water

MDPI

Review

Water Management as a Social Field: A Method for Engineering Solutions

Miguel A. De Luque-Villa * and **Mauricio González-Méndez**

Departamento de Ecología y Territorio, Facultad de Estudios Ambientales y Rurales, Pontificia Universidad Javeri-ana, Carrera 7 N 40–62, Bogotá 110231, Colombia; gonzalez.alex@javeriana.edu.co
* Correspondence: mdeluque@javeriana.edu.co

Abstract: This paper proposes the use of Pierre Bourdieu's sociological concepts of social fields, capital, and habitus to analyze water management in Colombia. By mapping the social dynamics of water management, this study examines the interactions and power relationships among agents, including government agencies, private companies, academic institutions, non-profits, and local communities. The analysis reveals how various forms of capital, such as economic, cultural, social, and symbolic, influence water management practices, policies, and the distribution of power. Integrating agent-based modeling with hydrological simulations provides a more nuanced understanding of how social dynamics influence water management. This interdisciplinary approach helps develop more adaptive and equitable strategies by capturing the complex interactions between human behavior and environmental factors. This study highlights the need to localize the analysis of the social field to capture regional customs and specific social dynamics. This localized approach ensures that water management strategies are more relevant, context sensitive, and sustainable. This paper advocates for the wider adoption of agent-based modeling in water management, proposing a methodology that combines the engineering principles of practical problem solving and adaptive design with an understanding of the social complexities in water management.

Keywords: agent-based modeling; Bourdieu; engineering method; social field; water management; participatory modeling

check for updates

Citation: De Luque-Villa, M.A.; González-Méndez, M. Water Management as a Social Field: A Method for Engineering Solutions. *Water* **2024**, *16*, 2842. https://doi.org/10.3390/w16192842

Academic Editor: Maria Mimikou

Received: 4 September 2024
Revised: 3 October 2024
Accepted: 5 October 2024
Published: 7 October 2024

1. Introduction

In recent decades, water scarcity has become a critical global issue due to significant climate shifts and societal developments [1]. It poses a severe threat to human sustainability, ecosystem balance, and socioeconomic progress [2,3]. Global population growth has sharply increased water demand, revealing a stark contrast between regions with abundant water resources and those facing severe shortages and pollution [4]. This imbalance often leads to conflicts over water distribution, underscoring the need for improved water management and infrastructure planning across continents, especially in arid regions, where economic dependence on water is high [5–7]. Climate change is expected to exacerbate freshwater scarcity, underscoring the importance of addressing this issue for the 21st century's economy and global health [8,9].

Decisions concerning water use and distribution have been occurring for millennia, starting with the development of irrigation systems to facilitate agricultural expansion and progressing into the sophisticated automated monitoring and operational frameworks present today [10]. Water management is an increasingly significant issue globally. There exists a wide array of organizational models, with varying distributions of responsibilities among stakeholders that are dependent on regulatory frameworks. The water distribution and sanitation sector features diverse organizational arrangements, ranging from fully private to mixed ownership to fully public entities, each with varying levels of responsibility [11]. These organizational structures and decision-making processes directly impact water availability, accessibility, and quality [12]. To achieve effective water resource management, the global water system involves numerous interconnected physiological, socioeconomic, and institutional factors. Therefore, various strategies and tools have been used to assess the dynamics of water resources in different areas [13].

Water management is a critical challenge for human sustainability. Issues related to water quantity, quality, and access pose significant challenges for both society and ecosystems [14–18]. Addressing these challenges requires us to consider the system's dynamics. This encompasses the general socio-political processes, operational decision making, and management that affect the dynamics of the water cycle. Currently, water management primarily focuses on surface waters, land, and climate governance [19]. However, numerous studies [20–27] suggest that the interactions between agents and their engagement with nature are crucial for effective water management. Water scarcity is not just a consequence of natural factors like reduced rainfall or decreased river flow due to climate change and melting glaciers; it is also influenced by social aspects related to land use and water resource distribution [28–34]. Many regions face imbalances in power dynamics regarding water availability, usage, and management [35–40]. This paper examines how water management is shaped more by the relationships and dynamics between different stakeholders. It draws on the key concepts from Pierre Bourdieu's theory, including fields, capital, and habitus, to analyze the power dynamics in water management.

