RAFAELA GRAÇA SCHEIFFER

NATURE BASED SOLUTIONS FOR WATER SENSITIVE COMMUNITIES:
GOVERNANCE CHALLENGES AND OPPORTUNITIES IN THE SUBSYSTEM VALE DO LOBO, CAMPINA DE FARO AQUIFER, LOULÉ, PORTUGAL

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INSTITUTO SUPERIOR DE ENGENHARIA

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Masters in Urban Water Cycle
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Declaração de Autoria de Trabalho

Declaro ser o autor deste trabalho, que é original e inédito. Autores e trabalhos consultados estão devidamente citados no texto e constam da listagem de referências incluída.

Rafaela Graça Scheiffer

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Abstract

Urban watersheds face increasing water stress that demand resilient water systems to ensure water security. This issue is illustrated within the subunit Vale do Lobo of the Campina de Faro aquifer in Loulé, Portugal, where both water quality and quantity are compromised due to rampant over-exploitation and saline intrusion. The study area relies mainly on groundwater to sustain its tourism and agriculture sectors. There is potential to increase local water availability through diversification of water sources, encompassing alternatives such as treated wastewater or water for reuse, stormwater, and desalinated water, as well as the integration of Nature-Based Solutions. While technically viable, these solutions pose governance challenges that must be addressed for successful implementation.

Water stakeholders were engaged through workshops with the eGROUNDWATER Project and interviews to assess their perceptions, identify interventions, evaluate the viability and utility of various typologies, evaluate funding and implementation challenges, assess institutional coordination required, and recognize factors that facilitate or impede balanced water use in the area. Green infrastructure, ponds, and wetlands were identified within the area, although some deviated from Nature Based Solutions principles. Treated wastewater emerged as the most promising water source in terms of aligning supply with demand, featuring the importance of advancing in this direction. The combination of treated wastewater with stormwater applications, notably Nature Based Solutions, presents a potential avenue for aquifer rejuvenation. Nevertheless, collaboration among stakeholders was identified as paramount in achieving a sustainable water future, potentially through the establishment of a new participatory governance entity. Moreover, this study advocates for the development of a water sensitive strategy that elevates the value of water, positioning it at the core of the region's developmental agenda.

Keywords: Alternative Water Sources, Nature Based Solutions, Participatory Governance, Campina de Faro aquifer, Water Sensitive Regions, Algarve.

Resumo

As bacias hidrográficas em regiões de stress hídrico requerem sistemas de água resilientes para garantir a segurança hídrica. Esta questão é ilustrada na subunidade Vale do Lobo do aquífero Campina de Faro em Loulé, Portugal, onde tanto a qualidade como a quantidade de água estão comprometidas devido à extensa sobre-exploração e à intrusão salina. A área de estudo depende principalmente das águas subterrâneas para sustentar os setores de turismo e agricultura. Existe potencial para aumentar a disponibilidade local de água através da diversificação de fontes de água, incluindo alternativas como águas residuais tratadas, águas pluviais e dessalinização, bem como a integração de Soluções Baseadas na Natureza. Embora tecnicamente viáveis, essas soluções apresentam desafios de governança que devem ser abordados para uma implementação bem-sucedida.

Os atores locais da gestão hídrica foram envolvidos através de workshops do Projeto eGROUNDWATER e entrevistas para avaliar as suas perceções, identificar intervenções, avaliar a viabilidade e utilidade de várias tipologias, analisar os desafios de financiamento e implementação, avaliar a coordenação institucional necessária e reconhecer os fatores que facilitam ou dificultam o uso equilibrado da água na área. Infraestrutura verde, lagos e áreas húmidas foram identificados na área, embora algumas delas se afastem dos princípios das Soluções Baseadas na Natureza. A água residual tratada emergiu como a fonte de água mais promissora em termos de alinhamento entre oferta e procura, destacando a importância de avançar nessa direção. A combinação das águas residuais tratadas com aplicações de águas pluviais, nomeadamente as Soluções Baseadas na Natureza, apresenta uma potencial via para a regeneração do aquífero. No entanto, a colaboração entre os múltiplos atores sociais foi identificada como fundamental para alcançar um futuro uso sustentável da água, possivelmente através do estabelecimento de uma nova entidade de governança participativa. Além disso, este estudo defende o desenvolvimento de uma estratégia de sensibilidade à água que eleve o valor desta pelas comunidades, posicionando-a no centro da agenda de desenvolvimento da região.

Palavras-chave: Origens Alternativas de Água, Soluções Baseadas na Natureza, Governança Participativa, Aquífero Campina de Faro, Regiões Sensíveis à Água, Algarve.

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1. Introduction

1.1. Scope

Population growth, increasing water demand, urbanisation, lack of adequate infrastructure, failing water governance and climate change put considerable stress upon urban watersheds, hence driving water insecurity. Climate projections for Portugal show a rise in temperatures and rainfall decrease. The agricultural and touristic region of the Algarve suffers from water scarcity, a structural issue influenced directly by water governance and the management of surface water and groundwater supplies. Using multiple water sources would be a beneficial strategy that promotes resiliency, alleviates overexploited aquifers and contributes to climate adaptation by helping to secure the water supply. This is so due to the adoption of new sources matched to their most appropriate use, mitigating climate change by increasing water availability.

Coordination between the institutions in charge of origins and water services is crucial for effective water governance. The development of Water Sensitive City-Regions enables a sustainable water future in areas with peri-urban and rural surroundings whose influence transcends watersheds and administrative boundaries and where urban water services enrich a city's liveability and sustainability, resilience and productivity.

Alternative sources such as treated wastewater, desalinated water and stormwater could match uses to the adequate water quality according to the *fit-for-purpose* principle. However, apart from treated wastewater, alternate sources are scarcely covered in the legislation. Multifunctional, resilient Nature Based Solutions (NBS) are mostly based on stormwater and their implementation hugely benefits urban and peri-urban regions. They strengthen ecosystem functions, provide ecosystem services, increase water availability locally, and complement grey infrastructure by forming hybrid systems. The full potential of NBS is enabled by a co-design and participatory governance process driven by *Waterwise communities* in partnership with local institutions.

1.2. Research Objectives

The aim of this work is to investigate the perceptions of stakeholders regarding the need to increase water availability through the adoption and balanced use of alternative water sources, as well as the use of Nature Based Solutions, and to identify governance practices proper of Water Sensitive Cities to be proposed for the subsystem Vale do Lobo of the Campina de Faro Aquifer, Loulé, Portugal.

This aim is organised into three Research Objectives (RO):

- RO1: Review the different water sources in the literature while listing their pros and cons, as well as the legal framework and public policies that make their use possible.
- RO2: Identification of key water stakeholders, assessment of their perceptions about alternative water uses and balanced water uses, and presentation of Nature Based Solutions (NBS) cases designed for water availability increase; comparison of NBS use in the study area, and discussion on their use as part of a strategy to increase water sensitivity in the study area.
- RO3: Identify enablers and constraints to a balanced use of water sources as part of a strategy to increase water sensitivity in the study area.

The general and specific aims presented above are in the scope of the United Nations' Sustainable Development Goals (SDGs) 6 - *Clean Water and Sanitation* due to the water availability increase emphasis; 11 - *Sustainable Cities and Communities* which connects to the strategy of *Water Sensitive Cities*, the employment of NBS and participatory water management; 13 - *Climate Action* that relies upon resilient water systems that increase water availability and employ NBS for extreme weather mitigation and climate adaptation*;* and 16 - *Peace, Justice and Strong Institutions* which implies Participatory Governance for its achievement.

2. Literature Review

2.1. The Making of Water Sensitive Cities

2.1.1. Resilience in Socio-Ecological Systems

Traditional spatial organisation, population growth and the resultant pressure on natural resources caused essential alterations in the planetary cycles and complex environmental and ecological problems, which, for their resolution, demand new models conducive to greater sustainability and resilience, two complementary concepts. Redman et al. (2004) defined Socio-Ecological Systems (SES) as 'a coherent system of biophysical and social factors that regularly interact in a resilient, sustained manner'. The ability of a city, amongst other SES, to exist in the long run is related to its ability to adapt and respond to perturbation. Adaptability, resistance, transformability, flexibility, diversity, redundancy and decentralisation are, amongst other aspects, closely related to resilient systems and highly dependent on the maintenance of ecological integrity to their health and correct functioning (Rosa, 2018).

Water infiltrates the soil and evapotranspirates through the vegetation, which plays the role of ‘water recycler’ rather than water consumer; vegetation removal has several impacts on rainfall in drier areas, leading to increased water scarcity, land degradation and desertification (Keys et al., 2016). Because of rapid urbanisation, the water cycle is altered in cities and intensified by climate change; thus, wet regions become wetter and dry regions drier (Liu et al., 2021). Urban planning must attempt to consider urban ecosystems' provision of ecosystem services that provide benefits to human populations, amongst them many related to urban water, e.g. climate and hydrological flows regulation, water retention, water purification and waste treatment, as well as erosion and natural hazard regulation (UN Water, 2018). A resilient city is, therefore, one where the need to enhance ecosystems’ diversity and ecological functions are valued, according to environmental policymakers, urban managers and urbanists who sustain a holistic perspective and support decentralised urban solutions that adopt blue-green infrastructure within and around cities (Rosa, 2018). Thus, conditions are provided for the rapprochement of the urban water cycle to the natural water cycle (Morgan et al., 2013). Cities also need to be water sensitive: cities providing ecosystem services through blue-green infrastructure, cities comprising participatory water sensitive communities, and cities defining themselves as water supply catchments, as they use multiple water sources (Wong et al., 2020).

Innovative visions in sustainable water management were created in Australia and China. Cities such as Melbourne and Sydney started their transition to an evolutionary stage of Water Sensitive Cities (WSC) that represent the coming together of water supply, sanitation, flood protection and environmental protection servicing measures with liveability, sustainability, resilience and prosperity. They recognise that infrastructural and political advancements are impossible without citizens who actively create a new relationship towards water and engagement in decision-making (Wong et al., 2020). China created *Sponge Cities* to mitigate the negative impacts of construction on natural ecosystems, according to the goals of improving water permeation, retention, storage, purification and drainage, water saving and reuse in urban environments by absorbing and reusing 70% of its rainwater. Measures such as green roofs, green walls, permeable pavement, rainwater gardens, bioretention swales and the revitalisation of wetlands and lakes were promoted to ensure water availability for irrigation and cleaning during drought periods. More than 80% of urban areas in China are projected to follow Sponge Cities' practices by 2030, and to do so, a central planning policy was specially developed for local-level implementation, as well as the concept has been incorporated into urban planning and ecological restoration (UN Water, 2018).

Assessment tools, such as the *City Water Resilience Framework* (CWRA), were created to assess criteria in 4 dimensions formed by a set of goals and subgoals, such as empowered communities to account for the need for community input into water governance, the creation of an adequate environment for meaningful engagement, and other important factors to enable healthy and prosperous communities (Saikia et al., 2022).

2.1.2. Water Sensitive Cities have Resilient Water Systems

There is growing agreement about the inability of conventional approaches to urban water management and governance to provide adequate responses to complex challenges in cities (Franco-Torres et al., 2021; Wong et al., 2020; de Haan et al., 2015). In this context, water resilience is defined by the CWRA as the ‘water systems and stakeholders’ ability to persist, transform and adapt under any water-related shocks and stresses’ (ARUP, 2019). A so-called ‘Water Sensitive Paradigm’, also mentioned as the ‘New Water Paradigm’ (Franco-Torres et al., 2021), transcends hard-engineering approaches that traditionally value economic growth over shared prosperity, passive users over empowered communities and shallow environmental protection over ecosystems health (Ferguson et al., 2013).

Cities' sustainable and economic growth is tied to the innovation of water systems in water-stressed cities and reliable and diverse water sources (Crosson et al., 2021). Their use is considered an essential solution toward achieving Net Zero Water. This term means avoiding water depletion in quality and quantity over a year by averting indiscriminate uses and returning water to the same watershed (EPA, 2020).

Therefore, a shift from the demand-supply mentality toward a whole-of-water cycle approach should be taken into consideration in the creation of innovative infrastructures that would enable water supply diversification, where difficulties are admitted in implementing flexible water systems to adopt an approach which selects the most suitable water treatment or water source in function to the use of water, for instance, by matching rainwater to flush toilets, wash cars and irrigate gardens while leaving high quality, treated, potable water for drinking purposes (Serrao-Neumann et al., 2019).

2.1.3. Evolution of Hydrosocial Contracts: Levels of Water Sensibility

Unspoken agreements between citizens, governments and businesses on the way water is managed, shaped by history and affected by dominant cultural views are mentioned by some authors as a *Hydrosocial Contract* (HSC), expressed in frameworks and reflected physically in the water supply public infrastructures (Ferguson et al., 2013). Over the decades, governments were demanded to provide cheap and efficient water supply at the cost of the externalisation of environmental services, which caused environmental pollution and over-extraction, a reflection of an institutional perspective which separates economy and nature, placing the environment at a much lower priority (Brown et al., 2008). Meissner & Turton (2003) report that after the Industrial Revolution, water was even more manipulated on a grander scale to facilitate the production of consumer goods and lower the spread of waterborne diseases.

A complex project such as the Lesotho Highlands Water Project (LHWP) took three decades of negotiations between South Africa and Lesotho - two different transition phases were identified, the latter culminating in 'the birth of a new social consciousness in which non-state institutions played an important role'. Hence, HSC expresses transitions of relationships in the use of water by humans during different historical phases and 'indicates the progressive utilisation of a society's water resources' (Meissner & Turton, 2003).

The framework developed by Brown et al. (2008) has been widely reproduced in articles featuring the concept of *Water Sensitive Cities*. Through it, a historical context was provided to support an inquiry into the possibility of transforming cities by aligning academics, practitioners and other stakeholders in urban management, design, and social and institutional systems, not only in Australia, where both concepts originated, but worldwide. The description of different levels of water sensitivity and a summary of the main characteristics of each stage of sensitivity to water from an evolutive perspective is integrally present in Brown et al. (2008), as presented in the following session (**Figure 1**).

2.1.4. Levels for Water Sensitivity

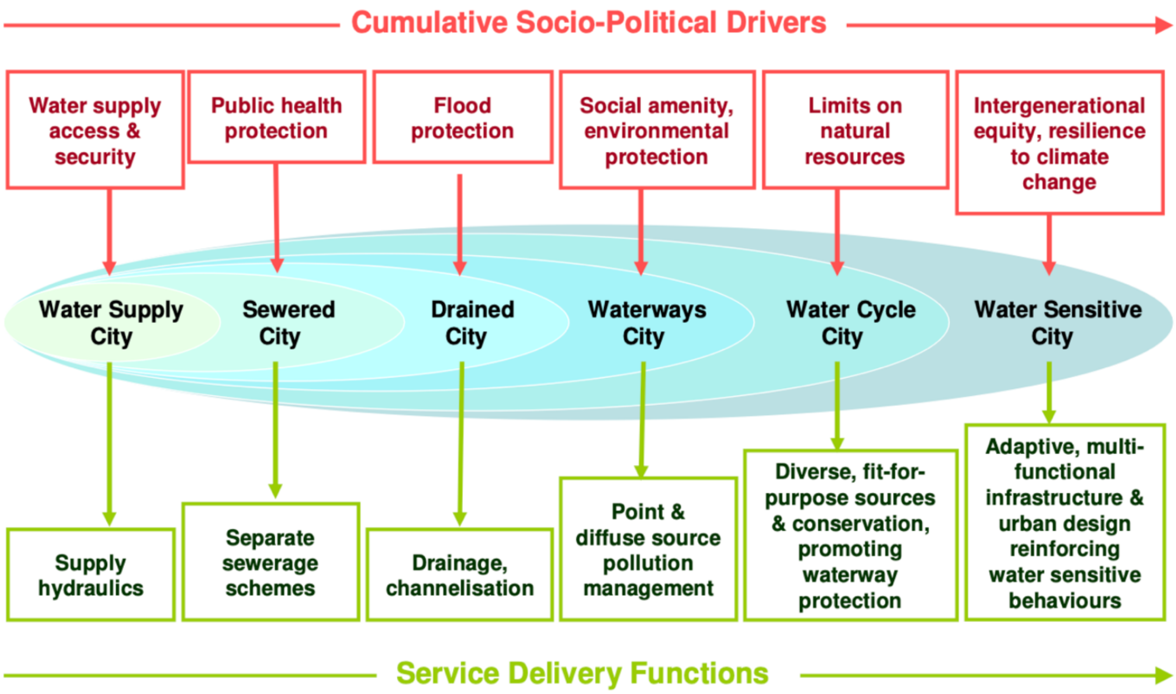

Figure 1: The Urban Water Management Transitions Framework. Historical levels are labelled in red for a main socio-political characteristic that generated an infrastructural innovation in green (Brown et al., 2008).

In the early 1800s, the first type of modern urban water organisation had substantial British influence, reflecting the British colonisation of Australia. The population was growing, and the focus was on engineering the provision of safe, secure, cheap and large amounts of water through building dams and pipes as part of a centralised city water supply system. For this reason, the hydrosocial contract in the *Water Supply City* was characterised by a view of 'limitless fresh water' as a public right delivered by the government at a meagre cost to enable access by the poor and disadvantaged groups (Brown et al., 2008).

The discovery of infectious diseases, such as cholera and typhoid, transmitted through sewage, waste and industrial effluents in the mid to late 1800s motivated the design and construction of combined sewerage and stormwater systems with effluents disposed outside cities in a *Sewered City*. Some Australian cities invested in separated stormwater systems to direct their intense and stochastic rainfall, as done in the United States of America. At that point, the hydrosocial contract promised public health control and the delivery of sewerage services to a waterway environment, while its overall structure remained unchanged from the previous stage (Brown et al., 2008).

With governments coming out of the major depression after the second world war, investment in welfare and infrastructure increased in the 1900s. Citizens with an automobile moved further away from cities, further away from the consequences of flooding and property damage. Urban hydrology emerged in the 1960s to enable the rapid direction of stormwater out of cities, whose rapid expansion allowed great piped waterways and river systems to be channelled to enable urban development over floodplain areas, giving rise to *Drained Cities*. Rivers were seen as waste dumping grounds, thus not valuable as part of the urban landscape. The hydrosocial contract initially remained unchanged, adding cost-effective flooding protection services to a centralised system involving a growing number of urban water service providers (Brown et al., 2008).

Since the 1960s, with the rise of environmentalism, citizens demanded more green areas and developed concerns about the state of local waterways. Slowly, the water became translated into urban planning as visual and recreational features for liveability. Efforts were made to regulate industrial and wastewater environmental discharges, as septic tanks were replaced with centralised sewerage systems. Industry guidelines and capacity-building programmes were robust features as new decentralised technologies, such as bio-filtration and wetlands, were created; however not yet mainstreamed in any Australian city. At this stage, the hydrosocial contract never included any kind of payment for environmental services, resulting in over-extraction and pollution of water bodies. In contrast, traditional water supply values collapsed against new environmental protection practices. Despite tension around the partial institutionalisation, stormwater management remains a field by managers advocating change in Melbourne's transition to a *Waterways City* (Brown et al., 2008).

The *Water Cycle City,* the next stage, is not only a response towards overcoming environmental disruption and pollution absorption, but it is also sensitive to energy and nutrient cycles that demand integrated management praising water conservation and a *fit-for-purpose* approach to a water supply ranging from rainwater, stormwater, sewage and seawater tailored to uses such as drinking, irrigation, industry and household. The hydrosocial contract at this stage challenges the previous one, where the environment is the last priority, and the government claims to deliver risk-free water; changes include the promotion of co-management of resources between a myriad of stakeholders and the development of flexible and diverse solutions. On the other hand, governmental responses to climatic challenges comprised the expansion of centralised systems, providing new services based on old premises and keeping controls and promises from the previous stage. Nevertheless, it may be possible for a smoother transition to this water sensitivity state (Brown et al., 2008).

The last level of development, the *Water Sensitive Cit*y, would most likely reflect community engagement and ecological lifestyle, employment of flexible and accessible technologies designed for sustainability, construction of intergenerational equity and resiliency to climate change as drivers. Despite the inexistent example of a WSC, its hydrosocial contract would be in constant evolution through a flexible regime that integrates normative social and environmental values. Thinking about the territory from a hydrosocial perspective is another step toward water governance that appropriately responds to the challenges of the XXI century (Brown et al., 2008).

Nowadays, a path towards higher levels of water sensitivity, namely *Water Cycle Cities* and *Water Sensitive Cities,* seems to imply in the active engagement of communities to generate transformations in the hydrosocial contract and effectively create a co-governance, co-management and co-design approach, approximating experts to citizens by recognising the limitations of the actual HSC (Meissner & Turton, 2003). Furthermore, more participatory governance is required, and a renovated perception of water territories beyond their biophysical dimension, integrating the social and political aspects present at the interconnections between natural, social and technological elements (Boelens et al., 2016).

2.1.5. Achievement of Higher Levels of Water Sensitivity

Each city-state has framed problems for which experts have instituted 'large-scale engineered responses' based on an engineer or water resource planner's prevailing view (aligned to a 'hydraulic worldview') to move water from point A to point B to encourage economic development. Rather than a purely technical problem, water issues involve non-technical aspects to which engineers cannot find an answer (Meissner & Turton, 2003). Throughout history, water provision was turned into a hidden process, alienated from the public, as water access was denied and put under the control of governments (Farrelly & Brown, 2014).

Professionals who seek to solve issues 'objectively' by employing technical and managerial knowledge overlook the political and social dimensions of water conflicts. There is a gap in the water practitioner’s perception which reflects in a hydrosocial contract where governmental technocrats and water experts constitute a professional elite that makes decisions on behalf and in isolation of the public. The gap is visible, for instance, when experts underestimate the willingness of some communities to adopt alternative water supply technologies (rainwater, seawater, treated wastewater, greywater and stormwater) for potable and non-potable use at diverse scales, and they become a challenge for the widespread of such alternative sources. One of the reasons for that might be the way information is assessed. A separation between an elite of professionals and the general public is reinforced through data collection based on surveys rather than generative and deliberative dialogue engaging the civil society (Farrely & Brown, 2014; Dobbie et al., 2016).

Furthermore, decision-making is carried on with a traditional technocratic approach that privileges rational and objective decision-making by expert water practitioners over 'irrational' public debate. Technocratic governments picture technology as a central element for achieving reliance and stability, prompting citizens to accept their decisions passively, a characteristic of the first three city-states. Coercive behaviour towards the public is also described as standard practice for encouraging treated wastewater adoption; for instance, experts think that once educated with technical information, the general public would necessarily accept their position (Farrelly & Brown, 2014).

The path to the achievement of higher water sensitivity status is unclear. However, this reality will involve the adoption of a different sort of hydrosocial contract. On the one hand, governmental water agencies and other water organisations must be interested and actively open spaces for meaningful public participation, engaging all stakeholders and facilitating the shared responsibilities in a holistic picture built prior to decision-making. On the other hand, they must be able to lead with conflicts of interest and multiple agendas, which can be more demanding in the short term, however, this action can potentially avoid future disputes (Farrelly & Brown, 2014).

2.1.6. Hydrosocial Territories

Historically, water systems result from divergent narratives and actors reproducing specific technological models, infrastructure, and mindsets manifested at larger than the watershed scale, which is incapable of containing all stakeholders, narratives, agendas and decision-making activity. There is a myriad of hydrosocial relations arising in this context. The hydrosocial cycle complements the water cycle since it sees water as a resource flowing from 'a complex tubulation, water legislation, meters, quality standards, garden taps, consumers, leaking taps, rain, evaporation, leakages, runoff amongst others'. For this reason, changes in the water use, management or political organisation of its cycle, when combined with water cycle transformations, produce new forms of hydrosocial relations in the regional and global water circulation (Empinotti et al., 2021).

