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Adopting System Thinking to Explore Possible Maladaptation: A Case Study of "Méga-Bassines" in France

Anta systemtänkande för att utforska möjlig felanpassning: En fallstudie av "Méga-Bassines" i Frankrike

Giorgia Dal Molin

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Abstract

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Water scarcity, exacerbated by global population growth and climate variability, poses significant challenges to sustainable development. In this context, numerous initiatives are emerging to secure access to water, particularly for agricultural activities. Here we look at the case of big farm ponds also called as "mega-basins" recently installed in the Pointou-Charentes region in France. Mega-basins are designed to provide access to water for a few groups of farmers. Filled by pumping abundant groundwater during winter, these reservoirs are designed to supply crops (mainly maize) that need water in summer, while reducing the amount of groundwater withdrawal in summer. Although based on good intentions, these developments are the subject of much controversy and strongly polarize public opinion. Some of the critics point to the risk of maladaptation, without explicitly defining what this means. This study aims to identify what could be potential maladaptive outcomes associated with mega-basins.

To do so, this paper first reviews the literature on maladaptation to gain a clearer understanding of the concept from the point of view of academic research. It then explores the emerging field of socio-hydrology, which addresses the complex interactions between human activities and water dynamics in human-modified water systems. Socio-hydrology uses methods such as system thinking and causal loop diagrams to understand these interactions and assess the risk of unintended consequences of water management strategies.

The results of the study show that there are several potential maladaptation risks associated with mega-basins, as these structures involve several socio-hydrological archetypes already known in other complex systems (fixes that fail, band-aid solutions, success to successful, limits to growth) that induce maladaptive outcomes.

Keywords: mega-basins, maladaptation, system thinking, system archetypes, adaptation

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Populärvetenskaplig sammanfattning

Anta systemtänkande för att utforska möjlig felanpassning: En fallstudie av "Méga-Bassines" i Frankrike

Giorgia Dal Molin

Vattenbrist är ett växande problem världen över i takt med att befolkningen växer och klimatet förändras. Det är viktigt att hitta hållbara sätt att säkerställa tillräckligt med vatten, särskilt för jordbruket. I Poitou-Charentes-regionen i Frankrike har man infört en ny lösning som kallas "megabassänger". Dessa stora dammar lagrar vatten som pumpas upp ur marken under vintern. Jordbrukarna använder vattnet på sommaren för att bevattna grödor som majs, vilket bidrar till att bevara grundvattnet under de torra månaderna

Även om megabassängerna är utformade för att hjälpa till med vattenbristen och stödja jordbruket, har de orsakat mycket debatt och oenighet bland allmänheten. Vissa människor oroar sig för att dessa dammar kan leda till "missanpassning", vilket innebär att de kan orsaka fler problem än de löser. I den här studien undersöks dessa farhågor för att förstå vad som kan gå fel med megabassänger.

Först granskas vetenskapliga artiklar för att förstå missanpassning. Därefter undersöks sociohydrologi, som studerar hur mänskliga aktiviteter och vattensystem påverkar varandra. Sociohydrologin använder verktyg som systemtänkande och diagram för att förutse möjliga negativa resultat av vattenförvaltningsstrategier.

I studien konstateras att megabassänger kan leda till flera problem. Det handlar bland annat om snabba lösningar som inte är hållbara, lösningar som bara tar itu med ytliga problem, fördelar som bara gynnar redan framgångsrika grupper, och begränsningar av tillväxten. Det är viktigt att förstå dessa risker för att kunna utveckla hållbara metoder för vattenförvaltning.

Nyckelord: megabassänger, missanpassning, systemtänkande, systemarketyper, anpassning.

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1. Introduction

Water, one of the most important resources for sustaining life, has emerged as a focal point as global population growth increases water use, particularly in agriculture, and escalates the demand for high-quality water for domestic purposes (Dalezios et al., 2018). At the same time, climate variability has a direct impact on water availability, especially in the agricultural sector. Changing weather patterns, unpredictable rainfall, and more frequent extreme weather events threaten the stability and reliability of water resources. Water scarcity and droughts are expected to worsen as climate change progresses, increasing competition for water resources, particularly between agriculture and other sectors (FAO, 2017).

The agriculture sector, which relies on reliable access to water for crop irrigation and livestock management, faces increasing pressures and uncertainties. With many regions of the world reaching critical thresholds between water demand and availability, new water management strategies are needed to optimize social and economic well-being without compromising ecosystem sustainability (Adla et al., 2023).

Recognizing the urgency of these challenges and understanding the complex relationship between water and human activities in different contexts is crucial (Sivapalan et al., 2014). Thus, socio-hydrology is emerging as a practical scientific field, that prioritizes the study, analysis, and scenario planning of human-modified water systems. Central to socio-hydrology is the study of the interactions between human activities and water dynamics, using methodologies such as system thinking and causal loop diagrams. (Sivapalan et al., 2012).

Furthermore, to effectively address the vulnerability of socio-hydrological systems to climate change, it is essential to identify initiatives that strengthen their capacity for long-term adaptation (Magnan et al., 2016). However, some initiatives may inadvertently cause harm. While such efforts provide short-term adaptation benefits, they risk undermining long-term coping and mitigation efforts. This phenomenon, known as maladaptation, highlights the need for cautious decision-making in water resource management.

Expert opinion highlights the necessity for a balanced approach in the new water policy, focusing on managing both water supply and demand (Grimonprez, 2019). The first approach focuses on enhancing water supply by ensuring more water for agricultural purposes, primarily through storing excess winter water, exemplified by initiatives like mega-basins. The second component aims to limit agricultural water demand by optimizing resources and reducing needs. This involves promoting new farming techniques, such as precision farming, crop diversification, and agroecology.

To establish a sustainable path for water management, it is important to integrate both approaches effectively (Grimonprez, 2019). On one hand, enhancing water supply through measures like storing water surpluses is crucial for bolstering agricultural water availability. On the other hand, addressing agricultural water demand by optimizing resource usage and promoting advanced farming techniques plays a pivotal role. A balanced integration of these strategies is essential to ensure sustainable water management practices.

Mega-basins represent a strategy to increase water supply, designed to address water shortages during dry summer months. These reservoirs are intended to collect and store water during winter, ensuring a sufficient supply during periods of scarcity (Deloménie, 2024). Despite their good intentions, mega-basins have become an issue, dividing public opinion. Critics highlight the potential maladaptive risks, including unintended consequences that could undermine long-term sustainability.

These issues are at the heart of the debate raised in France by the mega-basins, which has motivated this work. This paper aims to review the existing literature on maladaptation and analyze the dynamics and decision-making processes that could culminate in maladaptive outcomes. We focus on a specific case study: the implementation of mega-basins, a new irrigation technique, in the Poitou-Charentes region of France. Through this investigation, we aim to explore potential maladaptive consequences that could be associated with the adoption of mega-basins and water storage solutions.

2. Theoretical framework

2.1 Maladaptation

This study delves into the concept of maladaptation by conducting a literature review, focusing on four key articles that offer insights into its meaning.

Barnett and O'Neill (2010) were among the first to systematically define maladaptation as "the action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increase the vulnerability of other systems, sectors or social groups" (Barnett and O'Neill, 2010: p.211).

Barnett and O'Neill's definition specifically addresses how an initiative can heighten the vulnerability of 'other' systems, sectors, or social groups. This formulation, however, excludes instances where initiatives may also adversely affect the territory, sector, or group of people implementing the initiative, leaving the definition somewhat inadequate (Magnan et al., 2016).

Barnett and O'Neill (2010) introduced various types of maladaptation, but their typology remains limited to specific examples of action. Juhola et al. (2016) aimed to develop a more comprehensive framework by presenting a typology consisting of three generalized types of maladaptation:

1. *Rebounding vulnerability*: adaptation actions increase vulnerability to current or future climate change.
2. *Shifting vulnerability*: adaptation actions heighten the vulnerability for external actors by increasing exposure, sensitivity, or reducing adaptive capacity.
3. *Eroding sustainable development*: adaptation actions reduce vulnerability, but lead to resource degradation within the system, undermining sustainable development on a global scale.

Despite efforts to define maladaptation, ambiguity remains, limiting its practical application. Juhola et al. (2016) identified crucial elements for analyzing maladaptation, including defining system boundaries, encompassing both geographical and temporal scales of the study, and understanding interconnections between physical and social entities.

Maladaptation has both temporal and spatial dimensions, with short-term adaptation measures potentially leading to long-term adverse effects and local adaptation actions impacting broader regional or global scales (Juhola et al., 2016).

Hence, to put the concept into practice, Juhola et al (2016) observed that it would require an agreement on the specific threshold applicable to a given case study. Clear suggestions on how to accomplish this are still lacking, making it challenging to evaluate the criteria for assessing the severity of the consequences.

To define maladaptation, it is crucial to differentiate between maladaptation and unsuccessful policy implementation(Juhola et al., 2016). An unintended consequence of an adaptation action does not automatically qualify as maladaptive, but it could simply represent a failed policy that neither mitigates vulnerability to climate change impacts nor achieves effective adaptation. However, if the action amplifies vulnerability or undermines the capacity of stakeholders to address climate impacts or pursue sustainable development goals, then it can be classified as maladaptive. Similarly, Juhola et al. (2016) exclude the absence of action from the concept of maladaptation as it is de facto maladaptive.

In our exploration of the concept, we find that maladaptation offers a dual utility: first, it fosters discourse on the efficacy and suitability of adaptation policies and measures, highlighting the diverse impacts; second, Juhola et al. (2016) propose that maladaptation can serve as a starting point for examining the actual or potential adverse outcomes of specific adaptation measures. To effectively apply this concept, it's essential to consider three key elements: determining whether maladaptation is viewed as an outcome of an adaptation action or a maladaptive process, delineating system boundaries, and identifying thresholds.

While the approach by Juhola et al. (2016) focuses on assessing outcomes, Magnan et al. (2016) advocate for proactive measures to reduce the risk of maladaptation. Addressing one aspect of risk may inadvertently create new vulnerabilities, underscoring the importance of careful consideration in adaptation planning.