Different studies have addressed Bourdieu's theory to study the problems of water management. The authors of [41] discussed the management of water resources in local communities from a social capital perspective. A comparative case study was conducted in two regions in Kepulauan Riau, Senggarang, and Mantang to explore the role of social capital in governing water resources. The findings contribute to understanding the importance of social capital for local water resource management. In [42], a case study applying Bourdieu's field theory to understanding social interactions and interests among agents was conducted. Effective water management requires not only technical solutions but also a deep understanding of the cultural and social factors that shape human interactions with water resources.

The balanced triangle concept [43] provides a crucial framework for understanding the intricate interactions among planetary resources, ecosystems, and human societies. This triangle distinguishes three key vertices: planetary resources, ecosystem-based resources, and societal needs (Figure 1). In the context of water management, this model highlights the dynamic relationships between these elements, illustrating how human appropriation and use of water resources influence both planetary and ecosystem processes. As societies draw on these resources, feedback loops are created that affect not only the availability of water but also the broader environmental and societal systems.

The complexity of water management requires an interdisciplinary approach to fully understand the dynamic interactions between humans and water systems. Traditional disciplinary methods are inadequate to address the interconnected challenges presented by water-related sustainable development goals [44]. Interdisciplinary approaches, which draw insights from fields like hydrology, engineering, economics, social–ecological systems, and political science, are necessary to explore the synergies and trade-offs across different sectors [45]. Water management methodologies are crucial not only for the physical management of water as a vital resource but also for addressing the socio-political complexities that influence water access. Water management strategies in many advanced and developing countries have primarily focused on improving infrastructure, such as pipelines, reservoirs, and treatment facilities. While this simple infrastructure approach is vital for distributing water, it often fails to ensure equitable access. In regions like Sub-Saharan Africa, challenges go beyond the need for infrastructure and involve issues of poor governance, financial constraints, and social inequalities [46]. Is "inefficient management" a socio-political issue? Thus, effective water management requires attention to diverse environmental, social, and political factors, which can be achieved through the use of interdisciplinary methods.