A gradual humanisation of waters and nature, which are also a result of human imagination, social practices and knowledge systems, is implied in the concept of hydrosocial territories. They influence 'river basin management, flows, water use systems and hydrological cycles' and are mediated by governance and physical intervention - its functions, values and meanings are perceived differently by different actors, who contest each other, provoking inclusion/exclusion, resource accumulation, dispossession of social groups, as well as social and environmental inequalities. Hydrosocial territories are formed by *hydrosocial networks*, which are shaped by and around the water use in a particular territory. Friction produces different scales, or geographical levels of social interconnectedness nested on one another, that exist and operate at overlapping levels, such as the administrative, cultural, legal and hydrological. Marginalised groups attempt to free themselves from the scale they are confined to by challenging it, acting and amplifying their influence at other scales (Boelens et al., 2016). Hydrosocial territories shed light on the nature-society power relations from the point of view of political ecology since water and water technologies encompass nature and society. It proves that water systems have a political nature in water planning, in the form of rights and discourses underlying policies and hydroterritorial reforms, for instance. Social phenomena such as political exclusion, misrecognition and socio-economic inequality are often dissociated from the dominant water governance discourse (Boelens et al., 2016).

Water governance should transcend water distribution to work in stakeholder inclusion in decision-making processes, while governance models are not enough to assess the complexity of a water cycle that is much more than a physical cycle but shapes and is shaped by social and political processes. Consequently, water management and governance are currently apolitical and treat different stakeholders differently, but they must transform and consider socio-political and biophysical territorial processes (Empinotti et al., 2021). Thinking about the territory from a hydrosocial perspective is another step toward water governance that appropriately responds to the challenges of the XXI century.

2.2. Diversification of Water Sources

2.2.1. Multiple Water Source Logic

Resilient urban systems make use of centralised and decentralised solutions arranged in hybrid infrastructures, municipal sewer and potable systems combined with additional alternative water supplies at different scales, such as rainwater harvesting (RWH), sources which historically have been hindered in the face of grey infrastructures, which are the first choice of conventional water management (Crosson et al., 2021).

Mitchell 2006 *apud* Neale et al., 2020 registered potable water savings of 40-80% when combinations of reuse systems and conservation measures were put to use in Australia, results which are consistent with Neale et al. (2020), who have shown a considerable potential of alternative sources to reduce demand for traditional water supply, while stormwater provided the higher offset potential, even though economic wise, wastewater for irrigation presented a lower cost. Stormwater was shown to be a substantial water source, suggesting irrigation as its best-performing end due to fewer treatment requirements and diminishing costs. Thus, stormwater should be considered when the goal is to balance cost and traditional supply-demand reduction. Nevertheless, stormwater is generally obstructed by the lack of regulatory frameworks that, when in place, improve the reliability and size of the supply and reduce costs (Crosson et al., 2021; Neale et al., 2020).

In Australia, the population growth outweighed water supply in many urban areas, which caused water reuse, recycling and reclamation to be integrated as essential underutilised sources of wastewater management (Adapa et al., 2016). Furthermore, adopting alternative water sources is mainly influenced by public acceptance, an underexplored research field.

Silva et al. (2014) advocate for the integration of different water sources in a self-sufficient irrigation unit for urban gardens by harvesting rainwater through the use of NBS in central Brazil, obtaining a decrease in water consumption of 64% (compared to manual irrigation) while rainwater has met 60% of the demand throughout the year. Neale et al. (2020) stressed that treated wastewater (also known as ‘reclaimed wastewater’ or ‘recycled water’) and desalinated water could be treated to supply either potable or non-potable demand.

2.2.2. Surface Water

Surface water is open to the atmosphere and results from overland flow, such as streams, rivers, lakes, reservoirs, rain catchments, and springs. Their use is advantageous because they are easily located and generally softer than groundwater, which makes treatment more accessible and cheaper. However, they are more subject to pollution with microorganisms and discharge of chemicals, often displaying fluctuant turbidity and temperature, besides suffering increased evapotranspiration as a consequence of climate change and often requiring a licence for its use (ADEC, 2014).

In the face of climate change and increasing drought events, freshwater stored in reservoirs becomes a less reliable water origin, thus increasing the dependency of the agricultural sector on alternative water sources, preferably sourced in a logic of *fit-for-purpose,* crucial for the long term (Hristov et al., 2021). Lower than average precipitation and higher than normal temperature is causing excessively high evapotranspiration, soil moisture deficit and depleted surface water reservoirs; among the four driest years since 1931 was the year of 2017, with drops of more than 40% in water reservoirs nationwide. The climate forecasts for 2041-2070 show high indexes for drought severity and frequency in all scenarios (Neves et al., 2019). Climate change will affect semi-arid regions causing surface water scarcity, as well as groundwater overexploitation and depletion, whilst effects of couplings between climate patterns might prompt extreme events (Neves et al., 2021). According to Neves et al. (2020), the total water budget of the region was quantified in approximately 63% precipitation and 32% evapotranspiration, respectively, out of total water storage changes. Other climatic phenomena, such as the large-scale circulation modes, the North Atlantic Oscillation (NAO) and the eastern Atlantic pattern (EA), were shown to play a critical role in precipitation and temperature in the Algarve and the rest of the Iberia (Neves et al., 2019; Neves et al., 2021).

Surface water and groundwater are the traditional supply sources (**Table 1**) for domestic and agricultural purposes in this area (APA, 2016), with low hydroelectric potential, prolonged droughts, and large rivers' absence. There are six major surface water reservoirs, all artificial dams, used for public water supply and irrigation: Bravura, Arade, Beliche, Funcho, Odeleite and Odelouca. Their water flows vary from 199-1269 hm^3, respectively, in dry and wet years, while the average annual long-term aquifer recharge is about 168 hm^3/year, and the potentially available groundwater volume (without abstraction) ranges around 151 hm^3/year. The absence of surface water during drought events affects and will continue to affect water supplies and energy consumption, with increased costs for pumping water from greater depths and lower surface levels (Neves et al., 2021).

Table 1: Summary of surface and groundwater bodies from the watershed Ribeiras do Algarve (Translated from APA, 2022b).

Category		Natural	Strongly Modified	Artificial	Total
Surface Waters	Rivers	58	4	2	64
	Dams	0	4	0	4
	Transition waters	3	0	0	3
	Coastal waters	10	0	0	10
Subtotal		72	8	2	81
Groundwater		25	-	-	25
Total		97	8	2	106

2.2.3. Groundwater

Groundwater can be defined as water below the Earth’s crust, generally not more than 762 metres below. It is generally less contaminated than surface water, often presenting fewer microorganisms and more stable quality. On the other hand, once contaminated, it is difficult to recover this water source; it usually shows higher levels of hardness and metals and requires treatment, is more susceptible to oil spills contamination and saline intrusion, as well as it usually requires increased costs with a pump to be accessed (ADEC, 2014).

This water source accounts for over one-third of all water withdrawals worldwide, of which half or more of the total irrigation water is used to water the world's food production. It takes the role of strategic reserves during a prolonged drought when there is not enough rain and snow. Despite its critical importance, groundwater is poorly monitored and managed compared to visible surface water supplies (rivers, reservoirs, lakes). Frequently, access to this source is restricted to those who can afford to drill wells. Most aquifers in arid and semi-arid regions that rely basically upon groundwater are experiencing fast rates of water depletion, which means that groundwater is being extracted at higher rates than it can be replenished - examples range from the North China Plain, Australia's Canning Basins, the Northwest Sahara Aquifer System, the Guarani Aquifer in South America, the High Plains and Central Valley aquifers in the US, and aquifers in India and the Middle East, which often coincide with the world's most significant agricultural regions (Famiglietti, 2014).

The problem of groundwater overexploitation refers to the natural response to water scarcity, which is to pump more water, which is likely to accelerate depletion and mid-latitude drying, as well as to motivate the pumping of water from increasingly greater depths, increasing general costs, power consumption, and the need to treat lower-quality water. Some unintended consequences of groundwater depletion are land sinking, seawater intrusion, sea-level rise, streamflow depletion or reduction, and drying of streams and wetlands whose baseflow was sustained by groundwater, amongst other ecological consequences (Neves et al., 2021).

Nevertheless, energy consumed to pump groundwater is known to be seven times more intensive than employing surface water. It is essential to accept that in many dry parts of the world, more water is used than is available on an annual, renewable basis, and aquifers have been explored similarly to oil drills. Efficient use of agricultural water and joint surface and groundwater management is needed, or streamflow will be depleted (Neves et al., 2021).

Prevention should be made by measuring groundwater levels; data must be the basis of water governance. Efficiency must be recognised nationally and internationally as a critical water supply element. Joint management of the water body should be made through transnational cooperation for rivers and lakes when necessary. The decline of groundwater availability potentially culminates in civil and international violent conflict in water-stressed regions, given that it may be the only perennial source of freshwater in these regions. For this reason, the governance of aquifers is crucial for global security (Famiglietti, 2014; Taylor et al., 2013).

It is essential to state that until the late nineties, groundwater was the primary water supply source for the Algarve until a district water supply system based on dams was implemented in 2001 in the face of dramatic droughts, pointing to the necessity of having a mixed-source supply system (Neves et al., 2021). Groundwater storage is influenced by climate modes, as previously mentioned, as phase couplings relate to extreme events such as droughts so that further understanding of this mechanism will improve future predictions of groundwater availability and recurrent drought forecast, assisting in water management in the region (Neves et al., 2019). Currently, groundwater supplies 88% of the water used in agriculture, which is 60% of the water demand in the Algarve (Neves et al., 2020). Azinheira et al. (2019) stated that the Campina de Faro aquifer is the primary subterranean source and water supply backup of the Algarve, presenting water levels below 20% in 2017/2018 - this could be a result of seasonal variation in water consumption and decrease of natural aquifer recharge due to climate change, variability in precipitation, and region desertification. In this context, desalinated water could add resilience to regional water systems; however, it is one of the most energy-intensive processes and demands high energy production, resulting in environmental costs that cannot be ignored (Azinheira et al., 2019; Neves et al., 2021).

2.2.4. Desalinated Water

Desalinated water goes through any process that removes salts and minerals from the water or even a chemical process that transforms seawater into potable water, applied mainly for municipal, industrial or commercial uses. The result is freshwater with a low concentration of salt and minerals and a brine, or concentrated, presenting salt and mineral concentrations higher than feed water (seawater). After this process, it is crucial that freshwater is remineralised and the brine is disposed of in an environmentally proper manner. Two primary technologies are used, thermal desalination (distillation) and membrane desalination. Distillation is the most energy-intensive and expensive since it is based on separating water from salt by boiling. Membrane desalination uses a membrane to move water or salt and produces two zones with different concentrations to produce fresh water. Membrane desalination can be based on reverse osmosis, electro dialysis or membrane distillation. The various technologies attest to the reliability of this water source, which can be applied at different scales, from small communities to cities. Nevertheless, this solution still invariably costs more than freshwater (Thimmaraju et al., 2018).

Desalination technologies, namely seawater reverse osmosis (SWRO), decreased energetic consumption over the last decade, which placed this source from being considered the last resource to being included in water diversification strategies. This was possible by combining desalination plants with renewable energy resources (RES), such as solar photovoltaic (PV) and wind turbines and leading with intermittent power sources, providing low carbon-emission desalination. It is essential to optimise this integration to lower the cost of desalinated water, avoiding the expensive and polluting solution of water transportation (Azinheira et al., 2019).

Azinheira et al. (2019) assessed alternatives to guarantee water security in the Algarve. This region needs operational flexibility since demand varies with the season - it is possible to match desalination processes to coincide with the lower tariff hours, resulting in lower electricity costs. This district has a water exploitation index of 27% versus a 14% national average. A recommended solution for desalination in the Algarve is a decentralised solution (fewer carbon emissions and increased savings): a 175,000 m^3/day desalination plant to be installed at the windward location of Portimão and a 155,000 m^3/day plant at the leeward site of Monte Gordo. Even though this is the best cost-benefit solution suggested by the study, electricity accounts for a significant portion of the levelised cost of water (LCOW), a measure of water efficiency, which is still 61,3% higher than the reference cost of conventional water supply. The authors advised that this solution was dimensioned to supply 100% of the region's drinking water demand, even though the employment of multiple water sources could be more cost-effective and sustainable (Azinheira et al., 2019). The decentralised renewable energy-powered desalination plant is widely considered cost prohibitive, even though renewable energy could be used to extract, convey and treat water throughout the year. For this reason, renewable energy should be promoted, especially for pumping groundwater for irrigation. Holistic and integrated management of energy and water resources must become a reality because if this link is neglected, the overpumping will cause groundwater depletion and reliance on cheap non-renewable energy sources for desalination (Lesimple et al., 2020; Neves et al., 2021).

It is interesting to investigate the use of desalination by Spain, especially in water-stressed regions such as the Algarve. In mainland Spain, desalination was not a synonym for more water but rather 'less and more expensive' to be afforded by the urban, tourism and agricultural sectors due to the internalisation of costs compared to cheap surface water. For instance, farms can afford it only if prices are subsidised or if this source is combined with cheaper sources. Thus, desalination should be considered if a tailor-made solution for each geographical and socioeconomic environment is possible, not as a final solution to water crises or as an excuse to overlook other water sources and ignore a *fit-for-purpose* approach (Morote et al., 2017).

Desalinated water has the advantage of helping reduce the overexploitation of aquifers while being a resource not affected by weather conditions, suggesting a potential to end political conflicts regarding water transfer in several areas. Nevertheless, this water source has several adverse effects on marine ecosystems under brine discharge, as well as high carbon dioxide emissions by being energy intensive, presenting high costs which could exclude users such as farmers and groups with low purchasing power. Furthermore, it is frequently rejected by the public (Morote et al., 2017).

2.2.5. Treated Wastewater

Treated wastewater, also known in Portuguese with the acronym ApR ('Água para Reutilização' or 'Water for Reuse') is defined here as wastewater that goes through processing at a facility, allowing it to be reusable with definable treatment reliability and meeting appropriate water quality criteria (Asano et al., 2007). It potentially increases water stock at a lower marginal cost while improving environmental and social outcomes (Wilcox et al., 2016). It is a component of Integrated Urban Water Management (IUWM), an approach toward more sustainable solutions for water, sewerage and stormwater systems (Saikia et al., 2022).

A combination of different methods is used to achieve a specific water quality level, matching the purpose of that water most economically. It is essential to highlight that drinking water differs fundamentally from wastewater in terms of the presence of pollutants derived from industrial activities, so treatment should be specific in each treatment plant for water to meet legislation requirements. There is no universal method for the elimination of all pollutants from wastewater. Thus, the process consists of five steps employed or not according to wastewater characteristics: (1) physical and mechanical pre-treatment; (2) physicochemical and chemical primary treatment; (3) chemical and biological secondary treatment; (4) physical and chemical tertiary treatment; (4) treatment of the sludge formed (Crini & Lichtfouse, 2018).

Treated wastewater is a conventional solution for urban irrigation in the arid areas of the Middle East and North Africa (Wilcox et al., 2016). It has been increasingly used in southern European countries over the years while presenting numerous advantages in arid, semi-arid and Mediterranean countries. It is advantageous as effluents are unlocked as alternate and sustainable water sources that provide a reliable source of micronutrients, phosphorus, and nitrogen, while increasing the fertility levels of the soil over the years, aiding in the preservation of surface water and groundwater, and representing economic savings (Ofori et al., 2021). Furthermore, it is argued that treated wastewater is a reliable source that prevents environmental degradation, reduces freshwater use, improves both agricultural and environmental sectors, and reduces the pressure on freshwater, especially during drier seasons, which can be argued to be an adaptive strategy (Hristov et al., 2021). Despite its benefits, wastewater should be treated and controlled carefully to avoid being a source of chemical and microbiological contamination and soil salinisation (Ofori et al., 2021).

The chemical treatment technologies can present disadvantages such as high energy consumption, high costs for small and medium industries, formation of sludge, formation of secondary water pollutants (dioxins), high costs for the installation and maintenance of the infrastructure, no effect on salinity, pH-dependent selectivity, high-pressure conditions required, low efficiency of the technology, low removal of important pollutants (heavy metals), corrosion of metallic components, use of potentially toxic solvents, non-biodegradability of some compounds, possible cross contamination of the aqueous stream, and increased fire risk at facility. On the other hand, it can be employed on a large scale and be economically advantageous for the final user while presenting the ability to inactivate pathogens, allowing for disinfection and efficient elimination of oils and greases, metal selectivity, degradability of phenols, unrequired chemicals during some phases, easy removal of insoluble solvents, and low retention time (Crini & Lichtfouse, 2018).

Hristov et al. (2021) have found that economic externalities may substantially impact the adoption of treated wastewater. Once that, farmers will always find freshwater more profitable once they consider its adoption's environmental benefits. This is exemplified by farmers in Germany and Italy paying 0,005 - 0,12€/m^3 for freshwater. In contrast, Spanish farmers, used to water scarcity, are willing to pay around four times more to ensure water supply. The study used the flat rate of 0,5 €/m^3 (0,08€ for treatment and 0,42€ for transportation costs to the fields), a high price that only a few EU member states could afford. For this reason, the *fit-for-purpose* approach is preferred for its potential to address water scarcity at lower prices.

Adopting treated wastewater systems can be complex, depending on land and energy availability, water markets, technological development, existing infrastructure, public acceptance, freshwater availability, technical arrangements, and local governance. The ageing of current infrastructure may present an opportunity for a change of paradigm in water supply, and public acceptance is expected to increase with supportive research. Furthermore, establishing the new regulation is expected to encourage the emergence of water reuse technology (Wilcox et al., 2016).

2.2.6. Stormwater

Two interconnected alternative sources are stormwater (water flowing on an urban surface) and rainwater (roof runoff stored in tanks). The little distinction between the terms stormwater and rainwater is made by Sharvelle et al. (2017), even though they vary in terms of pollutants and chemical characteristics (e.g. low pH, presence of heavy metals, hydrocarbons, and animal excrement) given different surfaces. Authors such as Lundy et al. (2018) classify rainwater systems as one component of stormwater use extensively discussed in the literature, while stormwater applications have limited evidence of widespread adoption and are yet to receive the same attention regarding legislation support and practice. Rainwater is frequently mentioned as a purer source (Sharvelle et al., 2017) in the context of rainwater systems. In this work, both sources will often be cited under the term stormwater.

Collected stormwater, which does not require water to be of potable quality, is a potentially sustainable and economical option. Stormwater use is relative to water reuse and as much as 50-80% of domestic water consumption does not require potable water quality. It is estimated that using stormwater for toilet flushing could reduce demand for water in the UK by 26%, lowering water use *per capita* to 110L. Often, stormwater use is seen as useful only for household harvesting applications rather than applicable at a larger catchment scale. However, stormwater use was extensively identified as an effective and sustainable solution for conserving water and reducing urban flood discharge, offering cost benefits, providing ecological improvements and supporting community wellbeing.

The use of stormwater is becoming increasingly more acceptable to the public (Mankad et al., 2019). Their most common uses are toilet flushing, firefighting, vehicle washing, garden water features (including lawns, flowers and shrubs), ornamental water bodies and groundwater recharge for household scale. In contrast, at the sub-catchment and catchment scales, their functions of street cleaning, dust control, use in parks and playgrounds, sports grounds and golf courses, detention and retention basins and surface reservoirs are also considered. Nevertheless, only limited technical guidance is available to evaluate and quantify the potential use risks. For instance, the presence of nutrients may encourage algal growth and bacterial proliferation, a barrier to scaling up the use of stormwater. Gutter guards, first flush diverters, screening of roof flows, the use of mosquito larvicide, floating vegetable oil, occasional bleach cleaning, UV disinfection and membrane filtration are practices potentially solving water quality challenges (Lundy et al., 2018).

Rainwater collection systems are recognised for their ability to provide a reliable water supply, besides additional benefits in stormwater management (Quinn et al., 2020). They collect, filter, retain, store and sink water for aquifer recharge, microclimate regulation by increasing air moisture, urban heat island effect mitigation, flood risk mitigation, decreasing energy use in water systems and reducing expensive infrastructure management. Given these benefits, some US, Europe, and Australian cities offer rebates to encourage their adoption for residential and commercial purposes (Crosson et al., 2021).

From a modern perspective, stormwater must be seen as a water source rather than a 'nuisance that should be collected'. Multiple terms are used to refer to the employment of Rainwater Harvesting Systems (RWH) and Sustainable Drainage Systems (SuDS), also known outside the US as Sustainable Stormwater Management, Low Impact Development (LID), Best Management Practices (BMPs), Water Sensitive Urban Design (WSUD), and Green Infrastructure (GI), not to forget of associated terms Ecohydrology, Biomimicry, and Nature Based Solutions (NBS). These soft-engineering practices encourage and highlight the advantages of reducing water pollution from contaminated runoff, reducing the inflow of stormwater into sewage systems, mitigating flooding, alleviating potable water consumption, replenishing water supplies, potentializing ecosystem services, reducing urban temperatures, improving urban air quality, and contributing to a natural-looking and aesthetically pleasing cityscape. Nevertheless, they can present higher maintenance costs than conventional approaches. Their knowledge and management are restricted to a few Mediterranean countries (Morales-Torres et al., 2016), while regulations are absent in many countries. The previously cited pros and cons of each water source are summarised in the **Table 2** below:

Table 2: Summary of the main costs and benefits of different water sources (Elaborated by the author).

Water Source	Pros	Cons
Treated wastewater	Soil fertility building, increased water supply at a marginal cost, social and environmental benefits, *fit-for-purpose* treatment leading to economic outcomes, reliable source of nutrients, reduced pressure of traditional sources, and new regulations available in Europe.	Potentially a source of chemical and microbiological contamination and soil salinisation, treatment can be complex; adoption relies on public acceptance.
Surface water	Easy access, easily treated for potable use, cheap, hydroelectricity potential, and big reservoirs in the Algarve.	In constant physicochemical parameters, high susceptibility to contamination increases evapotranspiration due to climate change and demand for other sources.
Stormwater	Runoff contamination reduction, water supply replenishment, potable water consumption alleviation, NBS providing ecosystem services and natural aesthetic value.	High maintenance costs, knowledge of SuDS restrained to a few Mediterranean countries, lack of regulations.

Table 2: Summary of the main costs and benefits of different water sources (Elaborated by the author - continuation).

Water Source	Pros	Cons
Groundwater	Less susceptible to contamination, making agricultural development in the Algarve possible.	Higher hardness, complex contamination treatment, pump requirement with high energetic costs, poorly managed and monitored worldwide, overexploitation presents several environmental consequences and shallow piezometric levels in the Algarve.
Desalinated water	Energetic costs are reduced, several technologies are available at different levels, diversification of the water supply, combined with renewable energies is very effective, relieves pressure on traditional sources, and is independent of weather conditions.	Water needs to be remineralised, is costlier than freshwater, has high environmental impacts if brine is improperly discharged, has high electricity costs, needs subsidisation to enable farmer access, and centralised systems classified as 'cost prohibitive' in the Algarve.

2.3. The Potential of Nature Based Solutions

2.3.1. Introduction to Nature Based Solutions

Nature Based Solutions (NBS) was described by Stafford et al. (2021) in a dedicated publication as 'an umbrella term that brings together a diverse range of stakeholders and disciplines into collaboration, resulting in transdisciplinary work and a range of differing perspectives'. The term is defined in the context of actions, interventions, processes and green technologies employed to restore ecosystems while generating benefits for human well-being and biodiversity. The use of nature as a solution is yet beneficial for climate change adaptation and mitigation and also effective in alleviating disaster risk reduction, food and water security, health and economic development (Stafford et al., 2021).

Stafford et al. (2021) documented 12 definitions for NBS, all converging to acknowledge ecosystems' ecological functions and the role biodiversity plays as crucial for the health of nature and humans. The EC Expert Group considers the term convergent and compatible with terms related to ecosystem services, ecosystems approach, ecosystems-based adaptation/mitigation and blue and green infrastructure (O'Hogain & McCarton, 2018). The concept supports the practice of circular economy, green growth and green economy, generating a wide range of social, economic and environmental benefits from human health and livelihood improvement to sustainable development, decent jobs, ecosystem rehabilitation, protection and enhancement of biodiversity (Stafford et al., 2021).

