Prevent droughts and build climate resilience in the Upper Rhine Plain in Southern Palatinate

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Master Thesis
Environmental and Infrastructure Planning, Water and Coastal Management

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Colophon

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Date:	10/11/2023
Place:	Groningen
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Title Page:	Images own source, created with PowerPoint

Acknowledgement

I want to take this opportunity to thank everyone involved for their help, because without them this work would not have been possible. My thanks go to my parents for their encouragement and support in the background. My thanks also go to my friends and fellow students who stood by my side, both professionally and mentally.

Last but not least, I would like to thank all the interviewees who made themselves available in the course of this work and contributed significantly to the results.

Abstract

In the research area, recent trends indicate more frequent droughts and heat waves. Reduced groundwater recharge from decreased precipitation has led to diminishing water resources. Drier conditions are already affecting regions, with lower groundwater storage or heightened agricultural irrigation needs. These trends are expected to worsen in the future, posing significant challenges. This study aimed to identify measures of climate adaptation and integrated water resource management, as well as related barriers, to achieve a transition of the current water management in the research area towards drought resilience. For this, a combination of literature review, document analysis and semi-structured interviews was conducted to answer the research questions. The results show that a larger number of actors are involved in the region's water management. Nevertheless, the main responsibility lies with the upper water authorities. A vast list of possible adaptation measures was identified together with multiple barriers which need to be overcome. Otherwise, a successful transition towards drought-resilient and sustainable water management is not possible. For effective water management in this research area, several key steps are recommended. Robust monitoring of water extractions to evaluate the water balance must be established to address the current lack of supervision. Communication and consultation among stakeholders should be enhanced to bridge the gap between awareness and action, especially in agriculture and water supply. For this specifically, a drought information network is recommended. The Agricultural sector as a main actor in the research area must be engaged to adapt to the changing climate by implementing more efficient irrigation technologies and changed land-use practices. Further, a focus shift from flood prevention to more holistic water management is needed, promoting strategies like on-site infiltration and retention for groundwater recharge. Lastly, the introduction of legal obligations and political support will ensure compliance with necessary changes.

Keywords: drought resilience, water management, climate adaptation, drinking water protection, on-site infiltration, agricultural adaptations, irrigation, natural water balance

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1. Introduction

1.1 Background

Climate change is a global phenomenon that results in local changes. Similar to most parts of the world, Germany observed a more frequent occurrence of extreme weather events in recent decades. Climate change has already arrived and is, according to the IPCC (2022) set to get even worse. For this reason, adaptation strategies should be implemented to mitigate its effect, reduce vulnerability and increase resilience. The management of critical water resources is of particular importance in an attempt to support life on earth and ensure sustainable development. Inspired by the ZDF documentary "Die große Dürre " (The Big Drought) (Harrich, 2022) and reports in regional media (Deutsche Welle, 2022; SWR, 2022a; SWR, 2023) this Master thesis deals with the question of what can be done to better adapt and prepare for extreme drought conditions created as a result of climate change? In this study, the effects of climatic and non-climatic factors on the local water cycle are investigated to develop adequate suggestions and provide solutions for a sustainable water management strategy for the research area.

Over the last few decades, changes in the major ocean currents and increased variance of precipitation patterns were found globally, which is indicative of a change in local climatic conditions. This is important because how we live is heavily dependent on the local climate, as it determines the framework conditions and availability of resources necessary for survival (Dore, 2005). Water is an important resource, which impacts the environment on many different levels (Kemps and Glaser, 2020). The hydrological cycle is affected by climate and human interventions, including freshwater abstraction for (agricultural) irrigation, drinking water supplies, construction and industrial activities. Urbanisation, changes to the topography and construction of stormwater-drainage systems also alter natural drainage systems and impact infiltration and groundwater recharge systems (IPCC, 2022; Huang et al. 2015). These changes influence the availability of water, which will also lead to a change in the visible landscape, the ecosystem and all its functions, and the occurrence of extreme events. The more these changes deviate from a stable system, the lower the resilience of the environment and the greater any damage will be (Kempf and Glaser, 2020).

Climate change has had a significant impact on Germany, particularly in the Upper Rhine Lowlands. The region has experienced a rise in temperatures, changing precipitation patterns, and an increase in the frequency and intensity of extreme weather events like droughts (DWD, n.d.). Local climate change is evident and to ensure resilience to future conditions, the region must adapt to these changes.

The present study examines water management in the research area in general. This means that aspects of water management in the settlement area and the agricultural use of water are examined for a holistic view.

1.2 Research Question

This study aimed to discover how existing water management strategies and policies in the Upper Rhine Lowlands, Germany, can be improved to enhance drought resilience and adapt to the challenges posed by climate change. Additionally, the study identified the parties involved and the barriers that need to be overcome to establish drought resilience and mitigate future drought-related challenges. The investigation was structured around the following questions:

- What are the key stakeholders involved in the implementation of adaptation measures to address the impacts of drought events and changes in water management strategies in the research area?
- Which potential adaptation measures are applicable to increase drought resilience in general in the research area?
- What are existing or potential barriers to a successful implementation of adaption measures and changes in the water management strategies?

1.3 Introduction of Research Area

It was decided to choose a section of the Upper Rhine Lowlands in Germany as the research area. The Upper Rhine Lowlands (Oberrheintiefland) is a vast landscape predominantly characterized by agriculture, particularly vegetable and wine cultivation. It is also known for being one of the warmest areas in Germany. The loess soils of the Lower Palatinate (vorderpfälzisches Tiefland), with their sandy-gravelly to loamy composition, are particularly well-suited for agriculture (Landesamt für Umwelt Rheinland-Pfalz, n.d.; LUWG, 2005). Through human influence, the original natural watercourse network has been significantly altered to reduce flooding and improve agricultural use (Keller, 2013). Today, it is characterized by a pronounced regulatory system, including dividing weirs, mill ditches, irrigation wells, and drainage ditches (Landesamt für Umwelt Rheinland-Pfalz, n.d.; LUWG, 2005). Therefore, many changes to the local natural water system have occurred for or through agricultural use.

Agricultural land use is highly prevalent in the area, which can be seen in Figure 1, and it heavily relies on groundwater resources for irrigation (BGS Umwelt, 2011). Given this substantial dependence on groundwater, any reduction in its availability due to drought conditions is expected to have a profound and detrimental impact on agricultural activities in the region (Bundesinformationszentrum Landwirtschaft, n.d.). Not only will they affect the local economy and food production, but water shortages may also lead to conflicts with other water usages in the region, such as drinking water supply, private water use for gardens and pools, or industrial water use (LUBW, 2022). Moreover, public and political support for agricultural water usage has historically been strong due to its pivotal role in food production and its broader economic contributions to the region. Until today, farmers have held a special position and enjoyed certain rights or faced limited controls on their water usage. Unfortunately, this leniency has, in some cases, led to unregulated and excessive water consumption by certain agricultural practices, with limited consequences for non-compliance (SWR, 2022b).

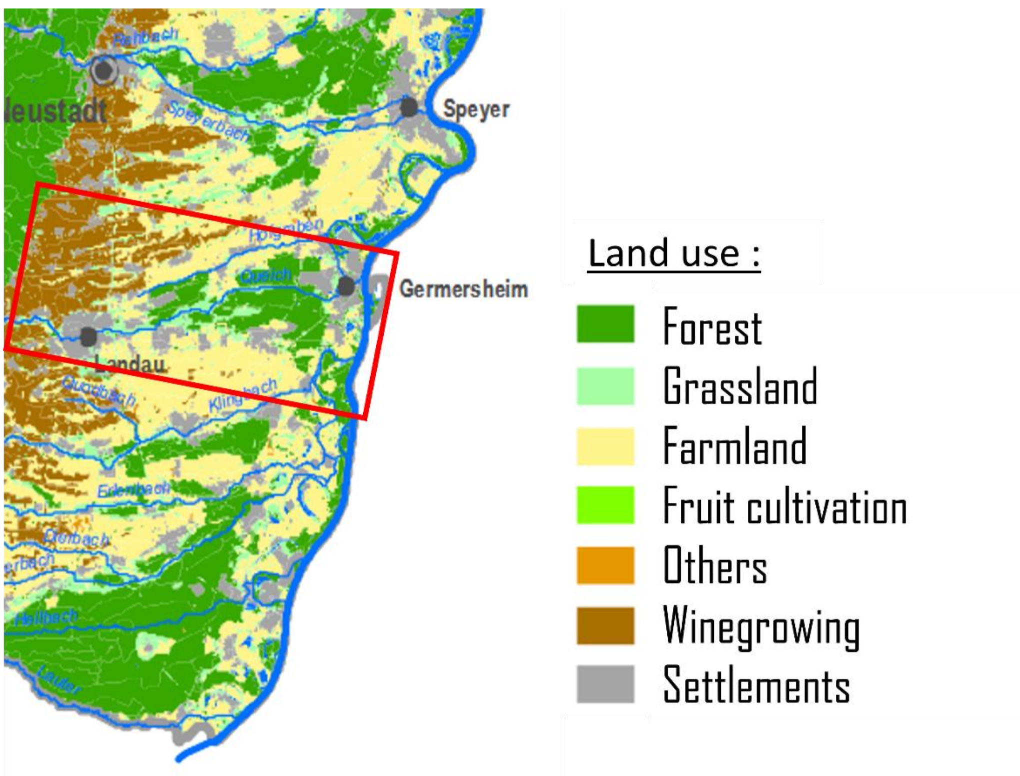


Figure 1: Representation of land uses in the Upper Rhine lowlands. The selected section for the research area is roughly marked with a red box. The region is characterised by cropland and vineyards. Source: LUWG, 2005 – Sheet 02.

A section of the Upper Rhine Plain was chosen as an example to develop specifically tailored solutions in a small-scale area and to provide recommendations on how current water management could be improved to address the consequences of climate change. The research area, illustrated in Figure 2, is bordered to the west by the Palatinate Forest and to the east by the Rhine. The chosen Research Area consists of the association municipalities Lingenfeld, Bellheim, Offenbach an der Queich, Landau-Land, Herxheim, Rülzheim, the county town Germersheim and the municipality Landau in der Pfalz. The eight association municipalities comprise 38 localities and a total population of 154,796 inhabitants (Statistisches Landesamt, 2019).

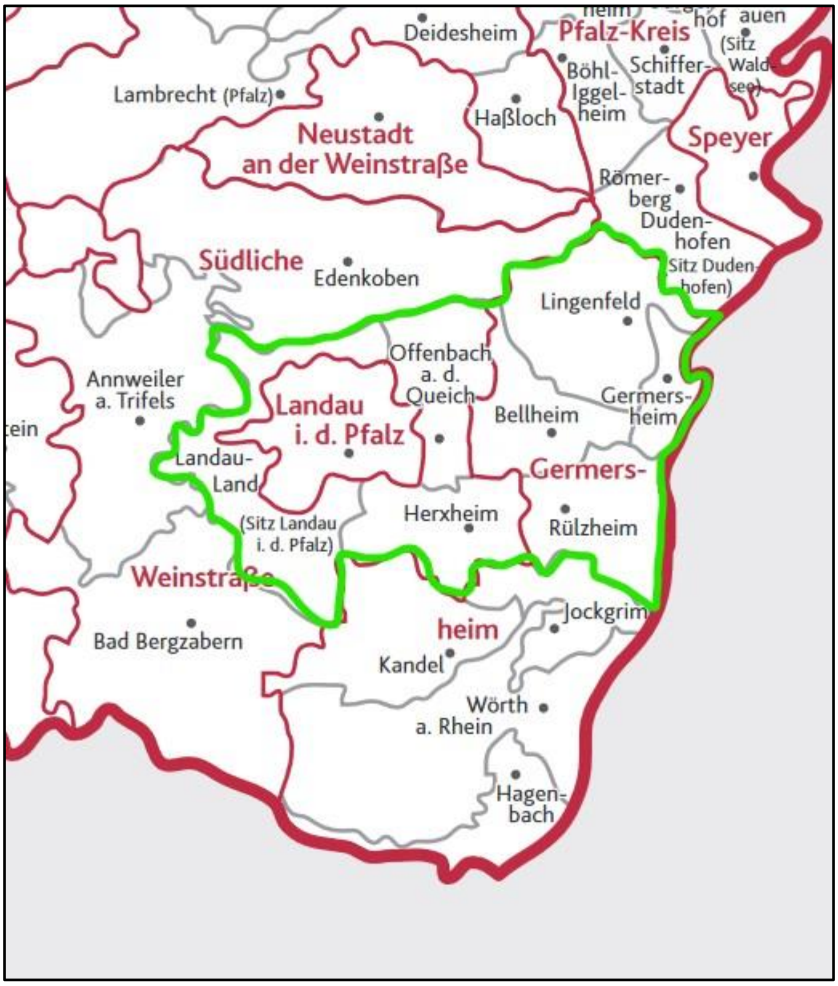


Figure 2: The Figure shows the southeast of Rhineland-Platinate with the association municipalities there. The chosen Research Area is marked in green. Source: freely according to (LVG, 2020)

1.4 Relevance of the Topic

A large number of studies discuss and document changes in Europe and Germany due to climate change (Some examples: IPCC, 2022; Dore, 2005; Fliß et al., 2021; Huang et al., 2015; BMUNV, 2021; UFZ Helmholtz, n.d.; Koop et al., 2018). These studies highlight an increase in extreme weather events such as floods and droughts, as well as changes in annual temperatures and associated impacts on ecosystems and resource availability. These changes have far-reaching impacts on ecosystems and the availability of vital resources (LUBW, 2022).

This context is of paramount importance to the research area, as the Upper Rhine Plain is strongly characterized by intensive vegetable, fruit, and wine cultivation. The selected research area has experienced drier conditions in the recent past, and this trend is expected to continue (DWD, n.d.; UFZ, 2023) which will have a strong impact on public health and the economic sector (IPCC, 2022).

However, despite the extensive discourse on climate change, there is a noticeable gap in practical climate adaptation measures tailored to the specific needs of the research area. Current local strategies primarily focus on climate change mitigation through emissions reduction and renewable energy, with limited attention given to climate change adaptation, mainly revolving around flood protection efforts (Kleber and Kotremba, n.d.; Kleber, 2019).

Yet, recent developments, such as the release of the National Water Strategy by the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety, and Consumer Protection, signal a growing awareness of drought issues and a commitment to improving water management in Germany (BMUV, 2023). Still, these strategies lack location-specific solutions.

This highlights the need for a dedicated study that focuses on the specific context of the Upper Rhine Plain. The study aims to bridge the existing gap by offering recommendations for what can be further done to improve existing water management strategies and policies in the specific research area. This will include suggesting concrete adaptation measures to become more drought resilient as a whole, as well as identifying barriers which might hinder this process of improvement. These recommendations may also serve as a model for addressing similar climate-related challenges in other regions.

The social relevance of this study lies in its potential to reduce the direct and indirect impacts of drought on society, by enhancing drought resilience and safeguarding the community's water resources within the research area (Krysanova et al., 2008; LUBW, 2022). Creating a local drought-resilient water management system will directly reduce water shortages, safeguarding agricultural production and economic stability. Adequate water availability and especially sustainable water management practices can help maintain crop yields, reduce agricultural losses, and secure the livelihoods of farmers (Rey et al., 2017). This, in turn, supports the economic stability of the region by preventing income losses, ensuring a stable food supply, and sustaining the local agricultural economy (Ziolkowska, 2016). Indirectly, it will protect public health, promote environmental sustainability, and enhance social equity by mitigating the impacts of drought on vulnerable populations and ecosystems (IPCC, 2022).

2. Thematic Background

2.1 Climate Change and Drought in the Rhine Area

Climate data and models indicate that Germany is experiencing an increase in both flood and drought conditions. The southern region of Germany has witnessed rising annual temperatures, reduced precipitation, and declining soil water storage over the past four decades, particularly in the last two decades (Huang et al., 2015; Fliß et al., 2021; UFZ, 2023). These regional climate changes have amplified drought conditions. Specifically in the Rhine area, drought events are projected to become more severe in this century compared to the past (Huang et al., 2015). Droughts, characterized by extended periods of low precipitation and elevated temperatures, result in water shortages, and their frequency, duration, and severity are uncertain (Shivakoti et al., 2019; Krysanova et al., 2008).

Groundwater drought, a manifestation of drought in subsurface and interconnected systems, leads to a decline in groundwater recharge, storage, and discharge due to lower groundwater levels, subsequently reducing water availability for all purposes (Shivakoti et al., 2019).

Drought events are not just a future concern but also a current pressing issue in Germany, evident from historical weather and climate records maintained by various institutions, supported by data from the Helmholtz Centre's Drought Monitor (DWD, n.d.; UFZ, n.d.). Figure 3 illustrates that in 2023, soils are under severe drought stress due to prolonged dry spells, and these conditions are projected to worsen under the continued influence of climate change.

