitat rehabilitation	▪ Decrease in biodiversity ▪ Poor ecological status of the river ▪ Reduction in groundwater recharge ▪ Loss of ecosystem services benefits

6.1.1 | Environmental Flow Adoption

Even though there are environmental flow defined in the Spanish Tagus Basin Management Plan, there is a lack of explanation for the method, as it is questioned by scientists. The problem is that the environmental flow defined in the plan for the Cedillo Dam is the same as the minimal flow defined in the AC, which does not use the environmental concept to be defined. Figure 4.2 illustrates that Spain can adequately meet its water needs during normal years, with the current inflow from Spain to Portugal being twice the minimum annual flow of 2,700 hm^3 specified in the AC. This indicates that Spain has sufficient water resources to maintain an appropriate ecological flow regime, which should be implemented to preserve the river's ecological health, guaranteeing a necessary flow for the good ecological status of the river, especially downstream of the Water Transfer. For future demands it was seen that this might not be true, however, the adoption of environmental flow is only one of the solutions proposed, keeping in mind the current state of the ecosystem, which has suffered significant damage due to prolonged periods of no flow in certain parts of the river, making this solution crucial for the future, as without adequate flow, the potential for aquifer recharge diminishes, exacerbating the situation further.

Therefore, the adoption of environmental flow regulations for a greater stretch of the river, especially at the Cedillo Dam, is essential. As demonstrated in this study, currently, the primary issue often lies not in the quantity of available water, but in how it is managed and released from the reservoirs. To apply this solution, the values defined by the AC should also be environmental flows instead of only minimal flows. Therefore, implementing this solution would transform reservoir management without necessitating structural changes, eliminating the variability of the dam releases.

6.1.2 | Removal and adaptation of dams

Alongside the adoption of environmental flow, the removal and adaptation of dams can be done to restore the natural river and improve its water quality. Before considering an increase in current storage capacity to meet future demands, it is crucial to assess the existing dams in the region. A comprehensive study should be conducted to determine whether any of these dams are obsolete and in need of adaptation or even removal. According to several interviewees, some of the dams in the area are very old and, due to issues like high sedimentation, often cause more harm and incur higher costs than the benefits they provide. Many countries are already following this approach, with cases being found in the US, Sweden, and France. The removal of obsolete barriers can be integrated into plans for restoring riparian ecosystems and is promoted by legal, conservation, and/or socioeconomic factors. There is the possibility of removing high-risk dams or fortifying them to store excess water, sediment, and pollutant loads. In anticipation of droughts, it might also be prudent to remove dams located below shallow reservoirs in regions with high evaporation rates—especially given the expected rise in evaporation due to climate change, which is already a significant concern in areas like Spain. If the dams remain intact, it may be necessary to adjust the elevation of the outlet that releases reservoir water to the downstream river to ensure the delivery of high-quality water.(Palmer et al., 2009) Another solution is the construction of off-river local reservoirs as an adaptation for irrigation areas. This approach would provide a more consistent water supply to these regions without disrupting the river's flow.

For the sediment accumulation in the dams, which leads to eutrophication and a poor quality of the water downstream of the dam, there were no measures to clean the environmental liabilities existing at the bottom of the dams in Spanish Extremadura (Torrejon, Valdecañas, Alcântara, Cedillo, etc.). The situation recurrently leads, in consecutive hydrological years, to eutrophication phenomena and algae blooms with cyanobacteria in these dams in Spanish Extremadura, which are discharged downstream, contaminating and deteriorating the ecological state of the water bodies of the Tagus River in Portugal.

Therefore, a sediment management plan could be conducted, bringing advantages not only in the water quality but also in the storage capacity of the reservoir. The sedimentation management and removal can be done in many different ways, as shown (Schlunegger et al., 2013). In some cases, the sediment can be bypassed around the reservoir, if the geometry allows it, preventing the sediment buildup and allowing the sediment to flow downstream, leaving it closer to natural conditions. Other techniques are drawdown routing or flushing. The former is recommended for reservoirs with large outlet capacities and it allows the sediment to move quickly through the reservoir during high flows, preventing sedimentation, while the latter is more recommended for narrow reservoirs with steep gradients and involves re-suspending sediments that were once settled then transporting them through low-level dam gates. Another option that does not require the lowering of the reservoir level is using turbidity currents.

6.1.3 | Water treatment improvement

A study has shown that even if the Water Transfer was closed, there would still be pollution problems in the Middle Tagus, due to the high volume of water coming from the WTTPs. Therefore, the solution for the nutrient accumulation in this part of the river is an improvement in the tertiary treatment in the region.