NBS's most prominent feature is to mitigate climate change by constituting low-impact infrastructure and sequestering atmospheric carbon, reducing flood risk, stabilising riverbanks and creating a microclimate (Stafford et al., 2021). It is estimated that NBS will provide 37% of climate change mitigation until 2030 to keep the climate below 2ºC (IPBES, 2019). Despite the multiple and cost-effective benefits (EC, 2022) and co-benefits, such as an increase in biodiversity - identification of hotspots, habitat creation and restoration, and increase in resilience by improving genetic diversity - land use must be monitored since large-scale developments, such as monocultures and intensive bioenergy plantations, have negative impacts on biodiversity, water security, and local livelihoods, also potentially causing social conflicts (IPBES, 2019; Stafford et al., 2021). In addition, their use is complementary to climatic and conservation actions, not substitutive. The interventions that negatively impact climate, biodiversity or local communities, regardless of their benefits, cannot be considered nature-based (Stafford et al., 2021).

Adaptation to climate change can also be achieved through saltmarsh restoration, re-naturalisation of water courses, wetland restoration and cooling of the urban environment (Stafford et al., 2021). NBS can be applied on different scales and aim to conserve or rehabilitate a natural ecosystem or enhance biological processes in an artificial setting while aiding climate adaptation. They bring increasingly more natural features into cities, landscapes and seascapes, adapting to local realities and employing resources smartly and systemically. NBS can also approximate citizens to nature by bringing natural habitats to urban environments, providing restorative health and well-being benefits, a sense of belonging and improvement of emotional well-being since people spend more time in green spaces, especially during the recent pandemics. Substantial research is being produced on Blue Health and Green Health, demonstrating how observation and engagement with surface water and green terrestrial areas can benefit people of all age groups, promoting good physiological health and mental health recuperation (Stafford et al., 2021).

2.3.2. Nature Based Solutions for Water Availability Increase

By definition, Nature Based Solutions (NBS) refer to interventions that mimic or are inspired by natural processes and contribute to improved water management (UN Water, 2018). They retain water, enhance biodiversity and ecosystem services and are relevant to the urban water cycle (**Table 3**) due to the influence that ecological processes exert over hydrological processes: approximately 40% of global terrestrial rainfall is produced by vegetation through evapotranspiration. Therefore, land use decisions may significantly impact water resources, people, the economy and ecosystems in distant watersheds (UN Water, 2018).

Forests and water resources interact and impact the hydrological cycle in terms of soil moisture, drainage patterns, and watershed water discharge, amongst others, thus affecting the climate system (Singh et al., 2023). They also influence the flow of water into other water masses, such as aquifers and streams. Growing forests, as well as restoring wetlands and lakes are examples of Natural Water-Retention Measures (NWRM), defined by the European Commission as ‘measures to protect and manage water resources and to address water-related challenges by restoring or maintaining ecosystems, natural features and characteristics of water bodies using natural means and processes’ (Zal et al., 2015). These can be designed and implemented as Nature Based Solutions specifically applied to promote water retention, while promoting other environmental and wellbeing improvements, usually in small scale, potentialising natural water processes (Strosser at al., 2015). Afforestation is a Nature Based Solution that stabilises water resources by increasing water availability and quality, mitigating floods, droughts and sedimentation, and recharging aquifers, so it is important for water cycle regulation. At the watershed scale, it can be a form of ‘payment for environmental services’ (PES) since it mitigates the negative impacts of climate change and reduce the risk of extreme weather events. In some cases, afforestation can lead to water shortages if species of trees are inadequate for that ecosystem or tree placement is done incorrectly (Singh et al., 2023). The table below shows different categories and measures applied, of which blue and green infrastructure deserve distinction for mitigating extreme weather events in urban environments due to the great diversity of water retention measures.

Table 3: Examples of Nature Based Solutions. Whether directly or indirectly related to the water cycle, the examples address climate adaptation and disaster risk reduction (EC, 2021).

Category	Broad Measure	Example measures	Impact addressed
Agriculture	Agricultural habitats	Agroforestry and crop diversification; Buffer strips and hedgerows; Improved water retention in agricultural areas, Meadows and pastures	Floods Flash floods Droughts Water availability
	Agricultural management	Crop rotation; Low till agriculture; No-till agriculture; Green cover	
Forestry	Forest planting	Reforestation; Afforestation; Forest in riparian buffers; Land use conversion; Maintenance of forest cover in headwater areas	Climate change mitigation Landslides Floods Heat waves
	Forest management	Water sensitive forest management; Coarse woody debris; Continuous cover forestry	
Coastal		Beach nourishment; Coastal managed realignment; Dune reinforcement and strengthening; Cliff stabilisation	Sea level rise Storm surges Landslides
Urban	Green infrastructure	Green roofs; Raingardens; Soakaways; Swales; Urban green space; Urban forest park; Urban trees and forests	Heat waves Flash floods Floods Water availability
	Blue infrastructure	Basins and ponds; Basins and rills; Detention basins; Filter strips; Infiltration basins; Permeable surfaces; Retention ponds; Sediment capture ponds; Sustainable Urban Drainage Systems (SUDS); Temporary flood water storage	
Water management	River restoration	Elimination of riverbank protection; Natural bank stabilisation; Re-meandering; Reconnection of oxbow lakes and similar features; River restoration and rehabilitation; Riverbed material re-naturalisation; Stream bed re-naturalisation	Floods Flash floods Water availability
	Floodplain restoration; Groundwater restoration; Lake restoration; Wetland restoration		

EC (2021) states that NBS ‘improve water quality, quantity and reduce water stress’. While their application is not new to water management (UN Water, 2018), these solutions also are increasingly proposed because of their effectiveness and flexibility to address water security, amongst other societal challenges. Rainwater harvesting is highlighted to increase a farm's resilience to water scarcity and droughts while enhancing water quality and availability, increasing production for a unit of area and saving energy (Blackburn et al., 2021).

Similarly, NBS are integral to water management plans in cities worldwide. Some solutions aim to increase water availability in urban environments according to specific objectives, local conditions and different levels of citizen participation (EC, 2021). Even as authors remain divided by the debate, some share the common understanding that NBS constitute an alternative water source within cities and improve urban water security, amongst other benefits (Tsatsou et al., 2023). O'Hogain & McCarton (2018) characterise and define Nature Based Solutions as water sources in a circular economy logic; they promote nutrient recover in a logic of water as a resource, promote ecosystem restoration, build resilience in the system, and after all, are waste free. This view is valid by challenging the linear approach to the water cycle (importing water over long distances, treating, using, and disposing of) and the practice of discharging unused rainwater in expensive drainage systems. Duker et al. (2020) describe sand river aquifers as nature-based water storage that form a renewable water source for irrigation in African countries, such as Zimbabwe and Mozambique.

Similarly, Oral et al. (2021) regard NBS as a circular solution which provides multiple benefits and mentions rainwater recovery as relevant for local uses. In this context, dual-use rainwater harvesting systems are mentioned to combine stormwater management with other supplies. Solutions such as retention ponds and cisterns can store and make available water that could otherwise cause floods, overflowing drains or remain unused (Kabisch et al., 2017). Finally, rainwater is seen as a valuable resource whose harvesting can reduce reliance on other supplies, relieve urban drainage infrastructure, reduce drinking water use for different purposes and protect downstream rainwater from pollutants (Oral et al., 2021).

A solution combining water management and climate mitigation may involve measures for water retention on agricultural land, soil conservation, reversing river canalisation to improve water infiltration, as well as river restoration to improve water retention capacity and reduce urban runoff due to the increased permeability in cities (EC, 2021). Interventions in agricultural settings are crucial given that a 1% carbon content increase in soils can represent over 20 000 gallons of water retained in the ground, according to USDA-NRDC conservative estimates (Hoyk et al., 2022). In this sense, Nevertheless, the use of NBS in water supply has the challenge of facing traditional sectors averse to risks and uncertainty associated with the employment of underutilized green technologies, such as biofilters. These solutions mimic biological and hydrological processes and reinforce the landscape's ability to filter stormwater and slow its flow before it percolates in aquifers or reaches a surface water body (Blackburn et al., 2021).

Oral et al. (2021) also mentioned circularity in urban water solutions when diverse NBS typologies related to two main circularity principles were analysed (maintenance of water cycles and the recovery and treatment of water and wastewater). NBS offers significant gains in irrigation and presents great potential to address water availability in urban settings as water security increases. Furthermore, NBS is recognised as a critical practice in providing sustainable water for agriculture, the most crucial issue when achieving overall water resources sustainability, given the pressing demand for water for agriculture. They address water supply by managing water storage, infiltration and transmission and acts on supply-side management (UN Water, 2018).

In Southern Portugal, there is increased mention of the use of NBS in urban and rural settings. While investigating stakeholders' perception of NBS in the capital city of Algarve, Faro, Ferreira et al. (2021) detailed several potential typologies in the urban space: green walls, natural swimming pools, rehabilitation of riverbanks, wetlands and floodable parks, drainage corridors, live crib walls, stormwater tree pits, raingardens, bioswales, urban trees, green shadow, green barriers, cycle-pedestrian green paths, leisure and sport spaces, green resting areas, permeable paving, bioretention ponds, community gardens and composting, potted plants on streets, green tram tracks, and religious & cultural green spaces.

The capacity of NBS to promote increased water availability in the Algarve, where managing water under conditions of scarcity and water quality remains challenging, is also mentioned. Runoff is stored during floods by harvesting rainwater from greenhouse rooftops and employed in Managed Aquifer Recharge, so risks of floods decrease and water availability for future use is increased. This action can minimise the impacts of drought, manage flood risk and positively impact rainfall precipitation patterns under Mediterranean conditions, thus decreasing the risk of agricultural losses. In a modest portion of the territory, such a solution is expected to retain 1,63 hm^3/year in rainwater volume to be forwarded to the aquifer Campina de Faro (Lobo-

Ferreira, 2017). Another stormwater harvesting solution installed at Napier Park, Moonee Valley, Australia, stores over 200 000L over 5 hours at 11L/s (Farrant, 2010).

Therefore, Nature Based Solutions can potentially increase water availability in a territory, which must not be ignored. In conclusion, they can serve as an alternative water source that builds resilience and should be employed in a *fit-for-purpose* logic to maximise benefits for people and the environment.

2.3.3. Design and Implementation of Nature Based Solutions

There are different typologies of solutions adopted worldwide - a list of NBS/habitats catalogued for Great Britain includes Peatlands, Woodlands, Saltmarsh, Hedgerows and Field Margins, Agroforestry, and Urban Street Trees (Stafford et al., 2021). The design process of a Nature Based Solution involves a change in mindset and the training of 'hybrid engineers', experts with a background in social science, ecology and ecosystem services. It is based on a multidisciplinary approach encompassing not only the physical site of its construction but also the governance and socio-economic context, involving stakeholders in all design stages and aligning interests to the primary function of the NBS. It is required to integrate the dynamism and multifunctionality of nature in the project to the example of the landscape, which provides multiple ecosystem services. The associated level of risk and uncertainty should be assumed and managed by building a knowledge base, building adaptive measures and embracing the underlying principle of 'learning by doing' (O'Hogain & McCarton, 2018).

Some principles for implementation are to understand the context of the challenge from different perspectives: the project, the natural environment, governance and the knowledge base. A feasible NBS has to be identified, and each alternative should be evaluated, in the light of local governance and practical limitations, as an adequate solution is prepared for implementation (O'Hogain & McCarton, 2018).

Water Sensitive Urban Design (WSUD) is a process that originated from the acknowledgement that the relationship between water and urban areas should be given a higher priority. It integrates water cycle management with the built environment through planning and urban design, attaining itself to the need for sustaining natural environments and managing each component of the urban water cycle in an integrated way. From this optics, water management must celebrate the local character and community, optimize the cost-benefits of infrastructures, improve quality of life and provide resource security and resilience. A Water Sensitive Place is aesthetic, resilient and prosperous, based on soft-engineering applications (Morgan et al., 2013). Creating green areas provides means for water infiltration in the soil, improves evapotranspiration and can also be used for rainwater storage (EC, 2021). NBS can mitigate flooding and droughts in urban and agricultural land, such as ponds, swales, raingardens and green roofs linked to cisterns - NBS regulate water flows, thus lowering the risk of floods and droughts (EC, 2021). WSUD can be applied in cities to reduce runoff, attenuate floods, and promote aquifer recharge by using permeable pavements combined with storage systems (also improving water quality due to its filtering properties), promoting water retention and heat alleviation through infiltration basins, retention ponds, raingardens, constructed wetlands and vertical greening. Local species must integrate the interventions to ensure plant water consumption is as low as possible since they are adapted to the local reality (EC, 2021). This work adopts a simplified classification used by Kabisch et al. (2017), amongst which NBS typologies related to the increase water availability are highlighted:

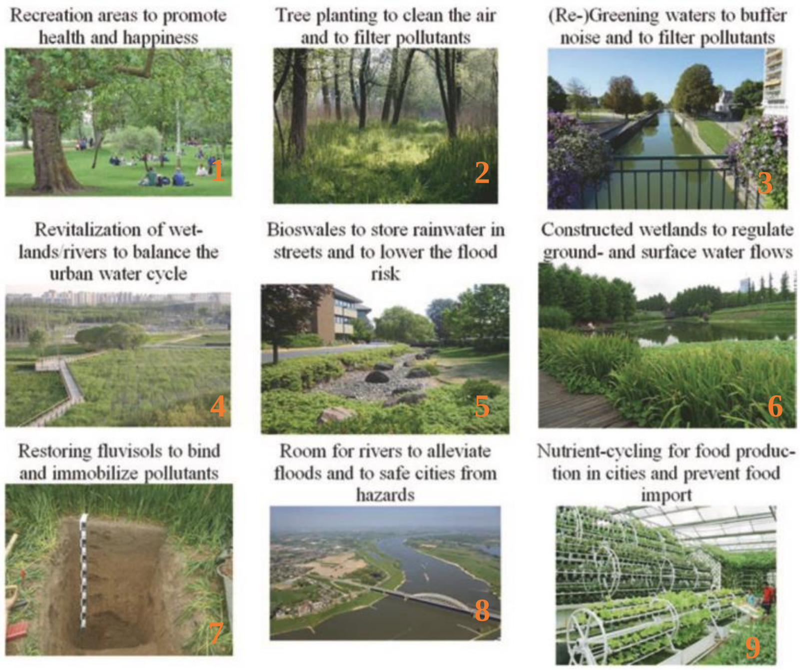

Figure 2: Examples of Nature Based Solutions typologies. Examples 1-9, from left to right, are related to Wetlands, Riparian Forests, Flood Plain Restoration, soil filtration and urban food production (Kabisch et al., 2017).

Filter strips, Bioswales, Raingardens and Bioretention Basins (Bioretention Measures): Landscape features that use soil and vegetation to retain and store stormwater (**Figure 2**,

typology 5), making it available for plant growth, soil biodiversity and air moistening in urban areas.

Wetlands, Lakes and Ponds: Wetlands are unique ecosystems of great complexity that can lead to large volumes of water in precipitation or flooding events (**Figure 2**, **typologies 4 and 6**), also suggesting the potential to be employed for aquifer recharge, provision of cooling effects, shade, aesthetic green spaces. Lakes and ponds retain water, making it available for posterior use, as well as they allow water to infiltrate the soil and constitute essential habitats for plant and animal life. Combined with riparian forests, they provide healthy forest products to forage.

Floodplain Restoration: Reconnection of rivers and floodplains (**Figure 2**, **typologies 3 and 8**) enhances natural water storage in the catchment system, distributing rainfall over larger areas.

Permeable Surfaces and Filter Drains: Promote moistening and water percolation in urban areas, filter stormwater (**Figure 3**) and allow its posterior collection if combined with other drainage solutions.

Green Roofs (Rainwater Harvesting Systems): Roofs covered by soil and plants that can absorb and store rainwater, and by doing that, they alleviate sewage and conventional urban drainage systems. Furthermore, they increase thermal insulation in the building and constitute functional spaces for recreation, food production (**Figure 2**, **typology 9**; **Figure 4**) or biodiversity habitats while reducing temperature and energetic costs in the edification. Some governments provide financial incentives to support their citizens in installing green roofs.

Trees, Green Areas, Green Barriers and Community Gardens: Permeable areas with locally adapted plant species that absorb water and sequester carbon, providing habitat for biodiversity, creation of microclimate, runoff absorption, as well as potentially acting in groundwater recharge while providing recreational benefits (**Figure 2**, **typologies 1 and 2**) (Kabisch et al., 2017; Morgan et al., 2013).

Figure 3: Permeable pavement used in cities (Kabisch et al., 2017).

Figure 4: An urban farming roof in the US (Kabisch et al., 2017).

NBS supports the achievement of many EU policies' goals by creating a Green Infrastructure that contributes to the maintenance of healthy ecosystems, reconnection of fragmented natural areas and restoration of damaged habitats (EC, 2012). Often misunderstood, neglected, and perceived by water practitioners as less efficient and riskier than grey infrastructures, NBS demand institutional cooperation that can be difficult to achieve (UN Water, 2018). NBS are cost-effective and contribute at different levels to achieving all Sustainable Development Goals

(SDGs) (IPBES, 2019; UN Water, 2018). For their implementation, however, legislation, policy and investment changes are necessary - e.g. bridging public and private interests (Stafford et al., 2021). Partnerships are required to enable efficient coordination across different governance scales, policy areas and shared knowledge resources. Working groups are recommended to assess opportunities and frameworks needed for NBS implementation.

In contrast, new projects require collaborative work and a participatory community approach (CPA) through a multi-stakeholder approach and multi-level governance framework (Stafford et al., 2021). Furthermore, the EU cohesion policy, standard agriculture policy and LIFE programme funds have been cited as tools for NBS implementation. Scientific evidence for its use rapidly expands in Europe due to the number of Horizon 2020-funded research projects (EC, 2021).

2.4. Participatory Governance

2.4.1. Examples of Community-Based Water Management

The Landscape Revitalisation and Integrated River Basin Management Programme for the Slovak Republic for 2010-2011 was a programme that implemented over 80 000 cheap and effective retention measures in almost 500 different municipalities of Slovakia. The goal was to ensure flood prevention and diminish flooding risks, drought risks, and risks of natural disasters while improving rainwater retention where rainwater falls and over degraded land. The governmental programme involved local communities, which became supporters of the measures, and provided 7000 temporary jobs for the unemployed. Initial implementation projects supported 23 municipalities to reduce flood damage and save around 500 000€ in preventive and rescue work during the following spring and summer. Over 18 months, the First Implementation phase involved building 6.1 million m^3 of rainwater retention capacity over 190 municipalities, while the Second Implementation phase created 3.9 million m^3 of water retention elements in the landscape of 354 municipalities. The interventions consisted of wooden steps, fishponds, lakes, stone dams, wooden check dams, and water holdings, amongst others, and were claimed to be known by ancient Slovaks. The water retained in torrential rains in 2011 was released throughout the extreme drought that affected Slovakia that same year. The results include flood alleviation, decreased soil erosion, increased water resources in the landscape, improved water quality, and aesthetically designed interventions. Nevertheless, hundreds of workshops were held to engage mayors, water forepersons, restoration measures contractors, and representatives of public administration bodies, amongst others, crucial to the development of the Landscape Revitalisation Programme (Kravcik et al., 2012).

Everard (2019) describes the restoration of traditional water solutions that support the regeneration of rural sub-catchments previously abandoned by community-based water stewardship practices in north Rajasthan, India. Cases of replenishment of aquifers by rejuvenation or adaptation of water management practices, such as stone dams, support ecosystem services and contribute to water security. Traditional solutions include downstream tunnel systems in hilly terrains that direct groundwater stored within the hills to downstream users, moisture flow interception over broad landscapes for crop production, and terracing interventions maximising water storage and promoting its efficient use in dry landscapes. Such techniques are currently in decline, as wells and other mechanised solutions are presented as the solution, thus decreasing people's collaboration for efficient and conscious water use (Everard, 2019).

Portugal presents an emblematic example of community-based water management. Tamera, in the region of Alentejo, southern Portugal, is an intentional community that designed a Water Retention Landscape (WRL) to regenerate the ecosystem through rainwater conservation, reforestation and soil renewal, assisted by the Austrian permaculture specialist Sepp Holzer (Esteves, 2021). The construction of 19 lakes, terraces and contour swales with orchards and agroforests to retain water, erosion and promote soil regeneration started in 2005. Water management is a central ecological topic where water cycling and storage are enhanced and supported; the community design, develop and test diverse structures for water retention in the landscape employed for posterior community use. The *Global Ecology Institute* at Tamera was founded to monitor such interventions, produce knowledge and disseminate such practices (Tamera, 2023).

In a similar intentional community, Dancing Rabbit Ecovillage, in the United States, it was found that water use was 23% of the average of the United States citizen, mainly due to water saving and employment of rainwater catchment technologies. Therefore, Vizinho et al. (2021) advocate for local, regional and national promotion of rainwater harvesting, reforestation, soil conservation measures and tree density increase in the Montado ecosystem through local policies. Citizens can carry out community-based water management on their own. However, mutual benefits are unlocked when citizens gather efforts with local authorities since their activities can be legitimised and supported, resulting in policies extending benefits to other territories.

2.4.2. Multi-level Water Governance and Public Participation

Water supply crises are often governance crises. As described by OECD (2015), the water sector experiences significant variation and limitation of the resource, over-abstraction of aquifers worldwide, an increasing number of people excluded from access to water & sanitation, ageing infrastructure and the need for significant investment to solve current water-related challenges. These can often result from poor resource management, institutional constraints, excess bureaucracy, lack of investment funds, and so on (SIWI, 2023). As ultimately, there is only one hydrological cycle. However, managing water is a complex activity; the sector should rely on multilevel governance to manage a resource whose boundaries often do not coincide with administrative perimeters, connecting across sectors and involving diverse stakeholders locally and globally. It is usually a monopolistic and capital-intensive economic sector with a massive impact on development - sub-national governments accumulate complex responsibilities delegated by the country, requiring coordination to overcome fragmentation in governance (Gupta & Pahl-Wostl, 2013). Top-down approaches can enable the resolution of environmental disputes; however, they can compromise long-term sustainability by failing to address social equality, fairness and inclusion and engage a multiplicity of citizens in the different stages of conception of NbS (Kiss et al., 2022). It is clear that there is no 'one-solution-fits-all', but every context requires tailor-made governance and water policies that should be kept updated. Furthermore, a multilevel approach to water management is adequate by correctly identifying which problem should be allocated at which administrative level.

It is much discussed whether water should be managed locally or as a crosscutting issue across multiple sectors - the subsidiarity principle advocates for water management at the lowest governance level. Water has to be dealt with at the local level because ‘local people are more competent to solve their problems than those from other levels of governance’ and due to the high ownership and commitment. Nevertheless, the global level is also a relevant dimension since local problems have a global impact, especially when it concerns the global hydrological system. It is crucial to achieve a common understanding of water drivers and cumulative impacts, which is helpful to materialise standard norms, increase the effectiveness of policy measures, deal with global drivers and ensure coherence. There are valid reasons for actors to scale water issues to the global or local/regional levels. A balance between bottom-up and top-down approaches and between decentralisation and cross-level coordination must be reached (Gupta & Pahl-Wostl, 2013).

Community-based water management in India is based on the existence of bottom-up community-based institutions for water governance: *Panchayats* are groups of five elders who represent small villages and communities, while *van panchayats* govern community use of forests and water resources within the village boundaries; *pani panchayats* are water governors instituted by the government of the Uttarakhand state to engage farmers in irrigation issues; *panchayat samitis* are committees of panchayat groups interfacing with the government; and finally, *Gram Sabha* are village councils with elected representatives that discuss village development needs, including local water management, that influence *panchayats* and *panchayat samitis* to seek government funding. They are examples of a stewardship-based view that is threatened by conflicts over land property and prioritisation of management at the catchment level. A shared understanding of water systems and the impacts of current management is essential for water governance to develop a stewardship-based approach to water management (Everard, 2019).

The case of implementation of an Urban Forest strategy in Melbourne, a mode of governance based on co-creation that includes values, norms and points of view from many actors, was established before the Nature Based Solutions (NBS) implementation. It showed that wicked socio-environmental problems can be approached by acknowledging and questioning the neoliberal *status quo* and current power relations. The correct implementation of NBS should provide political benefits to all stakeholders, as it should be based on participatory processes during the design and implementation stages, which strengthen participatory democracy and develop a culture of participation that is required to solve water governance issues (Kiss et al., 2022).