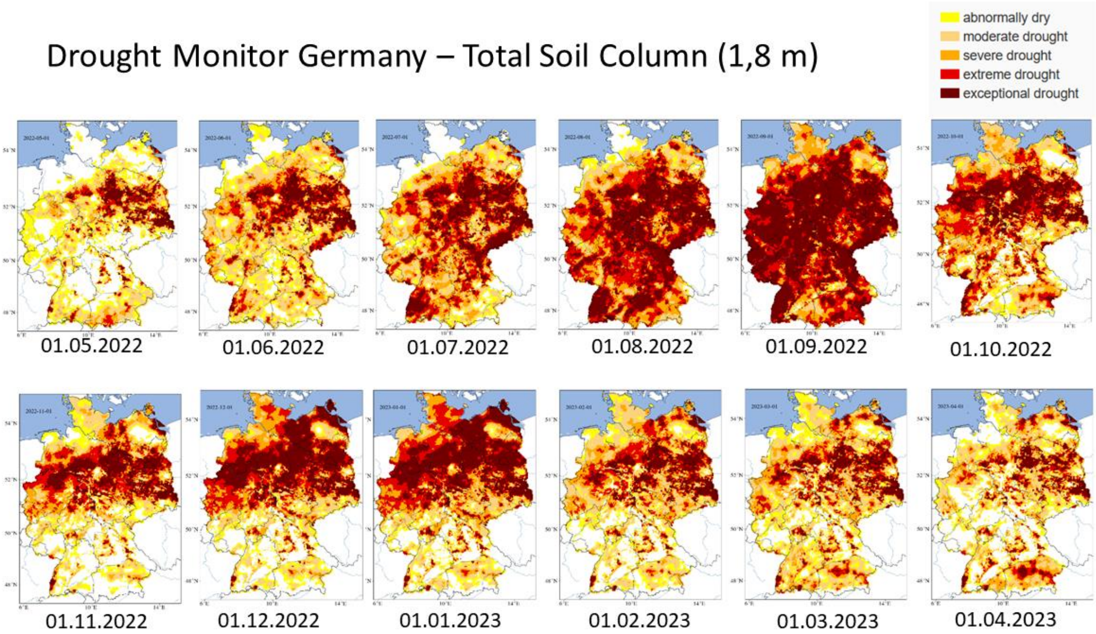


Figure 3: This Drought Monitor Germany from the Helmholtz Centrum shows the huge drought stress all over Germany from May 2022 to April 2023 within the total soil column (1,8 m). (Source: UFZ, n.d.)

In 2018, Germany faced its first major drought since 1976. Subsequently, the country experienced persistently high temperatures and scarce rainfall in the following years, hindering soil recovery and prolonging the significant drought conditions compared to previous years (see Figure 4).

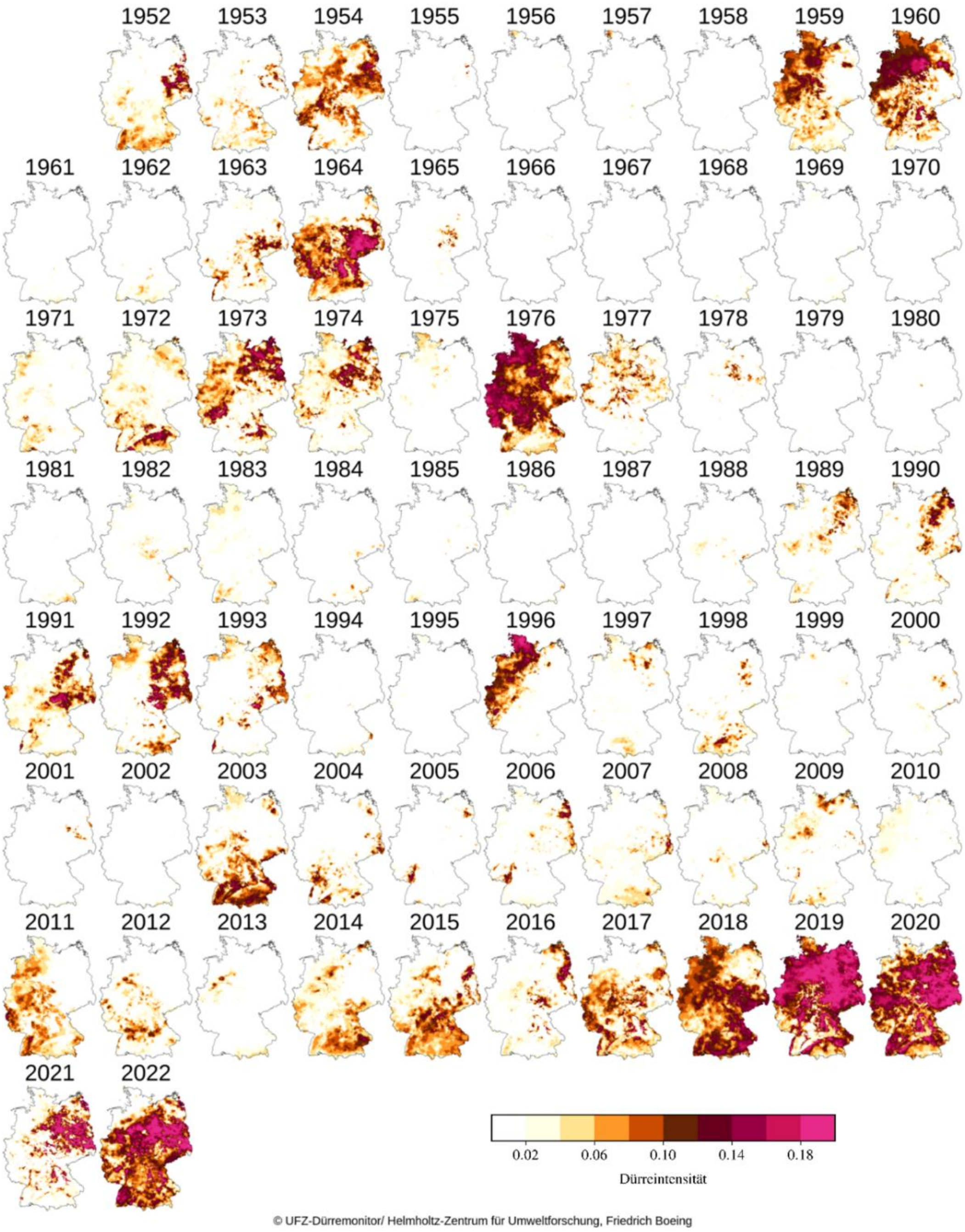


Figure 4: This Figure showcases the drought intensity in the growing season April to October for the total soil (0- max. 2 metres) shown from 1952 - 2022 (70 years). (Source UFZ, n.d.)

Data from the German Weather Service (DWD) since 1881 indicates a consistent upward trend in annual temperature anomalies for Rhineland-Palatinate and Saarland, as illustrated in Figure 5. In addition to changing temperatures, precipitation patterns were also altered in Germany. While some regions have experienced an increase in precipitation, the Upper Rhine Lowlands have seen a decrease in average rainfall (DWD, n.d.).

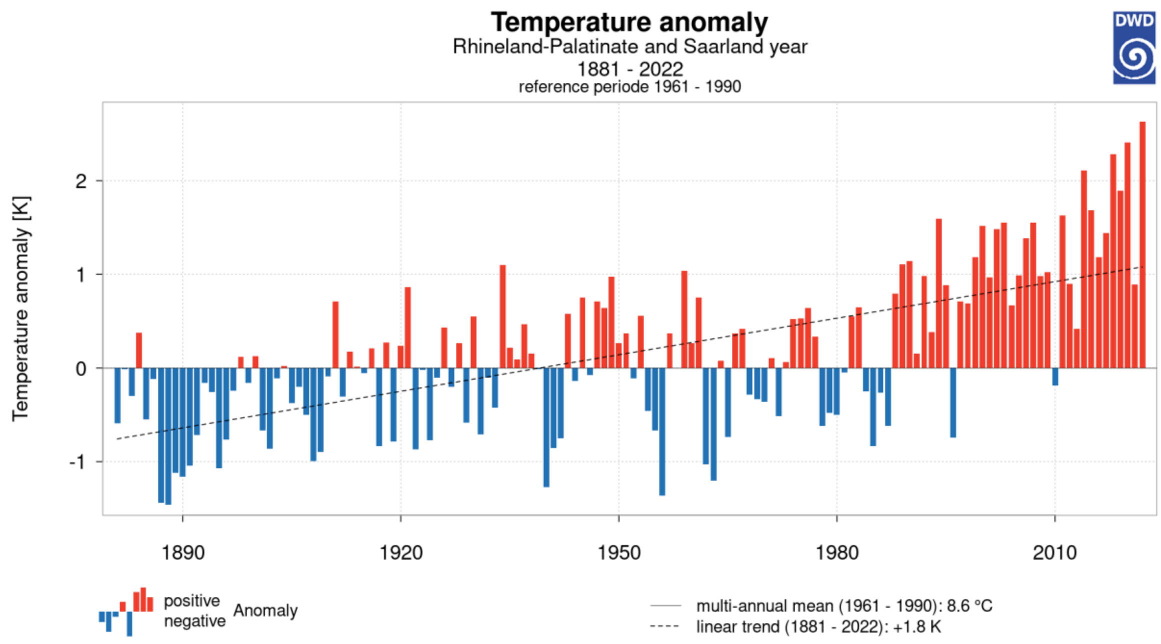


Figure 5: Anomalies in average temperature per year in Rhineland-Palatinate and Saarland from 1881 to 2022 compared to the average temperature of the years 1961 to 1990 (Source https://www.dwd.de/EN/ourservices/zeitreihen/zeitreihen.html?nn=24778#buehneTop)

2.2 Water Balance, Drought and Water Management

The increasing frequency and severity of droughts have far-reaching implications for water management and the need to improve drought resilience (Shivakoti et al., 2019). Adapted water management in the context of drought and climate change involves optimising the allocation and use of water resources to ensure sustainable access to water for different sectors such as agriculture, industry and households. Climate change is significantly altering the components of the water balance, which, in turn, is intensifying drought conditions. The water balance is the equilibrium between water inputs and outputs in a specific system. It considers factors like precipitation, evaporation, runoff, and groundwater recharge and thus provides a means of determining changes in the water balance (Mohammadi et al., 2014). As temperatures rise in the research area, evaporation increases, depleting soil moisture and elevating water demand (Fliß et al., 2015). Since the research area falls within a winter rainfall region, more precipitation falls in winter, and less in summer. This leads to increased seasonal water stress, especially during the summer months when water demands are at their highest (Reiter et al., 2019). This negative water balance leads to reduced soil water storage, exacerbating groundwater drought. A comprehensive understanding of the water balance and its dynamics is essential for effective water management strategies, ensuring sustainable water availability amidst climate change.

2.3 Non-climatic Factors Inducing Drought Conditions

Climate change is not the only reason for issues in water management and drought. The study conducted by Kempf and Glaser (2020) examined the southern Upper Rhine region during the period from 2018 to 2020 and observed far-reaching effects on ecosystem services due to land overuse. The significant regional warming and reduction in summer rainfall led to a sharp decline in the groundwater level. This trend was intensified by increased freshwater consumption, irrigation practices, and the expansion of monocultures.

Groundwater withdrawals for irrigation and human consumption, heavily impact local and regional aquifers, altering the hydrological cycle. Human land use and the intensified use of urbanization, deforestation, wetland loss, agricultural activities, irrigation, etc., have social, spatial, and temporal implications. All these factors contribute to a deterioration of the natural environmental interconnections and increase the vulnerability of ecosystems to extreme events such as prolonged droughts or sudden floods. Furthermore, these changes lead to additional alterations in land use and cover, reinforcing the destructive cycle (Kempf and Glaser, 2020).

2.4 Consequences

The impacts of droughts will not only cause enormous environmental damage but also affect our socio-economic systems (Fliß et al., 2015; IPCC, 2022). Various water management uses, and ecological functions depend on sufficient water quantity or quality. Navigation and freight transport, tourism, leisure and recreation, wastewater management, water quality preservation, fisheries, aquatic ecology, heat dissipation for industries, energy production, and the supply of drinking and service water, as well as agricultural activities, all experience negative consequences when facing low water conditions. Adding to the complexity, these uses often interact in intricate ways, resulting in conflicts over water usage when availability declines (LUBW, 2022). In southern Germany the water supply depends mainly on the availability of groundwater (Baden-Württemberg 71 %, Bayern 90 %, Hessen 100 %, Rheinland-Pfalz 85 %) (Destatis, 2018). Freshwater resources' availability will become more critical in future due to climate change and population growth. The demand for freshwater resources will rise, while the magnitude and frequency of extreme events will also increase.

Further, the reduction in groundwater and soil moisture due to droughts leads to an increase in forest fires and an increased risk of erosion (IPCC, 2022).

Among the sectors that will suffer the most, agriculture stands out, disproportionately affected by significant losses in agricultural production (Rey et al., 2017). Impacts of drought on agriculture will be associated with loss of income, unemployment and reduced availability of food, increasing stress on society (Ziolkowska, 2016). Furthermore, depending on the specific circumstances, it could lead to differing impacts on individual parties in the same area, potentially increasing injustices, and inequalities (Rey et al., 2017).

It is recommended that future government regulations and decisions concerning land use and freshwater consumption should consider alternatives to preserve the regional hydrological network (Kempf and Glaser, 2020). This is also in line with EU provisions that support a comprehensive approach to water management and aim to reduce land degradation (DN ENV, 2021; WFD, 2000). This suggests that due to climate change, areas in southern Germany, especially in the Rhine basin must adapt to a higher drought pressure.

3. Theoretical Framework

The following section discusses transition theory and its application in water management, as well as the importance of climate adaptation measures and the concept of Integrated Water Resource Management (IWRM) in this context.

3.1 Transition Theory

Transition theory is an approach in the social sciences that is used to understand change processes. In this context, a transition represents a fundamental change over a longer period of 25 to 50 years that is characterised by a change from a stable equilibrium to a new stable equilibrium through a phase of development and reorganisation of the system (Loorbach, 2010; Van der Brugge et al., 2005). These are often triggered by critical events that represent an abrupt or significant change. In this process, a change and review of the prevailing structures are stimulated. An adaptation to internal and external circumstances takes place on multiple levels accompanied by social, economic or demographic upheavals (Van der Brugge et al., 2005). In transition theory, individuals and groups play a crucial role in shaping and managing these transitions. This happens at both the individual and societal policy levels (Huitema et al., 2011).

Concerning water management, transition theory can help to understand and facilitate changes in the way water resources are used, managed and protected. Factors such as population growth, urbanisation, climate change and economic developments influence the demand for and availability of water and must therefore also be considered in water management (Fliß et al., 2015; IPCC, 2022; Schoeman et al., 2014). New developments in these areas can be decisive events that stimulate a transition process. These can be technological changes but also resource scarcity and conflicts over distribution and use. Transition theory can serve as a tool for long-term planning and strategy development. It makes it possible to anticipate possible transitions and developments in advance and to develop policies and measures that respond to these changes (Loorbach, 2010). Not every transition follows the same approach. There are substantive transitions where a change in approach to certain issues is promoted. For example, in the context of water management, the previous focus might change from technical engineering solutions to ecosystem-based water management (Huitema et al., 2011). This would mean not relying solely or less on dyke construction in flood protection and advancing more efforts in river restoration and natural flooding opportunities (Woltjer and Al, 2007). However, there are also governance transitions where the change relates to the way decisions are made and responsibilities are distributed. Here, for example, decentralised and participatory water management could be pursued, in contrast to top-down planning approaches often used in the past (Huitema et al., 2011).

To initiate such a change, it is helpful to understand existing discourses in combination with current developments as an opportunity and to point out a new path (Huitema et al., 2011). Most conventional approaches to water management have proven inadequate in addressing the complex and wicked problems related to water adaptation (Brown et al., 2020). Thus, a paradigm shift is necessary towards more sustainable and adaptive methodologies that consider the unpredictability of socio-ecological systems (Schoeman et al., 2014). Consequently, a shift within management approaches is needed from primarily resisting and controlling water ('fighting with water') to more integrated and adaptive approaches ('living with water') (Laeni et al., 2019). Here, the concept of transition management provides a prescriptive approach. Space must be created for innovation and social learning. Internal structural change can be driven through stakeholder participation and practice adaptation (Loorbach, 2010).

In any transition process, the primary objective is to promote sustainable development in the long term (Van der Brugge et al., 2005). Overall, the application of transition theory in water resource management can help to gain a more comprehensive and systematic view of the complex changes and challenges facing water resources. This can help to develop more sustainable, efficient and resilient approaches to water resource use and management.

3.2 Climate Adaptation & Integrated Water Resource Management

Climate adaptation and Integrated Water Resource Management (IWRM) respond to climate change in water management, influenced by climatic changes and human interventions (IPCC, 2022).

Climate adaptation modifies our systems and actions to minimise damage or reduce the risk of harmful impacts of climate change on the hydrological cycle. This can take the form of structural changes, behavioural changes, or new techniques e.g. industrial or agricultural water usage. Key aspects include risk assessment and developing sector-specific strategies, such as promoting drought resilience in selected areas. (NASA, n.d.; WWF, n.d.; European Environment Agency, n.d.). In the context of climate adaptation and sustainable water management, IWRM plays an important role. This approach aims to plan, develop and manage the availability and use of water in a way that is socially, economically and environmentally sustainable (Savenije and Van der Zaag, 2008). As climate change affects water availability and quality, it becomes crucial to address these challenges effectively.