Magnan et al. (2016) emphasize that maladaptation extends beyond the realm of climate change and can occur in various contexts. Its application within the climate change context is relatively recent. In this context, Magnan et al. (2016) present a more generally applicable approach to define maladaptation, delineating it across four dimensions crucial for evaluating the ex-ante risk of maladaptation. Initially, they characterize maladaptation as a process that connects adaptation measures and vulnerability, where the two variables are linked: increasing vulnerability will increase the risk of taking maladaptive measures, exacerbating vulnerability even further. Secondly, this process is shaped by numerous drivers and intricate interactions. Lastly, the third and fourth dimensions encompass the spatial and temporal scales delineating this process.

Magnan et al. (2016) also present five mechanisms driving maladaptation, termed the Pathways to Maladaptation Framework, adapted from Barnett and O'Neill (2010). Although the initial mechanism in the framework pertains specifically to escalating greenhouse gas emissions, they posit that the same mechanism applies to intensifying the exploitation of any finite resource crucial for the system's welfare. The five mechanisms are the following:

- *Increase resource exploitation:* although escalating resource exploitation may fulfill immediate needs, it can initiate a positive feedback loop that exacerbates the long-term risk.
- *Disproportionally burden the most vulnerable*: adaptation may prove to be maladaptive when fulfilling the needs of one group or sector occurs at the expense of more vulnerable ones.
- *High opportunity costs:* the expense of a particular measure should not exceed that of equivalent alternatives.
- *Reduce incentive to adapt:* maladaptive actions happen when they discourage adaptation, whether by discouraging community participation, penalizing early adopters, or fostering unnecessary dependence.

- *Path dependency*: current decisions shape future adaptation possibilities, either by cementing irreversible adaptive trajectories or by reinforcing the sunk investment fallacy.

Reckien et al. (2023) subsequently introduce a new framework aimed at mitigating the risk of maladaptation, the Navigating the Adaptation-Maladaptation continuum (NAM) framework. The continuum approach reflects the nature of adaptation implementation, highlighting how interventions can yield mixed outcomes, influenced by various assessment criteria. This framework comprises six criteria that include the outcomes of adaptation concerning ecosystems, climate, and social systems, as well as equity-related outcomes for disadvantaged populations such as low-income groups, women/girls, and marginalized ethnic communities.

Reckien et al (2023) offer a methodology suitable for decision-making in practical contexts, evaluating the degree to which responses formulated under the guise of adaptation result in favorable outcomes or elevate the risk of maladaptation. The key takeaway is that adaptation options rarely fit into purely adaptive or maladaptive categories, instead, they exist along a dynamic continuum, shifting in their positioning across spatial and temporal dimensions.

2.2 Socio-hydrological System Archetypes

Decisions regarding water management rely on coupled human-water system models, which presuppose human reactions to evolving environmental and socio-economic circumstances (Di Baldassare et al., 2024). To understand how society and water interact we adopt an approach to understand the complexity of the systems. System thinking is a method used to identify key elements of a system and their interactions, developing a conceptual model that serves as a foundation for predicting the system's behavior. It can also be used to formulate predictions and hypotheses about the dynamics of the system.

To understand and classify the socio-hydrological phenomena we use system archetypes, which are analytical tools marked by feedback loops that lead to dynamically complex emerging behaviors and serve as tools for conceptualizing complex systems and recognizing dynamics within socio-ecological and socio-technical systems (Biella et al, 2024). These system dynamics models are causal loop diagrams, where multiple nodes are interconnected by arrows denoting positive (reinforcing) or negative (balancing) causal connections, representing a complex system (Di Baldassare et al, 2024). Causal loop diagrams serve as visual representations of cause-effect relationships among individual system variables within a system containing closed feedback loops, highlighting the importance of recognizing feedback loops as a fundamental aspect of system thinking.

A positive feedback loop is a reinforcing loop that amplifies a change in one system variable as it circulates through the loop, reinforcing the initial change, and characterizing continual growth or decline (Di Baldassare, 2024). A negative feedback loop operates by circulating a change around the closed loop, resulting in a change in the opposite direction (Di Baldassare, 2024), minimizing the difference between the current state and the desired state (Bahaddin et al., 2018).

Here is a list of the most common archetypes that can emerge from a large variety of complex systems and which have also been documented within the context of socio-hydrological systems (Di Baldassare et al., 2024):

Fixes that fail: the archetype refers to a scenario where short-term solutions are taken without tackling its root causes (Bahaddin et al., 2018). The short-term solution usually leads to unintended consequences and the issue is exacerbated.

Band-aid solutions: this archetype refers to short-term interventions that address the immediate symptoms of an issue, resulting in instant benefits, thereby reducing the perceived necessity for long-term measures, while the underlying causes of the problem remain unattended (Biella et al., 2024).

Eroding ambitions: it illustrates a complex system that results from delayed responses to interventions and a loss of confidence in achieving progress. It creates uncertainty in the efficacy of long-term measures compromising ambition goals, that are attainable in the short term but do not sufficiently address sustainability concerns in the long run (Moallemi et al., 2022).

Downplayed problem: the scenario illustrates progress stimulated toward a specific goal, which may experience diminishing effectiveness over time. This decline is especially pronounced as progress nears a limit imposed by trade-offs with conflicting goals, a dynamic that may manifest with a delay (Moallemi et al., 2022).

Escalating tension: when one party's actions are seen as a threat by another, that responds with an escalating threat (Di Baldassare, 2024). With each subsequent action and reaction, the sense of threat intensifies as parties become progressively more competitive over time.

Success to successful: this archetype illustrates a unique dynamic where the ongoing success of a single entity can lead to monopolizing access to resources (Di Baldassare, 2024). It benefits the actors with greater initial resources, often at the expense of others, increasing inequalities (Biella et al., 2024).

Limits of growth: the archetype refers to a scenario where persistent and accelerating demand growth, driven by reinforcing feedback loops, results in overshooting due to constraints on supply within natural systems (Di Baldassare, 2024). Once the system reaches a critical level, balancing feedback loops becomes predominant, regulating the system's behavior to prevent its collapse (Bahaddin et al., 2018).

Tragedy of the commons: the archetype describes a scenario where multiple users compete for a finite, collectively shared resource, acting in their own interests (Di Baldassare, 2024), and it can lead to unsustainable consequences for all actors (Moallemi et al., 2022).

3. Case Study Background

3.1 Study Area

The study area is situated in the Poitou-Charentes region of France encompassing Vienne, Charente, Charente-Maritime, and Deux-Sèvres. Specifically, our case study focuses on the Marais Poitevin, a region characterized by limited runoff (ENS Géosciences, 2024).

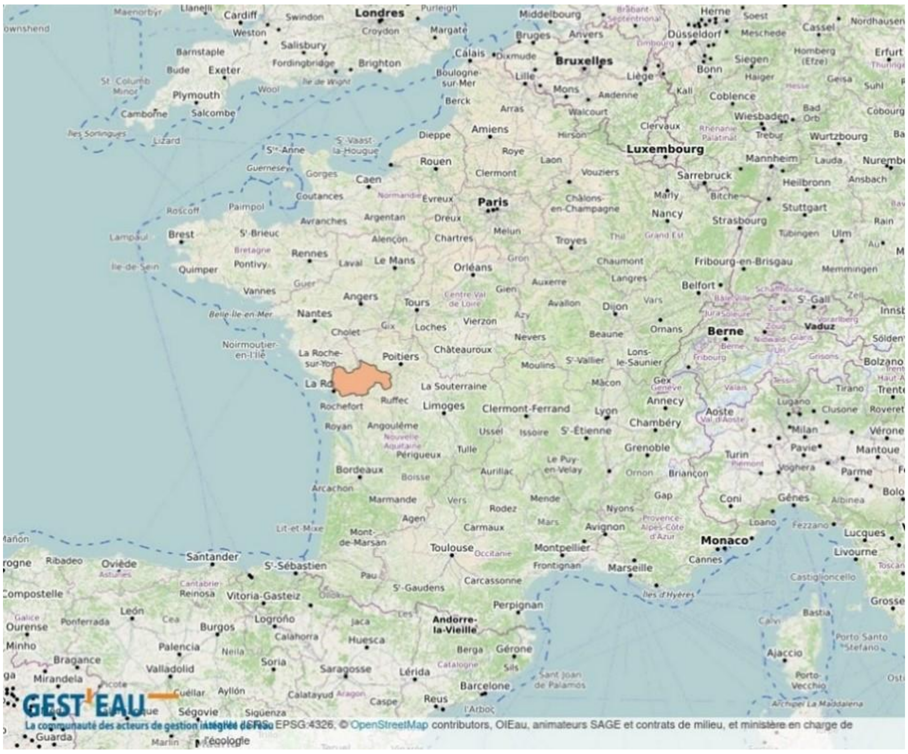

Figure 1. The Marais Poitevin region, France (Gest'eau, 2023)

The Poitou-Charentes region is situated at the intersection of two major sedimentary basins: the Paris Basin to the north and the Aquitaine Basin to the south (Douez, 2010). These basins are separated by the Poitou sill, which connects the edges of the Massif Armorican and Massif Central.

The basement terrain features a wide variety of granitic and metamorphic rocks and is extensively structured with the major Armorican-trending (NW-SE) faults (Douez, 2010). The dense hydrographic network indicates that the bedrock contains limited underground resources, with groundwater primarily localized within the weathered zones, and surface runoff accounting for most of the effective rainfall.

Directly above the bedrock, there are the Lower Jurassic formations, which underlie the Infra-Toarcian aquifer (Douez, 2010). This aquifer consists mainly of limestone with varying degrees of dolomitization and sandstone, and it is typically confined beneath the Toarcian marls. Above the Toarcian, the karstified limestones of the Dogger are found. This reservoir consists mainly of oolitic limestones, and it becomes confined beneath the marly formations of the unaltered Oxfordian (Upper Jurassic).