6.1.4 | Water Waste Reduction

Water waste reduction is a crucial solution to consider, especially in light of future scenarios that highlight the need to decrease current water demand. Sondermann and Proença de Oliveira (2022) evaluated potential demand-side adaptation strategies to manage water abstractions and prevent future increases, or even achieve reductions and concluded that reducing irrigation water consumption by 25% to 40% would notably enhance the performance of the Tagus River transboundary system, which would help sustain the current conditions in the face of projected climate change scenarios. In addition, this study also revealed that agriculture presents the greatest potential for improvement in water usage. Hence, to reduce water waste, investments in agriculture efficiency and climate-smart agriculture practices have to be made. According to a specialist, if the intention is to solve the drought problem with irrigation, there will never be enough water, as "If we use it to irrigate autumn-winter crops, we can achieve productivity four to five times higher than spring-summer irrigation". Therefore, the key is to maximize water productivity, combining the strategy with good soil drainage to prevent production loss due to water logging in rainy years. (de Notícias, 2017) This indicates that changing crops could enhance productivity, but there is also significant potential for reducing losses associated with the crops currently in use.

6.1.5 | Water Reuse

There are currently some initiatives in Spain to increase water reuse projects. Therefore, studies in water reuse and recycling should be made to evaluate the possibilities to expand the practice in the area, as it is recommended as one of the main alternative solutions for water supply. The solution reduces the water that has to be taken from the river reducing the pressure on the basin, and can be a solution for non-domestic purposes like agricultural irrigation, industrial needs, and other urban uses.

6.1.6 | Ecosystem Restoration

Ecosystem restoration is recommended to solve problems such as reduction in groundwater recharge and decrease in biodiversity. The Tagus River is highly regulated and that leads to a big loss in biodiversity and the capacity of the river to recover itself, affecting the ecosystem services it provides.

Part of this solution is also the removal of the dams, as previously discussed. Therefore, these are practices that many times go together.

In affected areas, or in areas in which the dam removal was made, to maintain the good ecological status of the river and guarantee water for future generations, restoration of channels and floodplains is recommended. These aim to enhance stream health by reshaping banks to their natural form and restoring lost functions. Besides the removal of dams, this also includes practices such as stabilizing channels, filling incised channels, eliminating legacy sediments, planting vegetation along buffers, and reconnecting the stream to its natural floodplain. (ICRA, 2021)

6.2 | Albufeira Agreement and Water Management

In this study, we also analyzed the current water management of the basin, aiming to identify gaps, assess adaptation for climate change, and determine the need for improved cooperation between countries. Table 6.2 shows an analysis of the AC, with its highlights, gaps, and recommendations. The highlights and gaps outlined here summarize key points previously discussed in Chapters 4 and 5. The recommendations will be further discussed next.

Table 6.2: AC analysis

Category	**Subcategory**	**Details**
Positive Points	Institutional Framework	Successfully institutionalized interstate collaboration, providing stability and continuity insulated from political changes.
	Technical Management	Decisions are entrusted to a technical body guided by scientific principles.
	Conflict Resolution Mechanisms	Provides an agreement for cooperation and conflict resolution.
	Willingness for Centralized Resolution	Single convention for all shared basins shows commitment to resolving issues at a national level.
	International Joint Effort	Emphasizes the need for an international joint effort in basin management planning through stakeholder analysis and participation.
Gaps	Minimum Flow Requirements	Current minimum flow requirements are the provisional ones for years and need revision.
	Ecological Flows	Does not follow ecological flow requirements as per the WFD.
	Public Consultation	Lacks public consultation and participation mechanisms.
	Climate Change	Does not address climate change.
	Lack of Effective Monitoring	Poor monitoring of water flows and quality, with no continuous, hourly tracking.
	Exception Clauses	Allows exceptions in flow requirements during exceptional circumstances, without a solution for those situations.
	Water Quality Indicators	Does not have indicators to guarantee good water quality.
	Meeting Frequency	Infrequent meetings of the Conference of the Parties (CoP), only three in twenty years.
	Implementation and Coordination	Coordination chosen over joint implementation for most actions, leading to issues such as differing water assessment systems.
Recommendations	Review and Increase Minimum Flows	Higher minimum flow requirements should be feasible and advantageous.
	Adopt Ecological Flow Requirements	Follow WFD ecological flow guidelines for better water management.
	Enhance Public Consultation	Incorporate public consultation and participation in the convention.
	Update Provisions for Climate Change	Adapt the convention to address climate change with new minimal and ecological flows.
	Refine Exception Clauses	Clearly define exceptions and ensure measures to mitigate consequences during exceptional circumstances.
	Foster Joint Implementation	Move towards joint implementation of river basin management plans for better coordination and compliance with environmental regulations.
	Include water quality parameters	Define minimum water quality standards for the water that enters Portugal