IWRM offers an encompassing framework for managing water resources efficiently and reducing community and ecosystem vulnerability to climate extremes. The integration of different sectors and stakeholders in water management is emphasised to develop and implement collaborative strategies. Affected communities and stakeholders should be involved in the climate adaptation process. Participation enables local knowledge to be used and ensures that community needs and challenges are taken into account (Grigg, 2008; Zuidema, 2016). By incorporating climate adaptation principles into IWRM, the resilience of water management practices and infrastructure against climate change impacts, such as droughts, floods, and water scarcity will be improved (Savenije and Van der Zaag, 2008). This integration minimizes conflicts, encourages efficient water utilization, and safeguards ecosystems (Woltjer and Al, 2007).

The efficient use of water is a key aspect of IWRM. This includes measures to reduce water waste and increase efficiency in agricultural irrigation and industrial processes (Grigg, 2008). Additionally, IWRM considers the long-term ecological impact of water management, ensuring the protection of springs and water bodies to maintain a healthy ecological and chemical state (Woltjer and Al, 2007). However, it is essential to note that the success of IWRM depends on governance and institutional structures. Thus, it necessitates not only broad participation but also horizontal and vertical integration within policies, authorities, and institutions (Grigg, 2008; Warbroek et al., 2023).

3.3 Adaptive Capacity

The success of transition processes and climate adaptation strategies is not always guaranteed. It depends on the ability of a system to respond to changes, disturbances or crises and to adapt without limiting its functionality. This is also referred to as adaptive capacity. Adaptive capacity is multidimensional, meaning that it consists of different elements or components. These include resources, knowledge, institutional structures, finances, market behaviour and learning processes (Spijkerboer, 2018). Simplified, this can also be expressed in terms of willingness and ability to act (Zuidema, 2016).

When local authorities lack the necessary resources and expertise for a task, central government support is vital for successful execution, given that larger organizations generally have more implementation resources than smaller ones (Zuidema, 2016). Furthermore, the worldview, values, and perceived urgency of an issue strongly shape actors' willingness to act, even if they can do so. Therefore, it is crucial to consider the intricate interactions among individuals, organizations, networks, and regimes within the social context (Loorbach, 2010; Zuidema, 2016). This means that aspects influencing the behaviour and perspectives of the various actors involved must be identified and analysed to bring about the desired change (Warbroek et al., 2023).

In this context, path dependency and institutional void have a special significance. Path dependency refers to the tendency to stay on already known and established paths. A system that is caught in path dependency has a lower adaptive capacity and has a harder time adapting to new challenges. Favoured by established rules, routines, protocols, and norms—

often seen as the "rules of the game"—free decision-making processes are influenced, and actions constrained. These long-standing path dependencies, shaped by a persistent narrative, change slowly. To alter them, external mechanisms are needed to introduce new mental models and gradually restructure the environment of individuals (Low et al., 2005). The concept of institutional void refers to the absence of effective institutional frameworks or regulations in a particular area. This creates contradictions in the organisation and a discrepancy between the existing "rules" and the implementation of new ideas. As a result, actors bring their assumptions about rules and authority into play, which can lead to a situation where no one feels responsible for a particular area (Spijkerboer et al.,2018). Such barriers can arise from discontinuous policies, insufficient political support, bureaucratic hurdles, or resistance due to lobbying (Woltjer and Al, 2007). Institutional voids create uncertainty and hinder coordination in adaptation efforts (Spijkerboer et al.,2018).

In theory, it is stated that to address these issues policy and institutional harmonisation is required (Spijkerboer et al., 2018). However, for the research area currently, lobbying is one of the main inhibitors. The agricultural lobby is extremely dominant in Rhineland-Palatinate. A rather weak climate adaption profile at the policy level affects local governance (Zuidema, 2016), which is the case here as the local political players do not intervene in the current agricultural practices and pass on the wishes of the agricultural lobbyists to the state government. This creates multipliers of interests that mean that water, for example, costs the farmer nothing. The biggest hurdle is breaking through the established lobby. Appeals for a voluntary change in farming methods are therefore ineffective as long as profit maximisation is the only determining factor. It might be helpful to gain more central-level influence to enhance local willingness and ability to act (Zuidema, 2016).

3.4 Increase Drought Resilience for Climate Adaptation

Due to climate change discourse evolves to increase the capacity of disaster-affected areas to recover from sudden shocks without external assistance (Manyena, 2006; Laeni et al., 2019; Wardekker, 2021). This shift underscores emphasis on resilience, rather than needs or vulnerability (Manyena, 2006). However, resilience is a complex, politically influenced concept, subject to interpretation, and contextual factors (Rey et al., 2017; Laeni et al., 2019; Manyena, 2006). Viewing resilience from an evolutionary perspective goes beyond mere resistance and recovery (Laeni et al., 2019) and emphasizes the importance of adaptability and transformation, enabling anticipation and adjustments to changing socio-ecological conditions. Given the increasing impact of climate change and the prevalence of 'unknown unknowns,' achieving absolute protection and preparedness appears nearly impossible (Laeni et al., 2019, Manyena, 2006). Instead, the focus should be on the long-term effects of climate change, necessitating integrated assessments, capacity building for transformation, and a proactive and adaptable approach (Wardekker, 2021).

The current developments highlight the significance and scarcity of healthy ecosystems and the resource of water (Schoeman et al., 2014). *"In the past, drought management has been strongly blurred and often politicised, as a result of confusions related to how droughts are defined and to the analysis of causes and effects of droughts"* (Rockström, 2003, p.870). This statement highlights the need for a transition in water management that recognizes the interconnectedness of the hydrological system, acknowledging the linkages between droughts, floods, human activities, and ecosystems on which we depend (Rockström, 2003). To adapt water management in response to climate change and more frequent and or intense drought events, it is important to increase the natural capacity of a system to absorb shocks and renew or reorganise when change occurs. It is important to increase its ecological resilience (Rockström, 2003; Manyena, 2006; Laeni et al., 2019). If a system has a low resilience, it becomes vulnerable to changes that it previously was able to absorb. Land degradation reduces the ability of the ecosystem to cope with environmental shocks, such as floods and droughts. Especially through agricultural land use, which often leads to soil erosion, the biodiversity and health of the ecosystem are affected. This effect is, then again, enhanced by extreme events like droughts or floods (Rockström, 2003).

Adapting water management to climate change requires significant changes in land-use practices, economic structures, and technology. An essential aspect to achieve this will be raising awareness in various areas (Krysanova et al., 2008). However, there are limits to how much we can prepare for and mitigate dry spells, as it is impossible to escape severe drought years or climate change (Rockström, 2003). Additionally, Krysanova et al. (2008) suggest that consideration should be given to the adaptive capacity of natural and social systems, including political drivers. Therefore, it becomes even more important to make the system as a whole resilient (Rockström, 2003). Local water managers should develop region-specific adaptation strategies through participative approaches, incorporating site-specific expert knowledge into the planning process to acknowledge the local context of the situation (Krysanova et al., 2008). The farming sector needs to be integrated into drought management and must adapt its management approaches to enhance decision-making in future drought events (Rey et al., 2017) Increasing resilience in the farming system will also enhance sustainable ecosystem services, which lead to a win-win situation as more crop is produced per drop of water in resilient farming systems, which reduces the amount of water needed to produce food (Rockström, 2003; Rey et al., 2017). As water management can be highly complex and involves uncertainty it is important to adopt a broad perspective and follow an IWRM strategy to achieve a systematic process for improving management policies and practices (Krysanova et al., 2008). Embracing these principles and approaches will empower water management systems to effectively address the challenges posed by climate change and uncertainties in the future.

3.5 Options for Action to Increase Drought Resilience from the Literature.

As already mentioned, there is a strong need to increase ecological resilience as part of improving water management and to increase drought resilience (Rockström, 2003). Further, diversification within the socio-economic structures of water demand and supply will play a crucial role and developing a resilient system (Krysanova et al., 2018) as well as a management approach which includes balance recharge, storage, and discharge aspects of groundwater resources (Shivakoti et al., 2019). In the following abstracts recommendations for improving water management towards higher drought resilience are further explored.

3.5.1 Supply Side

Firstly, on the supply side actions can be taken on the regulatory side for the management plans in general. Then a diversification of water resources as well as further protection of water resources and enhanced storage capacities are also options for action on the supply side. The supply side also should include robust monitoring and evaluation systems.

3.5.1.1 Regulatory Action

On the regulator side it is necessary to develop an integrated water resources management and drought management plan (Rey et al., 2017, Krysanova et al., 2018). Therefore, they should set priorities for water use in low-flow and drought periods and incorporate the expected effects of climate change in water management (Krysanova et al., 2018). To be better prepared it is advised to set a portion of the aquifer as fixed storage, exclusively for drought emergencies, and a dynamic part which can be accessed for day-to-day demands (Shivakoti et al., 2019). Policy changes to support drought resilience in irrigated agriculture

(Rey et al., 2017) and adequate water management laws to improve preparedness for extreme events (Krysanova et al., 2018). This should include changes in land-use practices and technology used, and awareness-raising campaigns to modify socio-economic structures (Krysanova et al., 2018). As severe drought and flood events are interrelated it is necessary to enable diverting and recharging excess runoff through managed aquifer recharge techniques to create balanced storage (Shivakoti et al., 2019). Further renaturation and the removal of invasive non-native vegetation from riparian areas will enhance the ecological resilience of water bodies and stream ecosystems (Fallon and Betts, 2010).

3.5.1.2 Water Resources and Storage

To protect and diversify water resources and enhance storage capacities multiple actions are possible. Especially in areas with higher temperatures, it is advisable to prospect and extract groundwater rather than surface water due to fewer evaporation losses (Falloon and Betts, 2010; Krysanova et al., 2018). Further water storage should be enhanced by building reservoirs, dams, and artificial basins. Well-managed water redistribution and expansion of rain-water storage not only increases drought resilience but is also helpful in dealing with floods (LUBW, 2022; Falloon and Betts, 2010; Krysanova et al., 2018). For more diversification in potential resource sources water reuse, water recycling and desalination of seawater are suggested to increase drought resilience (Falloon and Betts, 2010; Krysanova et al., 2018). Additionally, interconnected networks to enable water transfer from external sources and in between catchment areas can buffer times of severe droughts (Krysanova et al., 2018; Falloon and Betts, 2010).

3.5.1.3 Monitoring and Evaluation

Increasingly important are monitoring and assessment of the water balance, as this is the basis of sustainable management for groundwater quantity and quality. The purpose is to understand how water resources are distributed and used within a particular area and to assess the impacts of various factors, including drought, on the availability and distribution of water. (LUBW, 2022). Regarding the unknown effects of climate change, improved monitoring and forecasting, early warning systems, and the evaluation of water resource availability and water management by using models become more and more important. Efforts in this regard must be continued and/or increased (LUBW, 2022; Krysanova et al., 2018; Rey et al., 2017). Additionally, based on the gathered data, different scenarios should be evaluated and analysed to be better prepared for changing circumstances. One of these could be potential damage to buildings and infrastructure due to changing groundwater levels, which should be incorporated when designating potential building areas (LUBW, 2022).

3.5.2 Collective Action

In the pursuit of integrated and adaptive water management, joint efforts from both the supplier and consumer sides play a pivotal role (Shivakoti et al., 2019; Krysanova et al., 2018; Falloon and Betts, 2010). To achieve this, collective management, and negotiations, as well as training and support, are essential components (Rey et al., 2017). Additionally, effective information distribution, such as seasonal forecasting of water availability, is crucial for adapting water distribution strategies (Rey et al., 2017). Knowledge networking and regional collaboration also emerge as vital aspects of this endeavour (Shivakoti et al., 2019).

According to Krysanova et al., 2018 local experts must be involved in developing region-specific solutions to address water management challenges effectively. To foster cooperation and coordination among all stakeholders, action involving both authorities and farmers is imperative (Krysanova et al., 2018). The inclusion of representatives in discussions can facilitate voluntary water use reductions instead of imposing mandatory restrictions (Rey et al., 2017). For this, it becomes vital to achieve integrated drought management across temporal and spatial variability (Shivakoti et al., 2019; Rey et al., 2017). By incorporating the expertise and cooperation of all parties, a resilient and sustainable water management system can be built that adapts to changing conditions and secures water resources for the future.

3.5.3 Demand Side

On the other hand, the demand side considers social, behavioural, and political drivers, and therefore becomes a key aspect to increase drought resilience (Kempf and Glaser, 2020; Krysanova et al., 2018). The values and knowledge with which resource water is viewed are decisive for the way it is handled. It has become clear that, due to climate change and the associated changes, we must fundamentally change the way we deal with water (Schoeman et al., 2014). Therefore, efforts are needed to adjust land-use practices and irrigation techniques. It is essential to sensitize people to the use of water and address individual responsibility by developing drought management plans and diversification in water resources independent of the supply side and the authorities.

Individual behaviour has a major impact on water conservation. It is proposed to influence demand-side behaviour through incentives, for more efficient water use and water-saving programs in different sectors, e.g., agriculture, households, and industry. This could be done through economic incentives such as a system of water pricing and subsidies but also through awareness raising, information, and education on the proper use of scarce water resources (Krysanova et al., 2018; Falloon and Betts, 2010).

3.5.3.1 Drought Management Plans

To better prepare for extreme events, it is suggested that water users, e.g., farmers, develop their own drought management plans (Rey et al., 2017). This may include the development of water allocation strategies among competing demands and the exchange of water rights (Krysnaova et al., 2018). In areas where drought events become more frequent and severe, it is suggested to develop nonfarm livelihoods or reduce the water demand for irrigation by importing more agricultural or other water-intensive products (Krysanova et al., 2018; Falloon and Betts, 2010). Lastly, a drought contingency plan imposed by the authorities with restrictions on water use, rationing schemes, special water tariffs, and reduction in low-value uses, e.g., in agriculture will help mitigate dry spells and reduce the pressure on the system in extreme situations. This will help not only during the event but also with recovering after the event is over (Krysanova et al., 2018).

3.5.3.2 Diversification

By investing in alternative water sources, adopting rainwater harvesting and water trading methods, recycling water, and promoting conservation practices, a more resilient and sustainable water management system can be fostered. To avoid overuse and depletion of traditional sources like groundwater and surface water, it is helpful to invest in alternative water sources (Rey et al., 2017; Falloon and Betts, 2010). These alternative sources should not only be considered on the supply side but also by the communities and other users. Options for action are hereby rainwater harvesting (Rey et al., 2017), which involves capturing and storing rainwater for later use, for example, in a cistern. This has been common practice for centuries and promoting these and other indigenous practices for sustainable water use, as well as household, farming and industrial water conservation, will help to increase drought resilience (Fallon and Betts, 2010). Furthermore, water-use efficiency can be improved by recycling water and wastewater reuse technologies, particularly in industries and agriculture (Fallon and Betts, 2010). Lastly, water trading, a market-based mechanism, may enable efficient allocation of water resources and encourage water conservation (Rey et al., 2017).

3.5.3.3 Adapted Land-use

It is strongly advised to adapt land-use management to the climatic circumstances. Improved land use in agriculture can be achieved through various measures. A different type of cultivation could be used such as agroforestry. These include changes in the crop mix (Rey et al., 2017; Krysanova et al., 2018; Falloon and Betts, 2010), adjustments to crop residue management, intercropping, cover cropping, or modifying vegetation cover to reduce evapotranspiration, soil erosion, and surface runoff (Rockström, 2003; Krysanova et al., 2018). In addition, it is recommended to reduce water demand for irrigation by implementing changes to the cropping calendar and the area used for planting (Falloon and Betts, 2010). Maximizing rain infiltration and water-holding capacities of the soils can be achieved through practices like conservation tillage systems to reduce run-off or small-scale water harvesting systems (Rockström, 2003). These approaches will help conserve water resources and improve ecological resilience.

3.5.3.4 Irrigation Techniques

Improved or adapted irrigation methods will help to further control and secure water supplies (Rockström, 2003). Irrigation techniques can be improved by reducing leaky water systems (Falloon and Betts, 2010; Rey et al., 2017). Furthermore, more efficient irrigation techniques should be used, such as drip irrigation, and irrigation should preferably take place at night to reduce water losses through evaporation (Rey et al., 2017; Krysanova et al., 2018).

However, there are also obstacles for farmers to adapt to droughts. They are often bound by certain contracts and face significant financial losses if they change the way they supply water to their fields. As a result, they often have certain priorities when it comes to land management. To overcome these barriers, collective action between supply and demand, as well as policies and regulations that support change in water management, are becoming increasingly important (Rey et al., 2017).

3.6 Conceptual Model

To clarify the underlying concepts and their interrelationships in the context of this work, a comprehensive conceptual model is presented. As illustrated in Figure 6, the starting point is the currently prevailing water management in the designated research area, which is to be improved through an adequately designed transition process. The overall objective is to establish a paradigm shift in water management that promotes sustainable water supply while making the system resilient to drought-related stresses. This will be achieved through the systematic application of climate adaptation measures with drought resilience strategies and through horizontal and vertical integration in water resource management. However, the successful implementation of this transition project as well as the effectiveness of the adopted strategies depends on the adaptability of the system. At this point, the willingness and ability of the actors involved in this transition to facilitate and manage change is of key importance. These aspects can potentially lead to the generation of new or existing barriers that undermine the achievement of an improved water governance framework.

The study suggests that to figure out how to improve water management in the Upper Rhine Plain, the formulation and concretisation of plans and actions, combined with a careful assessment of the adaptive capacity of the area is needed. This will make the area more resilient in the face of drought-related challenges.