At the surface, the altered marl-limestone series form the Upper Jurassic aquifer, underlain by unaltered gray marly limestone, at a depth of around 20 to 30 meters (Douez, 2010). This generally “free” aquifer is closely linked to watercourses. The Cretaceous formations, which underlie the Jurassic, extend beyond regional boundaries. During the Quaternary, marine transgression along the Charente coast created the Marais-Poitevin, an ancient gulf filled in by fluvio-marine clays.

North of the Marais, rivers originate in an area with low-permeability bedrock and a dense hydrographic network. As these rivers approach the Marais, they transition into a highly permeable zone dominated by groundwater flows (ENS Géosciences, 2024).

Considering the low flow rates and the dynamic nature of the water tables in this region, it was developed the Jurassic regional hydrodynamic model (Douez, 2010). The objectives of this model are to:

- Enhance the understanding of the functioning of all Jurassic aquifers, particularly the intersections between water tables and rivers.
- Address various water management issues, specifically:
    - Assessing the availability of groundwater resources for irrigation
    - Evaluating the winter impact of filling reservoir projects.

The model has already been applied in the watersheds around the Marais Poitevin, where various simulations have been conducted to inform groundwater management.

3.2 The Project

French agriculture predominantly relies on rainwater, with only 6% of arable land under irrigation and merely 15% of farms utilizing irrigation systems (Grimonprez, 2019). While irrigation networks have historically provided water access in southeastern regions, areas like the western basin (Poitou-Charentes, Pays de Loire, Centre) with erratic rainfall patterns are increasingly adopting irrigation practices to sustain agricultural production. Consequently, the construction of more reservoirs and dams has become essential to cope with water shortages and protect farmers from droughts (Habets et al., 2014). However, while water storage may seem like a potential solution to mitigate the impacts of water shortages, it also poses the risk of exacerbating the issue by leading to negative consequences.

‘Mega-basin’ is a recent term to describe a reservoir built on the surface, elevated by embankments, with a waterproof plastic liner at the bottom (Deloménie, 2024). They are filled by pumping water from nearby or more distant aquifers during times of abundance, typically in winter, so that the stored water can be utilized during periods of scarcity, such as summer.

Originally referred to as ‘substitution reservoirs’, the term ‘mega-basins’ has emerged more recently to convey the gigantism of these basins (Deloménie, 2024). The reservoirs can store up to 851,000 cubic meters of water, the equivalent of 340 Olympic swimming pools. In contrast to other types of basins or reservoirs, which may gather runoff or precipitation for various purposes, mega-basins are predominantly designed for agricultural water supply. A key distinction lies in how mega-basins manage water distribution compared to traditional reservoirs. While conventional reservoirs typically utilize gravity flow or river diversion to discharge water, mega-basins often utilize electric pumps to extract stored water for irrigation purposes.

Overall, mega-basins represent a specialized form of water infrastructure designed to address specific requirements of agriculture, particularly in areas where water availability undergoes seasonal fluctuations (Deloménie, 2024).

The initiative for constructing a mega-basin project was launched in 2011 along the Sèvre Niortaise river in Deux-Sèvres, France, aiming to build 16 basins (Deloménie, 2024). The project was initiated by a collective of farmers from the region known as the Water Cooperative 79 (Cooperative de l'eau 79), with support from the Chamber of Agriculture and the Cooperative Agricole du Poitou Charente. Gradually, the project was put together, culminating in the signing of the 'Protocol of Understanding for Sustainable Agriculture in the Territory of Sèvre Niortaise – Mignon Basin' by various stakeholders, including farmers, government entities, regions, and associations. The first project started in 2021 in Mauzé in Mignon.

The concepts of the mega-basins project were conceived as a response to climate change and water scarcity challenges (Grimonprez, 2019). The primary objective of substitution reservoirs is to shift water withdrawals from low-water summer periods to high-water winter periods, thereby ensuring continuous water availability for agricultural purposes.

Between 2022 and 2023, in Sainte-Soline the subject was brought to the forefront of the media scene due to the demonstrations between government supporters of productivist agriculture and a coalition comprising environmental activists, politicians, and various associations (Deloménie, 2024). At the heart of this conflict lay the utilization of scientific arguments, prominently shown in the BRGM study report (L. ABASQ, 2022). This report stood as the primary scientific document advocating for the necessity of mega-basins to address increasingly frequent droughts attributed partly to climate change. Despite this endorsement, numerous scientists aligned with the opposition, arguing that these reservoirs are not a viable solution to mitigate the effects of climate change.

3.3 Pro-basins Argumentation

The arguments advanced by the proponents of the basins center on several key points. First, they emphasize the necessity of adapting to climate change, particularly with the escalation of droughts. They argue that by constructing these reservoirs, the region can secure its water supply and transition towards a more resilient and productive agriculture model (Deloménie, 2024). Furthermore, they assert that the project has meticulously followed all legal procedures required for implementation, and cite the scientific validation provided by the BRGM (Bureau of Geological and Mining Research) study report to support their claims of positive ecological impact.

Central to the proponents' objective is the goal of reducing water drainage during the summer months to preserve groundwater levels (Deloménie, 2024). They point to the favorable geological conditions of the region, where the water table, known as 'free', experiences short residence times. During winter, when the water table reaches capacity, excess water often leads to local flooding. The construction of basins would enable the collection and management of this excess water, preventing its wastage.

Additionally, supporters argue that the basins would contribute to environmental preservation by enhancing water table levels and safeguarding aquatic ecosystems (Deloménie, 2024). They highlight the extensive involvement of environmental associations throughout the validation process, with endorsement from the local water commission and oversight by a public establishment ensuring responsible management.

From a scientific perspective, the project appears to be validated by BRGM, commissioned by Coop 79, which assess the impact of mega-basins. These reports suggest that the basins alone could lead to improvements in groundwater levels and river flows (Deloménie, 2024). The 2022 report concludes that summer flows in the basins have increased by approximately 6%, with some rivers experiencing even higher increases, up to +40% in cases like the Mignon, contingent upon the outlined abstraction scenarios and management protocols. Proponents argue that considering the imperative to address climate change and preserve agricultural and aquatic environments, there are no substantial reasons to oppose the development of these reservoirs.

3.4 Against-basin Argumentation

Despite initial appearances suggesting no negative repercussions, these projects have garnered significant criticism. Opponents raise various concerns, including the monopolization of a common resource, exacerbation of inequalities among users, degradation of water quality and quantity, maladaptation to climate change, promotion of an unsustainable agricultural model, and the gigantism of infrastructures (Deloménie, 2024).

One prominent argument from opponents highlights the impact of collecting groundwater and exposing it to open air, leading to substantial evaporation and degradation of water quality. Open-air reservoirs have faced substantial evaporation of stagnant water and degradation through eutrophication caused by heat (Grimonprez, 2022). Christian Amblard, a CNRS research director, estimates that evaporation rates during dry seasons can range from 20% to 60% (Deloménie, 2024). Moreover, the accumulation of agricultural storage water on the surface can exacerbate drought conditions in the area. (Habets et al., 2014).

Critics also decry the monopolization of water resources inherent in mega-basin projects, as only a select few farmers stand to benefit. In the case of basins in the south of Deux-Sévres, it's noted that just 7% of farmers will benefit from them (National Assembly of France, 2023). This concentration of benefits is viewed as a form of privatization, contradicting the notion of water as a public responsibility when it remains underground, yet becoming restricted once stored in reservoirs (Deloménie, 2024).

Despite the utilization of public funds for construction, access to these reservoirs has been granted to only a minority of farmers so far.

Furthermore, dissenting voices within the scientific community argue that these projects are an example of maladaptive responses to climate change (Deloménie, 2024). They highlight the absence of democratic debate surrounding the imposition of these projects, with protocols primarily aimed at validating basin construction rather than engaging in meaningful dialogue. The reliance on the BRGM report as the only scientific justification for the basins is also criticized, as it exhibits numerous limitations, indicating a failure to fully consider scientific perspectives in addressing environmental challenges.

3.4.1Environmental impacts of mega-basins

Several scholars have raised concerns about the sustainability of dams and reservoirs due to their environmental and social impacts (Di Baldassarre et al., 2021). These concerns include negative effects on human health and livelihoods, as well as changes in hydrological regimes that significantly affect biodiversity and ecological processes.

The adoption of mega-basins promotes the extensive use of synthetic chemicals. This approach encourages agronomic practices that harm soil health, such as limited crop diversification and heavy reliance on water-intensive crops like corn. In the face of escalating climate change and increasingly frequent, intense, and prolonged droughts, the industrial agricultural model (predicted on monoculture and substantial use of chemical inputs) demands progressively larger volumes of water sustain yields (U.S. Climate Change Litigation, 2023). Moreover, it’s argued that a significant portion of the crops would be exported to international markets rather than being used for local and national consumption, leading to additional environmental costs.

The water table level significantly influences the volume of water present in the soil’s upper layers. This water is crucial for plant growth and soil health. Moreover, the water table directly feeds springs and rivers. Disrupting this natural exchange by extracting large volumes of water can accelerate the depletion of river water levels. This disruption affects the river’s flow and jeopardizes the aquatic ecosystems, leading to habitat loss and negatively impacting biodiversity (Guillot, 2023).

When stored in open-air reservoirs, water becomes stagnant and evaporates under high temperatures, accumulating sediment (U.S. Climate Change Litigation, 2023). This process can degrade soil quality by reducing its fertility and overall productivity. Exposure to light and heat promotes the growth of algae and bacteria, including toxic cyanobacteria, which can render the water unsuitable for irrigation (Grimonprez, 2022)

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4. Objective method

4.1 Objectives

This study employs the Pathways to Maladaptation Framework by Magnan et al. (2016) to identify the mechanisms defining a process as maladaptive. For a process to be labeled as maladaptive, one or more of the mechanisms outlined in the framework must be evident. To elucidate these processes, we utilize system archetypes, that are described in the subsequent section. Finally, we utilize the typology of maladaptation proposed by Juhola et al. (2016) to specify the type of maladaptation identified in each case.