A review of the minimum flow requirements is necessary, as these were established many years ago temporarily but have never been reassessed. This study suggests that an increase in the minimum flow could be feasible at present; however, it remains uncertain whether this will be possible in the future. Therefore, a comprehensive study should be conducted to evaluate whether the minimum flow should be adjusted. Regardless of any changes to the minimum flow, the adoption of ecological flow requirements is recommended, as discussed earlier in this chapter. Throughout this study, it has become evident that the issue may not solely be the quantity of water available, but also its variability and how it is released. Consequently, implementing ecological flow measures is crucial and may be sufficient to maintain the ecosystem and satisfy water demands.

Public participation in the decision-making process requires improvement, as stakeholders often feel excluded. There is a general impression that they are not included in decision-making. Although there is public participation in the river basin management plans, the flow decisions most critical to many stakeholders are made under the AC, which currently lacks a mechanism for public consultation. Therefore, it is recommended that the AC incorporate public consultation and participation regarding decisions that significantly impact stakeholders, such as minimum flow values and exceptional rules. In addition, it was seen that the governance system is overly centralized around the two main cities, Madrid and Lisbon.

The AC could be improved when it comes to climate change. Climate change should be considered when deciding minimum flows and should be discussed by the technical body of the convention when it comes to measures and programs. Both countries agreed in bilateral meetings that hydrological plans for the basin should integrate the effects of climate change. This includes calculating future water resources and mapping related risks. However, future predictions have not been sufficiently accounted for in long-term water allocations and they should. Moreover, although climate change considerations are included in both basin management plans, they often rely on the most favorable model scenarios. Another significant issue identified is that management efforts often focus on meeting water demand rather than adapting this demand to the available supply, especially in light of climate change. An example of this is new projects in Castilla-La Mancha and a proposal for constructing four new weirs and two new dams to expand agriculture in the region from Vila Franca de Xira to Abrantes. The focus should instead be on better management of existing infrastructure and improving irrigation efficiency techniques before expanding agricultural areas, which are already at risk.

One of the most critical and urgent changes needed in the AC pertains to its exceptional clauses, which outline the circumstances under which they apply. However, these clauses do not provide a clear solution for such situations, allowing for interpretations that could result in zero water transfer from Spain to Portugal, for example. It is recommended that a percentage of the current minimum flow be established to determine a new minimum value, taking into account the difference between the average water availability on the Spanish side of the basin and the current water availability during the exceptional year. To achieve this, comprehensive studies should be conducted using a complex model of the basin that incorporates water availability in both countries.

The need for a joint management plan was identified and recommended. Currently, the management strategies in the two countries are not synchronized and differ in indicators and objectives. Also, different numbers for the same parameters were found in both management plans, making it harder for decision-making. Financial problems were also identified, including a decline in investment in the river basin management plan over the years. This has led to a gap between the planned measures and those implemented.

Lastly, it is crucial to incorporate water quality parameters into the AC, as these are currently absent. Without such standards, water can be transferred from Spain to Portugal even when it is in extremely poor ecological condition, which is problematic. This issue is particularly urgent given recent incidents where reservoir management in Spain led to algae blooms, with the affected water subsequently released into Portugal. Addressing this gap would help prevent such ecological harm and ensure healthier water quality in transboundary transfers.

6.2.1 | Adaptive Water Management

To better analyze the policies and management in the basin, an evaluation to see how adaptive and integrated the water management in the basin is, was made. The framework adopted by Huntjens et al. (2010) included the Guadiana Basin, in Portugal. Even though the Guadiana Basin has a different management plan and authority, the basins all follow the same structure, both in Portugal and Spain, and the same agreement, the AC, and therefore can be used as a comparison. The evaluation was made giving scores, from 0 to 2, for each of these topics, and the Guadiana basin got the worst score for Governance and only 'Effectiveness of International Regulation' got a higher score than 1, with all the others with room for improvement. For the analysis of the Tagus Basin, it was used the framework developed by Raadgever et al. (2008), utilizing also some perspectives adopted by Huntjens et al. (2010) and the result can be seen in Table 6.3.