2.4.3. Institutional Coordination for Alternative Water Sources

Nature Based Solutions involve changes in water management and governance. Firstly, NBS implementation requires information on the costs and benefits of a given solution/project. The prioritisation of certain projects for implementation should be well evaluated based on factual information, which could consist of monitoring ecosystem services not commonly accounted for in decision-making but increasingly recognised. In addition, flows of natural capital stocks could be included in municipal budgets and quantified for future evaluation on the value and investment in blue and green infrastructure. In certain cases, the benefits of NBS extend to neighbour cities and inter-municipal exchanges are recommended, as well as platforms for municipalities to exchange good practices and learn from each other's mistakes and successes. Frequently cooperation between public and private landowners is required for implementation, and public participation plays a role in monitoring and implementing green infrastructure through initiatives such as urban gardens, green buildings, citizen science or consultation processes (Kabisch et al., 2017). Strategies in mixed governance in Glasgow enabled local communities to influence and manage public green spaces, increase the sense of belonging and release some financial strain (Stafford et al., 2021).

NBS implementation in cities is complex, and challenges include a lack of knowledge, skill gaps, and lack of coordination between sectors at local authorities. Working groups to assess existing policies, governance structures, and opportunities are part of the governance of NBS during design and implementation (Stafford et al., 2021). It often requires work amongst different departments of different governmental levels. For instance, a given NBS may require the tourism sector to join efforts with the environmental and social departments to align policies that maximise benefits and minimise trade-offs amongst sectors. The duration of the implementation process and efficiency may be enhanced by establishing an integrated planning and decision-making process. Institutional coordination is necessary to connect sources, water services and functional governance. At the municipal level, NBS mainstreaming strategies might include specific adaptation strategies, multidisciplinary working groups and integration of NBS in adaptation strategies into internal policies and tools. The city of Bonn in Germany uses a 4-step approach based on cross-department information and discussions, educational events, the launch of a climate adaptation measure and integration of climate adaptation into municipal working routines and local development. The creation of a knowledge base by the Metropolitan Ecological Network (MEN) in Lisbon was followed by strategic guidelines and climate adaptation measures, including management requirements for implementation at the institutional level in Lisbon. For mainstreaming practices, strategies must be implemented at the local, institutional and interinstitutional levels to implement measures on the ground and challenge mainstream governance at different levels. Similarly, it is recognised that cities cannot handle climate change effects by themselves anymore and need their citizens' engagement, so cooperation amongst stakeholders to favour NBS is important (Kabisch et al., 2017).

In urban areas, public institutions are the main bodies providing NBS financing (Kabisch et al., 2017). Some cases mentioned the development of governance mechanisms to coordinate funding for NBS. The best cost-effectiveness and maximised benefits are provided in those situations with the right conditions, regulations and governance structures (Stafford et al., 2021).

2.4.4. Enablers and Constraints for a Participatory Governance of Multiple Water Sources

Governance obstacles to the implementation of NBS may difficult their adoption, many of which are political, as some stakeholders defend tried and tested solutions over alternatives; however, the engagement of all stakeholders during the design process is decisive (Van Cauwenbergh et al., 2022). Other challenges might include an insufficient budget for implementing and maintaining green space projects during financially challenging times, given that efforts should be made to sustain long-term activities (Frantzeskaki & Kabisch, 2016).

Van Cauwenbergh et al. (2022) proposed the concept of Institutional Readiness (IR) to tackle knowledge uncertainty for implementing and mainstreaming NBS, applied to Rotterdam. It was found that most uncertainties emerge from the inadequacy of institutions to address stakeholder concerns and gaps in implementing existing policies. Furthermore, there is a demand for new technology that must be co-designed given a specific context. However, its implementation is complex due to its dependency on resources, capacity, quantity, and quality of relationships among involved stakeholders. However, one approach to understanding NBS adoption and mainstreaming, subject to problems due to the challenge of counting for system complexity, is the Technology Readiness Levels (TRL) proposed by NASA to understand the maturity of a society to use a given technology.

Nevertheless, current water plans address multiple interests, preparedness strategies, and the value of NBS, stated as co-benefits. However, a business plan for NBS could define how value is created and who is willing to pay for this. Continuous monitoring and evaluation are challenging since there are dispersed responsibilities and a lack of funding. However, agility and flexibility were essential aspects of creating IR, as open, inclusive and transparent governance is required to deal with all uncertainties in NBS implementation (Van Cauwenbergh et al., 2022).

Strategies to overcome difficulties mentioned include flagship NBS as champion-projects and wide advertisement of their co-benefits, even though they might take years to manifest fully; the use of problem-based and reflexive governance as models incorporating collaboration and partnering for innovation; connect climate change efforts and enhancement of biodiversity to promote the implementation of NBS; promotion of studies on the cost-effectiveness of implementing NBS to justify new investments, while encouraging wide-scale implementation, ‘learning-by-doing’ and advances through experience; and the development and communication of governance frameworks to policy and society (Kabisch et al., 2017).

The development of a Water Sensitive City (WSC) requires NBS that will perform to benefit citizens in different ways; therefore, participation is essential. Kabisch et al. (2017) mentioned the importance of considering socio-environmental justice in the implementation of such measures since they often go hand in hand with a rise in land prices and rent, potentially leading to the displacing of the population who cannot afford higher prices, for whom the green spaces would be most beneficial. To counteract this effect, participatory modes of governance should counteract displacement processes and ensure that affordable housing and nearby green urban areas are compatible.

2.4.5. Advancing Water Sensitive Regions through Participation and NBS

Building resilience in SES includes action at the urban management and planning level and at the governance level through an adaptive quality in multi-layer or polycentric decision-making structures, enabling collaboration, participation, deliberation, equity, inclusiveness, accountability and transparency. Other recognised principles include having a substantial role of diverse water actors, transformational and social learning, recognising local and traditional knowledge systems, creating conditions to build risk awareness, encouraging self-organisation and reorganising dysfunctional urban water systems - all properties that must be present in the design and implementation of crucial governance processes of the urban water sector to build resilience in a city’s water system. Nevertheless, the effectiveness that leads to resilience depends on how the water sector manages and governs water services and resources and addresses crises and other water-related perturbations (Saikia et al., 2022).

Even though leadership is not consistently recognised as an essential factor in the evolution of urban water systems, the context of the transition to Water Sensitive Cities demands a complex arrangement of elements and actions to be championed in Australia, particularly in Melbourne and Sydney, where actions unfold. Action at the local level is fundamental. Governance at the local level has a better potential for regulation and implementation of solutions, as Ashley et al. (2013) affirm that interest in environmental protection and access to locally available water are the main reasons for taking a Water Sensitive Urban Design (WSUD) approach in countries such as Singapore. The climate benefits of WSUD resulted in the encouragement of the implementation of WSUD through policy. Examples include the 'Tasmanian State Stormwater Strategy' and the 'Victorian Planning Provision'. Indeed, new institutional arrangements and modes of government, such as 'science-policy bridging organisations', may be necessary while complexity in the water sector increases (Floyd et al., 2014).

Ferguson et al. (2013) describe the design and implementation of a programme to enable transformative change towards achieving the status of Water Sensitive Cities (WSC) in Melbourne. Four guiding questions were posed about socio-technical difficulties, strategic planning and management use, accommodation of the systems' complexity and coping with uncertainty, visioning, experimentation, innovation, social learning, shadow networks, leadership and bridging organisation defined as strategic initiatives. The need to include space for strategic and rational planning and letting the emergent process play a role was identified. The aim was to encourage a diversity of perspectives and high-quality discussions to understand how a WSC can become concrete. Transition scenarios were presented in a creative process that united the creation of collective visions and analytic techniques to examine how the desired future can be reached. Workshop participants were selected, and researchers assumed the role of facilitators and analysts. The data were synthesised into one transition scenario for Melbourne and analysed independently and collectively by the authors, resulting in a strategic program encompassing goals and processes at layers of decision-making context, coordinating and disseminating action and the control of performance outcomes. It can potentially guide urban water practitioners in creating policies and instruments for sustainable solutions beyond the water sector.

A city aiming to manage water sustainably regards all urban water sources in a way that maximises liveability and resilience to unexpected social, economic and biophysical challenges. For that, a shared vision is necessary to ensure reforms and implementation of new policies that maximise the benefits of water and synergise action, allowing cross-disciplinary work at different scales for long-term measures. In this spirit, *Waterwise Cities* is a concept that encourages collaborative effort, shared local visions and active engagement of stakeholders driven by more efficient urban use and reuse of resources while taking advantage of the densification of urban spaces to increase efficiency in water services, incorporate modularity, and reduce dependencies in the water system while designing for an uncertain future. The stakeholders contribute their expertise, create educational programmes and are enriched with other cities' examples, using and developing planning tools to connect land use and urban water system planning decisions. They detailed risk assessments in cross-sectoral teams, identified co-benefits in projects and ensured stakeholder ownership while writing regulations that enable innovation and incentives, as well as make use of financial tools to enable long-lasting improved service levels, such as shorter investment cycles to allow adaptation, innovation, and transition in cities, to higher levels of water sensitivity (IWA, 2017).

3. Public Policies and Legal Framework of Water Sources in Portugal

3.1. Legal Classification of Waters

The different uses, management orientation and classification of waters are present in the legislation of every country. For this reason, the understanding of laws and regulations in the Portuguese Water Law (Law nr. 58/2005, 29th December), European Directives and other relevant policy documents is crucial for the design of strategies to encourage the adoption of alternative sources. The 1st article of the Water Law classifies water into two categories defined by the 4th article:

Surface waters: internal waters, except for groundwater, transitional waters, and coastal waters, including in this category the chemical state 'territorial waters'. It is commonly referred to as a *surface water body*, a delimited and significant surface water mass, such as a dam, brook, waterway, stream, river or canal, transitional water or coastal belt.

- *Internal waters*: all lentic (still) or lotic (stream) surface waters with the addition of all groundwater bodies in the terrestrial side of the baseline delimiting territorial waters;
- *Transitional waters*: surface waters in proximity to the river mouth, partially saline as a result of the proximity to coastal waters, significantly influenced by freshwater courses;

- *Coastal waters*: surface waters located between land and a line situated within one nautical mile towards the sea, from which territorial waters are delimited and extending, when applicable, to the exterior limit of transitional waters;
- *Territorial water*: sea waters situated between the baseline and a line 12 nautical miles from the baseline.

Groundwater: all waters stored underneath the soil, in the saturated zone, and direct contact with the soil and subsoil, occupying porous spaces and rock fractures. It is commonly referred to as a *groundwater body,* a groundwater media that integrates one or more aquifers, or as an *aquifer,* defined as one or more underground layers of rocks or other porous and permeable geological extracts that allow for significative percolation of groundwaters or the abstraction of significative quantities of groundwater.

Other terms related to water use and sourcing are mentioned in the 4th article:

Water destined for human consumption: all waters in its original state, or after treatment, designated for drinking, cooking or other domestic finalities, regardless of its origin and of being or not supplied through a network, tanker truck or ship, in bottles or other recipients, with or without commercial purposes, as well as all water used by the food industry for food production, transformation, conservation or commercialisation of products or substances intended for human consumption, except when the use of this water does not affect the salubrity of foodstuff in its finished form.

Artificial water body: a surface water body created by human activity.

Heavily modified water body: a surface water body whose characteristics were considerably modified by physical modifications resulting from human activity and acquired a different character, designated in specific regulations.

The Watershed Management Plan classifies waters as surface (rivers, dams, transitional, and coastal waters) and groundwater. Natural surface masses and groundwater bodies were delimited according to guide nr. 2 *Identification of Water Bodies* (Kampa & Hansen., 2004). Regarding artificial and heavily modified water bodies, the EU *Guidance Document nr. 4 - Identification and Designation of Heavily Modified and Artificial Water Bodies* presented the methodology used to identify such water masses (APA, 2022b).

Regarding ownership of water resources, the Water Law establishes in Articles 1st and 18th that water can belong to the public or private domains. Even when there is a private resource, it is mandatory to have it licensed or give prior notice of its utilisation to the governmental entity in charge (Andrade & Stigter, 2012).

3.2. Water Legislation in Portugal

Europe’s Water Framework Directive (WFD) 2000/60/EC, 23rd October, was published with the fundamental aims of achieving environmental objectives, integrating economic recovery of costs of water services, and promoting public participation. In Portugal, the integration of water management into the environmental framework ended with the publication of the Water Law in 2005 (Law nr. 58/2005, 29th December). Administrative units were created to manage eight watershed districts reporting directly to the Portuguese Environmental Agency (APA, in Portuguese) and the *National Water Authority*. The Commission makes the integration of environmental and water policies for the Regional Coordination and Development Commissions, whilst the National Water Council is the consultant body. Other entities integrate this level of governance, such as state-owned companies (Águas do Algarve), the National Water Services Regulatory Bureau (ERSAR, in Portuguese), NGOs, and industrial, professional and scientific associations (Schmidt & Prista, 2009).

The management of water resources in the country is detailed; according to the Water Law's articles 3rd, 16th, 19th and 24th, legal instruments for managing, planning and ordering include the Watershed Management Plans and the National Water Plan, unique land use plans, measures for the protection and valuing of Watershed Region and specific strategies for water management to the aquifer or sub-basin levels (Andrade & Stigter, 2012).

According to the 84th article of the Water Law, promoting the active participation of individual and collective persons during the elaboration of Watershed Management Plans is one key competence of the National Water Authority. The plan is one of the essential tools for water management, with a strategy based on goals and stakeholder participation adopted to promote synergy and effectiveness. The plans are reviewed every six years; the first cycle is from 2009-2015, the second is from 2016-2021, and the third cycle goes from 2022-2027. Currently, the third phase of public participation regarding provisional versions of the plans is operative. The latest plan presents the reuse of treated wastewater as a promising practice to be applied, respecting health and environmental risk management and the *fit-for-purpose* quality norm

(APA, 2022b). Nevertheless, other alternate sources are not discussed. The management plans should address the inclusion of a wider societal discussion on the use of multiple alternate water sources in the Algarve for this topic to become part of institutional agendas.

For the third cycle of review of the Watershed Management Plans, APA (2022a) recommended specifically to Portugal the improvement of its citizen participation, detection of obstacles to conform water masses to a good state, integration of environmental costs and impact on water masses, improvement of surface waters monitoring, evaluation of each project at the level of water body, update of licenses and regulate water courses, and guarantee that specific goals for salt marshes meet the respective directive. From 2014 to 2020, the purpose of monitoring 100% of underground water bodies was met. From 2017 onwards, new private underground water extractions can be licensed only if authorised in Portugal. This is due to the extreme droughts affecting the country, so Water Exploitation Index Plus (WEI+) calculations will be integrated into the monitoring frameworks to verify whether current uses are sustainable and provide the basis for licensing (APA, 2022c).

The action plans that integrate Watershed Management Plans are strongly influenced by economic and ecological strategies adopted by the European Union. They are also affected by national and international plans for climate adaptation and the European Ecological Pact (Green Deal), which aims to instigate action to strengthen a clean and circular economy while restoring biodiversity and reducing pollution.

3.3. Groundwater Legislation

The invisibility of aquifers and late scientific research on groundwater areas are reflected in the legislation on groundwater, which may be a management challenge. Most water law policy was written a century ago when the interconnectedness between surface water and groundwater was not yet scientifically convincing (Neves et al., 2021). In Portugal, groundwater masses are privately owner and the challenge lies in their management due to the reliance on cooperation from private users; currently, a transition to a public status is being considered following the example of Spain (APA, 2023; TSF, 2023). Even the masses not considered for public supply are still regarded as strategic reserves. Water bodies destined for human consumption must be catalogued. In addition, the Decree-Law nr. 382/99, 22nd September, contains norms for the protection of perimeters of groundwater masses reserved for the public supply, based on hydrogeological research with restrictions to public utility and land use. Water bodies providing, on average more than 100 m^3/day must be monitored (APA, 2022b).

By 2015, all water masses should have met the ‘Good’ qualitative status in Portugal; however, it was not the case for nine of the groundwater masses. The nine areas in Portugal correspond to 4% of the national territory. Other notable areas include *Zones of Special Protection* (ZPE, in Portuguese), among them *Sites of Community Interest* due to the rich biodiversity and threats to the habitat. Protected Areas, according to European legislation, are those areas that require water protection and conservation of habitats and water-dependent species. They also encompass areas of maximum infiltration, where aquifer recharge is favoured and whose water resources protection should be promoted (APA, 2022b).

The ‘Good’ state of groundwater is determined according to a few criteria, such as water level not inferior to the mean rate of long-term abstraction, absence of saline intrusion, conformity to environmental goals and absence of significant damage to terrestrial ecosystems. Water bodies can suffer different kinds of pressure, such as punctual, diffuse, quantitative, hydro-morphological and biological. Amongst them, it is worth mentioning diffuse as the urban pollution source from agriculture and golf courses and quantitative from water extraction activities. Such masses must not be available for new licenses or an increased volume of extractions. The urban sector is the most significant in rejected loads (total nitrogen, total phosphorus, COD and CBO5) in *Ribeiras do Algarve*, corresponding to 97% of the total volume rejected (APA, 2022b).

The Water Framework Directive was also established to limit pollutant discharges in groundwaters, avoiding deterioration of all waters while securing a balance between amounts abstracted and recharges, to reach the ‘Good’ status of groundwaters. The chemical and quantitative states of all 25 groundwater masses are monitored through a network of 91 points of surveillance and 22 points of operational monitoring, sampled every semester. Monitoring water masses is done through the surveillance and operational monitoring network, while 34 points are used to monitor the 15 water masses destined for public supply. Regardless, all groundwater can be used during drought or unavailability of existing surface and underground waters, thus benefiting from the same protection as current sources, according to articles 8th and 54th of the Water Law (APA, 2022b).

The Decree-Law nr. 235/97, of 3rd September, transforms the area of aquifers into a protected area, in this case, *Nitrate Vulnerable Zone (NVZ)*, to reduce or ban pollution from nitrates from agricultural activities. The area occupied by the sub-system Vale do Lobo contains two such zones. NVZ were delimited and described according to Directive 91/676/CEE, 12th December, about waters that are polluted or susceptible to nitrate pollution from agricultural origins.

3.4. Regulation for the Use of Distinct Water Sources in the Algarve

The 3rd article of the Water Law presents three particular water management principles that should be considered in terms of the utilisation of multiple water sources:

- *The Social Value of Water is* access to water to fulfil basic human needs at a socially acceptable cost without economically excluding citizens.
- *The Economic Value of Water:* water is a scarce resource and should be used in an economically efficient way. Economic costs should be recovered by applying the *User Pays Principle* and the *Polluter Pays Principle*.
- *Integrated Water Management of Terrestrial, Aquatic Ecosystems and Wetlands:* attend to quantitative and qualitative aspects of water in its management as prerequisites to sustainable development.

Alternative water sources are not directly mentioned in the law. In the Algarve, treated wastewater, desalinated water and rainwater/stormwater are the three frequently mentioned alternative water sources. The first two have been officially included in governmental debates, while the latter has been employed in the past, but authorities have not appropriately considered it. For this reason, they have been chosen to be further discussed in this work.

Treated wastewater as an alternative supply was first recognised by the European Commission communications 'A Blueprint to Safeguard Europe's Water Resources' and ‘Closing the Loop - An EU action plan for the circular economy’ (EC, 2012; EC, 2015). The EU focuses on facilitating the adoption of treated wastewater for aquifer recharge and agricultural irrigation; however excludes stormwater - which is also a sort of water reuse - in the scope of the Common Implementation Strategy (CIS) guidelines for the planning and management of water (Lundy et al., 2018). Nevertheless, a regulation was recently adopted to facilitate the safe reuse of treated wastewater from urban treatment plants for agricultural purposes (Hristov et al., 2021), even though it may be complex, which might dissuade users. Hristov et al. (2021) reviewed the

WFD and the Urban Waste Treatment Directive in the search for encouragement for the use of treated wastewater. However, any specificity in conditions for its use was absent, especially when it comes to use aligned to a *fit-for-purpose* approach. Portugal updated the EU Directive 91/271/CE with the Decree-Law nr. 119/2019, 21st August, by adopting guidelines to promote water reuse to conserve water bodies and reuse treated wastewater in irrigation.

Desalinated water has also been much discussed in the Algarve. Its adoption recently migrated from the research stage (Neves et al., 2021) to the definition of a plant installation site at the Albufeira county, approximately 30 km from Vale do Lobo and Quinta do Lago, and its Environmental Impact Assessment (EIA) is under the Portuguese Environmental Agency (PEA) analysis and consideration (DN, 2023). Regulations are scarce. Since the company Águas do Algarve already has a 'dorsal spine' infrastructure for water distribution, the water from a desalination plant to be installed next to the Albufeira cost could be quickly injected into the ducts to supply the larger urban centres in the region. It is expected that desalinated water could alleviate the public use of surface water, and exceeding volumes could be redirected to agricultural activities. Nevertheless, the technologies employed are highly energy consumptive. Renewable energies imply in even higher initial costs while their dependency on the weather may be considered an obstacle to provide uninterrupted energy. Even though the Algarve is one of the European regions with the highest potential for implementing solar energy, paradoxically, it falls behind the rest of Portugal regarding renewable energies, with hydropower representing 38%, followed by wind and solar energies, 25% and 2%, respectively. A potential rise in water or electricity prices is reported to potentially make desalination infeasible (Neves et al., 2021; Serra et al., 2020).

The use of rainwater has been encouraged by countries like Germany, Japan and Australia through the development of initiatives and guidance to promote its adoption. The US has been using stormwater infiltration basins for groundwater recharge since the 1930s, besides the legislative mandates for Managed Aquifer Recharge (MAR) in many counties (Lundy et al., 2018). Regulations for rainwater and stormwater systems were developed by the National Association for Quality of Building Installations (ANQIP, in Portuguese) to enable the adoption of such systems. The Australian water recycling guidelines are among the best practice examples in communicating system safety methodologies to various potential reuse applications with *fit-for-purpose* policies (Lundy et al., 2018). The Water Framework Directive identify the reuse of water at different levels as a critical supplementary measure to be considered in the context of the development of watershed management plans and is presented as a specific action within the EU communication 'A Blueprint to Safeguard Europe's Water Resources' (EC, 2012; Lundy et al., 2018).

The Resolution nr. 10/2011, 1st February, recommended the Government to install secondary stormwater networks with the aim of water reuse in buildings, considering their environmental, energetic and financial gains (Sousa, 2015). Most concretely, the recently published Strategic Plan for the Public Supply of Water and Management of Stormwater and Reuse Treated Wastewater (2021-2030) aim to include stormwater as part of the management of water services (APA, 2022b). Nature Based Solutions mostly employ stormwater and are still unregulated. The *European Green Deal*, launched in 2019, affirms that a new, more ambitious strategy of adaptation to climate change will be adopted where NBS are named as climate adaptation measures that should receive public and private investments (Fetting, 2020). In addition, the *European Climate Pact*, launched in 2020, is affirmed in its section *3.3.1. Green Areas* to offer solutions to restore, enlarge and protect green urban areas to local authorities, those built on local initiatives and policies such as 'nature-based solutions that maximise quality job creation, business opportunities and climate resilience' (EC, 2020).

The WFD, whose core is sustainable water management, provides an indirect argument in favour of the use of NBS as they provide ecosystem restoration, enhancement, protection, and water bodies' capacity to provide multiple ecosystem services. Regarding drought alleviation, the WFD and watershed management plans fail to recognise the NBS's contribution to adaptation and disaster risk reduction goals (EC, 2021).

4. Case Study: Vale do Lobo Subsystem, Campina de Faro Aquifer, Algarve, Portugal

4.1. Characterisation of the Vale do Lobo Subsystem Area

The aquifer Campina de Faro is located in the Algarve region in southern Portugal, a Mediterranean climate region where dry and hot seasons merge; negative temperatures and frosts are not frequent in a sub-tropical character. Summers are long, hot, and dry, while winters are short, cold, and humid (Schmidt & Prista, 2009). Precipitation is concentrated and increases concerning the altitude and distance from the sea - most rainfall precipitates over the mountain range that keeps away the Algarve and the Alentejo regions. Long-term droughts are ever more frequent and promote water shortages - the ratio between the mean annual precipitation (500 mm) and the potential evapotranspiration (1300 mm) is the base to classify this area as semi-arid (Neves et al., 2021).