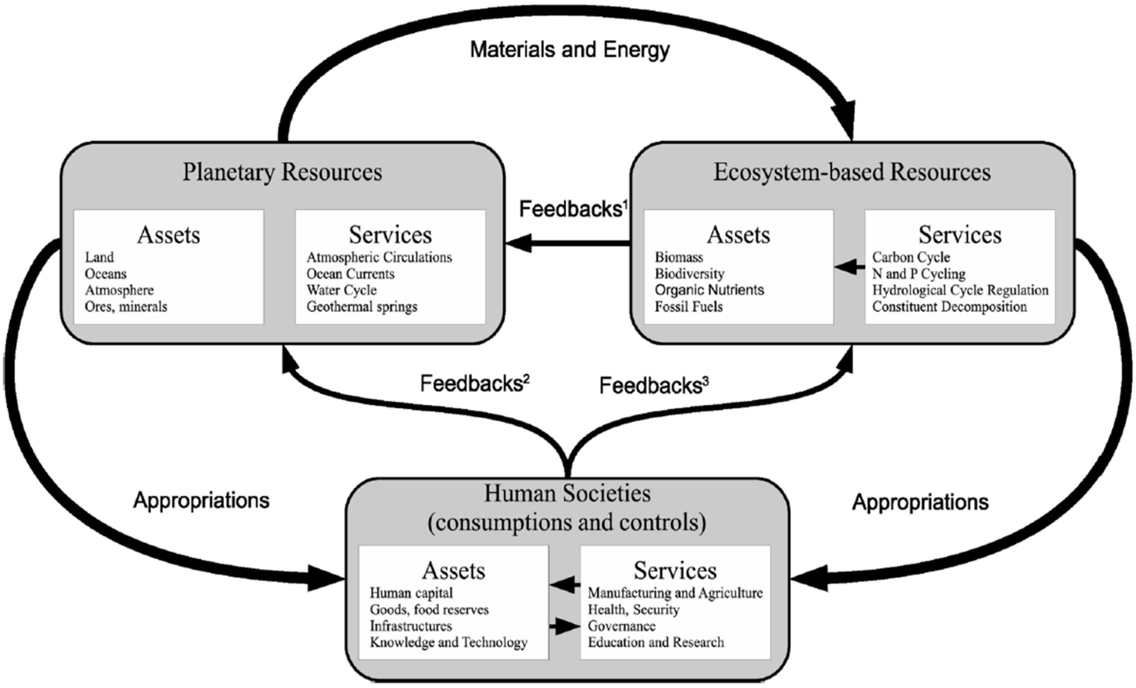

Figure 1. Balanced triangle of planetary and ecosystem-based resources and human societies. Reprinted with permission from Ref. [47]. 2013, Elsevier.

This paper aims to design an interdisciplinary methodology for water management by integrating Cohen's engineering approach [48] with Bourdieu's social field theory [49]. The combination of these frameworks is relevant because it addresses both the technical and social aspects of water management, a resource heavily influenced by infrastructure and technological solutions, as well as social, cultural, and political dynamics. While Cohen provides a focus on flexibility and adaptation in engineering planning, Bourdieu offers a lens to understand power relations and the distribution of social and economic capital in affected communities. This integration seeks to not only optimize technical resources but also to empower local communities and promote equity in water access.

The paper is organized as follows: Section 2 reviews the literature, identifying key gaps and opportunities for improvement in current water management practices and laying the foundation for an interdisciplinary approach. Section 3 discusses the central role of public policies in water management by examining how political frameworks influence water distribution and access, highlighting inequalities between urban and rural areas. Section 4 focuses on Pierre Bourdieu's theoretical framework, explaining how his key concepts of capital, fields, and habitus offer a deeper understanding of social interactions in specific contexts. Section 5 presents an overview of Cohen's engineering approach, emphasizing the epistemological difference between engineering and physical sciences, and discusses how engineering can incorporate social and cultural factors into its solutions. Section 6 applies Bourdieu's social field concept to water management in a case study of Magdalena department, Colombia, showing how different types of capital influence water governance and policies. Section 7 discusses the appropriateness of agent-based modeling (ABM) as a tool for simulating complex social systems, emphasizing how ABM captures emerging phenomena from individual interactions when combined with Bourdieu's social theory, providing a more comprehensive view of water systems. Finally, Section 8 presents the conclusions, recognizing that the proposed interdisciplinary approach promises a better understanding of the social and technical complexities in water management, potentially leading to more sustainable and equitable solutions.

2. Water Management Approaches

Water management has evolved from traditional command-and-control approaches to socio-ecological systems (SESs), such as integrated water resources management (IWRM), the water–energy–food nexus, nature-based solutions, and socio-hydrology. These approaches aim to integrate multiple disciplines and sectors to make decisions that benefit both people and ecosystems [44]. The subsequent section reviews the theoretical foundations and applications of each of these approaches, highlighting relevant case studies and lessons learned.

2.1. Integrated Water Resources Management

Integrated water resources management (IWRM) is promoted as a process aimed at the coordinated development and management of water, land, and related resources to maximize economic and social well-being equitably without compromising the sustainability of ecosystems [50]. IWRM is based on the principle that water is a finite, essential, and multidimensional resource, whose management cannot be performed in isolation but must be integrated with other related sectors, such as agriculture, energy, and the environment. Therefore, it is crucial to explore how and why this approach is applied. In response to the "how", IWRM is implemented through a participatory and inclusive process that involves all key stakeholders combined with a thorough technical analysis of the available water resources. It relies on legal frameworks that facilitate multisectoral coordination and focuses on the implementation of concrete projects that consider economic, social, and environmental needs. Finally, continuous monitoring is conducted to ensure that the actions taken are sustainable and adaptable to future changes.