In this context, our case study serves not as a determinant of whether we are encountering adaptation or maladaptation, but rather as a demonstration of scenarios where maladaptation manifests, and then pinpointing essential characteristics necessary to delineate the risk of maladaptation.

While mega-basins are frequently criticized as maladaptive, there has been no explicit study that characterizes their maladaptation. Furthermore, applying system archetypes to analyze maladaptation within a specific case study has not been addressed so far in the literature. The only being the study of Biella et al. 2024 who attempt to evaluate the risk of maladaptation regarding climate services by using the archetype framework. We hypothesize here that the archetype frame can provide a deeper understanding of the underlying dynamics driving maladaptive behavior. This approach helps identify potential strategies to foster adaptive and sustainable outcomes.

This study represents an advancement in the field by addressing a previously unexplored question: evaluating the potential for maladaptation in mega-basin projects. It introduces a novel approach that integrates socio-hydrological archetypes with the analysis of maladaptation concepts. By combining these frameworks, the research aims to provide an understanding of how mega-basins can inadvertently lead to maladaptive outcomes. It underscores the importance of considering the long-term consequences and unintended effects of water management strategies, particularly in the context of evolving climatic conditions and socio-economic pressures.

4.2 Methodology

In our study, we embark on an analysis of maladaptation, encompassing three pivotal stages designed to elucidate the complexities inherent in this phenomenon:

1. System definition:
    - The initial step involves delineating the boundaries of the study system encompassing various dimensions such as geographical and temporal dimensions, social structures, environmental factors, and political dynamics.
2. System thinking and socio-hydrological archetypes:
    - Here, we apply system thinking methodologies to delve into the system's intricate interactions and feedback loops.

- By constructing causal loop diagrams, we map out the primary components and their interrelations, illustrating the underlying dynamics.
- Utilizing socio-hydrological archetypes, we delve into the common structures within the socio-hydrological system, focusing on the interplay between human activities and natural systems.
- Through analyzing these archetypes, we aim to uncover potential vulnerabilities and unintended consequences associated with implementing mega-basin projects.
- Furthermore, we explore various archetypes to discern recurring patterns and dynamics that may lead to maladaptation.

3. Characterization of maladaptation
    - This stage involves identifying indicators and criteria for assessing maladaptation within the study system.
    - We utilize the *Pathways to Maladaptation Framework* (Magnan et al., 2016) to evaluate whether the processes outlined by the archetype exemplified maladaptation.
    - Additionally, we employ the maladaptation typology proposed by Juhola et al (2016) to categorize the type of maladaptation identified.

4.3 Delimiting the Mega-basin system

In the context of analyzing maladaptation, defining system boundaries is crucial for comprehending the extent and interactions concerning the case study of mega-basins in the Marais-Poitevin region. The specific boundaries that need to be identified include:

1. Geographical boundaries: the Marais-Poitevin region and adjacent areas that may be affected.
2. Temporal boundaries: duration of mega-basins construction, historical data regarding climate, and agricultural practices.
3. Social boundaries: local communities including farmers using mega-basins and farmers without access to mega-basins, but also agricultural cooperatives, as well as the French government (regional and local prefect)
4. Environmental boundaries: basins, aquifers, wetlands, and ecosystems surrounding the mega-basin areas.
5. Political boundaries: policies and laws governing water management.

In order to conduct a thorough analysis of the complex dynamics surrounding mega-basins, we adopt system thinking methodologies. This approach is indispensable for understanding intricate systems holistically, as it examines the interconnected cause-and-effect relationships and feedback loops among all components, rather than isolating individual elements (Di Baldassare, 2024).

Our analysis of coupled human-water systems involves using system archetypes to elucidate socio-hydrologic phenomena. Through constructing qualitative causal loop diagrams, we systematically trace causal connections across time and space. This method allows us to identify crucial feedback mechanisms, including reinforcing loops that amplify system behaviors and balancing loops that stabilize them.

Furthermore, our investigation identifies instances of maladaptation using the Pathways to Maladaptation Framework (Magnan et al., 2016). According to this framework, a process qualifies as maladaptive if it exhibits one or more of the specified mechanisms: increased resource exploitation, disproportionate burden on vulnerable populations, high opportunity costs, reduced incentives to adapt, and path dependency.

Additionally, we utilize the maladaptation typology proposed by Juhola et al. (2016) to classify the specific type of maladaptation observed in each case study. This framework helps us categorize and understand how different forms of maladaptation manifest within the context of mega-basin projects, providing valuable insights for future policy and decision-making.

4.4 Data used

This study draws upon a large and varied range of data sources to analyze the implementation and impacts of mega-basins in the Poitou-Charentes region, France.

Our investigation relies on scientific papers, reports, media sources, and other scholarly literature documenting various aspects of mega-basins projects. These sources provide a solid foundation for examining both the intended benefits and potential drawbacks associated with mega-basin adoption, ensuring a thorough analysis of socio-economic and environmental implications.

5. What does the existing socio-hydrological literature tell us about Mega-Basins

As mega-basins encompass the intersection of irrigation challenges, reservoir storage issues, and temporal shifts in water withdrawal (known as substitution abstraction), our focus narrows to three pivotal articles taken from the socio-hydrological literature addressing each of these aspects. Subsequently, we compare the causal loops observed from the literature review, identifying which system archetypes are relevant to our case study and finding similarities.

5.1 Irrigation Challenges

When discussing irrigation, Di Baldassare et al. (2024) examine the feedbacks between human activities and water systems, particularly in agricultural contexts. One notable archetype they explore is the “fixes that fail” archetype. A common example of this archetype is the rebound effect, manifested by the irrigation efficiency paradox (Fig.1). This paradox arises when improvements in irrigation systems create a perception of increased water availability, leading farmers to irrigate larger areas of land. Consequently, this increased irrigation contributes to water scarcity, prompting further investment in irrigation infrastructure.

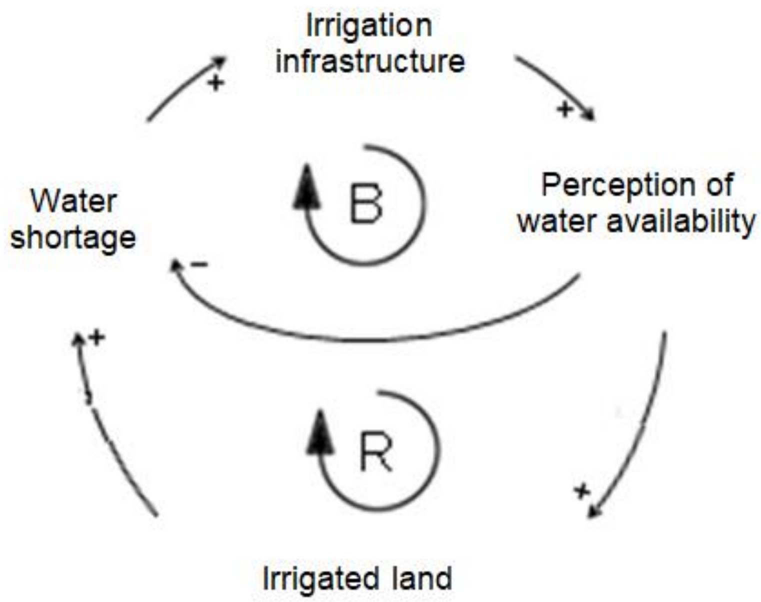

Figure 2. Fixes that fail: Causal loop diagram for the rebound effect R= reinforcing (positive) feedback loop; B= balancing (negative) feedback loop (Di Baldassare et al., 2024:10)

Examining the mega-basins case study reveals a parallel pattern, wherein introducing these substitution reservoirs creates a sense of security (Deloménie, 2024). Consequently, farmers may increase their irrigation practices, inadvertently exacerbating water scarcity, which then necessitates the construction of additional reservoirs.

Di Baldassare et al. (2024) illustrate the “limits to growth” archetype in the context of limits to agricultural growth due to groundwater usage (Fig.2). In this scenario, boosting agricultural productivity relies heavily on substantial water usage, resulting in heightened groundwater pumping. Over time, this continual pumping leads to a decline in the groundwater table and escalates pumping costs.

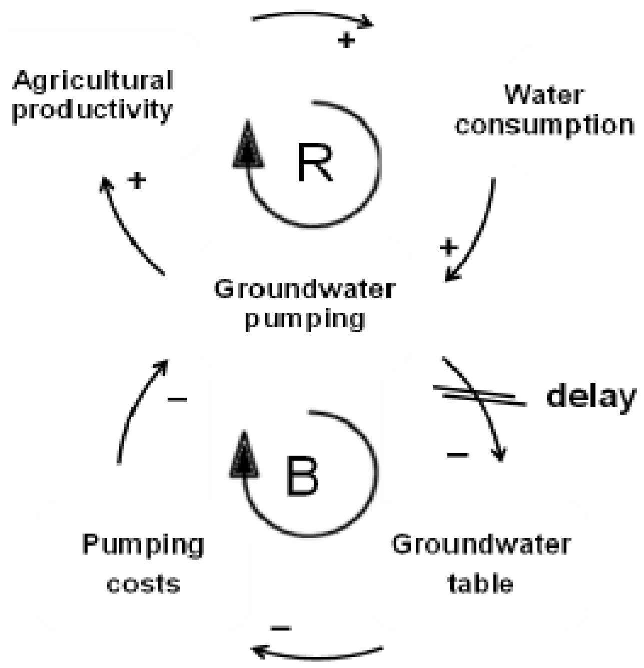

Figure 3. Limits to growth: limits to agricultural growth due to groundwater usage. R= reinforcing (positive) feedback loop; B= balancing (negative) feedback loop (Di Baldassare et al., 2024:11)

In our case study, increased agricultural productivity due to groundwater pumping may lead to a lowering of the groundwater table (Demorcy, 2023). This scenario may result in exacerbating groundwater stress and perpetuating a cycle of dependence on constructing new mega-basins.