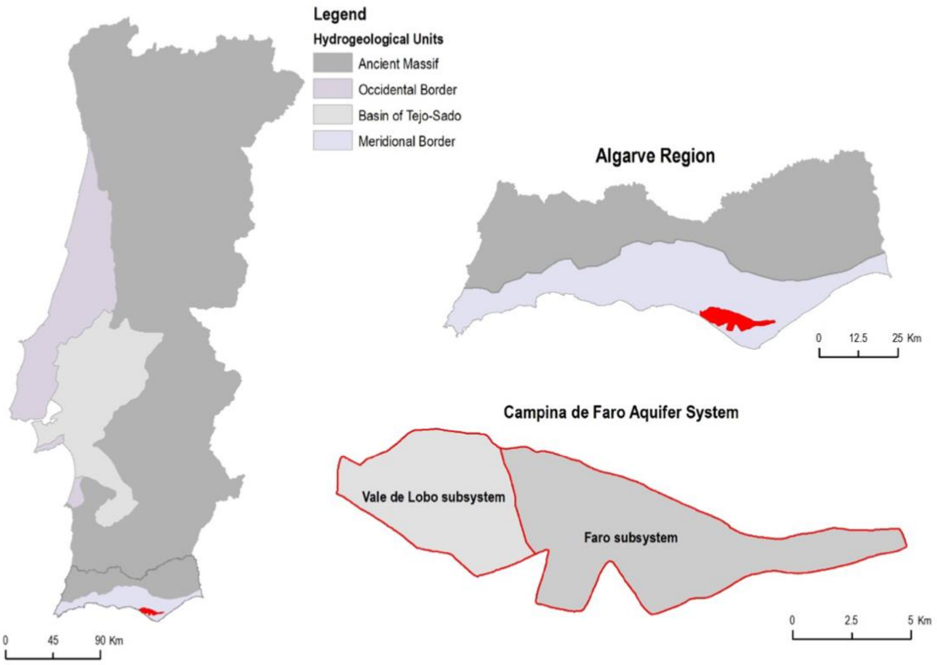

Figure 5: Location of the Campina de Faro Aquifer System (GeoERA, 2020).

The hydrosocial territory of the aquifer Campina de Faro (**Figure 5**), presents a set of unique characteristics (**Table 4**). It belongs to the watershed *Ribeiras do Sotavento (RH8)* in the Faro district, covering the municipalities of Faro, Loulé e Olhão. This is one of three aquifers that delimitate the Ria Formosa Natural Park, adding up to a total area of 86,4 km^2, of which the Vale do Lobo subsystem occupies 32,41 km2 and 53,99 km^2 by the Faro subsystem (Rocha et al., 2016). This division was adopted to distinguish the different water quality statuses.

Table 4: Summary of the Campina de Faro aquifer characteristics (Translated and adapted from APA, 2012).

Campina de Faro		
General characteristics		
Hydrogeologic unit	Southern rim	
Total area (km^2)	86,39	
Aquifer type	unconfined to confined - multi aquifer	
Outflow	Karstic and Porous	
Stratigraphy/lithology and depth (m)	Galvanised limestone	50,00
	Glauconitic silts of Campina de Faro	30,00 to 40,00

Table 4: Summary of the Campina de Faro aquifer characteristics (Translated and adapted from APA, 2012 - continuation).

General characteristics		
	Sands and gravel pits of Faro-Quarteira	30,00 to 60,00
Main discharge zones	Watershed network	
Relation between rivers and groundwater	Groundwater feed water courses	
Relation between seawater and groundwater	Yes (Geological context/interface groundwater mass-sea)	
Groundwater abstractions for public supply (nr.)	0	
Main users	Private (irrigation - 26,0%)	
Hydraulic characteristics		
Transmissivity (m^2/d) (min-max)	18 - 284 (*in* Almeida et al., 2000)	
Productivity (l/s) (min-max)	0,40	44,00
Hydrochemical characteristics		
Facies (Piper's diagram)	Bicarbonated and mixed chlorinated	
Water quality for irrigation (Wilcox)	C2S1 and C2S2 - medium to high risk of salinisation and low to medium risk of soil alkalinisation	
Water Quality to human consumption	Poor	
Groundwater masses associated with surface freshwater ecosystems and terrestrial ecosystems		
Hydrogeological characteristics of groundwater masses		
Porosity (mean, min-max) % tabulated values	Carbonated rocks	0,5 (0 - 1)
	Detrital rocks	16 (6 - 28)
	Biocalcarenite	3 (0,5 - 20)
	Fine sandstone	10 (0 - 20)
	Sand with boulder	25 (10 - 35)
	Sand and gravel pit	10 (15 - 35)
Confined	Yes	
Soil characteristics and surface deposits in the drainage area		
Soil (mm)	Red limestones	250,00 to 400,00
Hydraulic conductivity (mm/h)	5,50	
Adsorption properties	Medium to high	
Surface deposits	No cover deposits	
Pressures		
Agriculture		
Risk classification		
Groundwater mass in risk due to nitrates pollution (agriculture)		
Comply with environmental goals		
No (global quality)		

A great extension of the Algarve is categorised as a Site of Community Importance (*SAC*, in Portuguese) - according to the European Commission Habitats Directive 92/43/EEC, May 21st, regarding nature protection. There is an ensemble of protected areas at the surface of the territory occupied by the aquifer (**Figure 6**) associated with the Ria Formosa Natural Park, among them Ludo, a site of elevated environmental and ecological value comprehending pine forests and the alluvial valley of Ribeira de São Lourenço stream. The Ribeira de São Lourenço stream shows, upstream of the aquifer, areas of great significance to the aquatic and terrestrial ecosystems, which are protected according to the Annex IV of the Water Framework Directive (APA, 2012). The final portion of the stream, at the Ludo Valley, is characterised by intense extraction, having been drained for agricultural and pecuary purposes. It is potentially an area of increased groundwater percolation, even though no visible springs exist.

The total catchment area (300,46 km^2) surpasses the site of the Campina de Faro aquifer (86,39 km^2). The main river catchment areas integrated into the greater catchment area are the Rio Seco (22,9%), Ribeira do Carcavai (21,6%) and Ribeira de São Lourenço (15%) (APA, 2012).

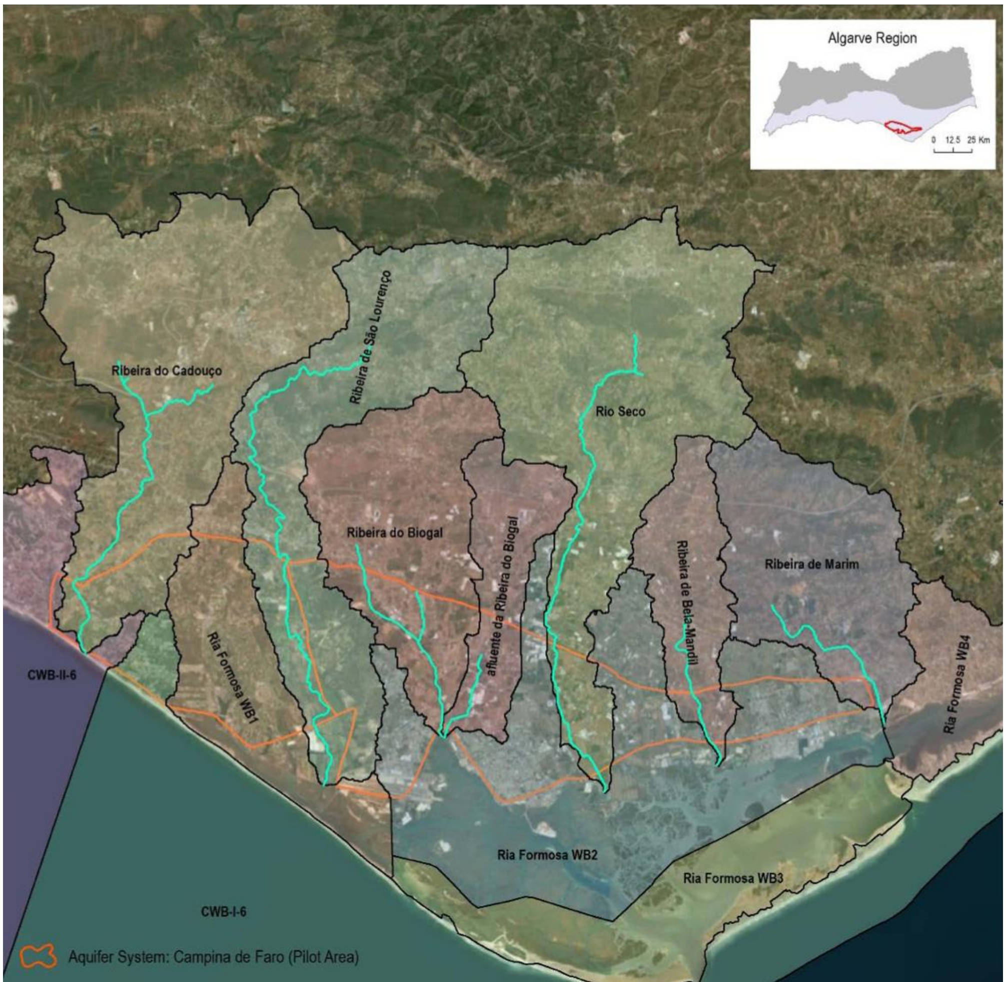

Figure 6: Area occupied by the Campina de Faro aquifer. The subsystem Vale do Lobo on the left, and the subsystem Faro on the right. The latter is under the influence of the Ria Formosa in the centre, Ribeira do Cadoiço watershed to the left, and Ribeira de São Lourenço to the right (GeoERA, 2020).

Although Water Sensitive City is a more popularly diffused concept, this work suggests the use of *Water Sensitive City-Region* as a term advocated by Serrao-Neumann et al. (2019) as appropriate to the study area because the territory transcends an actual city, embracing urban, peri-urban and rural areas, metropolitan or regional centres, and often multiple water catchments, which frequently influence urban functioning beyond administrative and hydrological catchment boundaries. Such status may be attainable through active Water Sensitive Communities in the hydrosocial territory, who propose practices, engage citizens and are valuable stakeholders to support the institutional coordination necessary for change.

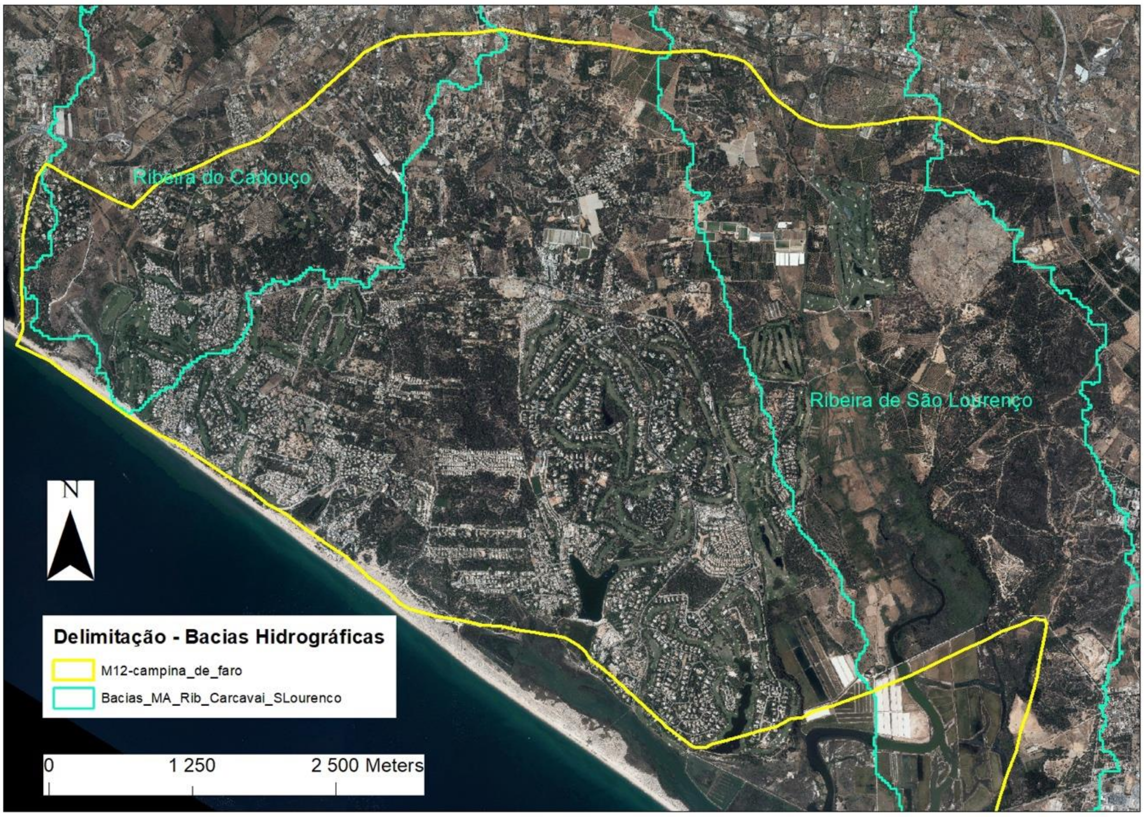

Figure 7: Delimitation of the Vale do Lobo subsystem. The Ribeira do Carcavai e Ribeira de São Lourenço watersheds are represented in 'blue' lines, while the 'yellow' line represents the territory corresponding to this subunit of the Campina de Faro aquifer (Elaborated by Ana Clara Simão Lopes).

The subsystem Vale do Lobo is located within the administrative limits of the Loulé municipality. It is in the influence area of the Ribeira do Carcavai e Ribeira de São Lourenço watersheds (**Figure 7**). An important local endeavour is the Vale do Lobo resort, whose area is managed by the public-private company Infralobo, that, amongst other services, delivers tailor-made water management to the neighbourhood, including areas with different land uses

(**Figure 8**), such as sport and leisure areas, coniferous forest, agricultural and irrigated land, shrubs and bushes, berries and fruit tree plantations, among others (GeoERA, 2020).

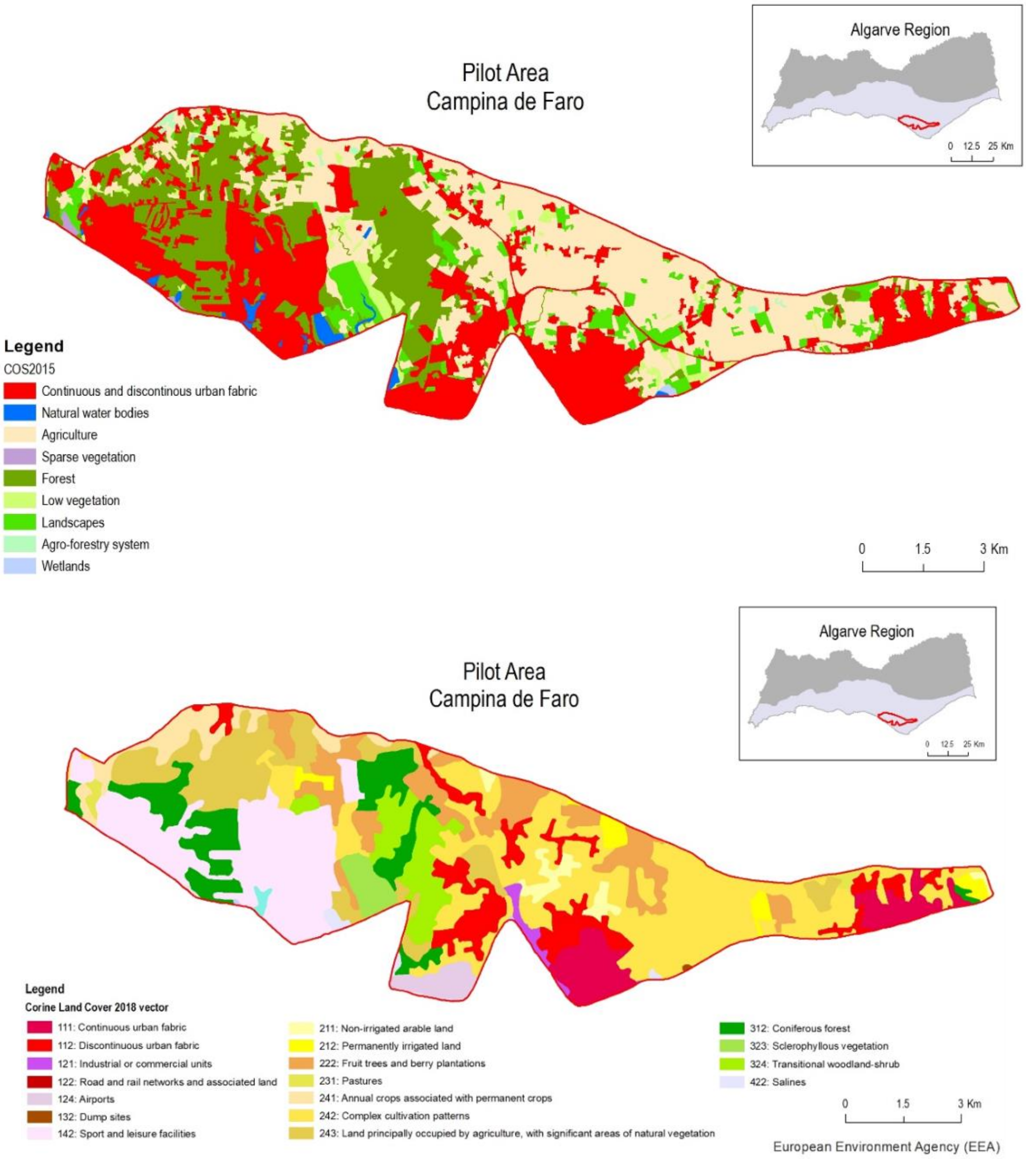

Figure 8: Comparative land use mapping. The territory corresponding to the Campina de Faro aquifer in 2015, on top, and in 2018, on the bottom (Corine Land Cover in GeoERA, 2020).

4.2. Qualitative and Quantitative Status

During the 2015-2021 cycle, the Campina de Faro aquifer subsystem Vale do Lobo presented a ‘Good’ quality status and ‘Mediocre’ quantitative status, resulting in a ‘Mediocre’ global state. This subsystem was not considered a Nitrate Vulnerable Zone (NVZ), but the criteria were modified for the 2022-2027 cycle.

Water quality is a constant concern throughout the aquifer due to the prolonged use of fertilisers and seawater intrusion processes in aquifers, though water quantity is also important. Substantial amounts of water are prevented from percolating into the soil and, as a result, reach the sea as surface runoff, river discharge, treated and untreated wastewater, and excess water discharges from various sources (Leitão et al., 2016). In the study area, twenty six waste management units are involved in accidental pollution discharges rated ‘Moderate’ in severity, affecting twelve groundwater masses, while six other pecuary installations affect one groundwater mass with the level of severity 'High'. Four other mining installations present discharge rate ‘Low’ levels of severity, affecting two groundwater masses (APA, 2022).

The parameter responsible for the ‘Mediocre’ qualitative status, preventing the aquifer from environmental parameters compliance, is chloride - a result of water abstractions performed by the agriculture and golf sectors, provoking a saline wedge to be interiorised (**Figure 9**), consequently resulting in seawater intrusion. Regarding the ‘Mediocre’ quantitative status, the RH8 presents five groundwater bodies in such a situation, including Campina do Faro's two sub-systems. In the case of subsystem Vale do Lobo, the reason for this classification is, namely, over-extraction for golf activities and agriculture (APA, 2022b). The evidence of Seawater Intrusion in this subunit and the presence of saline water in a few boreholes confirm that the aquifer is overexploited in an unsustainable way, putting the whole system and dependent ecosystems at risk (GeoERA, 2020).

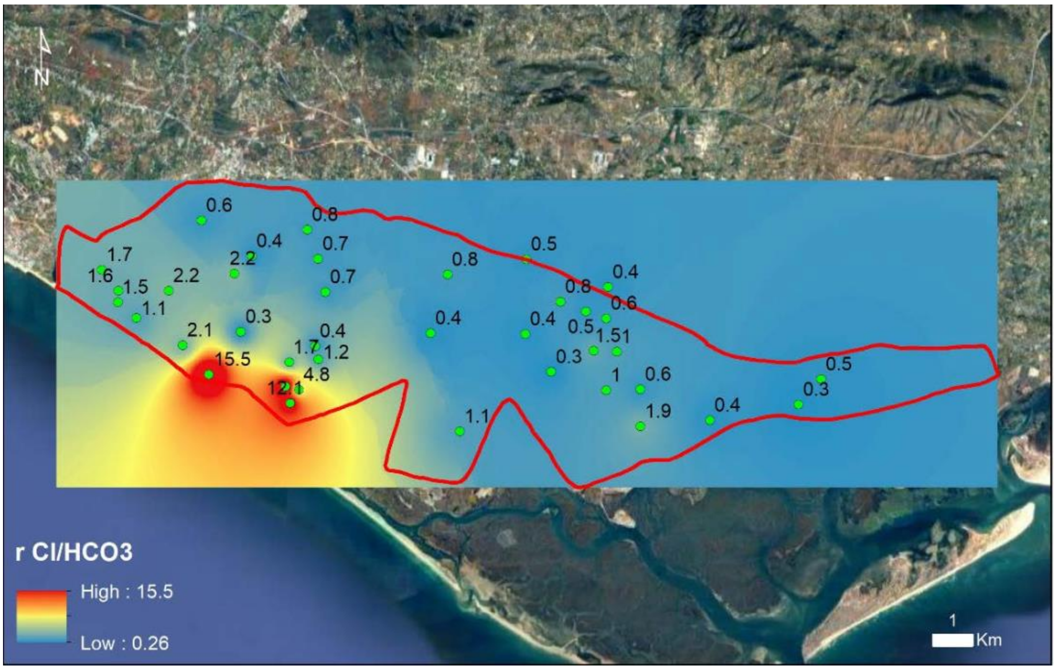

Figure 9: Salinity mapping in 2019. There are two points of high salinity in the west subsystem of Vale do Lobo, indicating a process of saline intrusion (GeoERA, 2020).

Moreover, according to the Regional Plan for Water Efficiency in the Algarve (2020), amidst all groundwater bodies, the subsystem Vale do Lobo was the only one with critical water availability, whose piezometric levels were below 20% (Costa, 2020), presenting a tendency to sink, a sign of use beyond sustainable levels.

4.3. Characterisation of Supply-Demand

In Europe, one-third of the water is used by agricultural activities; agriculture is an essential source of pollution, regarding fertilizers and pesticides related to or not to intensive animal production, thus decisive for the conservation state of water bodies. For this reason, irrigation technologies are contributing to increasing water efficiency. In the face of climate change will be increasingly necessary to reduce consumption while more adapted crops are preferred.

In the face of climate change, Portugal should expect significant decreases in annual precipitation and temperature increases, as well as extreme precipitation events caused by a boost in radiative forcing that produces more evaporation to be held by the atmosphere. For this reason, studies indicate that water-efficient technologies, such as rainfall harvesting and dripping irrigation, are highly recommended (Quinteiro et al., 2019). The water consumption in the country is 67% related to agriculture and 21% to public supply; however, agriculture water use is fundamentally groundwater. Irrigation of golf courses is a significant activity responding to 7% of all extractions. Irrigation of resorts and other touristic areas were not accounted for, however it is expected to reach considerable values (APA, 2022a).

It is possible to summarize by affirming that in Watershed Region 8 (Ribeiras do Algarve), groundwater volumes abstracted (121,8 hm^3) are twice the surface waters (62,1 hm^3), and the most significant consumer is agriculture (67%), followed by public supply (22%). The primary irrigated culture corresponding to almost 70% of consumption in the area is citrus orchards. Tourism is another relevant economic activity in the Algarve, especially activities related to golf courses that employ fertilizers and large amounts of water to keep the grass green throughout the year. There are 37 golf courses present in this area. In terms of quantitative pressure, the urban sector has small participation in water abstractions (8,6 hm^3), as well as the industrial sector (6,8 hm^3) and the golf sector (9 hm^3). However, the same is not valid for agriculture, responsive for 101,5 hm^3.