It can be concluded that the management of the Tagus Basin still needs lots of improvements when it comes to adaptive and integrated management, especially in information management, actor networks, and policies. Based on the analysis conducted in this study, the Tagus Basin would benefit from a more adaptive and integrated management approach. This shift is essential to effectively address climate-related challenges in water management and to incorporate adaptation strategies into planning. Given the projected impacts of climate change in the region and the current lack of integration of these considerations into management practices, the basin is inadequately prepared for the necessary adaptations, many of which are likely already required.

The study by Huntjens et al. (2010) demonstrates that higher levels of AIWM correlate with greater learning outcomes, particularly in terms of implementing physical interventions. A management approach with a higher degree of AIWM is more likely to explore various alternative actions and revisit guiding assumptions to identify the optimal solution—potentially one that has not been previously considered or implemented in the area. In the Tagus Basin case the opposite seems to happen, where, despite the availability of multiple alternatives to address the situation, authorities consistently opt for increasing reservoir volumes as the preferred solution.

The analysis presented in this chapter reveals that some of the most significant issues in basin management are also highlighted in Table 6.3. The Tagus River Basin has a lot to gain from improving its public participation and cooperation between different levels and both countries, as this would facilitate the management for both sides and bring different perspectives and possible new solutions. Opening the AC to public consultation or determining flow values outside of the convention—criteria, as that should involve input from various sectors and administrative levels, would enhance the adaptiveness of the management, particularly in terms of actor networks. Additionally, implementing a joint basin management plan would greatly improve cross-border cooperation. While stakeholder participation is theoretically encouraged, in practice, non-governmental entities often find themselves having to appeal to the EU to be heard on issues like drought management in the Tagus Basin, indicating a gap between policy and action.

Current policies could also benefit from significant improvements, particularly in incorporating climate change considerations into their planning, as previously discussed. The primary strategy for combating drought has been the construction of dams; however, this approach lacks flexibility, especially since dam removal is both challenging and not widely supported by current basin management. Additionally,

Table 6.3: Evaluation of Adaptive Water Management in the Tagus River Basin

Criteria	Indicator	Score	Reasoning	Total score
Actor Networks	Cross-sectoral co-operation	0	Good means of dealing with conflicts but could be improved, especially regarding political decision-making under the AC.	- / 0
	Cooperation between administrative levels	-	Lower level governments involved but not in decision-making.	
	Cooperation across boundaries	0	Spain involves Portugal in decision-making, but significant improvements are needed, e.g., Water Segura Transfer.	
	Stakeholder participation	-	Limited non-governmental involvement in agenda setting and decision-making.	
Legal Framework	Appropriate legal framework	+	AC effective but needs improvements.	0 / +
	Adaptable legislation	0	Legislation adaptable but lacks recent changes.	
Policy	Long time horizon	-	Plans consider climate change, but water allocation is based on historical data.	- / 0
	Flexible measures	0	Reversible measures exist, but removing dams is difficult.	
	Experimentation	0	Centralized focus limits experimentation.	
	Consideration of measures	-	Tendencies seen, but full consideration lacking.	
	Policy implementation	0	New policies emerging alongside existing plans.	
Information Management	Joint production	-	Governmental involvement are sufficient but lack non-governmental input.	- / 0
	Interdisciplinarity	0	Ecology considered but room for improvement.	
	Mental models	-	Research distant from community perspectives.	
	Uncertainty consideration	-	Climate change uncertainty underrepresented.	
	Broad communication	0	Data available online but accessibility issues.	
	Information use	0	New climate data informs plans, limited impact on agreements.	
Financing	Appropriate system	0	Complaints about under-investment despite available resources.	0

there is a noticeable lack of experimentation, as policy efforts are overly centralized, leaving little room for local initiatives. For example, experimenting with off-river reservoirs for irrigation could be a viable solution in certain regions but remains largely unexplored.

Regarding information management, there is a clear divide between the data produced by non-governmental organizations and governmental entities, with governmental bodies often neglecting to utilize the information generated by non-governmental groups. Although climate change information is included in management plans, it is not adequately integrated into policy-making or action plans. Another significant issue is the lack of cooperation in monitoring efforts, which hinders the production of high-quality data essential for improving management practices and developing effective drought adaptation strategies. Both countries should conduct systematic assessments of drought impacts, ideally through coordinated efforts. Additionally, specific guidelines for characterizing and recording drought impacts, along with the implementation of monitoring systems, are crucial for enhancing information management in adaptive management practices.