Another archetype taken into consideration is the “success to successful” archetype, which can also manifest in the intensification of agriculture. In this scenario, market expansion among powerful actors often drives land use changes, resulting in the expansion or diversification of crops (Di Baldassare et al., 2024). Typically, the most competitive farmers are those who can procure fertile lands and secure access to dependable water resources.

The mega-basin project began with the initiative of a collective of farmers from the region (Deloménie, 2024). However, despite the use of public funds for reservoir construction, only a minority of farmers have been authorized to access them. This scenario reflects the success to successful archetype, where a select few farmers gain disproportionate benefits, often to the detriment of others who were already suffering from water scarcity.

5.2 Reservoir Storage Issues

When discussing reservoirs, Di Baldassare et al. (2018) highlight how societal reactions to water scarcity often involve expanding reservoir storage to increase water availability. While this approach can reduce the occurrence and intensity of water shortages, it may also entail adverse repercussions. In the short term water shortages inflict economic damage, prompting public pressure to expand reservoirs in response. Di Baldassare et al. (2018) contend that when expanding reservoirs or designing water infrastructures, it is crucial to consider the enduring dynamics: the supply-demand cycle and the reservoir effect.

The supply-demand cycle describes how the expansion of water supply can lead to agricultural, industrial, or urban growth, intensifying competition for water resources and diminishing the initial advantages of reservoirs (Di Baldassarre et al., 2018). It can also be understood as a rebound effect, where greater availability of resources leads to an increase in consumption. Similarly, the reservoir effect manifests when the establishment of a reservoir diminishes the incentive for adaptation measures at other levels, consequently increasing the adverse consequences of water scarcity during severe droughts. In the long-term periods of water abundance, facilitated by reservoirs foster a growing reliance on water infrastructures, thereby increasing vulnerability and economic losses when water scarcity eventually arises. The reservoir effect can also be linked to a safe development paradox, where heightened safety measures may result in escalating damage.

Extending our analysis to the Marais-Poitevain region, where mega-basins are deployed, we observe analogous dynamics. The introduction of mega-basins augments water availability for agricultural irrigation during the dry season (Grimonprez, 2019), prompting an expansion of agricultural activities and amplifying water demand to sustain the growing agricultural sector. Similarly, the implementation of mega-basins reduces the urgency for other adaptation measures to address water scarcity, such as improving water use efficiency or implementing alternative water management strategies. This delays the development of alternative methods, including shifts toward more sustainable agricultural practices like agro-ecology (Grimonprez, 2019). Additionally, while mega-basins may protect farmers from the immediate impacts of droughts, their reliance on these structures perpetuates water-intensive practices (Deloménie, 2024). This reliance exacerbates the adverse effects of water shortages on both agriculture and the environment.

5.3 Temporal shifts in water withdrawal

Prasad et al (2022) examine a case study similar to ours, focusing on plastic-lined groundwater-filled (PLGF) farm ponds utilized for irrigating high-value crops in India. These PLGF farm ponds are replenished with groundwater extracted during the wet season, to ensure irrigation availability during the dry season. Drawing parallels between the PLGF case study and mega-basins, we uncover several noteworthy similarities, elaborated upon subsequently.

Prasad et al- (2022) explore the PLGF case study in-depth, elucidating the interplay of causal relationships and feedback loops. While PLGF farm ponds initially enhance farm productivity and resilience to water shortages, long-term consequences emerge in the absence of collective action and control. Likewise, the implementation of mega-basins aims to transition the agricultural model towards greater productivity (Deloménie, 2024) while also ensuring water supply security. However, a closer examination reveals potential pitfalls, as both interventions may exacerbate disparities in groundwater access, leading to exploitation and unsustainability.

Prasad et al. (2022) find two main pathways: the aspiration pathway and the vulnerability pathway. The first pertains to a scenario in which farmers with high-risk-taking ability choose to invest in irrigation technology with the anticipation of benefiting from it. The second refers to a scenario where farmers need to invest in the technology due to a lack of alternatives, driven by the treadmill effect they experience.

Prasad et al. (2022) construct a qualitative model (Fig.3) that includes two significant reinforcing feedback loops: "Aspirational intensification" and "Vulnerability-induced intensification", as well as one balancing loop, "Cost of assured water". The first illustrates how initial farmers invest in PLGF farm ponds and transition to horticultural crops, expecting higher profits. as these farmers succeed, more are motivated to adopt similar practices, creating a reinforcing cycle where more farm ponds are built. However, each intervention affects the region's hydrology, leading to increased groundwater stress, which in turn impacts the human system. The second loop highlights that groundwater abstraction rises to meet the water needs of expanding horticultural areas and to compensate for evaporation from PLGF farm ponds. This escalation heightens the risk of reduced groundwater access for everyone, particularly affecting asset-poor farmers and those with less favorable plot locations, resulting in reduced yields and crop failures. To manage this challenge, farmers must invest in securing water access to mitigate the risk of shortages, thereby influencing the hydrology and perpetuating a reinforcing cycle.

Together, these feedback loops indicate that the initial adoption of PLGF farm ponds tends to escalate investment and groundwater risk over time (Prasad et al., 2022). However, the "Cost of assured water" feedback acts as a balancing mechanism. It suggests that there will be no incentive to continue investing in farm ponds if groundwater risk reaches a point where the cost of securing water for irrigation exceeds the benefits of shifting to horticulture. This stabilizes the intensified use supported by farm ponds.

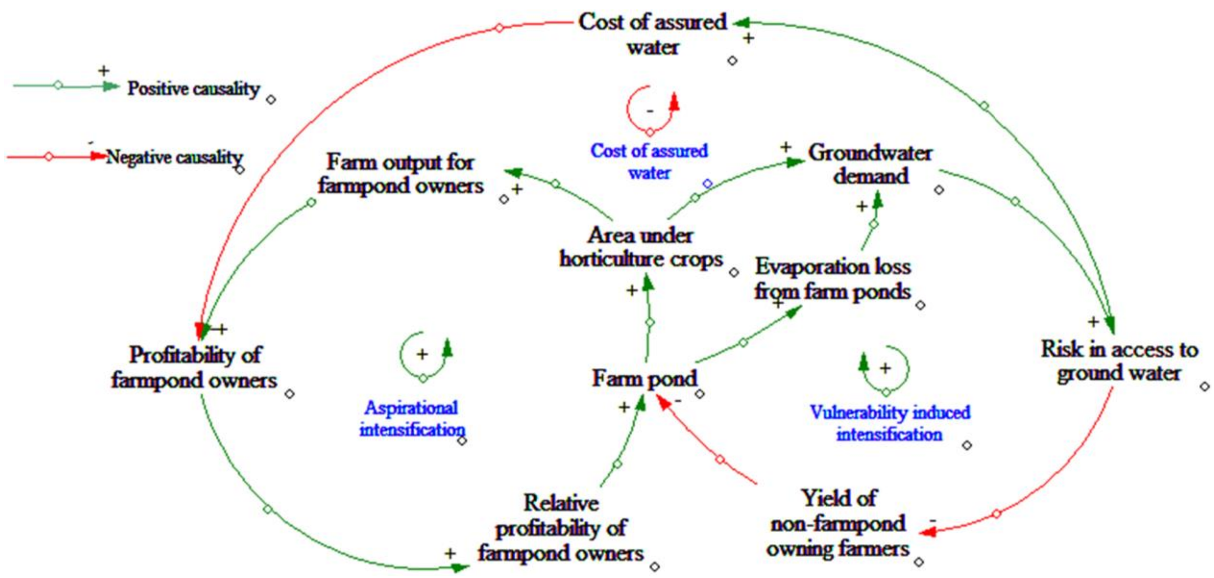

Figure 4. Causal loop diagram illustrating the two reinforcing (+) feedback loops and one balancing (-) feedback loop (Prasad et al., 2022:4).

Following this, the construction of PLGF farm ponds leads to a tragedy of the commons scenario (Prasad et al., 2022). The heightened profitability derived from these reservoirs incentivizes an accelerated proliferation of new farm ponds, exacerbating groundwater stress to the point where owners of these ponds struggle to meet their irrigation needs. Consequently, each owner experiences diminished profitability compared to the initial state, compounded by groundwater depletion and increased stress on drinking water resources. A similar scenario emerges in the case of mega-basins, where individual implementation may yield local benefits for stakeholders. However, when aggregated, these benefits contribute to the depletion of water resources over time.

In conclusion, the PLGF case study and mega-basins analysis reveal shared traits, including the initial benefits of enhanced agricultural productivity and augmented water availability. However, over time, these interventions also engender adverse outcomes, such as heightened inequality and increased reliance on water resources, exacerbating the repercussions of water shortages.

5.4 Limitations

Drawing on insights from the three key articles, we can refine our hypotheses and identify essential variables and relationships crucial to analyzing mega-basins. However, none of these articles individually provides an overall and comprehensive characterization of the systemic issues specific to mega-basins.

For instance, in Di Baldassare et al. (2018) and Di Baldassare et al. (2024), there is no consideration for seasonal withdrawal patterns. Specifically, Di Baldassare et al. (2018) do not consider the differentiation between withdrawal during dry and wet seasons when examining the expansion of reservoir storage. This is a limitation for our case study which could potentially impact the comprehensiveness of the analysis, as seasonal variations in withdrawal rates may have significant implications for water management strategies and the overall effectiveness of mega-basin projects.

On the other hand, Prasad et al (2022) consider seasonal withdrawal, yet discrepancies may exist between their case study and ours. Firstly, the Indian case study involves reservoirs of relatively modest dimensions, whereas mega-basins entail vast quantities of water collected in a single large basin. This distinction could yield varying consequences, as mega-basins may have more significant impacts on ecosystems due to their large scale.