Groundwater is the primary source for the intense agricultural and touristic activities at the Vale do Lobo (APA, 2022b). It is inferred that the primary source for drinking purposes is surface water since the data on abstractions for human consumption shows a low rate. The hydrological availabilities of the Vale do Lobo subsystem are 2,94 hm^3/year and 0,09 hm^3/km^2 year of underground availability per area unit. Values for subsystem Faro are 4,96 hm^3/year and 0,09 hm^3/km^2, respectively (APA, 2022c). Some 625 abstractions of groundwater are part of the inventory of this aquifer's subsystem (Reis, 2014 *apud* GeoERA, 2020), used for irrigation of golf courses 3,25 hm^3/year) and citrus groves and watercress irrigation (2,0 hm^3/year), but also for irrigation of urbanisations with a large garden area (0,0057 hm^3/year), not specified extractions (0,51 hm^3/year), summing up a total volume of 5,77 hm^3/year above the allowed volume of 4,25 hm^3/year, characterising this subsystem as overexploited (APA, 2022c).

It is not the scope of this work to analyse and discuss the potential of technologies to overcome the poor quantitative status of the Vale do Lobo subsystem. However, it is worth mentioning that the best-studied alternative solution to be applied in Vale do Lobo is to refill exploited aquifers through Managed Aquifer Recharge**.** It contributes to increasing groundwater quality and is a viable alternative water source in the context of Integrated Water Resources Management (IWRM). Flash floods from seasonal watercourses and rainwater harvested at greenhouse roofs were successfully used in large wells and infiltration basins on the riverbed of Rio Seco, an area with high water percolation capacity in the area of the Campina de Faro aquifer (Leitão et al., 2016). Another technology that could gain relevance in the area is the 'Seawater Greenhouse', based on seawater thermally evaporated within greenhouses using renewable energy and reverse osmosis, however not an NBS (Hristov et al., 2021). Current mapping of such ecosystem-level interventions in the study area is required to propose solutions to balance the use of multiple water sources and increase resilience to water scarcity.

4.4. Waterwise Solutions in Ancient Algarve

Throughout the development of the Mediterranean culture, water has been a limiting resource, crucial for the living standards establishment of villages and culture. The Algarve, the southernmost region of Portugal, took its name from the Moorish name *Al-Gharb,* translated as 'the Beacon' and 'the West', an important area that served as an essential trading route (Vaz & Walczynska, 2011). The Arabs were responsible for bringing elements to the rural landscape that remained, such as irrigation measures, house architecture and trees, like almonds and carobs, while occupying this territory for over five centuries. They were great conservationists of water, creating the tradition of cisterns (Lourenço, 2018).

Water supply using wells and manual pipes was once standard practice in the region. They are reported to have been significant social spaces, presenting storage and distributing water functions. They were commonly dry during summer, except for the wells connected to permanent springs, where the densest settlements were established. Some structures were public, while others were family inheritance. Cisterns, such as the one at the Castle of Silves, were used for public supply until the 1980s. Cistern dimensions varied with their finality: supply a house, a town or irrigate a crop field. The large harvesting surfaces were used during summer as drying surfaces for crops. At homes, first rains or *first flushes* were discarded by closing the whole with cork. Every two years, the cistern was emptied to be cleaned, and a decanter was present for regular cleaning. Internal walls were painted with a white lime solution mixed with iron oxide to maintain water quality and reflect light, preventing water oxidation. Limestone was also employed for water quality, and animals such as fish, frogs and turtles were used to eliminate mosquito larvae (Lourenço, 2018), showing a perception of ecosystem services.

The climate also assumed a decisive influence on towns and vernacular architecture during summer and winter. Edifications presented vast and open rooftops accessible by external stairs. As groundwater was a costly infrastructure, home cisterns were on the rooftops to store every rainwater drop and distribute it by gutters or drainpipes. When this water was insufficient, water was abstracted from other structures at the soil level, characterised by a tiled surface in a gradient to channel the water directly to a cistern (*eirado da cisterna*, in Portuguese) (Lourenço, 2018). For this reason, traditional shading features such as balconies, porches, terraces and water harvesting were incorporated into houses to increase yearlong 'climate comfort' in a region known for hot summers and water scarcity. Domestic rainwater harvesting systems were created using sloped roofing and guttering systems. In contrast, some used pitched roofs, eaves and gutters to diverge water into an underground cistern, to be shared by locals (Simões et al., 2019).

The so-called *Waterwise Solutions* (Sharma et al., 2017) to store rainwater persisted in the region, and it has been abandoned over time in favour of centralised supply systems. Such interventions are increasingly appreciated as sustainable conservation measures (Rodrigues et al., 2020).

5. Material & Methods

The selected study area encompasses the Vale do Lobo subsystem within the Campina de Faro aquifer in the municipality of Loulé, Algarve, Portugal. This area was chosen due to its high water consumption and overexploitation within this aquifer subsystem. It includes areas with different land uses. Intensive tourist and agricultural activities characterise the study area, such as golf courses, resorts, luxury residences, citrus and watercress production, and the irrigation of large public and private green areas. These activities contribute to the poor quantitative status of the groundwater body in this area.

Apart from a wide literature review, this work is based on field observations, interviews and data collection during workshops conducted in the context of the eGROUNDWATER project, to be approached in the following sections.

5.1. Field Visit

A field visit was conducted on May 8th 2023, to obtain an inside view of the community, identify water sources in use, potential sources within the study area, and observe existing Nature Based Solutions (NBS). The photographic register was employed to characterise the study area and give support in the elaboration of questions for the interviews.

A thorough literature review was conducted to present a different paradigm for water governance, identify multiple water sources, characterise, and present their pros and cons, while evaluating their potential use as sources within the study area. Additionally, the regulations governing the use and adoption of each water source were assessed based on the current Portuguese legislation and policies.

5.2. Data Collection

This work profited from data collected at two participatory workshops and a public debate held by the Portuguese research team of the eGROUNDWATER Project (eGW, 2023), which has previously worked in the area. Given their involvement with the study area, interviewees were selected after mapping water stakeholders - an exercise at one of the workshops. The workshops aimed to gather insights from stakeholders and experts in the field and observe their interaction (**Figure 10**). The perceptions and roles of public entities have been assessed by analysing the results of a workshop.

The eGROUNDWATER Project aims to support participatory water management in four aquifers in the Mediterranean region and employ designed and tested enhanced information systems (EIS) to improve the understanding of groundwater systems and engage stakeholders to co-develop sustainable groundwater (eGW, 2023). The workshop analysed in this work was designed for their institutional partners - public and private water stakeholders already engaged in the research. During a focus group held by the coordination of the project, the stakeholders identified the main causes behind the challenges to the sustainable management of the Campina de Faro aquifer, prioritising three for detailed debate in smaller groups. The themes prioritised were: (1) the difficulty of controlling illegal extractions; (2) extractions are superior to the aquifer recharge and excessive groundwater use; and (3) the irrigation of excessive public green spaces. The third problematic was selected to be approached in detail in this session, since the topic of employment of alternative water sources emerged spontaneously. The problematic of irrigating ‘excessive’ green spaces in the Campina de Faro aquifer was the selected topic to be described in detail and analysed in section '**6.1. Understanding Stakeholder Perceptions and Roles**'.

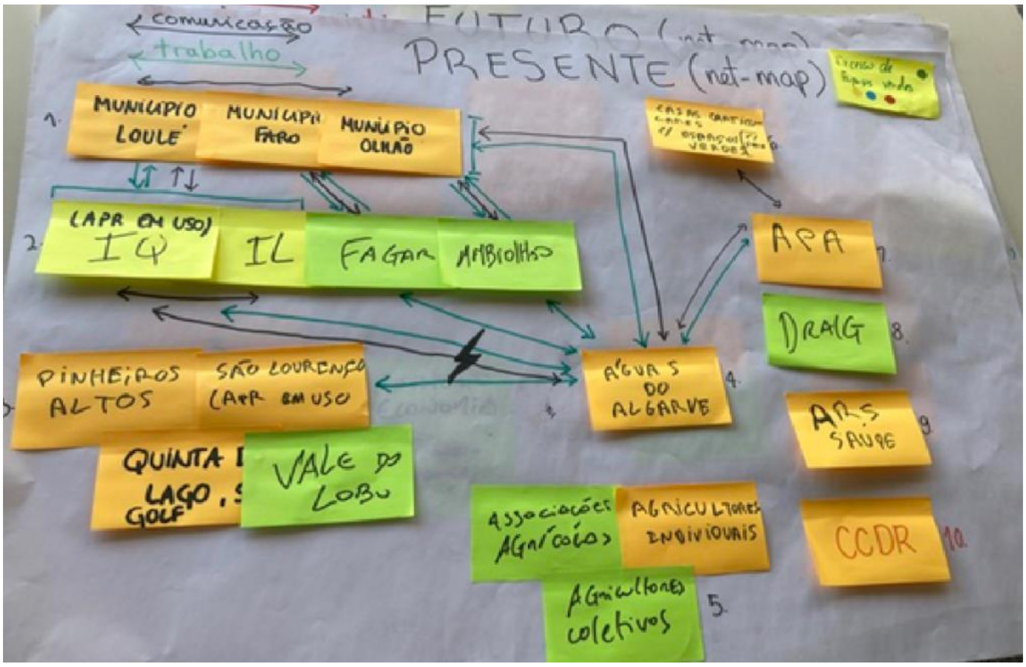

Figure 10: Map generated at the workshop. It was originated at the group that discussed theme (3) in the workshop with Institutional Partners of the eGROUNDWATER Project (Varanda et al., 2022).

The first collaborative exercise focused on the identification of water governance stakeholders and design of a map to represent the collective view on the current water governance in the area. It was joined by the representatives of two local infrastructure companies of the Loulé municipality, Inframoura and Infraquinta; the Loulé City Hall; and the regional water company Águas do Algarve (AdA). First, they were asked to draw a map with all institutions involved in the irrigation of public spaces, then connecting organisations through 'black' arrows to represent communication relationships and 'green' arrows to represent work relationships. They have been encouraged to signal conflicting interests between the two categories of relationships by drawing a 'thunder' sign on the respective line. During a second stage, the representatives have been joined by the representative of the Portuguese Environmental Agency (PEA) to design a map of an expected future scenario, or an ideal scenario, representing and naming the entities which should be present and drawing 'black' arrows to represent inter institutional collaborative relationships that should exist between the actors. The third and last step was to prepare an action plan with recommendations to solve the problem, but it will not be explored in this work.

A public debate on the viability of a groundwater irrigation association for Campina de Faro was organised by the eGROUNDWATER Project. After such workshops, where the suggestions for the composition of a 'meta organisation' that could work as an association for all users emerged. It constituted a public section attended by representatives of public entities, producers, and civil society. The successful case of the Central Irrigation Board of the Eastern Channel ('Junta Central de Regantes de la Mancha Oriental, in Spanish), in Valencia, Spain was presented, followed by a Questions & Answers session and subsequent open debate and assessment of participants' perceptions through voting.

5.3. Interviews and Validation

The main research methods selected were field observation, combined to interviews with water stakeholders. Challenges were encountered when attempting to interview political decision-makers and some institutions, mainly in terms of feedback absence. Online interviews were carried out, in a broad sense, to assess and evaluate the potential of Nature Based Solutions (NBS) as multipurpose solutions to promote increased water availability, as well as alternative water sources, regarding their utility and viability for implementation at the study area. Questions were designed in order to collect perceptions from stakeholders from public and private organisations on alternative water sources currently employed and to-be-used in the study area; understand the potential of alternative water sources to match water demand; evaluate previous knowledge of NBS, most known-examples, perceptions of usefulness and viability of typologies for the study area; understand the challenges to implement NBS in the area; perceive how stakeholders classify natural features as nature-based and evaluate their value; present an example on the use of NBS in golf courses, evaluate the likeliness for implementation and understand what measures are already in place; identify ways to engage and coordinate the various entities involved in water governance in the area, and also fund the interventions; and assess perceptions on whether is possible to employ multiple water sources and identify challenges and opportunities to enable balance amongst a number of different sources. The list of questions is present in **Annex I**, whilst answers are discussed in section '**6. Results and Discussion'**. The profile of interviewees (**Table 5**) was outlined through an online formular filled by the interviewees.

Table 5: Summary of the profiles of all stakeholders interviewed. The professional category, job and characterisation of the entity were also included. **S#**: stakeholder number (1-19), **Gen.:** refers to the interviewee's gender of the interviewee (F- Feminine or M- Masculine), **A.:** interviewee's age, **Ed.:** refers to the interviewee's schooling level (HE - higher education)*;* (Elaborated by the author).

S#	Gen	A	Ed	Category	Type of entity
1	F	42	HE	Professor or Researcher	Local University
2	M	41	HE	Technician	City Hall
3	F	54	HE	Professor or Researcher	Local University
4	M	61	HE	Technical Decision-Maker	Local Resort #1
5	M	56	HE	Technician	Regional Directorate for Agriculture and Fisheries
6	M	59	HE	Professor or Researcher	Local University
7	M	54	HE	Professor or Researcher	Local University
8	F	59	HE	Professor or Researcher	Local University
9	F	37	HE	Technical Decision Maker	City Hall
10	F	63	HE	Political Decision-Maker	Regional Tourism entity
11	M	61	HE	Technician	Regional Directorate for Agriculture and Fisheries
12	F	56	HE	Professor or Researcher	National Research Centre
13	M	59	HE	Technician	Regional Directorate for Agriculture and Fisheries
14	M	51	HE	Technician	Regional Directorate for Agriculture and Fisheries
15	M	54	HE	Employee at Resort/Golf	Local Resort #2
16	F	62	HE	Technical Decision-Maker	Regional Coordination and Development Commission
17	M	40	HE	Technical Decision-Maker	Municipal Water Company
18	F	39	HE	Technician	Portuguese Environmental Agency - Water Resources Division
19	F	38	HE	Activist	Local Activist

The feminine gender is declared in 55% of the cases, while 45% of the interviewees declared the masculine gender, and 0% declared other gender. All interviewees achieved Higher Education degrees, and their ages range from 37-63 years old. The 'Professor or Researcher' and 'Technician' categories are the best represented groups, with 31,57% of interviewees in each of the groups, followed by the 'Technical Decision-Maker' in 21,05% of the cases, and 'Political Decision-Maker', 'Employee at Resort/Golf' and 'Activist' with 5,26% of representation each. Interviewees represented public entities in 84,21% of the cases, private entities with 10,52%, and the Civil Society totalised 5,26% of interviewees.

Regarding the number of interviews, according to the scientific method, there is no fixed minimum number of interviews required in qualitative research, however the sample size for interviews rely on the point at which new data or interviews cease to provide significant insights or information, according to the principle of data saturation. Samples should be large enough to cover most perceptions, but if too large, information is repetitive, thus superfluous. An analysis of 560 PhD studies showed that 20 was one out of the two most common sample sizes, and that over 80% of all studies showed a minimum sample size of 15 (Mason, 2010). Hennink & Kaiser (2022) confirmed that data acquired from small sample sizes can fully represent participants' experience, and that the saturation point was reached at a narrow range of 5-17 interviews. For this work, determination of data saturation was done based on iterative analysis and ongoing evaluation of the collected data as interviews progressed, conducting additional interviews until the point of saturation, where little new information emerged, which was reached at the 19th interviewee.

To ensure the validity of questions for the interview, the questions were shown and evaluated by 10 expert reviewers based on the validation process used by Keyvanfar et al. (2018). For that, an online form was answered by reviewers from various professional backgrounds (**Annex I**), which aligned to the heterogeneous composition of the interviewees. Results of the evaluation are summarised in **Table 6**:

Table 6: Summary of the validation process. It aimed at identifying improvement needs in questions for interviews, according to clarity and relevance criteria. **E1-E10**: expert evaluators graded questions sections (1-5), **Con.:** refers to the conclusion of expert evaluators input, **V.:** questions are validated based on having more than 70% agreement for grades 4 and 5 (Elaborated by the author).

Criteria	Sections	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	Con.	Non-validated aspects
Clarity	**Section 1.** Interviewee profile	4	4	4	5	5	4	5	4	5	5	**V.**	
	Section 2. Use of alternative sources	3	3	4	5	5	3	4	5	5	4	**V.**	Wording of question 2.1
	Section 3.1. Knowledge of NBS and utility to the study area	5	3	5	4	4	3	4	5	4	5	**V.**	Image subtitled in English
	Section 3.2. NBS viability, difficulties and case evaluation	4	4	5	5	4	4	5	3	5	5	**V.**	Question 3.6 unclear objectives

Table 6: Summary of the validation process. It aimed at identifying improvement needs in questions for interviews, according to clarity and relevance criteria. **E1-E10**: expert evaluators graded questions sections (1-5), **Con.:** refers to the conclusion of expert evaluators input, **V.:** questions are validated based on having more than 70% agreement for grades 4 and 5 (Elaborated by the author - continuation).

Criteria	Sections	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	Con.	Non-validated aspects
	Section 4. Case study - NBS for golf courses	4	5	4	5	5	4	5	5	5	4	**V.**	
	Section 5. Water governance	5	5	5	5	5	3	4	4	5	5	**V.**	Annex I description not accurate
Relevance	**Section 1.** Interviewee profile	5	5	3	5	5	4	5	5	5	5	**V.**	Interviewee profile options missing
	Section 2. Use of alternative sources	3	5	5	5	5	5	5	5	5	5	**V.**	
	Section 3.1. Knowledge of NBS and utility to the study area	5	5	5	5	4	5	5	5	5	5	**V.**	
	Section 3.2. NBS viability, difficulties and case evaluation	5	5	5	5	4	5	5	5	5	5	**V.**	
	Section 4. Case study - NBS for golf courses	4	5	5	5	5	5	5	5	5	5	**V.**	
	Section 5. Water governance	5	5	5	4	5	5	5	5	5	5	**V.**	

The validation process consisted in grading each section of the questionnaire, (1-5 points) on aspects of clarity, relevance, and an analysis of qualitative feedback followed. The criteria for approving each section/group of questions were reaching a minimum of 60% of grades 4 and 5 (**Table 7**). The results of the questionnaire validation process are presented in the following tables:

Table 7: Results of evaluation carried out by expert reviewers. Results for grades 1-3 and 4-5, regarding clarity and relevance, are expressed in percentage (Elaborated by the author)**.**

	Section/Questions	Grades 1-3 (unclear to moderate clear)	Grades 4-5 (quite clear to very clear)
Clarity	**Section 1**	9,1%	90,9%
	Section 2	36,4%	63,7%
	Questions 3.1, 3.2 & 3.3	18,2%	81,9%
	Questions 3.4, 3.5 & 3.6	18,2%	81,8%
	Section 4	9,1%	90,9%
	Section 5	9,1%	90,9%

Table 7: Results of evaluation carried out by expert reviewers. Results for grades 1-3 and 4-5, regarding clarity and relevance, are expressed in percentage (Elaborated by the author - continuation)**.**

	Section/Questions	Grades 1 to 3 (irrelevant to moderate relevant)	Grades 4 & 5 (quite relevant to very relevant)
Relevance	**Section 1**	18,2%	81,8%
	Section 2	9,1%	90,9%
	Questions 3.1, 3.2 & 3.3	0%	100%
	Questions 3.4, 3.5 & 3.6	0%	100%
	Section 4	9,1%	90,9%
	Section 5	0%	100%

The profile of the expert reviewers is presented in **Table 8** below:

Table 8: Profile of invited expert reviewers for the validation process. It was outlined in accordance with their job title, sector of activity and their action in the context of a particular subtopic of this work (Elaborated by the author).

Expert reviewer	Job title	Sector of activity	Subtopic
#1	University researcher	University	Nature Based Solutions
#2	University professor	University	Alternative Water Sources
#3	PhD student & lecturer	University	Participatory Governance
#4	University lecturer	University	Alternative Water Sources
#5	University lecturer	University	Participatory Governance
#6	NGO consultant	NGO	Participatory Governance
#7	Wastewater researcher & Lab coordinator	Water & Sanitation	Alternative Water Sources
#8	NGO director	NGO	Participatory Governance
#9	NGO coordinator	NGO	Participatory Governance
#10	Attorney General of the Republic	Legislative	Legal regulations

All questions were approved in this validation process, and the feedback received was carefully considered and incorporated into the final questionnaire design (**Annex I**), as it follows:

- In the 'About the respondent' section, provide the option 'other' in 'Gender'; add the options ' Entrepreneur/self-employed' and ' Resident/Property Owner';
- In the Section 2 'Alternative Water Sources' provide examples of alternative water sources (treated wastewater, rainwater, desalinated water, etc.) in question 2.1;

- In the Section 3 'Nature Based Solutions' provide subtitles to all typologies in Portuguese, and also for all pictures provided and study area maps; formulate the question about NBS viability with fewer words; verify the purpose of question 3.6 and reword it to reflect the reason for the question;
- In the Section 4 'Case Study', clarify the meaning of the word 'viable'; Introduce the question by starting with 'In a study by the NGO...';
- In the Section 5 'Water Governance', correct description to reflect subsystem Vale do Lobo only; rewrite question 5.2 as it follows: 'What are the obstacles and difficulties in involving these various institutions?'.

6. Results & Discussion

6.1. Understanding Stakeholder Perceptions and Roles

6.1.1. Mapping of Involved Parties

In the context of the eGROUNDWATER project, the water governance within the territory encompassed by the Campina de Faro aquifer was the subject of an analysis conducted to identify stakeholders. This analysis also aimed to outline their interrelationships and highlight challenges in water management for the study area (refer to **Figure 11**). The list of identified institutions includes:

(1) Three municipalities - The City Halls of Loulé, Faro, and Olhão;
(2) A group comprising of four water management and infrastructure companies - Infralobo, Infraquinta, FAGAR, and Ambiolhão;
(3) Four tourism companies associated with golf activities which employ ApR - Pinheiros Altos, São Lourenço, Quinta do Lago, and Vale do Lobo;
(4) The regional public water company - Águas do Algarve (AdA);
(5) A group of agricultural associations, collectives, and individual producers;
(6) A group of private residences with green spaces;
(7) The National Water Authority: Portuguese Environmental Agency (PEA) - *Agência Portuguesa do Ambiente* (APA), in Portuguese;

(8) The Algarve Regional Directorate for Agriculture and Fisheries - *Direcção Regional de Agricultura e Pesca do Algarve* (DRAPAlg), in Portuguese;
(9) The Algarve Regional Health Authority - *Administração Regional de Saúde do Algarve* (ARS Algarve), in Portuguese;
(10) The Algarve Regional Coordination and Development Commission - *Comissão de Coordenação e Desenvolvimento Regional do Algarve* (CCDR Algarve), in Portuguese.

Within this context, four golf companies and Infraquinta were identified as entities utilising treated wastewater for irrigation. Additionally, four stakeholders (DRAPAlg, ARS Algarve, agriculture associations, and CCDR Algarve) participate in water governance within the area but are not directly involved in the irrigation of green spaces.