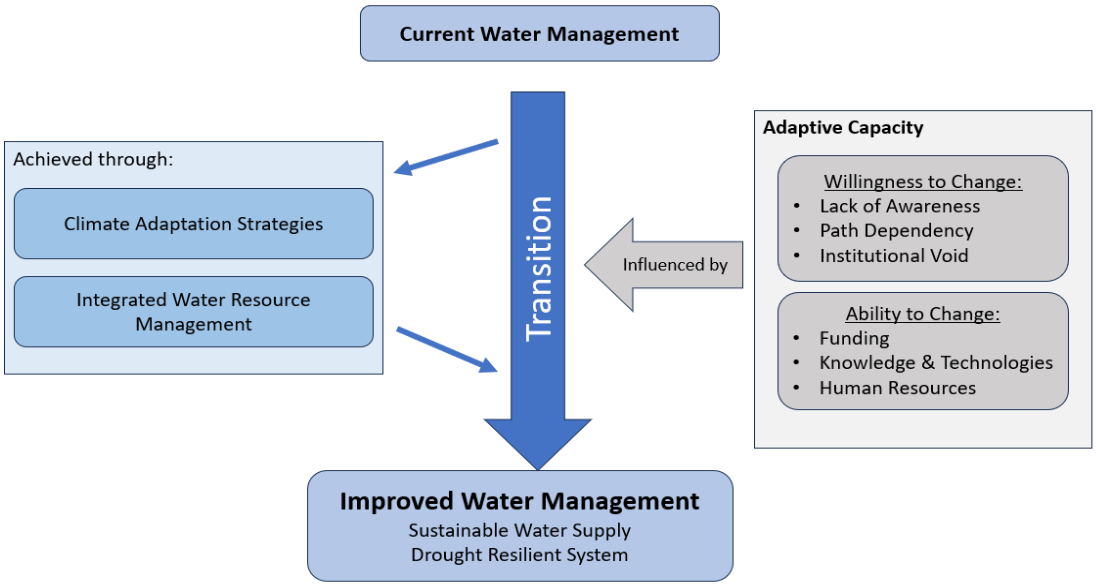


Figure 6: Conceptual Model

4. Methods

This chapter discusses the methodology of this research, including data collection and data analysis. To answer the main and sub-questions, explanatory research was conducted, using qualitative research methods.

4.1 Research Strategy

This study uses a qualitative research strategy to gain an in-depth and detailed understanding of the situation at hand. For this thesis, a single case study approach was chosen to best answer the main research question “How can improved water management strategies in the Upper Rhine Plain create drought resilience and help to adapt to challenges created by climate change?”. The case study approach is useful to understand, interpret and explain an actual case, event or phenomenon in the real world. It helps to analyse this concrete case in all its details, and from different perspectives, always considering the context in which it stands and comparing it to already existing theories to find successful drought resilience strategies (Yin, 2014; Crowe et al., 2011; Tellis, 1997). This study examined how water management in the research area deals with changes in the hydrogeological cycle and the water balance. Both climatic and anthropogenic factors play a role. Using a case study approach, it was possible to identify gaps and areas for improvement in the current water management (strategies) in the research area and make appropriate recommendations to increase drought resilience and improve the system as a whole (Yin, 2014).

4.2 Unit of Analysis

The unit of analysis is defined by its spatial boundaries, timeframe and theoretical scope (Yin, 2014). The spatial boundaries of the research area include, as previously mentioned, the association municipalities Lingenfeld, Bellheim, Offenbach an der Queich, Landau-Land, Herxheim, Rülzheim, the county town Germersheim and the municipality Landau in der Pfalz. The time frame of this study is focused on recent developments and the current state of the situation, as a refined understanding of it is necessary to answer the research question. The focus is on the years 2022 and 2023. Temporally, the research is limited to the data collection period, which lasted from May 2023 to August 2023. Since climate and landscape changes occur over extended periods, this study has also considered historical data to identify trends and draw comparisons. For the theoretical scope, the key concepts are transition theory, climate adaptation, integrated water resource management, adaptive capacity and drought resilience which are further defined based on literature studies.

4.3 Research Methods

To answer the research question, a combination of theoretical research and empirical research was conducted. For the theoretical research a (a) literature review provided academic knowledge into the underlying theoretical background of this topic such as climate change, transition theory and adaptation planning (see Chapters 2 and 3). The empirical research was conducted using qualitative data collection techniques within a case study approach, including (b) document analysis and (c) semi-structured interviews. This combination allowed for an understanding of context-dependent aspects within the study's environment, enabling the grasp of processes and interrelationships and facilitating an understanding of complex topics. This approach ensures that different perspectives and individual contexts are taken into consideration (Hennike et al., 2020). The information and statements retrieved from the interviews and document analysis are compared to the information found through the literature review. This helps to verify or further explore specific theories and increases the reliability of the study (Yin, 2014).

Table 1 shows how these research methods relate to answering the sub-questions and thus ultimately to the main research question. The applied methods are discussed in depth in the following sections.

Table 1: Presentation of the research methods used in connection with the sub-research questions

#	Sub Question	Main Method
1	What are the key stakeholders involved in the implementation of adaptation measures to address the impacts of drought events and changes in water management strategies in the research area?	Document Analysis Semi-Structured Interviews
2	Which potential adaptation measures are applicable to increase drought resilience in general in the research area?	Literature Review Document Analysis Semi-Structured Interviews
3	What are existing or potential barriers to a successful implementation of adaption measures and changes in the water management strategies?	Semi-structured Interviews

4.4 Data Collection Process

(a) Literature Review

The Theoretical scope in chapters two and three forms the basis of this study. Through a Literature Review, insights into the current challenges for water management due to climate change are provided. Furthermore, chapter three discussed how this topic is connected to concepts of transition management in water management and climate change adaptation. In addition, information on the impacts of these changes and how they can be mitigated or adapted to are gathered. The literature review was conducted by systematically searching for relevant scientific articles, books, and other sources related to the research topic in the open-source database Google Scholar and available scientific resources at the (online) library of the University of Groningen and Oldenburg. These insights are summarised and visualised in simplified form in Chapter 3.6.

(b) Document Analysis

For the empirical data collection, this study made use of a document analysis. This included reports, policy strategies, legislation, books, and brochures. The analysis of these documents provided information on the current state of water management in the research area and also about the historical development of water management in the region. Furthermore, insight into the structural order of water management systems was gained and corresponding obligations and rights of the actors could be interpreted and classified. Through this, it was possible to develop an in-depth understanding of the reasons, motives, challenges and opportunities of the region and its approach to water management. This allowed for a deeper understanding of the context of the regional actors. The documents were mainly selected through searching websites of the different actors of water management. A particularly large number of documents originate from the website of the Directorate for Structures and Approvals South (Struktur und Genehmigungsdirektion Süd). This also provided further information about the actors and any cross-connections. Other documents were selected via a targeted search for specific information. The documents have been reviewed in German. An overview of the documents that are collected is given in Appendix B.

(c) Interviews

In addition to the document analysis, semi-structured interviews were conducted. Semi-structured interviews offer the opportunity to ask a range of very open-ended questions that focus on the participant's experiences. As a result, this method allows for the exploration of practical experiences in conjunction with theoretical knowledge about the specific topic or phenomenon of the study. Interviews attend to the complexity of contextualization and leave space for participants to offer new perspectives to the study focus that may have previously been neglected (Galletta and Cross, 2013). To identify sectors and actors as relevant interviewees for the study a stakeholder analysis was undertaken. Stakeholder analysis is an approach or tool to safely assess the influence and resources that potential interviewees bring to decision-making or implementation processes. It involves questions about position, interest, influence, interrelationships, and network connections to pinpoint stakeholders of importance. This allows the researcher to gain a better understanding of stakeholder relations, which helps to analyse the results from a more objective point of view (Varavasovszky and Brugha, 2000). A List of identified water management actors for the research area can be found in Appendix C.

Through the semi-structured interviews, further information was gained about possible current and or future adaptation measures to increase drought resilience in the research area. Furthermore, information about the specific responsibilities of the different actors, and potential barriers or challenges for successful implementation of adaption measures was gained. The interview questions were designed to learn more about the different points of view of relevant stakeholders. This is relevant as multiple different sectors are involved in the research area's water management. An actor from the drinking water supplier has a different knowledge basis through their work than someone from the municipal administration. These differences in work experience and knowledge have to be considered for this study.

To avoid possible manipulation of the answers by the researcher, the questions were formulated as openly as possible so that the participant could freely present his or her perspective. First, the participants were asked for their assessment and evaluation of the topic. Based on this, their opinion on the opportunities for action (and obstacles) identified in the literature was asked. The interview guide can be seen in Appendix A.

The exact content of the questions was adapted to the participants, as they did not always have the same relevance depending on their position within the water management sector. All interviews were conducted in German as all participants are German native speakers and thus possible misunderstandings due to a language barrier can be excluded.

All Interviewees were contacted through email first and sometimes for further correspondence also through phone. When asking for an Interview the research and the researchers' intentions were explained thoroughly and there was also room to ask more questions, if needed. After achieving agreement for the interview, it was either performed in person or via an online meeting.

In total 9 interviews were conducted with 10 people, which can be traced in Table 2. The interviews were conducted individually, except for interview number 9, where two interviewees from the same organisation were interviewed in parallel. Further interview partners were requested. However, the request was declined by some agencies due to time constraints. The authorities of the city of Landau in der Pfalz refused an interview in principle.

Table 2: List of Interview Participants.

Participants ID	Institution	Interview Date	Duration [minutes]
#1	Climate protection management, Bellheim Municipality	26.05	52
#2	Climate balance consulting, Chamber of Agriculture Rhineland-Palatinate	26.06	37
#3	Building Department, Bellheim Municipality	28.06	36
#4	Management, Water Board Germersheimer Süd Gruppe	03.07	57
#5	Management, NVS Naturstiftung Südpfalz	07.07	72
#6	Lower water authority, Germersheim district	11.07	91
#7	Structural and Approval Directorate South (SGD Süd), Head of Department Water Management, Waste Management, Soil Protection	11.07	65
#8	BUND Southern Palatinate District Group	12.07	78
#9 & #10	Management and Watermaster, Water Board Verbandsgemeindewerke Landau Land	26.07	63

4.5 Data Analysis

According to Mayring (2022), qualitative content analysis is indispensable for the evaluation of text documents and interviews. Therefore, it was decided to conduct the data evaluation for this study in the form of a qualitative content analysis through inductive categorisation. Inductive categorisation is a process of deriving new categories or groupings directly from the material in a generalisation process through systematic analysis and identification of common features or patterns, without using pre-determined hypotheses or theories (Mayring, 2022). To develop the inductive coding scheme each transcript was analysed under the aspects of Table 3. This methodology is particularly well suited for the analysis of individual case studies to achieve the closest possible representation of the material without distortions (Mayring, 2022), which in this case allows a clear representation of the expert opinions on water management in the research area. The interview transcripts were coded using the programme Atlas.ti, based on the sub-research questions.

Table 3: Inductive Coding Scheme Framework

Research Question	Analytical question	Category Definition	Level of Abstraction
Which potential adaptation measures are applicable to increase drought resilience in general in the research area?	What measures are mentioned to improve the situation?	Ideas or suggestions for measures resulting from dealing with the issue in everyday work.	Selective choice of concrete measures to be taken.
Who would be responsible for the implementation of adaptation measures?	Which actors or organisations are identified to take care of specific measures?	Direct task assignments or responsibility for the implementation and improvement of water management in the region.	Selection of actors who actively influence water management, no general stakeholder list.
What are existing or potential barriers to a successful implementation of adaption measures and changes in the water management strategies?	What problems, obstacles or difficulties do the interviewees name?	All factors which are perceived as obstacles; based on the personal experience of the interviewee.	Barriers related to measures.

In this way, the data was classified into the appropriate categories, which allowed the researcher to identify patterns in the data. The final codebook can be found in Appendix D. This approach makes it possible to present the results systematically, combine them, make own interpretations of the data and link these with the theoretical background to identify potential solutions for the research area.

4.6 Ethical Considerations, Data Management and Quality

Confidentiality, integrity, and privacy are paramount considerations when conducting research, particularly when involving third parties. To safeguard these principles, all study participants were informed before each interview that they had the option to withdraw or decline any question at any point during the interview (Galletta and Cross, 2013; Connelly, 2014).

The data collected is securely stored on a password-protected computer and is exclusively utilized for this research. To protect the participants' privacy and mitigate potential disadvantages resulting from their involvement, they are all referenced anonymously, identified only by their function or an index to specify the source of information (Connelly, 2014). Each participant was also made aware of their rights before the interview, and with their permission, the interviews were recorded using a recording app on the researcher's phone and later transcribed using Microsoft Word.

It is important to acknowledge that the data and information collected in this study have certain limitations in terms of quality. The study relies on qualitative data, resulting in non-numerical, detailed, and descriptive information derived from observations and interviews. Such data are subject to interpretation by the researcher and inherently carry a subjective nature. It is essential to recognize that researchers are not entirely objective, as they may be influenced by their prior experiences, academic background, and personal biases. In this case, the researcher has endeavoured to maintain objectivity and independence from any affiliations or personal interests, solely focusing on the study's objectives. Furthermore, interviewees may also introduce bias based on their interests and perspectives.

Additionally, the study is constrained by a specific timeframe and word limit, potentially leading to the omission of particular details. Despite these constraints, efforts were made to maximize objectivity by immersing in the study's environmental and theoretical context, while minimizing preconceived opinions as much as possible (Yin, 2014).

5. Results

5.1 Policy Analysis

According to national law and legislation, the management of groundwater is regulated in section four of the Water Resource Act of Germany (Wasserhaushaltsgesetz WHG). §46 WHG states that in certain cases no separate permit is required to extract, convey, conduct or discharge groundwater, e.g. where normal soil drainage or small quantities of water are required for temporary purposes. §47 WHG stipulates that degradation of groundwater, in terms of quality and quantity, must be avoided. Finally, §23 WHG regulates that the State government and its highest State authority(ies) are responsible for legislation on water management unless the Federal Government orders otherwise.

Accordingly, further regulations for water management in the German federal state Rhineland-Palatiante (Rheinland-Pfalz) are set down in the State Water Act (LWG). It states that securing the public water supply has priority in water management and resources and energy are to be used efficiently (§13 LWG). Certain uses of water bodies, including groundwater use for irrigation, usually require a permit, which is granted in case of public interest. These permits may be restricted or revoked (§§14 et seq. LWG).

According to §§19, 92, 94 LWG, authorities responsible for water management are divided into three levels, i.e. the lower, upper and highest water authorities. Figure 7 illustrates this hierarchy of authorities that regulate the management of water sources in Rhineland-Palatiante.

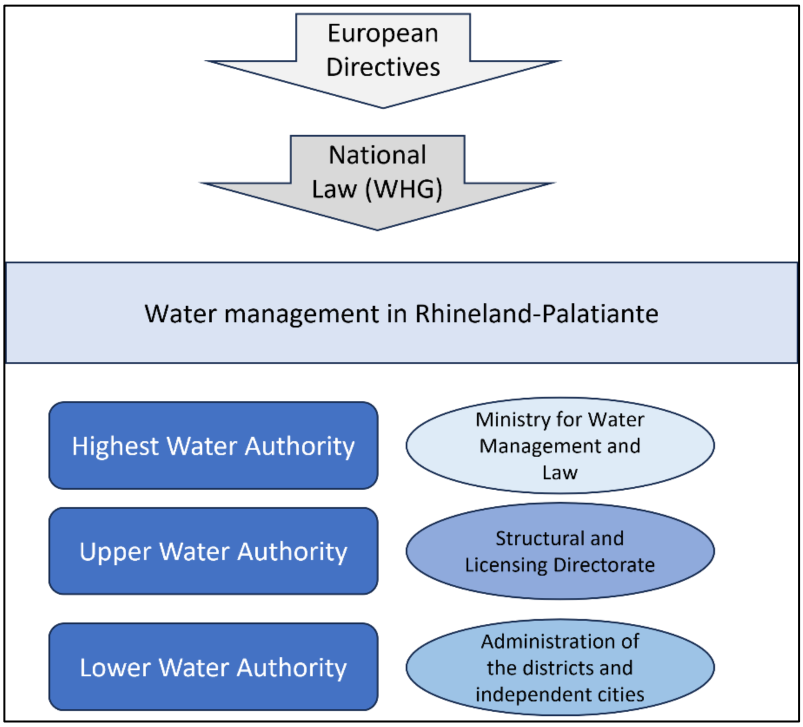


Figure 7: Hierarchy of Water Authorities in Rhineland-Palatinate (own creation)

The lower water authority is responsible for granting permits for groundwater abstraction unless larger quantities of water per day are involved for which the upper water authority is responsible (more than 24 m3 per day). They hold authority in the districts and independent cities and are generally responsible for the implementation of the Federal Water Act and the Land Water Act.

The upper water authority and the highest water authority, which is the Ministry for Water Management and Law, exercise technical supervision. The upper water authority is the Structural and Approval Directorate. They are responsible for the use or impairment of groundwater, on water bodies, dykes and installations if these are not subject to maintenance of the Land, the districts, or the independent cities.

According to §98 (1) LWG all water authorities shall be responsible for water supervision. This means they need to monitor the condition and use of water bodies, banks, flood protection facilities, water protection areas, dams and water reservoirs. The tasks of the water supervisory authority also include reviewing and, if necessary, adjusting approvals regularly (§98 (2) LWG). According to §119 LWG, the relevant competent water authority is responsible for prosecuting and punishing administrative offences.