Moreover, while we have noted some similarities between the tragedy of the commons scenario observed in the Indian case study and the situation with mega-basins, there are still some discrepancies. Unlike the decentralized decision-making and individual actions driving the tragedy of the commons in PLGF farm ponds, mega-basins are administered on a larger scale with centralized control. Access to water from mega-basins is usually regulated and limited to specific users (Deloménie, 2024). Consequently, although concerns regarding access and allocation of water resources may persist in mega-basin projects, the dynamics deviate from the tragedy of the commons scenario.

6. Mega-basin systemic archetypes and maladaptation

6.1 Causal loop diagram for Mega-basins system

In order to provide a specific overview of the systemic problems associated with mega-basins, we propose here a representation of the systemic effects associated with mega-basins. Our causal loop diagram (Fig. 5) delves into two primary objectives underlying the construction of mega-basins: enhancing agricultural productivity and addressing water scarcity. Through this qualitative model, we elucidate the causal relationships and feedback loops, revealing four reinforcing loops.

The first feedback loop (green), shown in Figure 5., delves into the transition toward adopting more productive agricultural practices facilitated by mega-basins. As mega-basins enhance the perception of water availability, farmers are incentivized to expand their irrigation activities. This heightened perception of water accessibility encourages increased irrigation and prompts a productive agricultural model. However, this reliance on mega-basins for sustaining agricultural productivity contributes to heightened groundwater stress within the region. As a consequence, farmers become increasingly dependent on mega-basin infrastructure to meet their water needs, exacerbating the strain on groundwater resources and perpetuating a cycle of dependence on these interventions. Moreover, the implementation of mega-basins effectively privatizes a shared resource, exacerbating inequalities among farmers. Only a select few will have access to increased water availability, enabling the select few to adopt more productive agricultural practices.

The orange feedback loop in Figure 5. delves into the dynamics surrounding the alleviation of water scarcity through the implementation of mega-basins. Initially, the introduction of mega-basins serves to increase water availability, effectively counteracting immediate water shortages within the region. This short-term effect provides a temporary perception of water availability, offering relief to the agricultural sector. However, despite the initial alleviation of water scarcity, the underlying issue persists over time, exacerbated by various factors such as evaporation loss from mega-basins, climate variability, and increased water demand. Consequently, in the long-term existence of water scarcity exacerbates groundwater exploitation and may lead to environmental degradation. In response to this pressure, the demand for the construction of additional mega-basins increases. We can also observe the purple loop (Fig.5) illustrating the supply-demand cycle, which suggests that responding to a new water shortage by expanding reservoir storage can perpetuate a cycle of increasing water demand. This, in turn, leads to higher water consumption and triggers unintended effects. The supply-demand cycle, suggests that addressing a new water shortage by expanding reservoir storage can perpetuate the cycle of increasing water demand, consequently increasing water consumption, and triggering unintended effects.

The four reinforcing feedback loops illustrate the cascading effects arising from the implementation of mega-basins, aimed at bolstering agricultural productivity and addressing water scarcity. Initially, the construction of mega-basins appears to offer substantial benefits by augmenting agricultural output and providing a buffer against water shortages. However, this initial advantage leads to a heightened dependency on water resources and exacerbates disparities among stakeholders, particularly between farmers with access to the reservoirs and those without access.

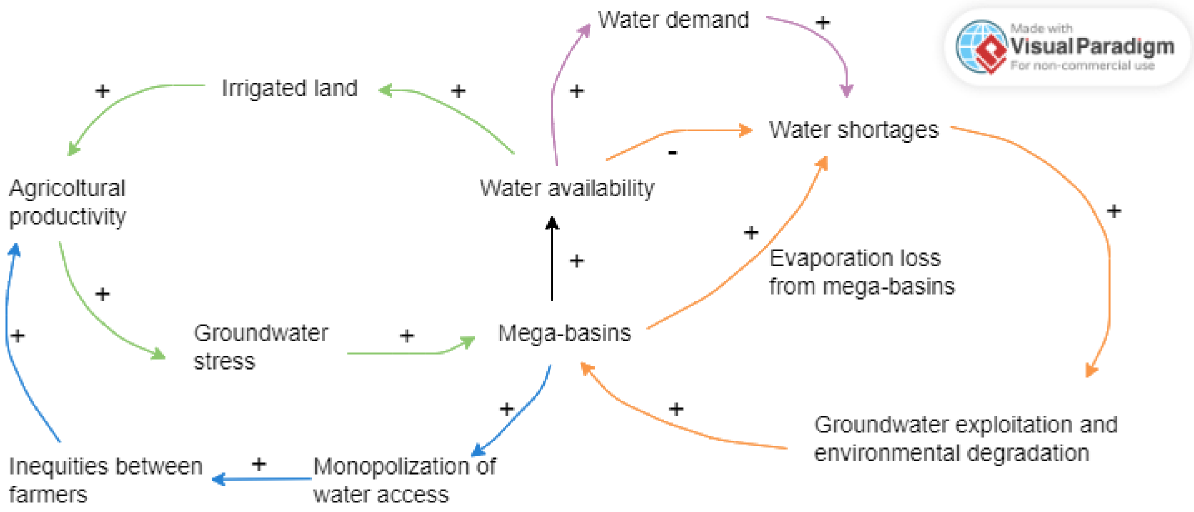

Figure 5. Causal loop diagram illustrating the reinforcing (+) and balancing (-) feedbacks between the processes involved in implementing mega-basins.

6.2 Identifying System Archetypes

In our case study, there is a clear inclination towards short-term solutions, aimed at addressing the immediate needs of stakeholders. However, the literature emphasizes the importance of long-term perspectives to prevent maladaptation, as short-term fixes may only alleviate the symptoms without addressing the underlying issue (Biella et al., 2024). In our case study, we recognize the 'fixes that fail' system archetype, as we observe a recurring pattern of favoring short-term interventions. Despite the recognition of the necessity of long-term perspectives for sustainability and maladaptation avoidance(Boon et al., 2021), short-term solutions garner more attention due to the urgency of addressing immediate concerns. The 'band-aid solutions' archetype can illustrate this.

'Success to successful' was the third archetype identified. This phenomenon arises from the observation that not all farmers could equally obtain the benefits of mega-basins. It was theorized that farmers who have access to mega-basins may gain disproportionate advantages from their utilization, ultimately benefiting overtime at the expense of other farmers who were not involved in the process.

The fourth archetype identified in reviewing Di Baldassare's (2024) literature was the 'limits to growth' archetype. This archetype is illustrated in the context of constraints on agricultural expansion due to excessive groundwater use. We observed that boosting agricultural productivity is heavily reliant on water consumption, which can escalate groundwater pumping, ultimately exacerbating groundwater exploitation.

Another archetype observed comparing our case study with the one illustrated by Prasad et al. (2022) was the ‘tragedy of the commons’ archetype. It was hypothesized that different users competing for a finite and shared resource result in resource exploitation, damaging all actors. Although initially identified, this archetype was ultimately disregarded since it didn’t align with the mega-basin case study.

6.2.1 Fixes that Fail

Fixes that fail archetype describes a scenario where short-term solutions may initially yield positive effects toward achieving a particular goal (Moallemi et al., 2022). However, these immediate fixes can lead to unintended consequences over time. This phenomenon emphasizes the importance of considering both immediate and long-term outcomes in decision-making processes.

In our case study, we observe the practice of winter withdrawals aimed at mitigating summer water scarcity (Deloménie, 2024). Initially, this strategy contributes to an immediate boost in water storage, offering a short-term solution to the issue. However, over the long term, it can exacerbate groundwater depletion, thereby amplifying its adverse effects. In this scenario, the system’s capacity to deal with water scarcity may be reduced.

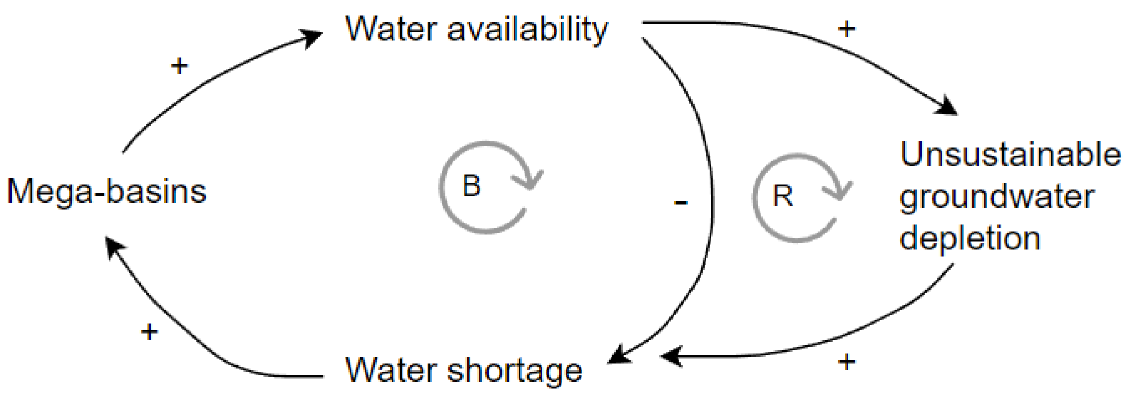

Figure 6. “Fixes that fail” archetype. R= reinforcing (positive) feedback loop; B= balancing (negative) feedback loop.

6.2.2 Band-aid solutions

The band-aid solutions archetype describes a situation where short-term solutions yield immediate results, offering quick relief by alleviating the symptoms (Moallemi et al., 2022). On the other hand, the long-term solution addresses the root cause of the problem, requiring more time but offering lasting results. Consequently, the short-term solution tends to be preferred due to its immediate benefits, often overshadowing the need to tackle the problem at the root.

In the context of our case study, it has been observed that the construction and excessive reliance on mega-basins can initially result in productive agricultural practices (Deloménie, 2024), but may ultimately lead to unsustainable practices in the long term. Increasing water consumption compromises environmental water requirements while collecting water in these substitution basins results in water loss and diminished water quality (Grimonprez, 2022). Short-term water management strategies may provide temporary solutions, reinforcing unsustainable water usage practices and fostering a false sense of security. Conversely, long-term water management strategies have the potential to address the solution to a more sustainable system. Therefore, incorporating both short and long term strategies within the same framework could mitigate the risk of maladaptive outcomes.