7 | Conclusions and Recommendations

The Tagus River Basin faces significant water quantity and quality challenges that will increase due to climate change and an increase in population. The region has experienced a reduction in average annual precipitation and an increase in temperature, leading to decreased water availability. The impacts are felt across various sectors, including fishing, tourism, and ecosystem health, highlighting the urgent need for adaptive management strategies. Although water demand is not currently a major issue, there are significant concerns regarding water quality and ecosystem health, largely due to pollutants and reduced river flow. This low flow is a result of both increasing drought events and reservoir management practices. Looking ahead, it is expected that by the end of the century, these problems will worsen, making it increasingly difficult to meet water demand.

In terms of governance and policy, the AC, while a cornerstone for international cooperation between Portugal and Spain, requires updating. Specifically, revising minimum flow requirements to incorporate ecological flow principles and ensuring public consultation in decision-making processes are essential steps. Stakeholder engagement should be enhanced to foster inclusive and transparent water management practices. Another important improvement would be to include water quality parameters at the same locations where minimum flow requirements are defined. Additionally, to effectively manage the Tagus River Basin under future uncertainties, it is recommended to develop a joint basin management plan that integrates adaptive water management strategies. It was also noted during the research a lack of studies focused on improvements in agriculture activities in the area and the possible consequences for the water resources.

Analysis revealed that the Tagus River Basin has a low level of AIWM, closely linked to several identified gaps that require attention. Enhancing stakeholder participation, information management, and policy making processes is essential. A significant shortfall in the current management approach is the failure to adequately integrate climate change considerations into policy and actions, despite their inclusion in basin management plans; for instance, climate change is not factored into water allocation. Additionally, improvements in monitoring are necessary to gather more comprehensive data about the basin, enabling better adaptation to new information and more effective planning. Therefore, a higher level of AIWM is a good option for the Tagus Basin, bringing many advantages for both countries and preparing the basin for the future. It is possible for it to be integrated in the current management, however, requires commitment from both countries in including more stakeholder participation, cooperating more and including climate change in their planning.

After the extensive document analysis, literature review, and interviews, many possible solutions were found. Due to the highly regulated characteristics of the Tagus River, it is recommended that the main focus be on adapting and making more effective the already existing infrastructures, focusing on preparing the demand for the available supply. Therefore, the management of dams, while providing essential water storage and energy generation benefits, can be detrimental to downstream ecosystems. There is a pressing need to reconsider dam management practices, including potential removal or adaptation to restore natural river flows and mitigate impacts on biodiversity and water quality, being a priority. Furthermore, a recommendation is a thorough assessment of existing dams to determine their viability and potential ecological impacts, with consideration given to removal where feasible or to adapt them if that would bring more advantages. In addition, addressing water quality issues by improving the WWTPs is crucial for the good status of the river. Improved water treatment technologies and agricultural practices must be implemented to reduce pollutant loads and enhance water quality across the basin. Water reuse and ecosystem restoration are other solutions that would increase water availability and ecosystem health. In conclusion, by implementing these recommendations, the Tagus River Basin can better navigate the complexities posed by climate change and human activities, safeguarding water resources for current and future generations while preserving its rich biodiversity and ecosystem services.

7.1 | Limitations

This research aims to provide a comprehensive overview of the Tagus River Basin and the challenges it faces, particularly in light of increasing drought events and the complexities inherent in a transboundary basin. Given the broad scope and various levels of complexity involved, a detailed examination of every issue is not feasible. As a result, the research may fall short of delivering effective solutions. Instead, it focuses on making recommendations for further research to assess the feasibility of potential solutions. Furthermore, due to the wide range of topics covered, developing a detailed model of the basin was not possible, which could have significantly improved the recommendations made. Instead, a simplified balance model was created. While this model aligns with the data from Sondermann and Proença de Oliveira (2021), it limits the ability to interpret those values effectively, particularly when key factors such as reservoir capacities, runoff and water uses are not included.

7.2 | Recommendations

For future studies on this topic, specific research on several essential solutions is recommended. A thorough investigation into potential values for ecological flow is necessary to understand how this would impact water availability for supply, transfers, and cross-border flow. Another solution that needs deeper exploration is the evaluation of dams and the potential for their removal. Without a detailed understanding of the specific conditions of each reservoir, it is challenging to recommend adaptation or removal; thus, focused studies are required in this area. Additionally, agricultural improvements should be prioritized, as this sector shows significant potential for enhancing water use efficiency. Research, possibly through local experiments, should be conducted to identify effective solutions that increase efficiency, including advancements in technology and crop diversification.

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