5.2 On-site Observations

While conducting the interviews in the research area, some field observations were made regarding agricultural irrigation. These observations are briefly described below with the help of photographs. Fields are irrigated in such a way that the infiltration of soil is exceeded, resulting in run-off and the occurrence of 'small floods' adjacent to dirt roads. This loss in irrigation water can be seen in Figure 8. Since irrigation is partly automatic, the farmer was not found in the vicinity of these fields during the irrigation. In addition, these practices occur during daytime, causing evaporation losses significantly higher when compared to night-time irrigation practices.

a)  b) 

Figure 8: Pictures of irrigated Fields between Freimersheim and Weingarten(Pfalz), taken on 7th of July 2023 at 11:55 am. Water which cannot infiltrate the soil floods the field (a) or runs off to the road (b).

Upon inspection, it was evident that leakages occurred within the pipe system, which can be seen as an example in Figure 9.

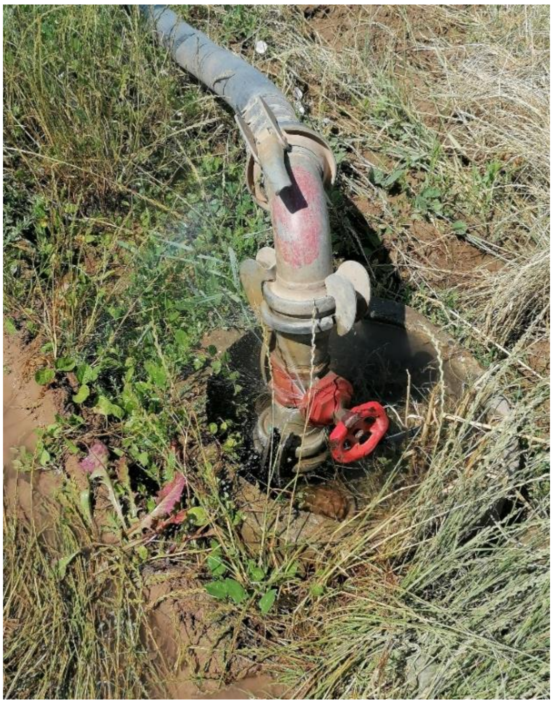
c)  d) 

Figure 9: Leaks of the irrigation system, due to leaking connections. Pictures taken along Fields at Lustadt (left) and Weingarten(Pfalz) (right) on the 7th of July 2023.

Due to this form of irrigation, erosion took place in some fields (see Figure 10). Signs of crusting were also visible, preventing infiltration, thereby further contributing to run-off and erosion. It is also suggested that insufficient tilling practices contribute to highly compacted soil, cracked in some places (see Figures 11 and 12), which again shows signs of reduced water absorption capacity.

e) f)

Figure 10: Pictures of Fields close to Hochstadt taken on the 7th of July 2023. Traces of water erosion of the fields (e) and soil settlement on the concrete tracks (f) due to irrigation. The area there has a slight slope which favours downhill runoff.

Figure 11: Edge of a fallow field between Hochstadt and Kleinfischlingen. The earth of the field is compacted and broken up.

Figure 12: Picture of a field path between Hochstadt and Bornheim taken on the 15th of July 2023. The soil is cracked due to the drought.

Figure 13 shows that this compaction of the soil still partially exists after ploughing and replanting. The soil of the field consists mainly of large and small lumps of earth.

Figure 13: A photograph of a freshly planted radish field near Lustadt. The ground is crumbly. There is also no vegetation between the path and the planted field.

5.3 Adaptation Measures

In the following chapter, the results are presented about possible adaptation measures to increase the drought resistance of the research area. For this purpose, the results of the interviews were used, as well as the findings from the selected documents.

At this point, particular reference should be made to the analysis of the national water strategy. This strategy, released on March 15th, 2023, aims to improve sustainable water management in Germany, with a vision to protect natural water resources by 2050, including increasing drought resilience (BMUV, 2023). These insights provide valuable guidance for the research area and broader trends in Germany's future water management.

5.3.1 Organisation

To ensure sustainable water management, a stable and modern organization is essential. This requires strengthening administrations, enhancing data flows, and optimizing the regulatory framework. The national water strategy aims to review and update water-related regulations, facilitate inter-municipal cooperation, and bolster administrative capacity through digitalization, following a nationwide personnel requirements survey. Additionally, the strategy seeks to enhance legal and technical data management and exchange to improve web-based services for users (BMUV, 2023).

5.3.1.1 Integrated management

From the various authorities as well as the interviewed water associations, the agricultural chamber, and nature conservation, there is support for participation and integration in water management. It is emphasized that various models of cooperation (top-down and bottom-up) should be used to effectively shape water management (#7, #1 and #2). This includes workshops and the involvement of stakeholders. Agriculture is identified by the #7 Upper Water Authority Structural and Approval Directorate South (SGD Süd) as an important actor in water management, and it is pointed out that the appreciation and responsible handling of water in this sector must be promoted. From an agricultural perspective, it is also welcomed when solutions are sought through a collaborative process. #2 Climate balance consulting, Chamber of Agriculture Rhineland-Palatinate: "That means the need is definitely there to monitor and regulate, but this regulation should not be carried out entirely top-down. Instead, it is necessary to establish a dialogue somewhere."

However, this collaboration between authorities and agriculture is seen as "too valuable" from a nature conservation perspective, as stated by #5 Management, NVS Naturstiftung Südpfalz, and it has been expressed that economic aspects would take precedence over environmental aspects here. #7 SGD Süd emphasized, the importance of including and integrating non-governmental organizations (NGOs) or environmental associations. They stressed that there is sometimes a lack of understanding from both sides and highlighted the need for both authorities and the environmental side to be involved so that they can learn from each other. Additionally, #7 SGD Süd advocates for fostering dialogue and information exchange with stakeholders, especially NGOs, despite the time and resource demands. It's acknowledged that public participation is currently lacking, and while reaching the general population can be challenging, there's a strong desire to engage more individual stakeholders.
A similar notion was mentioned by the national water strategy to further develop the water infrastructure in a climate-adapted manner. It was said that it will be examined whether the creation of structures for participation and mediation, in general, could accelerate the implementation of national requirements (BMUV, 2023). The integration of other organisations or individuals in water management decisions is thus seen as a possibility.

Projects are coordinated between the individual municipalities and authorities, with information typically flowing from higher to lower authorities, a process supported by #1 Climate protection management. They highlight the importance of recognizing that water systems and networks transcend district boundaries due to their interconnected nature and diverse impacts, advocating for a central overseeing office at a higher level. Further, #1 Climate protection management, Bellheim Municipality said, "but it would be helpful to have a local contact person in the sense of a coordinator. (...) So this track could be strengthened to be able to better place the topic of water and drought locally or to be able to give feedback." Furthermore, #3 Building Department, Bellheim Municipality, notes that municipalities may face limitations in their actions due to assigned responsibilities and financial constraints. Hence, they stress the significance of agreements and mutual support among authorities.

5.3.1.2 Drought Management Plan

#4 Management, Water Board 'Germersheimer Süd Gruppe,' and #9 & #10 Water Board Verbandsgemeindewerke Landau Land stress the legal requirement for drinking water suppliers to maintain an emergency plan and risk management system. While these plans are not drought-specific, they encompass provisions for such scenarios. For instance, Watermaster #10 highlights the maintenance of old wells for potential reactivation during emergencies, with constant monitoring and quality checks coordinated with the health department. Moreover, Landau-Land water board maintains a reserve tank of drinking water for outage contingencies. This emergency preparation and risk management plan necessitates collaboration with other water suppliers, as drought impacts can vary across the region. #4 Germersheimer Südgruppe water board spokesperson suggests the value of adopting such fundamental precautions in other areas. #4 Management, Water Board Germersheimer Süd Gruppe: "Drought management plans as a whole and now for each individual, for each consumer, makes sense." They say it would be appropriate for higher authorities to develop suitable concepts and, when necessary, provide financial support. Even if the support is in the form of creating a legal framework, it can still be viewed as financial assistance, as it provides clear guidance on what needs to be done.

The SGD Süd is currently in the process of developing so-called low-water precautionary concepts. Such concepts would clarify which areas are prioritized for water supply. However, this could also mean that as a consequence, certain sections could run dry. It is also known from other regions outside of the research area that in emergencies at the municipal level, water availability was essentially restricted, including bans on irrigating green spaces or washing cars on the premises. #1 Climate Protection Management, Bellheim Municipality: "In this region, we have not faced such a situation yet. It is not impossible for the future, and I am sure that if the need arises, municipalities will also resort to such measures." Here one of the goals of the national water strategy may help with this. The federal government wants to develop in dialogue with the Länder and interest groups, a nationwide guideline to provide prioritised decision-making orientation in the event of temporary water scarcity (BMUV, 2023). Both the #10 Water Board Landau-Land and the #7 SGD Süd confirmed that more information about water availability and regional demand is needed for such low-water concepts. This requires transparency among the involved stakeholders.

5.3.1.3 Review of existing rights and concepts

Spokesperson #5 from NVS Naturstiftung Südpfalz emphasized once again that existing extraction rights should be scrutinized more closely. #5 Management, NVS: "The wells, some of them are permitted for 19 meters, but at that depth, they hardly get any water in the summer now (...). So, the wells are much deeper than they should be, and no one is checking that." This is particularly relevant when drinking water protection areas are located in the vicinity of extraction wells and can therefore have an impact on the drinking water supply. #7 SGD Süd disputes claims of impairment caused by agricultural wells and questions whether any impact has occurred over the last 30 years, with no current evidence of drinking water extraction restrictions in monitoring reports or similar sources.

Nonetheless, both upper (#6) and lower (#7) water authorities concur on the importance of reviewing and adjusting water usage rights and concepts to safeguard water resources and sustainable water use. This necessitates periodic review of usage permits and extraction rights, particularly in response to significant changes in water availability, ensuring fair and equitable allocation during periods of scarcity. #7 Structural and Approval Directorate South: "Some of these rights date back to the 1980s. (…)That can no longer be the case. Accordingly, we need areas where we know exactly how much water we have, and that needs to be distributed strategically." However, there is also agreement that enforcement of measures can be difficult in some cases. For example, there is some guarantee of grandfathering for existing water rights. The challenge of getting users to accept water restriction measures is also pointed out. According to the SGD Süd, they have the possibility of regulatory intervention if necessary. But this also involves a considerable effort, which is seen as an obstacle.

5.3.1.4 Drought Information Network

Information and awareness are pivotal for addressing the issue of drought. To facilitate this, an information network dedicated to drought is crucial. Interviewee #6 from the lower water authority points out that there is room for improvement in the availability and communication of information on drought and dryness in the discussed regions. Currently, there is no well-established information platform or network for drought events, unlike other natural disasters such as floods. However, there are already considerations and precautions in place for forest fire risks.

Both #9 & #10 Wasserzweckverband Landau-Land and #2 Chamber of Agriculture express the need for establishing data collection networks for emergencies and water shortages, making this information transparent and easily accessible via web services. #2 Climate balance consulting, Chamber of Agriculture Rhineland-Palatinate: "So as farmers, we often work with tools that optimise our business processes, but also give us little hints again and again. Like caution storm warning or caution severe weather event." The suggestion is made to include the water levels in the relevant areas in a field mapping or on the website of the Center of Excellence in Trippstadt. By this, farmers could be easily informed about potential red zones or water restrictions, promoting awareness of water sensitivity in these areas.

These suggestions are in line with the efforts of the national water strategy. In cooperation with the Länder, the federal government wants to set up a programme in which nationwide, comprehensive modelling of the water balance in combination with climate models becomes possible. This includes water balance analyses, low water information systems, uniform definitions of parameters, groundwater real-time abstraction monitoring and a transparent water register. This data and information are intended to support users with planning decisions and risk-oriented groundwater management and to complement existing services (BMUV, 2023).

Coordination and communication between water users, municipalities and higher authorities would have to take place to react appropriately to drought events. Anyone noticing a shortage would have to report it and this would then have to be entered into a system. And if problems are repeatedly found in the same place, "help or a solution must be found", said the #10 Landau-Land water board. However, this also requires a certain openness and willingness on the part of the water suppliers to share their problems.

Furthermore, it is important to provide information to sensitise the population. When asked why the implementation of measures fails, the #1 Climate protection management, Bellheim Municipality, said: "Maybe it sounds funny. But I would say communication." The population is interested, but the difficulty is that this is a complex issue for which there are no simple and quick solutions. And there are also very different levels of information, up to and including misinformation. Municipalities play an important role in providing information and could initiate workshops and campaigns to inform the population. #1 Climate protection management, Bellheim Municipality "And another resource that would be necessary for this would be money. (...) For some measures, there are actually funding programmes and subsidies. The municipalities are usually reasonably well informed and use these funds."

5.3.1.5 Monitoring

The SGD Süd is accused of not carrying out sufficient monitoring of water extractions. Consequently, there is little indication of actual water consumption data in the region. #1 Climate protection management, Bellheim Municipality " There are reports that 8 to 10 times more water is used here than was actually allowed by the SGD. But there are still no controls to confirm or stop this.”

In principle, all respondents considered monitoring an essential part of water management, crucial for understanding and calculating groundwater availability, as continuous monitoring is necessary to make statements about the water balance. However, there is a clear deficit in implementation.

While there is a state monitoring network for checking groundwater measurement points and surface levels to monitor fluctuations in the groundwater table, done in collaboration with the hydrological service and the state agency (#7 SGD Süd), interviewee #3 from Germersheimer Water Association criticizes that monitoring points have been discontinued in recent years. This means that there can be no real calculation of water availability because crucial data is lacking or could be erroneous.

A monitoring deficiency is also recognized by the upper water authority itself. #7 Structural and Approval Directorate South: "But the bigger problem, in my opinion, lies in the implementation, in the controlling, in practical actions. (...) Here, we are somewhat the problem. We need to get into the implementation." The reasons cited for this issue include limited personnel and financial resources and a limited regulatory capacity to reduce or revoke rights. The SGD Süd states that they do not have the necessary means to carry out the required inspections or impose sanctions. Without these resources, it is currently challenging to effectively monitor the over 2000 wells within their jurisdiction.

The Landau-Land Water Board also points out that there are not only insufficient controls on withdrawal quantities but also on the construction and maintenance of wells. While appropriate applications are submitted to the authorities and reviewed, once the approval is granted, further measures to control the construction process are rarely taken. According to the Water Board, this lack of on-site supervision can pose a safety risk for the overall water supply. #10 Watermaster, Water Board Verbandsgemeindewerke Landau Land: "These wells are often drilled by farmers without much background knowledge, I would say. They need water in this field or in that area. A well is then created by a company, and no one cares about it afterwards. They are in a catastrophic state, I've heard, and they are not maintained. They are not inspected; sometimes there are no covers on them."

5.3.1.6 Digital Measurement Counters

#5 Management, NVS Naturstiftung Südpfalz, proposes the use of digital measuring devices to address the lack of controls, particularly in the context of water quantity measurement. Advocating from a nature conservation perspective, they view the introduction of digital flow meters as a valuable step to enhance monitoring and curb potential arbitrary actions by farmers. The responsibility for implementing this measure falls under the SGD Süd.

#7 SGD Süd reports ongoing pilot projects in various regions and acknowledges the importance of water usage control and monitoring. The introduction of digital measuring devices is seen as an advanced solution, making manipulation more difficult and improving data accuracy. However, it's recognized that the feasibility of implementing digital technologies for water quantity measurement may vary based on local requirements and conditions, and the current costs of such meters are relatively high. #7 Structural and Approval Directorate South (SGD Süd): "It's like this, only when there is a certain mass production does the price of these meters go down. Currently, the meters are relatively expensive. They range from €2,500 on the low end, up to €5,000."

Incentives could be created for farmers to still use this digital technology as a 'water-saving measure' by offering them concessions in terms of the water-cent (a unit of water charge). For instance, if a farmer adopts digital technology for efficient water use, they could receive reduced fees and reconciliation options. Similarly, when industries implement water-saving measures, the farmers can earn credits and lower their costs.

5.3.2 Savings Measures

The interviews explored a range of water-saving measures, emphasizing the importance of increasing awareness among water users and creating incentives for responsible water consumption. Practical strategies to enhance water efficiency were also considered.

In the following, the individual measures to regulate water consumption will be discussed further.

5.3.2.1 Reduce water consumption in the population in general

To better prepare for droughts, it is proposed to increase public awareness. This involves distributing information, as discussed in Chapter 5.3.2 and encouraging the population to conserve water during dry periods. The question is raised about the necessity of using drinking water for activities like lawn irrigation or pool filling in dry periods. According to #7 SGD Süd, it is the responsibility of drinking water suppliers to approach the public and initiate campaigns.

In addition, SGD Süd published a brochure to educate citizens about responsible water usage, which includes recommendations to use less hot water, avoid unnecessary running of taps, buy regionally and seasonally, and implement natural gardens, rain barrels, and cisterns for private water storage. The brochure also touches on the origin of regional drinking water and the effects of climate change on this resource (LfU, 2020).

Furthermore, the national water strategy aims to establish a communication strategy "Water" over a decade, focusing on information and communication measures to foster social acceptance of sustainable water resource management. It emphasizes the need for education in climate change adaptation, risk management, and water protection. The strategy also introduces a competition for innovative and efficient water use by companies, alongside training opportunities for specialists, managers, and municipal decision-makers to enhance their understanding of water management interrelationships (BMUV, 2023).