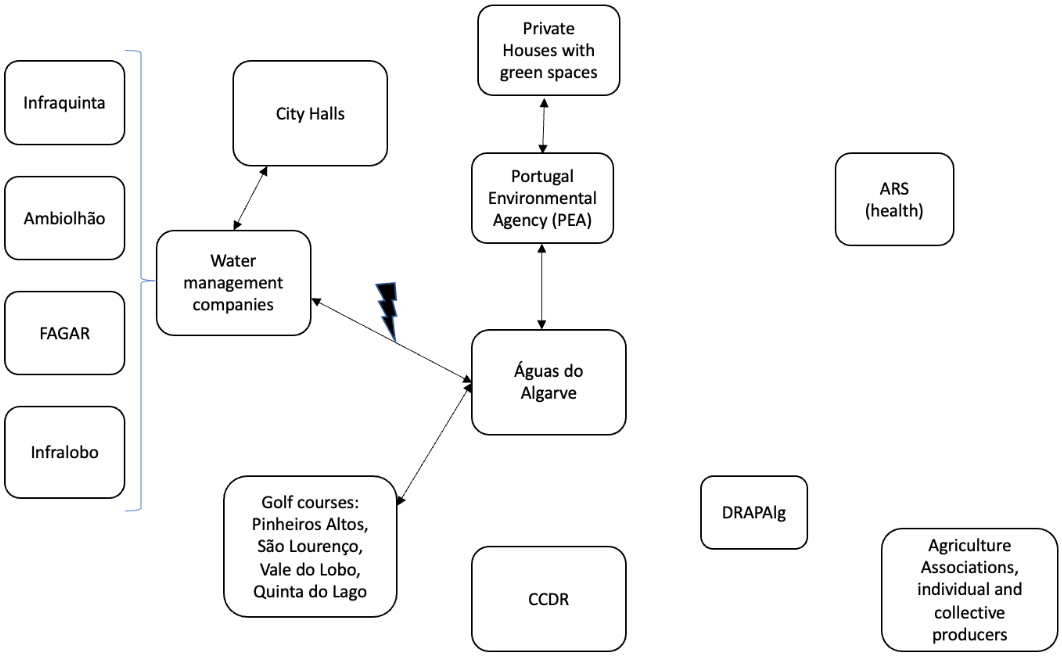

Figure 11: Map of the present situation. Identified stakeholders relationships in the context of irrigation of green spaces at the Campina de Faro aquifer (Translated from Varanda et al., 2022).

Challenges in communication among public infrastructure bodies were noted. A representative from a public infrastructure company highlighted communication constraints with Águas do Algarve, a pivotal stakeholder in the diagram, making it central to problem-solving. The discussion encompassed topics such as technology use for efficient irrigation monitoring, the paradoxical use of potable water for irrigation in a water-scarce region, high water consumption in specific residential areas, City Hall's responsibility in enforcing water-efficient measures for new projects, and the issue of unauthorized groundwater extraction.

A potential future scenario was contemplated (refer to **Figure 12**). The participants introduced two new entities, the Ministry of Finance and the Ministry of Economy, that could be brought to promote better management and communication amongst public water management and infrastructure companies and AdA, since they have different views of the situation. Concerns regarding the collaboration between AdA and the Ministry of Economy were raised. Three significant changes were proposed:

1. Direct engagement of City Halls in legal licensing processes for green spaces, regarding private residences;
2. Collaboration between City Halls and the PEA to establish regulations for monitoring private groundwater consumption, advocating for a legal change to convert groundwater into a public resource while further developing relevant legislation to safeguard water resources;
3. Formation of a new entity, overseen by CCDR, involving diverse stakeholders in water governance, analogous to the Association of Algarve Municipalities (AMAL) but inclusive of key users such as tourism and agriculture companies.

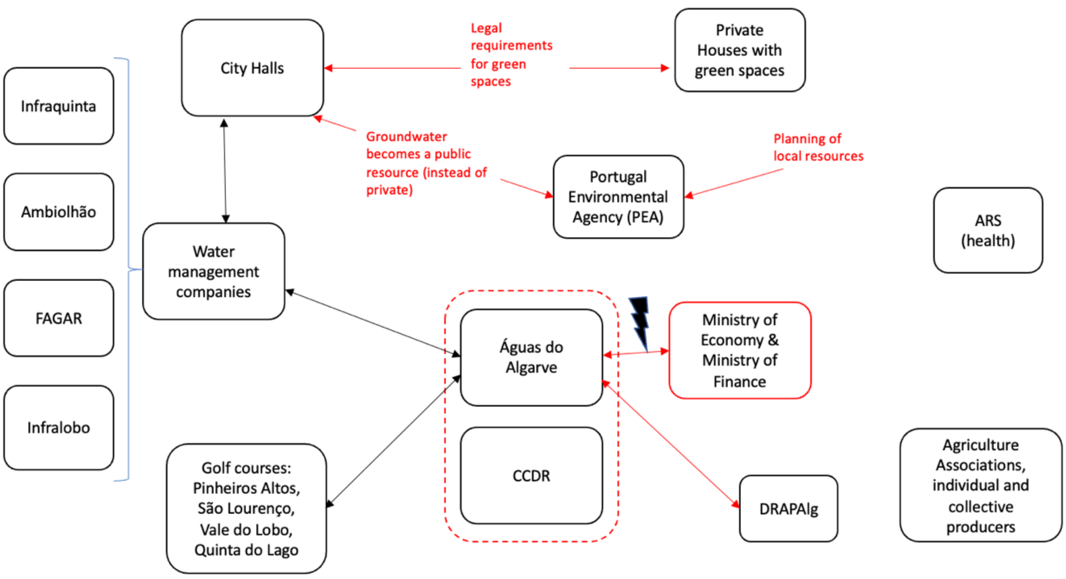

Figure 12: Map of a potential future situation. Identified stakeholders, proposed measures and ideal relationships in the context of irrigation of green spaces in the Campina de Faro aquifer (Translated from Varanda et al., 2022).

Apart from two new stakeholders, the transformed map introduces a fusion between two governmental bodies for an improved water governance, as well as three novel regulations concerning the City Halls and the PEA. To sum up, the changes required for a better water governance of the area would be regulatory and institutional; regulations would help secure efficient water use and an umbrella institution which could integrate the water management institutions that participate directly or indirectly in water governance. Participants emphasized the logical necessity of mapping and controlling water consumption for public green spaces.

Even though the exercise was in the context of irrigation of public spaces, the actors identified are the same actors that would be involved in the implementation of Nature Based Solutions (NBS), and for this reason, similar results would be expected.

Additional institutions involved in the water governance of the area were mentioned during interviews:

(1) The Environmental Ministry (EM) - *Ministério do Ambiente* (MA), in Portuguese;
(2) The Institute for Nature Conservation and Forests - *Instituto da Conservação da Natureza e Florestas* (ICNF), in Portuguese;
(3) The Water and Waste Services Regulation Authority - *Entidade Reguladora dos Serviços de Água e Resíduos* (ERSAR), in Portuguese;
(4) The State Secretariat for Tourism;
(5) The Algarve Tourism Authority - *Região de Turismo Algarve* (RTA), in Portuguese;
(6) Parish councils;
(7) Local decision-makers;
(8) Technicians and managers from public entities;
(9) Civil Society Organisations;
(10) Universities;
(11) All aquifer user sectors and groups;
(12) The Working Group ‘Water Agenda’ (coordinated by the tourism sector);
(13) Producer and irrigators associations;
(14) Residents associations;
(15) Protected areas managers;
(16) Investors;
(17) Private companies in the area;
(18) and more broadly, all productive sectors in society.

Stakeholders were solicited to identify actors, however entities not previously cited in workshops were named mostly by Universities and Public entities.

6.1.2. Engagement at the Institutional Level

When questioned regarding the challenges associated with unifying institutions within the context of implementing Nature-Based Solutions (NBS) and alternative sources in the study area, the primary obstacles recognized in mobilizing and harmonizing a variety of organizations for collaborative action include:

- Raising awareness of managers and technicians, centred around each organisations' particular objectives ('each institution paddles to its own side');
- Overcoming resistance to change, especially in terms of shifting mentalities (tourists, golfers, managers, decision-makers) towards acceptance of changes in the landscape;
- Persuading decision-makers to invest in NBS and ensuring the participation of private and other stakeholder during the project phase;
- Demonstrating the viability of solutions and tackling the absence of some technical bodies;
- Establishing mechanisms for City Halls to issue binding opinions on new constructions and water utilisation, namely demanding adoption of measures such as rainwater harvesting systems and native plant gardens;
- Absence of collaborative efforts in water management;
- Creating an atmosphere conducive to constructive dialogues amongst leaders;
- Facilitating access of private entities to public funding (consortium formation, mediation of Universities/public entities);
- Confronting excessive bureaucracy to enable access to alternative water sources, besides the lack of supportive regulation (i.e. stormwater management, NBS);
- Addressing the inclination towards technological solutions over nature-based alternatives;
- Managing communication difficulties, negotiation, and the creation of agreements between entities; understanding different technical languages, work contexts and challenges; assembling varied viewpoints and adopting equitable measures across sectors, which requires a certain level of detachment to one's own interests; overcoming financial motivations; improving transparency in information sharing.
- Creation of intervention manuals, and forming an extra working group amongst many;

- Addressing a perception of injustice from private entities (demanding public entities to take action against City Hall losses, unlawful extractions, and wastewater treatment plant enhancements).

6.1.3. Formulated Advice

Several significant recommendations emerged from the exercise within the realm of adopting alternative water sources and advancing water sustainability. These suggestions are conducive to the adoption of sustainable irrigation practices and the formulation of recommendations. The recommendations for improvement include:

(1) Modification and effective implementation of the municipal urbanisation plan to prioritise water efficiency within private green spaces;
(2) Establishing a regional water management observatory for better management and monitoring of the resource;
(3) Creating a centralised web platform to enable access to reliable information on water resources and consumption in green spaces;
(4) Altering legislation to elevate the status of groundwater, transitioning it from a private resource to a public asset;
(5) Fostering collaboration among water governance institutions to enhance surveillance and regulatory measures;
(6) Enhancing infrastructure to ensure the optimal utilisation of treated wastewater in terms of both quality and quantity;
(7) The renovation of both private and public green spaces to reduce water consumption.

6.1.4. Establishing Collaboration

A case-study in Spain inspired participants on alternative possibilities of collaboration for aquifer management between private and public stakeholders, jointly with the government. It was presented during the previously mentioned debate by two delegates of the Central Irrigation Board of the Eastern Channel ('Junta Central de Regantes de la Mancha Oriental', in Spanish), in Valencia, Spain. This entity emerged as a response to a drought in 1994, when individuals accepted that there was a problem after sanctions and fines proved inadequate. A formal group was established with governance powers over aquifer management, and over time, it evolved into a public law entity affiliated with the Hydrographic Confederation. The transformation implied mandatory involvement of all users and sectors in a collective manner, with a general assembly, a governing body (comprised of 13 members), and an irrigation jury (comprising 4 members). The latter apply sanctions when limits are exceeded by users, affecting the volume available for their use in the following year. The management is done through the integrated governance of all water sources, and since 2007, outcomes favoured the achievement of a positive water balance.

Another possibility of inter-stakeholder partnerships emerged during the debate on the viability of a groundwater irrigation association for Campina de Faro organised by the eGROUNDWATER Project. It is the concept of a 'Meta-Institution', or an institution comprised of institutions, that would be similar to the Association of Algarve Municipalities (AMAL, in Portuguese), but instead of municipalities. It would aim at the promotion of collaboration and communication across water stakeholders, including users and all strategic key decision-makers arranged in a sort of umbrella institution.

6.1.5. Financial Support for Solutions

In the context of financing Nature Based Solutions (NBS), the prospect of investment from private or public entities, was regarded as improbable. A divide was observed: all interviewees from public entities with the activist addition were aware of EU funds and mentioned that privates should pay for their implementation on private land, while private interviewees only mentioned that, in any case, it should be funded by the government.

The Recovery and Resilience Plan fund (PRR - Plano de Recuperação e Resiliência, in Portuguese) was the most mentioned, readily available for initiatives linked to the Water Pact, given their urgency. Other available European funds, such as Portugal 2030, are administered by the Algarve Regional Coordination and Development Commission. The EU Horizon 2030 was also acknowledged, however difficulties for organisations not affiliated to Universities/ or public entities to join a consortium.

6.2. The Potential of Nature-Based Solutions to Increase Water Availability

6.2.1. Observed Nature Based Solutions in the Study Area

The use of multipurpose Nature Based Solutions (NBS) within the Vale do Lobo subsystem of the Campina de Faro aquifer presents an additional avenue to increase water availability, facilitate aquifer recharge, foster new wildlife habitats, and increase human comfort in the study area, among other advantageous outcomes. During a site visit, most NBS identified encompassed green areas, ponds, and wetlands (**Figures 13 A & B**).


Figure 13 (A & B): Green areas at Vale do Lobo. They feature a mix of native and exotic flora, permeable materials, and a small pond (Author's archive).

However, certain aesthetic interventions were observed, exemplified by impermeable ponds constructed with plastic linings, subsequently filled with groundwater (**Figure 14**). Such interventions, although visually appealing, deviate from NBS principles as they incorporate artificial materials prone to causing pollution, microplastic liberation, and potential harm to biodiversity. Interviewees were not questioned about such artificial interventions. In addition, these interventions restrict water infiltration into the soil and aquifer and consume energy to maintain water levels.

Figure 14: Artificial lake at Vale do Lobo. It was constructed using a plastic lining, visibly deteriorated, and dependable on groundwater to be filled up (Author's archive).

6.2.2. Previous Familiarity with Nature Based Solutions

A notable 68% of the study participants demonstrated prior acquaintance with the concept and typologies of Nature Based Solutions (NBS). Examples encompassed rainwater harvesting systems, cisterns, retention basins, bioswales, community gardens, wetlands, terraced agriculture, permeable watercourses, lakes, green zones, infiltration zones, rainwater gardens, green roofs, agroforestry reforestation techniques, and soil restoration. However, four interviewees disregarded stormwater-based solutions as pertinent due to arid conditions throughout most of the year. The area has experienced a series of storms and floods, however, only one interviewee were aware of that.

Concrete examples of existing NBS within the study area were cited by 57,9% of interviewees. Isolated examples were cited, suggesting a scarce number of interventions. These included a small number of residential rainwater harvesting systems (mainly roofs and ponds) in Quarteira, whose adoption by a local resort is delayed due to the lack of a visually appealing solution. There were a few mentions to green roofs in Quarteira, and the traditional use of cisterns on small farms; a community garden ('Jardim das Comunidades') in Loulé, incorporating a number of adequate NBS such as retention basins and water tanks, intentionally implemented or revitalised by the municipality for stormwater management; a number of small interconnected ponds, green areas, native gardens, bioswales and retention basins adequated for stormwater management at a local golf course; as well as a scarce number of wetlands sustained by stormwater originating from nearby residences ('Dunas Douradas').

6.2.3. Prominent Nature Based Solutions for the Study Area

When presented with four categories of Nature Based Solutions (NBS) - 1. Green zones featuring native plants and trees; 2. Water filtration and revitalisation; 3. Bioswales; 4. Wetlands - as **Figure 15** evidence, interviewees were questioned about their suitability for the area. 42% of participants expressed that these all solutions held potential. Two participants stressed the need for customised experimentation and implementation, while another two advocated for a combined approach to optimise outcomes. The most favoured solution was '1. Green zones featuring native plants and trees' due to its simplicity, cost-effectiveness, adaptability, and other factors. Wetlands and bioswales were also highlighted for their water retention and infiltration potentialities, particularly relevant for agricultural areas. The solution '2. Water filtration and revitalisation' was less favoured, due to likely construction demands and uncertain outcome impact. Once again, some respondents highlighted that all stormwater-related solutions were less appealing, due to the region's reduced precipitation patterns.

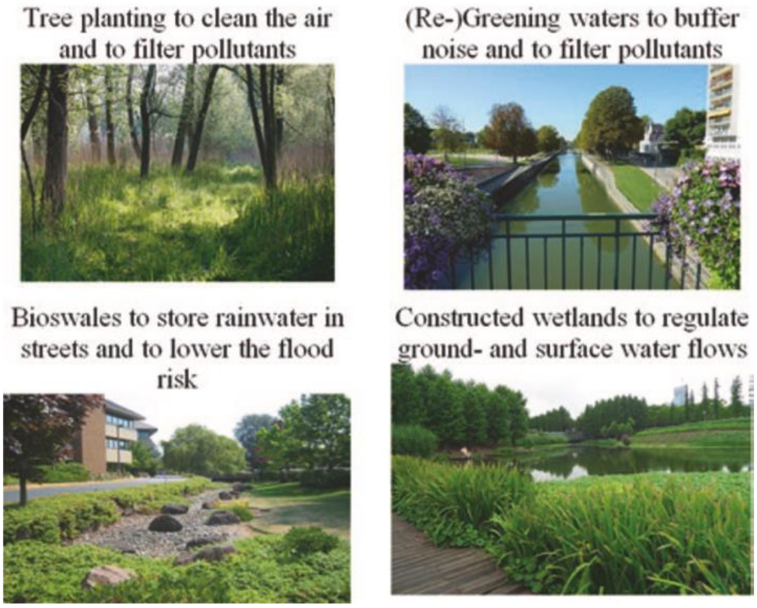

Figure 15: Four typologies of Nature Based Solutions. There have been presented for participant evaluation (Kabisch et al., 2017).

Regarding the viability of these four typologies, five participants concurred that all options held potential. The most viable choice, cited by 68,4% of the participants, was '1. Green zones with native plants and trees', due to its multifunctionality, positive impact on the water cycle, facilitated implementation, relative autonomy from precipitation, and immediate feasibility. '3. Bioswales' were mentioned by 26% due to their flood prevention and water retention function, coupled with ease of implementation. Additionally, 42% of respondents identified '4. Wetlands', as viable due to their aesthetic appeal, alignment with golf activities, stormwater storage capacity, and potential for natural area revitalisation. One interviewee noted that these solutions were all viable when comparing their implementation costs, considerably lower than conventional engineering approaches. Another participant indicated that the three solutions collectively contribute to increased water availability in the area. The final option '2. Water filtration and revitalisation' was declared viable once and marked unviable twice, based on space and investment requirements.

6.2.4. *Designating a Local Wetland as a Nature Based Solution*

Situated within the Vale do Lobo resort near the Dunas Douradas' Elevatory Station for Wastewater and Maria's Restaurant, the 'Dunas Douradas wetland' (**Figure 16**) remains an area for which scarce information is available. The City Hall informed that it is primarily fed by a riverside and stormwater collection from the drainage system. The notion of the wetland being supplied by treated wastewater was dismissed by the City Hall. Despite its presence in the Military Chart, the origins of the wetland remain indefinite. Natural areas are typically attributed a name upon. However, this is not the case for this wetland. It could potentially constitute a naturally occurring aquifer upwelling (groundwater dependent ecosystem zone), or even a requalified swamp, engineered to retain stormwater from nearby areas.

Figure 16: The wetland at Dunas Douradas. It comprises a green area in its surroundings and apparently lacks connection to Ria Formosa (Author's archive).

Even if artificial, the reason for its construction remains unknown - potentially aesthetic, given the area's prominence as a touristic site. An overwhelming 95% of the interviewees acknowledge this area as a Nature Based Solution (NBS), citing its multifunctionality. However, one participant was unsure due to scarce information provided. Reasons behind its recognition as an NBS include increase of water availability, facilitation of stormwater storage, provision of a constant water supply for flora and fauna, flood prevention potential, biodiversity habitat, natural supply devoid of energetic expenses, prospective benefits for water infiltration and aquifer recharge, water cycle regulation, microclimate creation and evapotranspiration promotion. Additionally, the wetland has ecological functions in place and constitutes a valuable water body considering the dry climate. Identified potential functions are irrigation, drought mitigation, and civilian defence purposes, such as firefighting.

Numerous interviewees concur that an increased number of similar areas, if multifunctional could be beneficial by revitalising the site, for instance the wetland at Dunas Douradas, promoting infiltration and water flow control, restricting saline intrusion, and potentially serving as models for implementation in other areas.

6.2.5. Main Challenges Identified for Nature Based Solution Implementation

Challenges to the implementation of Nature Based Solutions (NBS) within the Vale do Lobo subsystem of the Campina de Faro aquifer are consistent with issues documented in other cases. The lack of national regulation fomenting stormwater management and implementation of NBS was mentioned as decisive. There is a lack of cultural and political acceptance of NBS, as entities are not satisfactory educated about NBS and must be convinced of their value, outcomes and assured of investment retrieval to consider their implementation, yet need to be persuaded to work collaborative in during the project phase to maximise the benefits that an NBS will bring to the area selected. This is, in itself, a change of mentality, since it is relatively uncommon for water governance to be participatory and decentralise decision-making. Another kind of mentality change is required, one that values the ecosystem services provided by autochthone vegetation and considers the use of local species as fundamental, desirable and visually appealing. The common mentality across experts is to favour practical and standard engineered solutions and neglect the non-technical dimensions of a problem, where environmental concerns often reside and where engineered solutions frequently fall short - however, NBS have an interesting potential as holistic solutions that remain unexplored.

The main challenges mentioned for the implementation of Nature Based Solutions (NBS) at the study area are:

- Public and private institutions are unaware of NBS and their benefits or do not give them proper attention - campaigns could be in place;
- Current mentality, which devalue native plant species and dry gardens;

- Waste of water resources in new buildings resulted by the installation of solar water heaters, while water saving systems should be prioritised;
- Belief that solutions should come only from the government;
- Contradictory notions between public and private entities having will and funds available - divided opinions, since some think public entities are more open and capable than privates, and vice-versa;
- Private entities complain about a supposed 'decrease in competitivity' that some NBS may cause, lack of access to public funding to enable their implementation and claimed that the government should be funding these initiatives over accountability of tourism businesses;
- Legislation gaps to foment alternative origins (ApR, stormwater, managed aquifer recharge);
- Convincement of private entities;
- Flattened terrain difficult implementation of retention basins;
- High initial cost but long-term benefit (often unknown) discourages stakeholders;
- High cost of land in the study area, as well as dense urbanisation and NBS high space requirements;
- Rejection of NBS in face of technological solutions;
- A questionable lack of qualified staff to co-design and implement NBS;
- Absence of local and well-studied and monitored NBS.

While the concept of Nature-Based Solutions (NBS) is recognized and there are existing examples, their adoption in the study area remains limited. Interviews with various stakeholders revealed disagreements regarding the source of funding for these interventions. Nevertheless, there is no shortage of private or public funds according to the interviewees, as exemplified: 'there are PRR funds, all issues related to the water pact are favoured, other funds are available until 2030 and capital is immediately available...', 'there are PRR funds and others that make no obstacle (to finance) to NBS, but it could be plausible that they are fund directly by the resorts...' and 'there is money (referring to resorts and golf enterprises) and they will do anything to have water...'.

6.2.6. Nature Based Solutions to Increase Water Efficiency at Golf Courses

All interviewees have been presented and inquired about a pre-existing project of a Nature Based Solution (NBS) aimed at enhancing water efficiency on British golf courses (**Figure**

17), study participants discerned similar strategies implemented in the study area. The employment of lower water-consuming grass species, such as Bermuda grass (*Cynodon dactylon*) and resilient varieties from South Africa adapted to drought and salinity were highlighted at local golf courses. Additionally, gardens featuring native plant species are already an occasional reality. Efforts to reduce irrigated and grassed areas extended beyond public green areas, encompasses golf courses as well. Furthermore, the utilisation of treated wastewater (ApR) by both private and public entities emerged as an adaptation strategy. Some interviewees pointed out the concept of grassless courses (xeriscapes) found in the Middle East and Texas, USA, as potential adaptations for Algarve's context. Only one interviewee expressed scepticism about the actual presence of NBS in the study area.

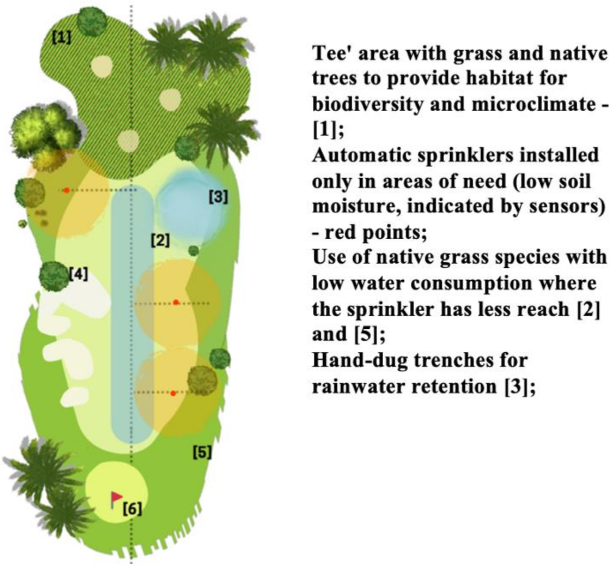

Figure 17: The Nature Based Solution proposed for golf courses. They are aimed at enhancing water resource efficiency and conservation (Surrey Wildlife Trust, 2022).