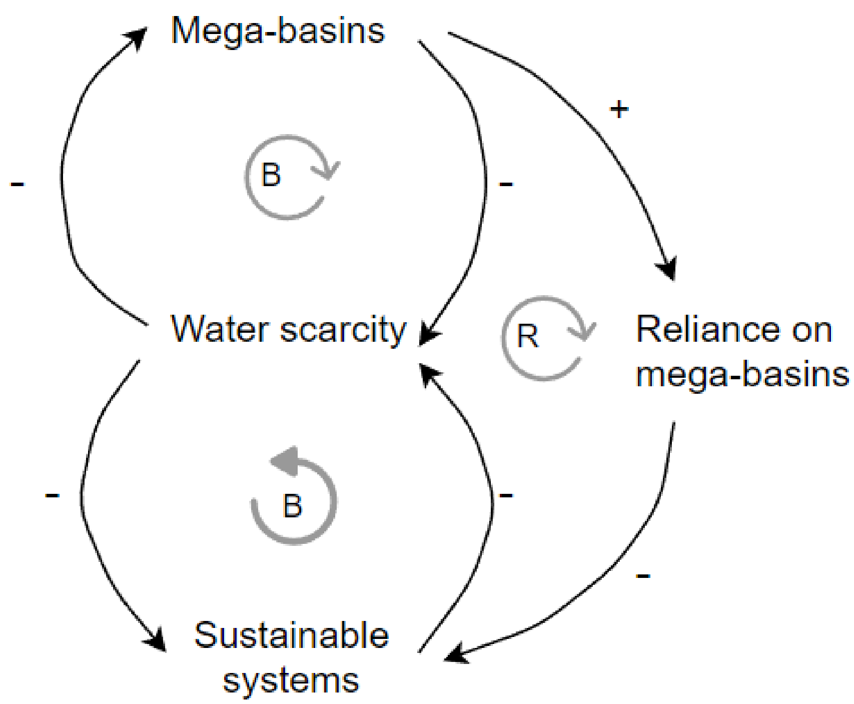

Figure 7. "Band-aid solutions" archetype. R= reinforcing (positive) feedback loop; B= balancing (negative) feedback loop.

6.1.3 Success to Successful

Success to successful archetype refers to a system in which various actors compete for scarce resources, with the most successful participants monopolizing access to resources or gaining a disproportionately larger portion of these resources (Moallemi et al., 2022).

Referring to our case study, only a minority of farmers have been authorized to access mega-basins (Grimonprez, 2019). In this scenario, only a few farmers experienced disproportionate advantages from the water storage facilitated by mega-basins, often at the expense of others within the community. This disparity in benefit distribution underscores the potential inequities inherent in the implementation of such a water management system. In this scenario, certain farmers emerged as the most successful competitors and effectively monopolized access to groundwater resources. This monopolization further disadvantaged other farmers who were already suffering from water scarcity issues.

This archetype demonstrates how certain groups may gain greater benefits from mega-basins while emphasizing that incorporating the interests of diverse stakeholders during the co-creation process can effectively mitigate the emergence of success to successful dynamics.

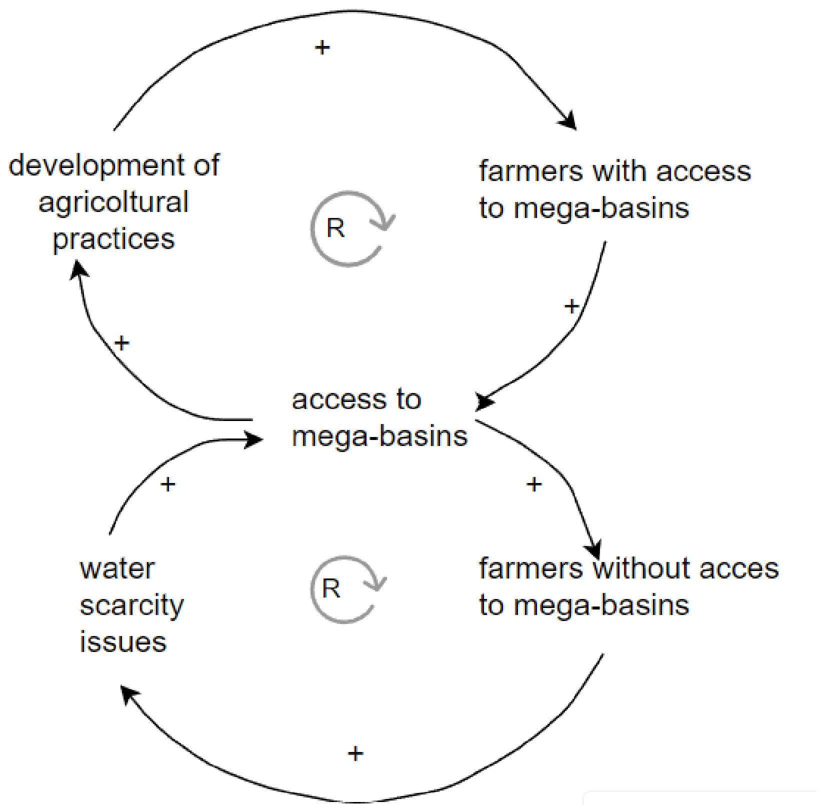

Figure 8. "Success to successful" archetype. R= reinforcing (positive) feedback loop; B= balancing (negative) feedback loop.

6.1.4 Limits to Growth

The limits to growth archetype describes a scenario where the continuous and accelerating expansion of demand, propelled by reinforcing feedback loops, results in overshooting the capacity of natural systems due to supply constraints (Di Baldassare et al., 2024).

In the context of the mega-basins case study, we note a significant dependency of agricultural productivity on substantial water consumption (Deloménie, 2024). Sustaining this heightened agricultural output necessitates increased groundwater pumping, exacerbating groundwater stress, and ultimately resulting in a long-term decline in the groundwater table and degradation of natural ecosystems.

The archetype illustrates how the initial expansion of agricultural activity leads to escalating groundwater stress, disregarding the ecosystem's capacity limits.

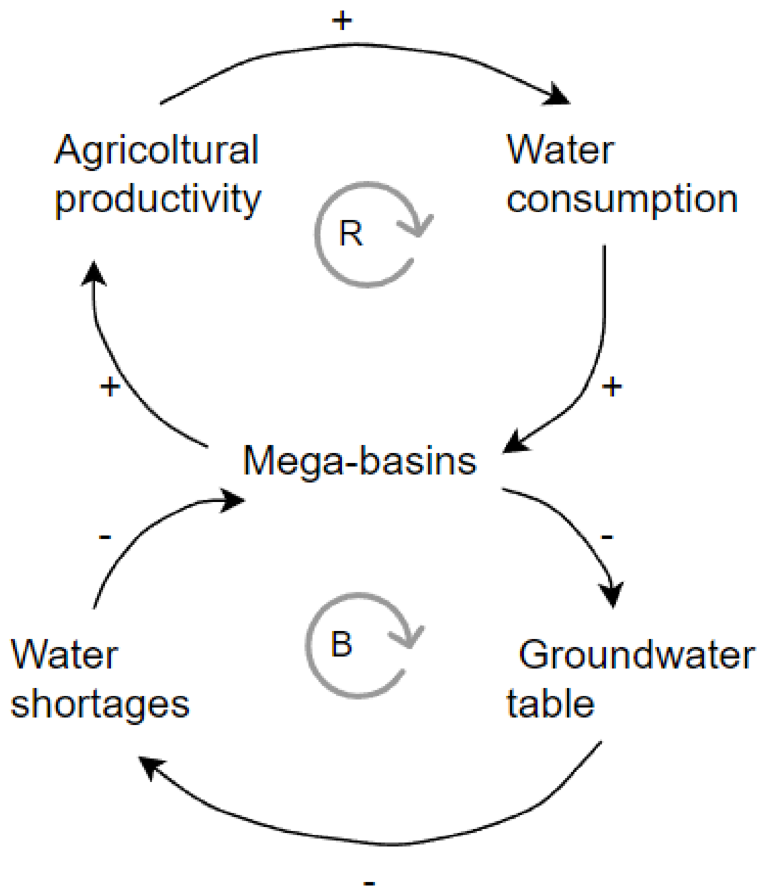

Figure 9. "Limits to growth" archetype. R= reinforcing (positive) feedback loop; B= balancing (negative) feedback loop.

6.3 Identifying Maladaptation

Based on the methodology adopted by Biella et al. (2024) the mechanisms observed in our case study were subsequently compared with the maladaptive processes outlined by Magnan et al. (2016) within the pathways to maladaptation framework. We observed that mega-basins may exacerbate resource exploitation, reinforce unsustainable practices, develop dependency over time, diminish incentives for adaptation, and disadvantage vulnerable stakeholders. These insights underscore the complex interplay between short-term solutions and long-term sustainability in the context of mega-basin implementation.

In scenarios such as those exemplified by “fixes that fail”, “band-aid solutions” and “limits to growth”, it was noted that mega-basins might exacerbate resource exploitation. Utilizing mega-basins often reinforced unsustainable practices, rendering them more resilient against water scarcity risks. Notably, these practices could develop a dependency on mega-basins over time, illustrating a form of path dependency. Furthermore, in the long run, implementing mega-basins diminished incentives for adaptation. Additionally, we observe that while implementing mega-basins may provide advantages to certain stakeholders, it could also disadvantage more vulnerable ones. A summary of these findings can be found in Table 1.

Table 1. Maladaptive mechanisms described by Magnan et al. (2016) identified in the various system archetypes in the mega-basin case study.

Archetype	Increasing resource exploitation	Disproport.lly burdening the most vulnerables	High opportunity costs	Reduce incentive to adapt	Path dependency
Fixes that fail	x			x	x
Band-aid solutions	x			x	x
Success to successful		x			
Limits to growth	x				

7. Discussion and Conclusions

In this study, we have demonstrated the utility of system archetypes as tools for anticipating maladaptive scenarios that may arise from the implementation of mega-basins. Systems archetypes serve as predictive aids for assessing both short-term and long-term impacts, including unintended consequences.