5.3.2.2 Water Cent

The upper water authority determined that a regulation for the Water Cent comes into force on 1st January 2013. The charges for water usage in this system vary based on different factors. Groundwater usage costs 6 cents per cubic meter (1000 litres), while surface water costs 2.4 cents per cubic meter. For specific purposes like cooling water or mineral resource extraction, the charge is 0.9 cents per cubic meter. In cases of once-through cooling for energy-efficient plants using renewable energy, natural gas, or waste materials, it's 0.5 cents per cubic meter (MULEF, 2012). The Water Cent, or the pricing of water, is seen as a control instrument that creates incentives for water conservation. In Rhineland-Palatinate, there has long been a special regulation for agriculture, so water use by farmers was associated with very few costs.

#1 Climate Protection Management, Bellheim Municipality: "Agricultural users have been able to use groundwater for free up to now. They just had to pay their energy bills for pumping."

Several exceptions exist for public interest uses e.g., firefighting. Small withdrawals under 10,000 cubic meters for groundwater or 20,000 cubic meters for surface waters per year are exempt from fees. Agricultural irrigation remains exempt for reasons of administrative economy, as do water withdrawals for hydropower or geothermal energy. Moreover, there's an opportunity to offset up to 25% of the annual abstraction charge (MULEF, 2012). However, these regulations are expected to change. #4 Management of the Water Board Germersheimer Süd Gruppe discussed a new proposal for the Water Cent in Rhineland-Palatinate. According to this proposal, farmers would also be charged a fee based on the volume of water they extract from the ground. Currently, the water fee for drinking water suppliers in Rhineland-Palatinate is 0.06€ per cubic meter of extracted water. The ongoing discussion considers whether farmers should pay a reduced rate of 0.02€ per cubic meter, but its acceptance remains uncertain.

Funds from the Water Cent are designated for sustainable watercourse management only (MULEF, 2012). According to #7 SGD Süd, the Water Cent not only promotes responsible resource use but also provides funds for enhancing system resilience and implementing specific strategies.

The proposed water price for farmers is lower than the current rate for drinking water suppliers and other users. This is justified by the fact that water used for irrigation remains within the natural cycle, and there's concern that higher irrigation costs might hinder farmers' competitiveness in the market, as explained by #4 Management, Water Board Germersheimer Süd Gruppe. But whether this will sensitize the farmers is another question. For nature conservation, this doesn't go far enough; it is criticized that the pricing is too low and likely won't bring about a change in the behaviour of farmers. #8 BUND Southern Palatinate District Group: "What they have to pay for water is a pittance. Depending on the irrigation method, they pay roughly the same for water as they do for the energy required for pumping and the associated infrastructure. (…) But with higher prices, the farmers' representatives immediately back out again, saying then food will also become more expensive. But no one can say how much more expensive it will become."

5.3.2.3 Cisterns

The use of cisterns was seen by the interviewees as a practical measure to use water efficiently on-site and to conserve drinking water resources. In drier periods, for example, the garden can be watered with stored rainwater. The local municipality Bellheim wants rainwater to be infiltrated on site as much as possible, and to this end, financial subsidies are granted for the installation of rainwater infiltration systems such as cisterns stated #1 Climate protection management, Bellheim Municipality. However, it was also noted that this possibility is only used to a small extent by the population. The main reasons for this are assumed to be the higher costs and the lack of space. Nevertheless, efforts are being made to encourage the population to make use of this opportunity. Interviewee #8 of BUND Southern Palatinate District Group said: "I even think it should be compulsory to install not only a solar system on the roof of every new building but also a cistern."

The use of cisterns has another advantage. In some areas, rainwater infiltration is difficult because the groundwater table is already high. Here, cisterns can be used to store the water and release it later into the sewage system in throttled quantities if not used for irrigation. This would also relieve the burden on drinking water suppliers in the long term. #10 Water Board Verbandsgemeindewerke Landau Land "Every winter we have tons of water, it flows away quickly and in summer there is a shortage. If people were privately promoted to store water like that, you would have large amounts stored privately with people, which they can then use at times for watering their gardens. You wouldn't have to use precious drinking water."

5.3.2.4 Water-Reuse

Another measure, which was also proposed by Fallon and Betts (2010), is the reuse of water. The term water reuse was also known to many of the interviewees but was viewed rather critically in some cases. For example, #10 Water Association Landau-Land noted that the use of water in private households is often associated with the fact that people are not familiar enough with the subject. And if used incorrectly, this can quickly lead to hygiene and health risks, or even to environmental damage. #10 Wasserzweckverband Landau-Land "Toilets were connected and even washing machines. We once took water samples by mistake from such a water connection. There were so many different germs in it. No one can imagine the highly dangerous germs in rainwater."

Nevertheless, the potential of this option is also recognised. The reuse of water can save not only drinking water but also treatment costs, which is also associated with a high energy demand. For this, of course, more concrete concepts would have to be developed, such as separate water systems. As things stand, the interviewees could not yet endorse the system. The reuse of water for agricultural food production was rejected by #7 SGD Süd also for hygienic reasons. However, golf courses could be irrigated this way.

5.3.2.5 Separate Sewage System

As already mentioned, there is a growing interest in the separation of wastewater and rainwater in the sewage system. It is indeed considered desirable by water authorities and municipalities. In newly developed areas, the concept of self-sustaining water supply, including the use of grey water and reclaimed water, is seen as sensible (#7 SGD Süd).

The spokesperson for BUND suggests that each house should have three different water systems: drinking water, wastewater, and reclaimed water (using rainwater for various purposes). Local wastewater treatment could also be considered as a way to further relieve the sewer systems.

#7 Structural and Approval Directorate South: " This is certainly something that will need to be done, but the difficulty could be in implementing it completely. Currently, it's still somewhat stigmatized."

It was also emphasized that a certain water flow rate in the sewer system is necessary to ensure proper function and cleaning of the sewer and to maintain certain hygiene standards. It is already necessary in some cases to flush the pipes with fresh water in the summer for cleaning. Furthermore, conversion of existing structures is more challenging to implement and expensive. #3 Building Department, Bellheim Municipality: "We have a developed sewer system that has been expanded over the decades, added to here, done something there. It doesn't look too bad in our network, hydraulically speaking, but there are always overloaded areas. (…) To intervene hydraulically in an existing sewer system is associated with immensely high costs. We want to avoid that and prepare ourselves for the future, so we aim for infiltration in all new constructions and additional sealed areas."

5.3.3 Agricultural Adaptations

Agriculture, particularly the cultivation of vegetables and special crops, plays a vital role in water management. The region's agricultural water usage has been critically examined by all interviewees, who expressed the need for improvement. The SGD South emphasizes the importance of agriculture adopting water-saving technology and being mindful of evaporation rates. Additionally, #2 from the Chamber of Agriculture in Rhineland-Palatinate highlights instances of water withdrawal stops in the Rhine Valley as an example of the current water management tensions.

However, it is acknowledged that achieving improvements in this sector is a lengthy process. The spokesperson #2 for the Chamber of Agriculture suggests that instead of imposing demanding measures on farmers, a more cooperative approach involving various stakeholders in water management is needed to drive change.

5.3.3.1 Land-use Change

The spokesperson #8 of BUND Southern Palatinate District Group repeated several times that too intensive cultivation of the soil strongly reduces its quality and especially its infiltration capacity. Agriculture is accused of not being sustainable and of neglecting the effects of soil erosion. This point was also made by #5 Management, NVS Naturstiftung Südpfalz: "Yes, they irrigate endlessly, and the soil cannot absorb it at all. You have flooding in midsummer and all the mud is on the field paths."

Instead, it is suggested to cultivate the soil less intensively. #2 Climate balance consulting, Chamber of Agriculture Rhineland-Palatinate suggested bringing in more structure with changing crop rotation. Using deep-rooted plants to create a kind of bio-path for water permeability. A permanent cover of the soil can also protect against drying out and erosion.

The Chamber of Agriculture also proposes the cultivation of more drought-resistant plants, such as legumes, which also serve as nutrient and nitrogen collectors. However, it is also said that despite increasing numbers of such legumes, a quicker and easier change of crops is not realistic. Here, the existing economic structures in agriculture are an obstacle. #2 Climate balance consulting, Chamber of Agriculture Rhineland-Palatinate: "So the scientific demands to simply grow other fruits also crashes the economic reality that we have fixed purchase contracts, the whole business structures are set up, if I have a biogas plant that I also feed with maize silage, so to speak. Then I have to produce a certain proportion of maize, which is a fairly full, water-intensive crop, and I can't just switch from one to the other."

And it was also noted by #2 Climate balance consulting, Chamber of Agriculture Rhineland-Palatinate that possible conversions in viticulture are even more difficult, as here one has to reckon with other periods of 15 to 30 years. In addition, viticulture also suffers from fluctuating climate conditions and it is not yet possible to foresee how this will behave in the future.

5.3.3.2 Green Walls

This measure is proposed or advocated by BUND, the upper water authority SGD Süd and the water association "Germersheimer Südgruppe". By erecting obstacles such as small walls, trees, bushes, mulch or even solar panels, shading is created and the wind is reduced. As a result, soil and water bodies are more protected from drying out. Such shading measures are already used, for example, by the Bellheim Municipality to protect its watercourses, as the #3 Building Department reports. The spokesperson #8 from BUND has also already used this method on private farmland for vegetable cultivation. #8 BUND Southern Palatinate District Group: "I have created a perma garden, a forest garden actually. I grow potatoes, which are now so tall (...) And I never watered them. It is still grass-green now. And next to it are the dry fields, if they're not irrigated, they get ruined."

5.3.3.3 Irrigation from the Rhine

There are different opinions and concerns about this topic from the perspective of water suppliers, nature conservation and the upper water authority SGD Süd. Overall, there seems to be a debate about how much water should be taken from the Rhine for irrigation and how this can be balanced with other water sources and environmental impacts.

#7 Structural and Approval Directorate South emphasised the need for irrigation for agriculture and food supply, while others point to the limited resources of the Rhine.

#8 BUND Southern Palatinate District Group: " Yes, we only take out 1% of the flow. One cubic metre per second to irrigate. Okay, you 1%, they 1% and the next 1%, and eventually that's 150% though ."

From #4 Management, Water Board Germersheimer Süd Gruppe it was added that the Rhine has periods of low water, and then the abstraction of water from it can affect the groundwater level. Nevertheless, it is argued that water supply in the region relies on various sources, and there are limited alternatives for irrigation of agricultural land.

5.3.3.4 More Efficient Irrigation Technologies and Drip Irrigation

In the Southern Palatinate, and thus also in the research area, the irrigation of agricultural land is carried out exclusively via individual wells from the aquifers near the surface. The individual wells are mostly maintained and operated by the farmers themselves or by water and soil associations (BGS Umwelt, 2011).

Several of the interviewees have mentioned that new ways of irrigation in agriculture are needed if water management is to be adapted to dry and drought periods. This is also because farmers' use of water for food production could compete with drinking water supplies in the long term, says #5 Management, NVS Naturstiftung Südpfalz. In the past, there have already been conflicts between groundwater use for agricultural irrigation and nature conservation, and they are still ongoing (BGS Umwelt, 2011).

In addition, water use for irrigation is not considered efficient. The sprinkler systems that are currently primarily used virtually shoot the water into the air. At the same time, irrigation often takes place in the middle of the day. As a result, a very large proportion evaporates and the water is not used efficiently and sparingly. #8 BUND Southern Palatinate District Group: "95 % of the water that is irrigated evaporates again, which does not benefit the plants at all." This can also be seen in Figure XX.

Figure 14: Sprinkler used for irrigation (Picture taken by Nathalie Neubauer, 2023)

#4 Water Board Germersheimer Süd Gruppe criticizes local farmers' reluctance to adapt to hot temperatures, citing international examples of successful strategies. That is why it is particularly important to provide advisory services and subsidies for investing in more efficient irrigation systems, says #2 Climate Balance Consulting, Chamber of Agriculture Rhineland-Palatinate.

About sustainable agricultural irrigation in the Southern Palatinate, a study was carried out in 2011 by Brandt Gerdes Sitzmann Umweltplanung GmbH on behalf of the SDG Süd. It was identified that mainly pipe irrigation is used in vegetable growing, while drip irrigation is only used economically for long-standing times or special requirements. In addition, there is also the possibility of mobile irrigation machines and row sprinklers. The use of semi-stationary irrigation machines requires large agricultural areas, which are not available in the Southern Palatinate.

Mobile sprinklers with electronic intake control could save nearly 10% of water, but these systems require a lot of work and have to be set up and dismantled during the sprinkling period. Fixed systems that can be operated automatically, but the investment costs are high.

Drip irrigation allows efficient application and distribution of water and reduces evaporation and wind drift, with estimated water savings of around 30%. Drip irrigation is mainly used in special crops but requires high investment and labour. It is said that shifting irrigation times to the low-evaporation evening and night hours offers only small savings. In conclusion, it is written that the greatest savings potential through irrigation technology has already been largely utilised (at that time), with future potential estimated at roughly 10%, insufficient to offset rising demand. (BGS Umwelt, 2011). However, this study was commissioned over 10 years ago.

5.3.4 Reservoir Recharge

In addition to conservation measures, it is crucial to incorporate groundwater recharge and maintain a positive, or at least neutral, water balance. The national water strategy aims to promote climate-adapted urban land use. Prioritizing water management in spatial planning is vital, adopting water-sensitive city principles like rainwater use, infiltration, and drought prevention. The federal government shall support such efforts with subsidies. To ensure sustainable water management and good water status, federal-state expert meetings should be held to coordinate spatial planning and water management. In addressing environmental concerns, measures for floodplain renaturation, preservation, and ecological enhancement must be developed (BMUV, 2023).

5.3.4.1 Water Balance

To better understand the current status of water resources and also to be able to adequately assess the efficiency of different measures, area-based water balances are necessary. This was confirmed by all interview participants. And especially on the part of nature conservation, the urgency of calculating the water balance was emphasised. #8 BUND Southern Palatinate District Group: "First of all, you need a water balance, which does not exist. It is always said that agriculture only needs 2% of Germany's water demand. However, that is not proven."

From #3 Building Department, Bellheim Municipality and #6 Lower Water Authority, Germersheim district it was said that the introduction of such a water balance is now a requirement for new building areas. After the realisation of a building project, it should be ensured that runoff and infiltration correspond to the original state before the building project. This should give more control in settlement areas and prevent a deterioration of the condition.

However, a water balance is not only significant in urban areas. #7 Structural and Approval Directorate South explains that it is essential to differentiate between the soil water balance in the upper area and the groundwater in the deeper area. Because of separation horizons in the soil, there is little exchange between the water-bearing layers. Therefore, it is always important to differentiate where water is extracted, especially in the agricultural sector.

Currently, there are various monitoring structures in place to track potential changes within the water storage said #7 SGD Süd. Among them is a monitoring program involving eight wells that are evaluated by external entities. A report for this specific program from HG Büro für Hydrogeologie und Umwelt GmbH was published this year. It reports a pilot project which was carried out as a follow-up study to the study of BGS Umwelt (2011). A total of eight wells of 40 irrigation wells were examined in the Hochstadt-Zeiskam area in the period from 1 January 2022 to 31 October 2022. Not only was the flow rate of the individual wells measured, but groundwater levels were also measured continuously using new technology. The data was transferred centrally to a data server for remote access. This was also intended to limit the amount of personnel required. Several of the eight wells experienced technical difficulties with the installed probes or the power supply. It was found that the tested system was suitable for monitoring despite the difficulties mentioned. Furthermore, it was stated that no adverse change in the hydrological situation in the monitoring area was observed as a result of the abstractions for irrigation. After the irrigation season, all measured wells show an increasing trend towards the initial level of the tapped aquifer (HG, 2023).
This report puts a strong focus on the technical aspects of a possible new monitoring system. It was also criticized by regional media that the report's statement that the groundwater level returned to its original level after the 2022 irrigation season neglects the fact that September 2022 was exceptionally wet. It is stated that if the dry season lasts longer, the results might have been quite different. Furthermore, the examined eight wells are not a representative quantity for the 2500 wells under the jurisdiction of SGD South (Schmidt, 2023).

5.3.4.2 On-site Infiltration

The suburban infiltration of precipitation plays an important role in replenishing water reservoirs. #9 Management, Verbandsgemeindewerke Landau-Land notes that there is already a legal basis under the Water Management Act, which stipulates that water should ideally remain on-site and allows for suburban infiltration. In urban areas, however, decades of human impact have compacted and sealed the soil to the extent that infiltration is no longer optimal. Instead, rainwater is directed out of the area to prevent potential flooding (#1 Climate Protection Management, Bellheim Municipality).

The #6 and #3 confirm that, according to the legal norm, suburban infiltration is desired, and they are trying to implement this wherever possible through stricter guidelines and financial subsidies. In new residential areas, there is also a greater emphasis on not directing rainwater into the sewer system but instead utilizing it on-site. Additionally, on the municipal level, efforts are being made to reopen sealed surfaces in urban areas and create more space for water retention measures. Moreover, they aim to counteract the 'Urban Heat Island' effect caused by the heating of asphalted or paved areas, as mentioned in #1 Climate Protection Management, Bellheim Municipality: "There are initiatives, some of them have already been implemented, to require in new development plans, for example, that areas should be sealed as little as possible, practically only driveways to the house, and that permeable areas should be created. There's also a prohibition on stone gardens, which is not allowed. Perhaps even the promotion of green roofs, if it fits, is within the municipality's discretion." These aforementioned stone gardens (shown in Figure XX) have gained popularity among the population in recent years. This is now to be counteracted.