Approximately half of the interviewees confessed uncertainty about the viability of this solution, with only 47,36% expressing confidence in its success. None deemed it unviable. A recurring affirmation was that NBS should be tailor-made for the unique attributes of each golf course, and it is the responsibility of the golf enterprises to assess and validate their viability. While unsure about local golf courses, one participant noted that other courses in the Algarve employed water recirculation, irrigation runoff collection through trenches, and internal water management practices.

Regarding opportunities, there is an increasing number of publications showing evidence supporting NBS, however, not specifically for the study area. There is a characterised problem of water scarcity and aquifer overuse which could be solved, in part, by the joint use of alternative water sources, NBS and waterwise strategies. In this sense, pioneering work could build political argument to encourage not only their implementation, but a shift in local water governance and management. Currently, the water crisis is on the spot and solutions are being discussed, so innovation might be possible. One interviewee mentioned that golf resorts could create courses inspired by xeriscapes and by lowering prices, attract a different social extract of golf players and increase accessibility to the sport. The main opportunities identified for the implementation of the proposed NBS (**Table 9**) centre around the demand for sustainable and water-efficient certified golf courses, the willingness of private and public entities to embrace solutions, increasing acceptance of native plant species, potential enhancements in golfing experience, environmentally aware residents, prospects of experimentation and innovation, and availability of financial resources. These opportunities may create conditions for a mentality shift that seems to be required to promote NBS as worthwhile solutions for the area, as mentioned before.

Table 9: Summary of opportunities and challenges to implement Nature Based Solutions in golf courses. Topics are followed by the number of times they were mentioned, in brackets. The absence of a number means that it has been mentioned once (Elaborated by the author).

Opportunities	Challenges
• Certification in water efficiency for golf courses (4); • Private sector willingness to implement solutions (4); • Enhanced current acceptance and use of native plant species by local entities (3); • Environmental aware local population (2); • Openness for experimentation and innovation, due to the pressing need for water(2); • Availability of public and private financial resources (2); • Municipal water companies' inclination toward solution implementation (2); • Creation of accessible 'second division' golf courses; • Collaboration between environmental experts and golf course designers; • Foment on-site water retention in NBS features;	• Shift tourists' and golfers' perspective on the demand for constant greenery (8); • Maintain courses' distinct characteristics while reducing water consumption (8); • Sustain competitiveness and appeal for the English market (7); • Convince golf enterprises to engage in participatory water management (4); • Integrate native plant species for shade and fresh air preservation (4); • Educate golf course designers on NBS (3); • Potential absense of water available for this economic endeavor (3); • Convince privates to invest in NBS with their own capital (3); • Popularise the use of drought-resistant vegetation (2); • Resolve the paradox of 'closing the tap' while irrigating without restraint;

Table 9: Summary of opportunities and challenges to implement Nature Based Solutions in golf courses. Topics are followed by the number of times they were mentioned, in brackets. The absence of a number means that it has been mentioned once (Elaborated by the author - continuation).

Opportunities	Challenges
• Optimisation of local wastewater treatment plants; • Augmentation of water availability in the Campina de Faro aquifer through water supply diversification; • Availability of Recovery and Resilience Plan (PRR) funds; • Initiation of transformative water management shifts.	• Inconsistent 'year-round' rain; • Convince individuals and entities to operate changes in their water use; • Reduce land sealing; • Educate residents and landscaping firms; • Adapt golf to Algarve's climate incongruity; • Contend with the perception of high NBS implementation costs; • Manage elevated client expectations at resorts and golf courses; • Embrace the concept of 'grassless' golf courses.

On the other hand, there is no guarantee of a mentality shift and that water use in this touristic area can become sustainable. Seasonal stormwater management could have a significant impact on the study area's water balance. Nevertheless, convincing citizens and organisations to operate changes may depend on a prominent institution championing the concept (also NBS). The main challenges comprise mindset shift of tourists and golfers regarding golf course aesthetics, achieving water consumption reduction while maintaining habitual appearance, retaining appeal to key markets like English tourists, involving golf enterprises in participatory water management, integrating shade and fresh air through native plant choices, awareness raising among golf course designers about NBS applications, addressing potential water scarcity in the golf sector, spatial demands for NBS implementation, absence of native grass species, and popularisation of drought-resistant vegetation usage. The development of work in close collaboration with the tourism sector would be required.

6.3. Enablers & Constraints to Promote a Balanced Water Use

Regarding alternative sources, most interviewees (73,7%) are aware of the use of treated wastewater (ApR) in the study area, an alternative source cited by over 94% of interviewees. A considerable number (31,6%) indicated its potential use. However, respondents generally agreed (over 90%) that current water needs are not met by alternative sources, and only a minority (10,5%) expressed optimism about rectifying this in the future. ApR was the most considered source, and interviewees were supportive of its use. Stormwater, due to infrequent precipitation throughout the year, was less considered. Mentioned on a desalination plant was made, but not commented. Additionally, Managed Aquifer Recharge (MAR) emerged as another water source, raised by an academic.

Another objective of interviewing local water stakeholders was to identify factors capable of promoting balanced water usage within a multi-sourced local water system, if implemented. **Table 10** reveals a total of 21 enablers against 21 constraints.

Table 10: Enablers and constraints to a balanced water use. Topics are followed by the number of times they were mentioned, in brackets. The absence of a number means that it has been mentioned once (Elaborated by the author).

Enablers	Constraints
• Availability of Golf Courses and Resorts to adopt ApR (5); • Utilization of Rainwater Harvesting Systems and diverse water sources (4); • Enhance water sensitivity in the population and combine with effective water management (3); • Enhanced adoption and acceptance of ApR (3); • Mitigation of the aquifer overexploitation and facilitation of its recovery (3); • Use of retention basins to enhance water infiltration and complementary irrigation (3); • Stormwater management through Nature Based Solutions (2); • Imperative for resilience building via alternative water source utilization (2); • Formulation of public policies linking users, utilizations, and water sources (2); • Promote water valuation and stakeholder awareness in the Campina de Faro area (2); • Increase of ApR in public garden spaces in progress; • Existence of dedicated water conduits for main street irrigation at Quinta do Lago; • Coordination of ApR Expansion under a regional body Águas do Algarve, instead of a local body; • Optimal performance of local municipal water entities (Infras); • Potential implementation of differential water consumption pricing schemes; • Certification of small-scale water desalination units for enhanced sufficiency;	• Population persuasion needed for water conservation (4); • Investment in infrastructure for alternative water sources (4); • Lack of current availability of ApR to golf course utilization (4); • Harmonize diverse source origins with lower pricing emphasis (3); • Attainment of ApR water quality suited to agriculture and golf applications (3); • Coordinated and facilitated licensing and allocation of ApR (3); • Selective prioritization among alternative water sources (2); • Acceptance of changes required by NBS within the golfing community; • Acceptance of native plant gardens and other features by golfers, tourists and locals; • Strict foreign residents resistant to change in the landscape; • Perceived need for public investment to harness stormwater potential; • Unfavorable water balance within the aquifer; • Uncertainty regarding self-sustainability of NBS, with EU funds as viable alternatives; • Prioritisation of ApR through cost reduction mechanisms; • Deprioritise surface water usage via cost escalation; • Striking a balance between tourism promotion and water resource preservation; • Quantification of water consumption to promote prudent utilization;

Table 10: Enablers and constraints to a balanced water use. Topics are followed by the number of times they were mentioned, in brackets. The absence of a number means that it has been mentioned once (Elaborated by the author - continuation).

Enablers	Constraints
• Potential implementation of mandatory guidelines by the City Hall for water self-sufficiency in novel constructions; • Foreseen interconnection of Barlavento and Sotavento surface water systems; • Potential prioritization and subsidization of aquifer recharge among alternative sources; • Formulation of a participatory water use strategy within study area; • Possible amplified aquifer recharge during high-demand summer periods.	• Identification of optimal equilibrium in the aquifer for efficient water use; • Absence of individualized water consumption monitoring mechanisms; • Lack of gradual payment systems for water services; • Absense of comprehensive reports deliberating pros and cons of each water source.

Regarding water balance, the establishment of a more efficient collaboration and institutional coordination based on participatory processes would aid for this goal since there is a number of stakeholders with different functions and key roles in local water management. However, they are still not in full alignment to expand ApR, apart from users expectation to adopt this source. Some key constraints include infrastructural demands, insufficient ApR availability, complexity in blending diverse sources and reducing the cost of alternative sources, aligning water quality with intended use, bureaucratic licensing for ApR, the prioritisation of certain alternative sources, and the need to persuade the local population to conserve water. One stakeholder highlighted the bureaucratic process necessary for requesting ApR use, particularly for irrigation purposes such as golf courses, where meeting ApR category B standards is required. Wastewater treatment plants are in the process to adapt to this specification; however, it is expected that ApR availability will be greatly increased in the near future.

Once more, some stakeholders emphasise the impracticality of stormwater reuse due to the prolonged lack of precipitation. Nevertheless, a university participant mentioned that on managed aquifer recharge (MAR) indicated its potential to form a small component of the solution locally, however, it could provide 10% of current water use in the Algarve (Standen et al., 2023).

In contrast, as for enablers, willingness of private companies to adopt ApR, utilisation of rainwater harvesting systems and other alternative sources, a potential synergy of effective water management and conscious residents, increased ApR usage and acceptance, measures that allow aquifer revitalisation, use of multipurpose retention basins, stormwater utilisation through NBS, resilient water supply from multiple sources, potentiality for integrative public policies, and water valuation by conscientious stakeholders were highlighted. Another University participant mentioned the great potential of ApR to match all irrigation needs locally. The identified enablers show acknowledgement of the added value of stormwater management, also through the use of Nature Based Solutions (NBS), even though the expansion of ApR is clearly the preferred route towards water balance.

6.4. Towards a Water Sensitive Region enabled by Nature Based Solutions

A series of interventions related to Nature-Based Solutions (NBS) and the utilization of alternative water sources are implemented within the Vale do Lobo subsystem of the Campina de Faro aquifer region. In golf courses, there is progressive increase in use of treated wastewater (ApR), coupled with the reduction of grass-covered area, use of exotic lower consumption grass species and integration of native plant species adapted to the ecosystem. In addition, stormwater retention in ponds and similar structures is used to conserve water resources. The wetland at Dunas Douradas is intersected by a stream and collect stormwater from nearby residential and commercial zones. The place fosters biodiversity strengthens ecosystem services, and potentially contributes to aquifer recharge, and even though not explicitly designed as a NBS, the benefits are clear.

One finding is that the most documented NBS were aimed at embellishing surroundings with features as gardens, lakes and ponds. Some of these water bodies are permeable, ecologically diverse, and visited by fauna, while others deviate from the NBS definition.

The learnings and results of this work inspired the development of recommendations to increase water sensitivity in the Vale do Lobo subunit of the Campina de Faro aquifer area, considering the unique characteristics of the aquifer, local ecosystems and local community. The blueprint is articulated under three principles of practice to a future Water Sensitive Region:

1. Potential Sources of Water Emerging within the Region

- Upgrade and modernize wastewater treatment plants to ensure the safe treatment of wastewater to the B category and maximising the guarantee of adequate quality delivery - placing this origin at the top of priorities and use it to their full capacity;

- License local enterprises to desalinating seawater through environmentally sustainable methods, providing an additional source of freshwater while creating opportunities for circular economy;
- Explore the potential for Managed Aquifer Recharge (MAR) projects, where excess surface water is intentionally infiltrated into the aquifer during times of surplus, serving as a supplementary water source during periods of scarcity;
- Provide incentives or subsidies for installing rainwater storage tanks and revitalising cisterns safely in residences and businesses in a *fit-for-purpose* approach, connecting them to appropriate end uses, even if only used seasonally.

<u>2. Socio-Ecological Landscapes Providing Ecosystem Services</u>

- Implement green infrastructures such as raingardens, bioswales, and constructed wetlands to capture and filter stormwater, allowing it to infiltrate and recharge the aquifer naturally;
- Identify key recharge areas for the Campina de Faro aquifer and implement measures to enhance natural recharge through practices like maintaining permeable surfaces, protecting natural vegetation, and creating infiltration basins;
- Promote the region with NBS such as green roofs, urban forests, and permeable pavements into urban planning to enhance water retention, mitigate heat islands, and promote aquifer recharge;
- Employ and study certain Nature Based Solutions (NBS) typologies for stormwater management and irrigation purposes, even if only employed seasonally.

<u>3. Ecological and Sustainable Urban Water Governance</u>

- Organize workshops and training programs for residents, businesses, and local government officials to raise awareness about the benefits of NBS and alternative water sources, and promote the adoption of water sensitive practices as part of a strategy for water sensitivity;
- Develop and update policies that incentivize the adoption of NBS, the utilization of alternative water sources, and water conservation in new construction buildings offering regulatory support and financial incentives for sustainable water management practices;
- Implement a comprehensive monitoring system to track the performance of NBS, alternative water sources, and aquifer resource consumption/availability, enabling data-

driven adjustments and improvements, while making data available to the public and informed decision-making through an intuitive and accessible platform;

- Establish partnerships among government agencies, local communities, NGOs, academia, and private sectors to ensure the successful implementation of recommendations, with a focus on nature-based solutions and alternative water sources.

7. Conclusions

Regenerating the Campina de Faro aquifer, both qualitatively and quantitatively, imply in water conservation, use of alternative sources, close monitoring, and collaboration from all stakeholders. Currently, there are necessary undertakings required to enable sources such as ApR, raise awareness on water uses across sectors, and engage citizens and institutions. However, it is consensual the importance to enhance water availability, mainly through conservation measures and alternative sources, to drive local water security.

The adoption of Nature-Based Solutions (NBS) represents a water sensitive practice that offers a multitude of advantages for both humans and ecosystems. Implementing these solutions is not only practical and feasible but also fundable, as they align with the criteria for EU funding; however, bureaucracy can be an obstacle. One finding is that the majority of interviewed stakeholders exhibited a basic understanding of NBS and could identify their defining characteristics. Examples of existing NBS initiatives encompass green spaces, ponds, and wetlands, although some other interventions diverge from NBS principles. Nonetheless, the likelihood of widespread NBS implementation remains uncertain. A weakness identified is the absence of monitoring mechanisms that generate supportive data regarding the effectiveness of NBS in the area, and the recommendation to address it is the cataloguing and close study of existing NBS. Another finding is a prevailing mindset shared by various groups, including tourists, golfers, managers, and decision-makers, that comprehensive solutions like NBS might reduce businesses competitiveness.

Regrettably, there are not locally developed NBS projects designed and implemented collectively. Furthermore, quantifying the benefits provided by NBS is a crucial step for demonstrating the value and cost-effectiveness of these solutions, which could inspire the development of policies and regulations to promote water conservation and efficient usage at all levels. Another recommendation is that water efficiency and conservation must be prioritized in water governance for NBS to be appealing and convincing. There is an additional challenge of identifying areas for NBS implementation and making necessary modifications to the terrain. A shift in mindset is required concerning the acceptable appearance of public spaces such as gardens and golf courses. The use of native plant species needs to be valued, and it is essential to recognize that every individual share a responsibility and should actively participate in finding solutions. To sum up, NBS are not yet culturally and politically taken into consideration since key water legislation fails to acknowledge their added value and to encourage their implementation.

Both NBS and managed aquifer recharge (MAR) represent effective stormwater reuse solutions, yet some participants discounted stormwater-based options due to low precipitation levels. However, when combined with other alternative water sources such as treated wastewater (ApR), they have the potential to boost water availability and support supply-demand alignment within the Vale do Lobo subsystem of the Campina de Faro aquifer. Interview participants unanimously agree on the necessity of diversifying water sources, with ApR emerging as the most promising one that should see expanded adoption. Stormwater was found to have the potential to contribute approximately 10% to the increased water availability, while ApR has the potential to fulfil all irrigation needs.

Effective collaboration amongst stakeholders is decisive for adoption of multiple water sources and successful implementation of NBS strategies, however stakeholders reported only a few working groups dedicated to tackle the water issue in the region. Participatory governance is inherently connected to water sensitive practices, and in this sense, governance needs a significative change. One recommendation is that power structures should transition from isolated specialists and decision-makers deliberating in isolation to a collective effort of stakeholders co-designing and testing solutions. Establishing a meta-institution that brings together users, water stakeholders, and facilitates communication, informed decision-making, engagement, and solution implementation is recommended to coordinate institutions in water management endeavors. Policies should incentivize the adoption of NBS and alternative water sources, protect groundwater, and offer regulatory support and financial incentives for sustainable water management practices. The introduction of payment scales and tax breaks was suggested by interviewees as a measure to encourage responsible water use.

Achieving water balance in a multi-sourced water system, for interviewees, is primarily based on wide adoption of ApR, and the challenges associated with advancing and prioritizing ApR as a suitable water source. This entails developing infrastructure, increasing the volume of ApR produced with adequate quality, licensing organizations for its use, and offering ApR at a competitive price. NBS are seen as adjuvant sources with limited potential due to seasonal precipitation, though a positive impact of their use is acknowledged by most interviewees. This may result from cultural, educational, political, and institutional factors. Some important drivers towards achieving water balance include growing acceptance and adoption of ApR, building confidence in a multi-sourced system, and the willingness of entities to adapt and embrace alternative sources. NBS could have an impact when stakeholders recognise and appreciate their surplus value, primarily due to the perceived lack of visual appeal in existing solutions.

Recommendations towards a Water Sensitive Region reflect principles for Water Sensitive Cities applied to the specific context of the subunit Vale do Lobo within Campina de Faro aquifer. The repurposing of this region as a hydrographic basin with a high capacity to meet the area's water requirements sustainably would possibly drive the integration of NBS for increased water availability and a governance ready for collective collaboration and action. Ultimately, water should be placed at the core of the region's development and its fundamental value deserved to be acknowledged. The future establishment of a participatory strategy could serve as a crucial asset in realizing the sustainable water future sought by all stakeholders.

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Annex I

This annex provides the interview guide, including all questions and pictures used during the interviews - translated from Portuguese, the language in which interviews were conducted:

About the respondent:

1.1 Gender: Male ☐ Female ☐ Other: __________

1.2 Age: ______ years

1.3 Educational Qualification (levels of education and/or degree):
No qualification ☐ Elementary or basic ☐ Secondary ☐ Vocational or technical ☐ Higher education ☐

1.4 Occupation: _______________

1.5 Profile:

Political decision-maker ☐ Technical decision-maker ☐ Technical expert ☐
Farmer ☐ Environmental/social activist ☐ Resort/Golf Employee ☐
Entrepreneur/self-employed ☐ Gardening Company Employee ☐ Teacher or Researcher ☐ Resident/Property Owner ☐ Other ☐

2. Alternative Water Sources

2.1 In the context of water scarcity, the Campina de Faro aquifer is facing degradation of water quality and quantity. **What alternative water sources are being used/known to be used and for what purposes? (E.g., treated wastewater, rainwater, desalinated water, etc.)**

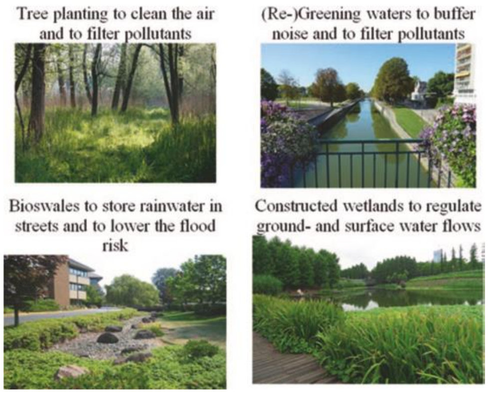
2.2 Can these alternative sources meet the needs? Yes/No, please explain.

3. Nature-Based Solutions

3.1 Have you heard of Nature-Based Solutions (NBS)? What examples do you know of?

3.2 Do you use any Nature-Based Solutions in general? Please provide more details about the type of NBS. (E.g., Figure 1: rain gardens, retention basins, ditches, wetlands, lakes, community gardens, green spaces, riverplain restoration, green roofs, etc.)
If the interviewee is not familiar, discuss the examples and continue the interview.

3.3 Among the presented NBS, which would be useful for the study area? (corresponding to the Vale do Lobo subunit of the Campina de Faro aquifer) Why?



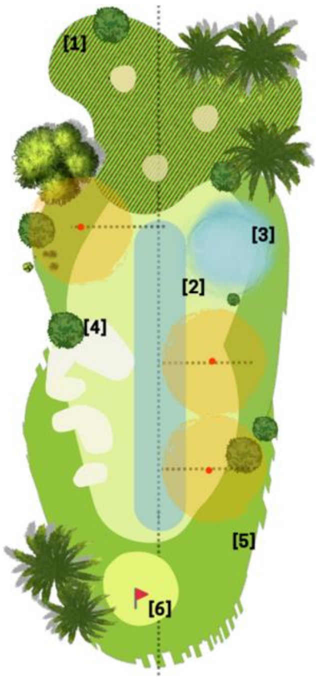
3.4 Which ones would be viable for implementation? Why?
Compare with what they have observed - understand why NBS are not used/considered.

3.5 What are the obstacles to using NBS? (they haven't thought about it/don't know/lack of qualified personnel/funding allocated to other solutions?)

3.6 In Dunas Douradas, an area of the Vale do Lobo Resort (near the Maria's restaurant and the Dunas Douradas Wastewater Pumping Station), there is a lake - it's not known if it's natural or artificial - that seems to be fed by a stream and rainwater.
Find out if the interviewees have additional information about the lake.

Is this a Nature-Based Solution? Why? Could the use of more solutions like this in the study area be beneficial? In what ways?

4. Case Study
4.1 In a study by the *Surrey Wildlife Trust* (2022), a Nature-Based Solution was proposed for golf courses to reduce water resource consumption.



Tee' area with grass and native trees to provide habitat for biodiversity and microclimate - [1];
Automatic sprinklers installed only in areas of need (low soil moisture, indicated by sensors) - red points;
Use of native grass species with low water consumption where the sprinkler has less reach [2] and [5];
Hand-dug trenches for rainwater retention [3];

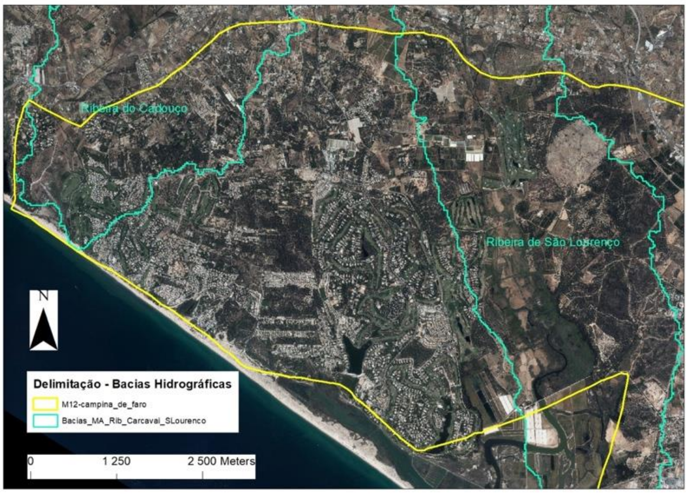
What NBS are currently being implemented in the study area? Do you think a solution like this is feasible to implement? What are the opportunities and challenges for its implementation?

5. Water Governance

5.1 Which institutions should be involved in implementing these interventions to increase water availability in VDL? What are the obstacles and difficulties in involving these various institutions? What is needed in terms of financing?

5.2 Is it possible to use multiple water sources, utilizing alternative sources in Vale do Lobo? What are the challenges and opportunities for a balanced use of water sources?

Attachment 1 - Study area (territory within the yellow zone), corresponding to the Vale do Lobo subunit of the Campina de Faro aquifer.



Attachment 2 - Watershed areas (outlined in black) and the Campina de Faro aquifer area (outlined in orange), with the Vale do Lobo subunit on the left of the horizontal dividing line (also in orange) and the Faro subunit on the right.