For example, the “Fixes that Fail” archetype demonstrates how mega-basins might inadvertently sustain an unsustainable use of resources, resulting in a compounded depletion of resources until the system becomes unsustainable. Conversely, the “Band-Aid Solutions” archetype reveals that immediate benefits provided by short-term solutions often overshadow long-term outcomes, leading to maladaptive consequences.

Furthermore, the “Success to successful” archetype examines the inequalities in resource access, where groups with greater access to resources disproportionally benefit from mega-basins. To mitigate potential inequality, it is crucial to adopt inclusive co-creation processes that encompass the interests of all stakeholders. This approach not only reduces the risk of creating disparities in water storage access but also emphasizes the importance of involving diverse actors and sectors to prevent the development of success-to-successful dynamics in the implementation of these basins.

Additionally, the “Limits to Growth” archetype offers valuable insight into the persistent and accelerating rise in demand, often surpassing the capacity of available resources. This archetype underscores the significance of acknowledging the limits of ecosystems’ capacities to prevent maladaptive outcomes.

This study reveals that implementing mega-basins can lead to unintended consequences, some of which may exemplify maladaptation. As previously demonstrated, the Pathways to maladaptation framework by Magnan et al. (2016) enables us to assess whether observed dynamics manifest a significant risk of maladaptation. Furthermore, by employing the maladaptation typology introduced earlier (Juhola et al., 2016), we can see how our case study example aligns with the definition of maladaptation.

For instance, the case of “fixes that fail” can be identified as an example of rebounding vulnerability. The implementation of mega-basins in an already fragile environment can result in long-term harm to the entire socio-ecological system. Additionally, the “band-aid solutions” and “limits to growth” cases can be attributed to a combination of erosions of the conditions for sustainable development and rebounding vulnerability. The “band-aid solutions” case illustrate how over-reliance on short-term solutions obstructs or delays transformative actions, thereby increasing vulnerability and impeding sustainable development. Meanwhile, the “limits to growth” case shows how taking actions without considering the overall natural system leads to resource degradation within the system, heightening vulnerability.

Additionally, the "success to successful" can be categorized as shifting vulnerability, since there is a shift in vulnerability from successful actors to less successful ones. While some farmers may experience reduced vulnerability to increasing climate extremes, this success may come at the expense of other farmers already vulnerable.

Table 2. Final findings connecting Archetypes, Maladaptation mechanisms from the Pathways to Maladaptation Framework (Magnan et al., 2016), and Typologies of Maladaptation (Juhola et al., 2016).

Archetype	Maladaptation mechanisms (Magnan et al., 2016)	Typology of maladaptation (Juhola et al., 2016)
Fixes that Fail	Increased resource exploitation Reduce incentive to adapt Path dependency	Rebounding vulnerability
Band-aid solutions	Increased resource exploitation Reduce incentive to adapt Path dependency	Rebounding vulnerability Eroding sustainable development
Success to successful	Disproportionally burden the most vulnerables	Shifting vulnerability
Limits to Growth	Increase resource exploitation	Rebounding vulnerability Eroding sustainable development

7.1 Limitations

While the study provides valuable insights into the dynamics and potential maladaptive outcomes associated with the implementation of mega-basins in the Poitou-Charentes region, France, several limitations should be acknowledged.

Firstly, the findings of this study are primarily based on a single case study, which may limit the generalizability of the conclusions to other contexts. The specific socio-economic and environmental conditions in this region may not be representative of regions facing distinct challenges or employing alternative water management strategies.

Secondly, the availability and quality of data used in this study pose inherent limitations. Despite efforts to utilize a diverse range of scientific papers, reports, and media sources, gaps in data completeness or reliability may impacts the robustness of the analysis.

Methodologically, while the application of system archetype and the Pathways to Maladaptation Framework provide a structured approach to analyzing complex systems, these frameworks have their limitations. Assumptions made during the modeling process or the interpretation of causal relationships could overlook critical factors not accounted in the study. Additionally, the study acknowledges the challenge of balancing detailed qualitative analysis with quantitative metrics, which could provide a more comprehensive understanding of the socio-hydrological dynamics.

7.2 Alternatives to mega-basins

When discussing the impacts of implementing mega-basins, it is essential to consider the balance of action between the supply and demand of water resources. Mega-basins increase water supply by securing water during winter to use during water shortages. However, this increased supply can drive higher water demand. By providing more water, reservoirs like mega-basins may facilitate agricultural expansion, which in turn leads to growing demands for water (Di Baldassarre et al., 2021). This phenomenon, known as the supply-demand cycle, describes a scenario where securing water for irrigation increases agricultural productivity and, consequently, water consumption. This cycle creates a spiral where growing water demand necessitates the construction of more reservoirs.

Addressing demand and usage involves tackling a broader system that includes large-scale strategies such as public policies and societal values. These elements are crucial for adapting to climate change and ensuring sustainable water management. Developing effective solutions requires a comprehensive approach that extends beyond the technical and environmental aspects covered in this study.

While technical improvements can help mitigate some of the unintended effects of mega-basins, it is crucial to be aware of the broader systemic impacts and associated maladaptive risks of these technical solutions. Therefore, it is important to continuously evaluate the implications of these solutions to ensure they do not inadvertently exacerbate existing problems or create new challenges.

Numerous alternatives to mega-basins for water management in agriculture have been explored and implemented, emphasizing sustainable practices that can mitigate environmental impacts. Agroecology and nature-based solutions, such as plant cover, humic-rich fertilizers, no-till farming, and agroforestry, offer promising sustainable practices for water management (Grimonprez, 2022). While these methods are essential for promoting soil health and water conservation, there is no guarantee they will be sufficient in a much more arid climate than today. Agroecology inherently depends on the pedo-climatic context and its widespread adoption faces numerous technical, organizational, and economic barriers. These challenges must be addressed and overcome for these practices to be effective on a larger scale.

Conservation management strategies, such as crop diversification, are widely embraced to improve and regenerate soil health (Raj et al., 2024). Integrating crop diversification, cover cropping, and conservation tillage has the potential to greatly impact the physical properties that contribute to soil health and water conservation.

Improving irrigation practices is another alternative, with techniques such as drip irrigation and precision irrigation significantly enhancing water-use efficiency (Yang et al., 2023). Drip irrigation is a precision technology that calculates the crop’s fertilizer and water needs on soil nutrient and water balance. It uses a drip system to deliver fertilizers and water directly to the root zone in stages, improving utilization and reducing consumption. Combined with mulching, this system efficiently distributes water through a network of pipes, slowly, and evenly reaching the soil near the plant roots.

Irrigating crops with treated wastewater is another sustainable development strategy that addresses water scarcity issues (Mishra et al., 2023). This approach offers benefits such as increased farmer profits, conservation of water resources, and mitigation of drought impacts during water shortages. However, it also has drawbacks, including increased soil salinity and potential health risks from exposure to pathogens and heavy metals. With proper management and planning, wastewater irrigation can be a safe and effective alternative to freshwater irrigation, promoting sustainable agriculture.

7.3 Conclusions

In this study, we present a detailed analysis of the systemic effects associated with mega-basins through the lens of various system archetypes. Our causal loop diagram highlights two primary objectives of mega-basin implementation: enhancing agricultural productivity and addressing water scarcity. Through this qualitative model, we uncover four reinforcing feedback loops that underscore both the benefits and potential pitfalls of mega-basins.

The first feedback loop illustrates how mega-basins initially increase water availability, incentivizing farmers to intensify agricultural practices. However, this reliance on mega-basins exacerbates groundwater stress over time, perpetuating dependence on these structures and privatizing water resources, which in turn exacerbates inequalities among farmers. The supply-demand cycle depicted in our analysis illustrates how expanding reservoir storage initially mitigates water shortages but escalates water consumption, triggering unintended consequences such as groundwater depletion and environmental degradation. These shifts underscore the short-term relief by mega-basins alongside long-term challenges in sustainable resource management.

Collective management and concerns regarding the long-term sustainability of the system are arising. In particular, through our study, we emphasize that meeting short-term solutions should not compromise long-term resilience and that prioritizing the interests of certain stakeholders should not overshadow those of vulnerable groups.

Through our analysis, we identify several system archetypes that help us assume the potential maladaptive outcomes. The “Fixes that Fail” archetype warns against unsustainable resource use perpetuated by mega-basins, while “Band-aid solutions” underscores how short-term gains may inhibit long-term sustainability efforts. Additionally, “Success to Successful” reveals disparities in resource access, potentially heightening socio-economic inequalities. Finally, “Limits to Growth” emphasizes the ecological constraints that may limit the efficacy of mega-basin solutions over time.

This study underscores the importance of anticipating and mitigating maladaptive outcomes in water resource management strategies, by applying frameworks like the Pathways to Maladaptation and assessing our findings against established typologies, we reveal critical insights into the potential risks associated with mega-basin implementation. Moreover, a balanced approach that integrates long-term sustainability with immediate needs is essential to foster resilient and equitable water management systems in the face of increasing global challenges.

Ultimately, it is important to recognize that relying on one approach, such as enhancing water supply through winter water storage, cannot effectively address water management challenges without simultaneous efforts to reduce water demand through the implementation of new techniques and policies. Achieving sustainable water management requires a balanced strategy that integrates both supply and demand measures.

For further research, it would be beneficial to compare how mega-basin implementation performs across diverse regions and countries, each with different socio-economic and environmental conditions. Additionally, conducting longitudinal studies to monitor the lasting effects of mega-basins on water availability, agricultural productivity, and environmental sustainability would provide insights into how these systems evolve and their resilience to changing climatic conditions. Developing adaptive management strategies could further enable flexible approaches to operating mega-basins. By integrating feedback mechanisms and drawing insights from previous experiences, water management systems can enhance their resilience to uncertainty and change.

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