The #7 SGD is taking a similar approach by thinking about concepts for more resilience in cities and creating more green infrastructure through adaptation of the sponge city approach. However, it is also objected that according to the legal situation, the urban land use planning here lies with the municipalities, i.e. the communities. At this point, the upper water authority can only make recommendations on how to strengthen the local water balance. The municipalities are the decision-making authority because local interests must always be considered.

5.3.4.3 Retention Areas

Infiltration should not only be made possible in settlement areas. A fact that is also very clear to the upper water authority. #7 Structural and Approval Directorate South: "Also the whole forest areas we have to design in a way that we create a buffer possibility there.". #1 Climate protection management explained that many aspects of the sponge city design are intriguing. However, it is unlikely that larger green areas for retention purposes will be implemented in this region. The demand for building areas is high and the areas of the municipalities for settlement space are limited. Clear priorities are set here. Instead of inside of the settlement areas retention possibilities need to be created where water can be held naturally on the landscape and thus also replenish the local water balance via slow percolation. #1 Climate protection management, Bellheim Municipality further suggests: "And maybe the drainage of the land needs to be rethought, reduced; that measures are taken to be able to keep the water on-site longer and better. For example, by renaturalising streams and lakes."

The interview partners #6, #3 and #10 talked about the renaturation of streams as well in this context. This could be further promoted, for example, within the framework of the 'Aktion Blau' program. In the region, many brooks were straightened in the past and there are also partly concreted out areas. Through appropriate measures, a renaturation could take place here. #10 Watermaster, Water Board Verbandsgemeindewerke Landau Land said that the environmental agency is currently carrying out some renaturations of the streams. It is believed that these measures, especially the establishment of light marshy areas, will help a lot to increase drought resilience.

Another type of retention space is said to be provided by stormwater detention basins, but this is sharply criticized by #8 BUND Southern Palatinate District Group. They say the existing basins are far too large and water is still drained from the area. It was further stated that there is a general mismanagement of the existing drainage ditches. Here it is suggested to close the ditches temporarily after heavy rain events to keep the water on site. In addition, a targeted irrigation of meadows and forest areas could also be created via this route. Partially the necessary infrastructure is still given, but personnel to supervise and implement this measure accordingly is needed.

This idea is based on an old tradition. Before artificial fertilisers were produced and agricultural land use changed accordingly, it was common practice to use the heavy winter and spring precipitation to deliberately flood fields and meadows, thus supplying them not only with water but also with nutrients (Keller, 2013). This so-called meadow irrigation is still practised as a cultural asset along the Queich meadows. #3 Building Department, Bellheim Municipality also noted, however, that in the recent past, they have only been able to carry out this irrigation once a year due to a lack of rainfall.

5.3.5 Drinking Water Protection

Another aspect is increased protection to safeguard drinking water supplies.

5.3.5.1 Drinking Water Protection Zones

Drinking water protection zones are the areas that lie within the catchment area of drinking water wells. For the upper water authority #7 SGD Süd it is clear that these areas are particularly worth protecting, especially the deeper water-bearing horizons that have the highest priority for drinking water supply. It must be ensured that other users do not compete with the public drinking water supply. To enable stronger protection of the drinking water resources, the possibility of an extension or reallocation of protected areas was discussed. #9 and #10 Management and Watermaster, Water Board Verbandsgemeindewerke Landau Land, explained that an expansion of protection zones could certainly secure the quality of the drinking water more strongly and that the process itself would also trigger a discussion among the population, which would create a certain awareness for the topic. On the other hand, there is also the question of where to set the new limit.

The spokesperson #7 SGD Süd reported in this context about a concrete plan, which received strong resistance, especially from the agricultural side. It was explained that in Weingarten the border for the new area was drawn at the 50-year line. This means that it takes 50 years for a drop of water to reach the extraction point from the outermost border. And yet it is still too big for some people, there might even be a lawsuit against it.

As a person in charge at water supplier #4 noted, an extension of the drinking water protection zones was a good thing in theory, but corresponding controls are also required to regularly check whether all the rules are being observed in the area. #4 Management, Water Board Germersheimer Süd Gruppe: "Let me put it this way: in principle, I am in favour of better protection. The main problem is actually the control, who actually controls all this? I have a protected area here, and then suddenly we find oil canisters over there because someone changed the oil in a protected area. Well, then the whole protected area is of no use to me."

5.3.5.2 Interconnections

Another measure that is strongly advocated by drinking water suppliers is interconnections. Interconnections are also mentioned as a measure in the national water strategy and should be included in spatial development plans in the medium term (BMUV, 2023).

Interconnectors can be used to compensate for any source failures or locally reduced water storage. This is particularly relevant in the research area, as due to the flow directions in the Rhine valley, water resources close to the Rhine are larger than in the sandstone mountains of the Palatinate Forest, where water is mainly extracted from springs (#4 Management, Water Board Germersheimer Südgruppe). The #7 upper water authority SGD South also says that in future it will only work via such networks of drinking water suppliers.

The #9 Water Board Verbandsgemeindewerke Landau Land and #4 Water Board Germersheimer Süd Gruppe both report that talks have already been held in this regard. In some cases, there has already been small-scale co-supply from neighbouring communities in the event of bottlenecks. However, it has been shown that regions closer to the Palatinate Forest have to deal with dry phases more often. And this is also one of the problems for the interconnected pipeline. To increase the security of supply, water suppliers must cooperate, and this means that even those who do not have dry periods must cooperate. Yet, not all of them are willing to do so. #9 Management, Water Board Verbandsgemeindewerke Landau Land: " It is understandable that the water suppliers who sit directly on the Rhine, who swim in the water, don't need this stress with these long-distance pipelines. What do they get out of it? It's just work and effort. A superior body would have to draw up such a plan for such a project, would have to get everyone on board, would have to explain the benefits, and what it means for everyone. And then; you can't just do it in a small community, the state government would have to initiate something like this practically. It would have to be said that this interconnection system has to be created now."

Therefore, more support and incentives are needed from the government and the state administration. In addition, the expansion and reconstruction of interconnected systems is very cost-intensive, the water boards alone cannot do this. However, this would be a long-term investment to ensure security in the region.

5.3.5.3 Limit risks from substance inputs

Another aspect which, was not specifically mentioned during the Interviews but as part of the national water strategy was to limit risks from substance inputs, such as medical residues or pesticides. The federal ministry wants to limit these through further research on substances and trace substances. EU directives are supported, promoting remediation of polluted water bodies, and plans to implement a fourth purification stage in sewage treatment plants using modern technologies such as ozonation or activated carbon filtration. However, financing for this stage is currently unavailable (BMUV, 2023).

5.4 Barriers

During the study, both potential actions and their associated barriers were identified. These barriers are presented in an overview in Figure 15, namely: lack of commitment, drainage vs. retention, financial problems, old building law, lack of awareness and acceptance, unused legal options, lack of specialist knowledge, time intensive, and shortage of staff.

Figure 15: The graph shows the barriers identified through the interviews (left) in connection with the respective measures identified (right). The graph was created with the programme Atlas.ti based on all coded transcripts. It should be noted that the thickness of the links shown here is only about the number of times the barriers were mentioned. It does not give any information about the rating of the barriers.

It was noted that a lack of awareness and acceptance was connected to almost all measures mentioned. In total, there were 51 citations in this category. Most remarks were made in correspondence to monitoring. A measurement which is currently facing the most barriers, although it is seen as an essential element of water management and is also a legal obligation. Further monitoring is also facing the barriers of shortage of staff, time intensive, financial problems, lack of specialist knowledge, and unused legal options. This was also highlighted by this statement: #7 Structural and Approval Directorate South, "And that is of course related to the issue of limited human resources. On the other hand, I also have users who are only willing to a limited extent, let's say, to accept restrictions with softer measures. So, I see more of a problem that you reach a point where you have to take regulatory action. And that, in turn, means a lot of time and energy, more effort. We are a constitutional state, we have possibilities. We have already established that we had some withdrawals that were clearly excessive. But when I think about how long it takes us to get fined in this case, how long the proceedings drag on. Is that also the realisation that this is tiring, I would put it that way."

The barrier shortage of staff was mentioned 20 times, mostly by the lower and upper water authorities, and it was used to explain why controlling measures (monitoring, review of rights and concepts, and drinking water protection zones) were not already in place or done efficiently. This lack of staff was also mentioned in the recently published Annual Report of the Structural and Approval Directorate South. A general shortage of specialised staff in the SGD Süd is described, despite some new appointments (SGD Süd, 2023).

Financial problems were mentioned by all interviewees, in total 21 times with different measurements. It was stated that to realise measurements a certain amount of funding is needed, but not always available for the specific party.

Regarding retention areas, #8 BUND Southern Palatinate District Group noted an unequal distribution of funding priorities. There is still a strong issue of path dependency, prioritizing flood drainage over flexible water management measures for future adaptability. Specifically, SGD Süd is contemplating using sheet pile walls to divert the Queich for a 200-year flood scenario, funds that could be alternatively used for holistic measures like sluice restoration in drainage ditches. This flood prevention focus aligns with the push for local flood and heavy rain prevention concepts (öHSVKs) supported by the SGD and the Ministry of Rhineland-Palatinate, aiming for economic and sustainable risk reduction. By December 2022, most municipalities in the research area began developing ecological flood risk management plans, although no concrete measures have been implemented as part of this framework (SGD, 2023). These concepts suggest natural water retention measures, such as floodplain renaturation, but lack specific measures addressing the link between drought and flooding (Rheinland-Pfalz ,2022).

The tendency to prioritise drainage was also noticed by the national water strategy and accordingly, it was stated that a natural soil function, including soil water balance and groundwater recharge, should be more strongly protected. To make this possible, there should be an amendment to §55 paragraph 2 WHG, which currently gives legal priority to sewer discharge over infiltration (BMUV, 2023).

Another path dependency barrier is the Old Building Law, particularly concerning separate sewage systems, on-site infiltration, water balance, and reviewing existing rights and concepts. These measures are primarily considered for new development areas or when renewing extraction well permits. #6 Lower water authority, Germersheim district explained that older structures enjoy grandfathered status despite changing external circumstances, limiting the application of newer concepts in old existing areas. New construction areas offer more flexibility.

Unused Legal Options are another barrier. This refers on the one hand to the non-implementation of legal obligations such as the monitoring of withdrawal quantities and the associated imposition of penalties if the approved withdrawal quantities are not adhered to. But it also refers to legal clauses that do not apply in practice, such as the Soil Protection Act Unsealing Paragraph 5. #6 Lower water authority, Germersheim. "From my point of view, a really important provision. I am not aware of a legal ordinance to this effect. This hint that one can regulate this via a legal ordinance has not been followed, I think."

Lack of specific knowledge and skills was mentioned 9 times. It was criticised that water management is above all an administrative task and that in the corresponding authorities and committees, it is not always those who have the appropriate specialist training who make the decisions, but often administrative employees. #4 Management, Water Board Germersheimer Süd Gruppe: "And it would be nice if it wasn't decided by some lawyers, but by people who are somehow used to doing things on a scientific basis." In addition, #5 Management, NVS Naturstiftung Südpfalz and #10 Watermaster, Water Board Verbandsgemeindewerke Landau Land noted that when installing irrigation wells, a lack of knowledge about the interrelationships of the hydrological system can cause damage, both to the quality and quantity of the groundwater.

The lack of commitment was a recurring concern mentioned 10 times. This issue pertains to projects and innovative ideas that often lack practical implementation due to the absence of specific responsible actors or binding commitments from politicians. This absence diminishes the effectiveness of promising approaches. For instance, #6 Lower water authority in Germersheim emphasized that programs of measures, like 'Aktion Blau', highlighting necessary actions at water bodies are not binding, leaving no clear person in charge. This voluntary approach in Rhineland-Palatinate and other states seeks measure carriers through incentives but lacks appointed individuals.

The aspect of time-intensity was another prominent topic raised eight times. It was emphasized by various actors, such as #1 Climate Protection Management in Bellheim Municipality, #4 Management at Water Board Germersheimer Süd Gruppe, and #7 SGD Süd. They noted that changes in water management, especially within organizational structures, are a long process. Additionally, results from specific measures may take time to materialize, making it challenging to garner acceptance for water management changes. #8 BUND Southern Palatinate District Group mentioned the extended residence time of groundwater levels, with changes often requiring up to 20 years to manifest, frustrating those seeking more immediate results.

6. Discussion and Conclusion

To achieve a better overview and deeper understanding, the results are discussed in this chapter. In the beginning, the findings for the sub-questions are summarized and their connections with the theory from chapter 3 are reviewed. Finally, this chapter brings the results into perspective of the relevant variables of the conceptual model to answer the main research question "How can improved water management strategies in the Upper Rhine Plain create drought resilience and help to adapt to challenges created by climate change?".

6.1 Discussion

The results of the semi-structured interviews and document review have for the most part reinforced and extended the insights established in the existing literature. This underscores the validation of the literature review as a robust foundation, albeit with a few notable exceptions. The following section explains this in more detail.

6.1.1 Sub-question 1

What are the key stakeholders involved in the implementation of adaptation measures to address the impacts of drought events and changes in water management strategies in the research area?

The key stakeholders include those directly impacted by drought events and water management changes, as well as relevant authorities.

Citizens of the area, drinking water suppliers, especially those closer to the mountain area, agriculture and forestry are directly affected by drought events. Over time, it will also impact industry, energy production and shipping, with nature and the environment suffering the most. Water management changes primarily affect farmers, especially vegetable growers, and some private households. Those will need to change their current behaviour and reduce their water consumption.

The primary responsibility for implementing adaptation measures rests with the structural and approval authority South, which serves as the upper water authority. As per the law, they are tasked with developing regional and cross-sectoral concepts. Responsibility also extends to the lower water authority and individual municipal administrations. The lower water authority primarily handles licensing, and functions as a monitoring and inspection body. Consequently, they share the responsibility for the successful implementation of water management measures. Municipal administrations have the authority to make local building regulations adjustments, a crucial aspect for adapting infrastructure in settlement areas. This distribution of responsibilities is enshrined in the law, ensuring a clear institutional framework.

Lastly, some responsibility also lies with the water users in agriculture. However, this is not a legal obligation (yet) but rather a social responsibility.

6.1.2 Sub-question 2

Which potential adaptation measures are applicable to increase drought resilience in general in the research area?

Structural changes to adapt to changing circumstances may include, as discussed in Chapter 3.1, a shift in governance. In building a stable and modern research organization in the water sector, it is crucial to implement a range of soft measures, including integration and collaboration with external stakeholders. As emphasized by experts in section 3.5.2 and the National Water Strategy (BMUV, 2023), these measures play a pivotal role in concept development.

It would be important to integrate the different actors equally, as current preference for cooperation between authorities and agriculture resulting in more frequent conflicts with nature conservation. Leveraging local knowledge networks through regional cooperation and efficient information distribution requires equal stakeholder engagement (Rey et al., 2017; Shivakoti et al., 2019).

The facilitation of information sharing through local coordinators and the establishment of a Drought Information Network, are instrumental in addressing water shortages and disseminating relevant information. Collaborative knowledge networking and consultation enable greater participation in water governance (Huitema et al., 2011). Such a Drought Information Network would be in form of a website or other service platform through which water shortages are reported and registered and further information is made available in this context.

A Drought Management Plan is another critical soft measure that increases preparedness for prolonged dry spells, as suggested by Rey et al. (2017). It would not only contribute to building drought resilience but also include an early warning system and strategically designed emergency response plan. This approach is already obligatory for water suppliers but not for other sectors or the authorities. The results of this study indicate that it would be important for drought resilience if transparent drought management plans were also established by the local authorities, in conjunction with other stakeholders, including the agricultural or industrial sectors.

Creating incentives and awareness-raising are recommended to improve water conservation, as discussed in Chapter 3.5.3. Improving water management involves adjustments on both the supply and demand sides. There is still a need for greater public awareness of reduced water consumption, necessitating increased efforts by authorities and water suppliers in public relations. The national water strategy's goals and projects can support this effort.

To create incentives expanding the water-cent, particularly for agricultural use, is a valuable step and should be continued. This plan involves making farmers responsible for the water they pump from the aquifer for irrigation, encouraging more efficient and conscious water use. Furthermore, the funds collected can be reinvested in water conservation-related projects.

Monitoring and control are key in the category of soft measures to improve groundwater recharge and aquifer storage protection, as advocated by LUBW (2022), Falloon and Betts (2010) and Krysanova et al. (2018). Plans for the introduction and stricter monitoring of water balances in new development areas are already underway. For the research region, the introduction of increased monitoring of groundwater abstraction, including digital meters, is an important further building block. This is an essential prerequisite for the implementation and enforcement of regulations to prevent over-extraction and groundwater depletion.

In addition to the soft measures discussed above, this study identifies several practical hard measures that can be implemented to address water sector challenges.