In response to the "why", this approach is applied to address the challenges arising from the complexity of the hydrological cycle, increasing pressures from climate change, and conflicting demands over water use. IWRM recognizes that water is not just a natural resource but also an economic, social, and environmental asset that requires coordinated management to avoid the fragmentation of policies and actions among different sectors and users [50]. Its flexibility allows local actors to adapt their policies and tools according to their specific conditions and needs, such as improving agricultural production, increasing access to drinking water, and protecting aquatic ecosystems [51]. Thus, IWRM focuses on stakeholder participation and the need to create an enabling environment with appropriate institutional frameworks for coordination among users, aiming to balance social, economic, and environmental needs while ensuring water sustainability without harming ecosystems [52].

Finally, IWRM is widely applied in contemporary water management with good results, as supported by studies in different countries, but it also faces limitations in contexts where power imbalances and a lack of effective governance exist [53–59]. Therefore, the implementation of IWRM can be hindered by factors such as a lack of institutional capacity, political barriers, and power asymmetries among the involved actors. These challenges highlight the need to strengthen not only the regulatory framework but also the creation of an institutional environment that promotes collaboration and equity in access to water resources [60,61].

2.2. Water–Energy–Food Nexus

The "water–energy–food (WEF) nexus" approach has gained prominence due to its ability to address the interdependence between the three sectors in an integrated manner. This approach was developed with the purpose of improving resource-use efficiency through coordinated cross-sectoral management. Its main objective is to foster economic development through incentives, enhance governance for cross-sectoral management, and leverage productive ecosystems, contributing to a green economy that improves human well-being and social equality while simultaneously reducing environmental risks and ecological scarcities [62]. It is important to note that while the nexus approach has the potential to stimulate economic development through incentives, this is not a guaranteed feature in all applications. It is necessary for the incentives to be aligned with local economic and environmental priorities and for their long-term impact to be evaluated.

This comprehensive approach suggests considering the productivity of water, energy, and land as a system rather than individually, identifying opportunities to improve efficiency through innovation, recycling, and waste reduction. By prioritizing the overall system's efficiency over the productivity of each sector, the nexus approach promotes a shift towards sustainability with fewer trade-offs while producing benefits that outweigh the costs of integration. These costs are related to tangible investments such as infrastructure and technology, as well as intangible ones like governance and multi-stakeholder participation. This means that instead of optimizing one sector at the expense of another, the nexus seeks a balance that maximizes the overall system benefits, reducing trade-offs and potentially generating net benefits in terms of resource efficiency, environmental sustainability, and social equity. Therefore, while integrating the nexus approach may require an initial investment in infrastructure or governance changes, the long-term benefits (greater system resilience and efficiency) tend to outweigh these costs.

Similarly, both IWRM and the water–energy–food nexus seek the integrated and coordinated management of natural resources [63]. However, while IWRM primarily focuses on water as a resource, the nexus approach extends this integration to include two other crucial components: energy and food. Both approaches recognize the interconnections and synergies between different sectors and aim to maximize the social, economic, and environmental benefits through balanced management. However, the nexus offers a more holistic vision compared to IWRM, especially in contexts where the interdependencies between water, energy, and food are critical. It does not treat water in isolation and gives equal importance to energy and food resources, acknowledging that any intervention in one affects the others. This can be particularly beneficial in areas where water and energy demands are closely linked, such as in intensive agriculture or hydroelectric power generation.