One practical hard measure involves cisterns. They are recommended in Chapter 3.5.3.2 as a means of reducing groundwater depletion, as rainwater is collected and can be used instead of drinking water, e.g. for watering gardens. To effectively implement these measures, the supply side has to support the demand side. Authorities can offer subsidies and promote these measures in conjunction with water conservation campaigns to the individual citizens.

Water reuse and desalination, suggested by Falloon and Betts (2010) and Krysanova et al. (2018), also offer opportunities to diversify water sources and enhance drought resilience. In case of extreme drought conditions, the use of recycled water may even extend for all non-consumption purposes., as was the case in Cape Town on Day Zero (Enqvist and Ziervogel, 2019). However, desalination is not applicable in the research area due to the absence of seawater. Water reuse and separate wastewater systems have been classified critically by local experts, mainly due to hygiene concerns and complex and costly infrastructure reconstruction. Nonetheless, there are filter systems technologies also for small scale options (Hagare and Dharmappa, 2009) so water reuse still could be a viable option for future developments in combination with advanced technologies and user education.

Another improvement measure is the development of on-site infiltration and retention areas. Increasing storage capacities and enhance groundwater recharge will increase drought resilience, while at the same time preventing floods and erosion during wet periods (LUBW, 2022; Falloon and Betts, 2010; Krysanova et al., 2018). The results show that current possibilities in this regard are low in number and/or poorly executed. Here it is recommended to develop new concepts to let the water infiltrate on-site and to create a better balance between runoff and retention, for example, by re-evaluating and re-engineering existing ditch structures. In settlement areas, more aspects of sponge city design, like the removal of paving and green infrastructure are helpful to increase infiltration and reduce the urban heat island effect. Furthermore, options for artificial recharge could be considered in case of heavy rainfalls (Sukhija, 2008).

For a sustainable drinking water supply, increased or enlarged drinking water protection zones and interconnections were discussed. Both measures recommended in the literature (Krysanova et al., 2018; Falloon and Betts, 2010) and welcomed by drinking water suppliers, require the understanding and cooperation of various stakeholders. Building an interconnection system is costly and includes multiple water suppliers, which all have to be supportive of this approach. Extended drinking water zones require the support and acceptance of the landowner and user, as these zones are associated with regulations that must be followed and controls are difficult to implement. Therefore, these measures are recommendable in the long run but need accompanying measures or previous campaigns to create awareness and acceptance.

A significant change in the agricultural sector is suggested by the interviewees and recommended in theory (Rey et al., 2017; Krysanova et al., 2018; Falloon and Betts, 2010; Rockström, 2003). Altering land-usage involving a change in the crops grown, intercropping, different tillage techniques and/or the implementation of green walls or agroforestry to reduce evaporation and erosion. Additionally, adopting more efficient irrigation technologies, such as drip irrigation, is advisable. It would also be advisable for the SGD Süd to conducting updated studies on local irrigation technology efficiency, as it appears that the last study was conducted in 2011 and the results are probably out of date. To implement these measures effectively, it is imperative that water authorities engage in negotiations with the agricultural sector on an equal footing. Cooperation between water management authorities and farmers, harnessing site-specific expert knowledge, is essential to develop an adapted land-use management system, with top-down decision-making as a last resort, as highlighted by Krysanova et al. (2008) and Rey et al. (2017).

Finally, the idea of using the Rhine as a direct water source for agricultural irrigation is discussed. This could enhance supply diversity for a more robust system. However, the idea is currently controversial among experts interviewed and cannot be recommended for the research area. The fundamental question is the allocation of Rhine water rights, as multiple small withdrawals could eventually deplete a river crucial for shipping. This approach also goes against the advice of Falloon and Betts (2010) and Krysanova et al. (2018), which favour groundwater over surface water in hot regions due to lower evaporation losses. Additionally, the Rhine is subject to influent conditions, i.e. the surrounding groundwater flows into the river underground. Withdrawals from the Rhine would therefore also have an impact on groundwater in the long term.

6.1.3 Sub-question 3

What are existing or potential barriers to a successful implementation of adaption measures and changes in the water management strategies?

As described in Chapter 3.3, the adaptive capacity can be restricted by multiple elements. The identified barriers to the adaptability of the research area can be divided into constraints on the willingness to act and constraints on the ability to act (Zuidema, 2016).

Firstly, the ability of the research area to act is restricted by financial problems, shortage of staff, and lack of specialist knowledge. These are obstacles which should be solved relatively easily with external help from the central government, as long as the existing bureaucratic hurdles are overcome. (Zuidema, 2016). However, another aspect is not the lack of the resource itself, but also how it is made available. The use and provision of resources (money, manpower and expertise) is related to the willingness to act. Some actors have already recognised the drought problem in water management and want to bring about changes to become more drought-resilient. Still, they are not able to do so without first convincing other actors and organising resources (finances and/or manpower) themselves, as there is no political support. If the higher authorities or other crucial actors do not provide their help, the capacity to act cannot be generated (Zuidema, 2016; Woltjer and Al, 2007; Spijkerboer, 2018). The identified barriers to the willingness are lack of commitment, time intensiveness, lack of awareness and acceptance, unused legal options, old building laws, and the preference for drainage over retention. These barriers result from a combination of institutional path dependency and lacking of sense of urgency. As described in Chapter 3.3, it is not easy to change institutional structures (Low et al., 2005). However, understanding these intricate networks and how they influence actor's behaviour is the first step towards a successful transition (Warbroek et al., 2023). By making use of transition theory, as suggested by Huitema et al. (2011), the current pressure from climate change developments can be seen as a window of opportunity to implement change. Local stakeholders are gradually recognizing that business as usual is not the way forward, particularly since the direct and indirect effects of climate change are increasingly evident within their immediate geographical vicinity.

Furthermore, the newly published water strategy gives reason to hope that the identified barriers in this study can be overcome through some external support from the government.

6.2 Lessons Learned

Based on the results of this study in combination with the underlying transition theory, some lessons are learned. As the challenges posed by climate change can no longer sufficiently be addressed with the current water management, in other words, a transition is needed. As described by Loorbach (2010), transition theory makes it possible to develop needed policies and measures to respond adequately. However, transition theory also implies that successful implementation as well as effectiveness of the adopted strategies depend on the adaptability of the system. This has proven valid during this study, as several barriers to the adaptive capacity of the research area were identified, which hinder the current water management system from becoming more drought-resilient. These barriers, also shown in Figure 16, need to be reduced or eliminated to enable a successful climate adaptation. Moreover, as a result of this study, some first steps towards a transition process can be recommended.

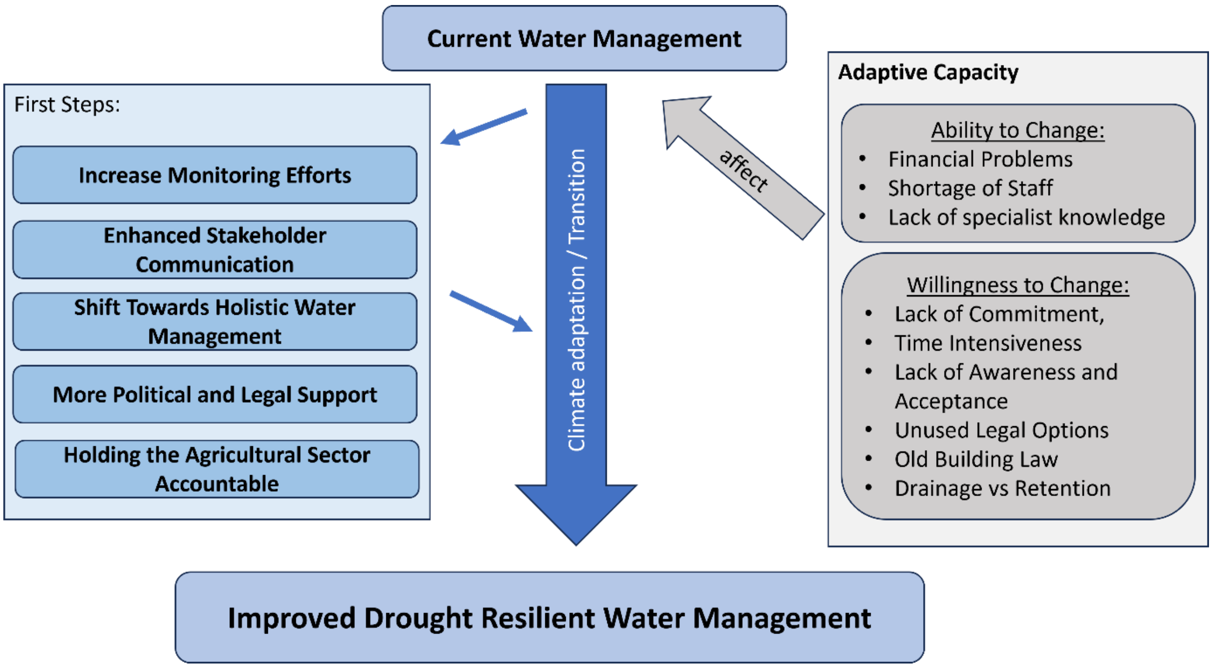


Figure 16: Adapted conceptual model to the results of this master's thesis.

First, the **importance of monitoring** of water extractions for evaluating water balance is crucial for sustainable water management. The research shows currently no proper supervision, which makes it impossible to enforce further measurements and control mechanisms. Therefore, this problem needs to be solved first as a cornerstone for the effective establishment of drought resilience in the research area.

Secondly, there is a need for **communication and consultation**, as awareness of environmental changes does not always lead to behavioural adjustments. Effective communication among stakeholders is vital. A drought information network can help bridge this gap, enhancing transparency and preparedness, especially in the agricultural and water supply sectors.

Thirdly, the research area needs a **shift in their water management focus**. Current water management primarily focuses on flood prevention and drainage, lacking specific regional concepts for drought management. This path dependency of the system needs to be overcome to create a more holistic water management. With the help of targeted on-site infiltration, groundwater recharge is promoted and flooding during heavy rainfall can be intercepted.

Fourthly, voluntary approaches may not be sufficient and **legal obligations and political support** are required. Some aspects need this backing to ensure that individual actors understand and adhere to necessary changes.

Fifthly, the agricultural sector, a significant water user, must adapt to changing water availability due to climate change. The **agricultural sector plays a vital role** in creating a drought-resilient system in the research area. Legal obligations and communication with agriculture are essential to driving necessary changes for better water management.

6.3 Main Research Question

The main research question of this study was: "How can improved water management strategies in the Upper Rhine Valley increase drought resilience and contribute to adaptation to the challenges caused by climate change?". The answer to this question is quite complex and not straightforward. To achieve drought resilience, water management must undergo structural changes that will include both institutional governmental measures and practical technical measures. These changes must be initiated by the organisation primarily responsible for the study area, the SGD Süd, but also require the cooperation of the other water stakeholders and users in the region. There are also some barriers to overcome at the official level, in particular the lack of personnel. Without this, important measures cannot be implemented. Volunteers could be a temporary solution here. There needs to be more monitoring. And there must be more communication and information opportunities between authorities, water suppliers and other users. Stakeholders in the region must become more aware of how they use water as a resource and no longer take it for granted. There is also currently a lack of preparatory measures in the region. Concepts need to be developed that come into play in the event of a water shortage. In terms of planning, more opportunities need to be created to replenish natural groundwater reservoirs through infiltration. Practical measures to diversify water resources or increase efficiency will reduce the pressure on drinking water sources. Co-operation between the various stakeholders must also be promoted.

6.4 Reflection

Transitions, as noted by Van der Brugge et al. (2005), are gradual processes that require further research and evaluation. Implementing proposed changes by experts will take time, raising the crucial question of how long we can afford to wait. The ongoing dilemma revolves around whether it is justifiable to prioritize economic factors over the environment in the long term, which in turn will itself have an economic impact if action is not taken now. Maintaining an acceptable balance between benefits and constraints is a difficult task in planning. This study not only highlights opportunities for enhancing water management in the face of climate change but also underscores our tendency to delay action and neglect theoretical commitments within our system. Planning theory offers a means to identify and solve system problems. It became evident in this study that identifying and implementing strategies for dealing with particular barriers and/or challenges is a crucial part of making sure planning practice can become successful. It is reasonable to believe that by effectively addressing the identified barriers, the research area can adapt to climate change and establish a drought-resilient water management system before it becomes too late. The region has demonstrated an interest in initiating changes and adaptations, offering hope for a successful outcome.

It is noteworthy that this study had some restrictions in time and capacity. In theory, there could have been other potential interviewees within this study's scope. Some requested stakeholders were unavailable for interviews during this study, and this situation may change in the future. Even though interviews with water consumers, like residents or local farmers, could have provided additional perspectives, it was beyond the scope of this research and would likely have shifted its focus. Nonetheless, future research into individual perceptions and acceptance of water management changes remains crucial. However, this study was the first necessary step towards developing actionable strategies to face and hopefully overcome the effects of climate change in this area.

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8. Appendix

A) Interview guide

1) Does the issue of water supply/availability or water scarcity play a role in your daily work?
2) Do you feel that enough is being done in water management to reduce the impact of a potential drought and make the region more drought-resilient? (now or in the future)
3) Who do you think is responsible for addressing these issues? (Do you think that the responsibility lies with one organisation alone or are several groups of people responsible)?
4) Are you aware of measures that could be taken to prevent a water shortage or to prepare for a drought? Do you have any ideas of your own on how we could reduce water consumption or otherwise adapt to the consequences of climate change?
5) In the context of various studies on drought resilience, research has already collected a variety of options for action and measures. What do you think about this? How realistic are they? A few of them would be: (name relevant action options)
6) What other means or resources do you think would be necessary to achieve actions or measures for drought resilience?

B) Document Analysis List

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C) List of Identified Water Management Actors for the Research Area

Upper Water Authority	Structure and Authorisation Directorate South							
District and city administrations (Lower Water Authority)	Kreis Germersheim; Gewässerschutz				Stadt Landau in der Pfalz; Gewässeraufsicht	Kreis Südliche Weinstraße, Allgemeine Bauverwaltung, Umweltschutz und Kreisstraßen, Untere Naturschutzbehörde		
Municipalicy	Verbandsgemeinde Lingenfeld	Verbandsgemeinde Bellheim	Verbandsgemeinde Rülzheim	Stadt Germersheim	Land i. d. Pfalz	Herxheim	Landau-Land	Offenbach a.d. Queich
Wasserversorgung	Zweckverband für Wasserversorgung „Germersheimer Nordgruppe“	Wasserzweckverband „Germersheimer Südgruppe“ Kö. d. ö. R.		Stadtwerke Germersheim	EnergieSüdwest Netz GmbH Landau	Verbands-gemeinde-werke Herxheim; Betriebszweig Wasserversorgung	Verbands-gemeinde-werke Landau Land	Grundwasser-werke Bornheim

Actors Outside Authorties	Aktion Südpfalz Biotope (Natureconservation)	Landwirtschaftskammer Rheinland-Pfalz; Klima-Farm-Bilanz (Johannes Dries und Phillip Holz)	Universität-Experte; RPTU; Arbeitsgruppe Landnutzungskonflikte (Jun. Prof. Dr. Janpeter Schiling)	BUND Kreisgruppe Südpfalz (Natureconservation)	Die DVGW-Landesgruppe Rheinland-Pfalz

D) Code Book

Code	Codegroupe 1	Codegroupe 2	Codegroupe 3
Lack of Awarness and Acceptance			
Lack of Awarness and Acceptance: Fehlendes Bewusstsein	Barrieren		
Lack of Awarness and Acceptance: Ignoranz	Barrieren		
Lack of Awarness and Acceptance: Informationsbedarf	Barrieren		
Lack of Awarness and Acceptance: mangelnde Akzeptanz von Maßnahmen	Barrieren		
Lack of Awarness and Acceptance: öffentlicher Wiederstand	Barrieren		
Lack of Awarness and Acceptance: Unerlaubtes Verhalten	Barrieren		
Lack of Commitment	Barrieren		
Shortage of Staff	Barrieren		
Lack of specialist knowledge	Barrieren		
Time Intensive	Barrieren		
Unused legal options	Barrieren		
Old Building Law	Barrieren		
Drainage vs. Retention	Barrieren		
Financial Problems	Barrieren		
Water Balance		Maßnahmen	
Water-Reuse		Maßnahmen	
Watercent		Maßnahmen	
Cisterns		Maßnahmen	
Digital Measurement Counters		Maßnahmen	
Drinkingwater Protection Zones		Maßnahmen	
Drop Irrigation		Maßnahmen	
Drought Information Network		Maßnahmen	
Green Walls		Maßnahmen	
Integrated Management		Maßnahmen	
Interconnections		Maßnahmen	
Irrigation from the Rhine		Maßnahmen	
Management Plan		Maßnahmen	
Monitoring		Maßnahmen	
More Efficient Irrigation Technologies		Maßnahmen	
On-Site Infiltration		Maßnahmen	
Retention Areas		Maßnahmen	
Review of Existing Rights and Concepts		Maßnahmen	
Saving Measures		Maßnahmen	
Seperate Sewage System		Maßnahmen	
Land-Use Change		Maßnahmen	
State Government / Ministry			Zuständigkeit
Lower Water Authority			Zuständigkeit
Municipalities			Zuständigkeit
Upper Water Authority			Zuständigkeit
Agriculture			Zuständigkeit
Citizens			Zuständigkeit
Drinkingwater Supplier			Zuständigkeit