The WEF nexus is applied through intersectoral analysis to identify how changes in water management, food production, and energy use affect the global system, generating multisectoral coordination by aligning sustainability policies and objectives across the three sectors and promoting technologies that maximize efficiency and minimize negative impacts, such as energy-efficient irrigation systems or agricultural practices that require less water. This approach is applied because it provides an integrated vision that maximizes benefits by considering the interdependence of water, energy, and food while minimizing negative impacts and improving the resilience of social and economic systems [62–64]. The benefits include resource efficiency, environmental sustainability, and economic and social resilience.

According to the above, the WEF nexus approach has gained global momentum as an innovative framework for addressing the interconnected challenges of water management, energy, and food security in a sustainable and integrated manner. It has been implemented in numerous regions around the world [65–68]. The potential of the water–energy–food nexus approach has been widely discussed in the literature, with one notable concern being that studies have primarily focused on macro-scale global resource security, overlooking the impacts on local livelihoods and the environment [63]. Furthermore, there has been a lack of participatory stakeholder involvement in designing and carrying out nexus research [64].

2.3. Nature-Based Solutions

The term "nature-based solutions" (NBSs) first appeared in the early 2000s in the context of addressing agricultural problems. Since then, NBSs have been discussed in relation to land use management, planning, and water resource management [69], such as using wetlands for wastewater treatment and leveraging ecosystem services from wetlands as a nature-based approach to watershed management. NBSs are systems that utilize and reinforce physical, chemical, and microbiological treatment processes. These processes underpin the scientific and engineering principles for water/wastewater treatment and hydraulic infrastructure. NBSs can be cost effective, energy efficient, and environmentally friendly while also providing valuable benefits to society. These include promoting biodiversity, mitigating climate change impacts, restoring ecosystems, and enhancing amenities and resilience [70]. NBSs have been widely applied in various geographic contexts across the globe [71–73].

NBSs differ from IWRM or the WEF nexus approach primarily because they rely heavily on natural ecological processes and require extensive coordination not only between different sectors (water, agriculture, and energy) but also across jurisdictions at multiple levels of government. This is because NBSs often encompass entire ecosystems, such as watersheds, wetlands, or protected areas, which frequently cross political and administrative boundaries [74–76]. Therefore, implementing NBS involves cross-sector collaboration, including agriculture, energy, biodiversity, and urban planning, as well as interjurisdictional coordination, which involves multiple jurisdictions (local, regional, and national governments), adding an extra layer of complexity to their implementation.

This need for greater coordination is a key difference from approaches like IWRM, which, while also requiring coordination, primarily focuses on the integrated management of water resources and does not necessarily involve broader ecosystems or actions that engage both ecological and urban sectors.

NBSs face several limitations, including the need for coordinated decision making across multiple jurisdictions and sectors, which can lead to conflicts and inaction due to a lack of policy coherence. Trade-offs, such as compromising agricultural productivity for environmental benefits, further complicate implementation. Additionally, unsupportive or conflicting incentives and regulations, as well as entrenched institutional norms and path dependency, hinder the adoption of NBSs [77].

NBSs face specific barriers, such as the lack of long-term funding for projects that require decades to yield full benefits (e.g., ecosystem restoration) or stakeholder resistance to moving away from traditional approaches like "grey" infrastructure. These specific barriers are not as common in approaches like IWRM or the WEF nexus, which focus more on infrastructure and direct resource management [78]. This perception underestimates the diverse benefits of NBSs and generates reluctance to adopt these alternatives. There is a critical need for policies that promote better participatory processes around NBSs to raise awareness, distribute benefits equitably, prevent conflicts, and encourage management [79].

Although some coordination challenges and institutional barriers are common to previous approaches, the implications and scale of these challenges may vary. NBSs, by relying more on nature and less on technological infrastructure, face unique implementation challenges, particularly regarding natural variability and climate uncertainty [80].

2.4. Socio-Hydrology

Socio-hydrology is a scientific discipline focused on understanding and interpreting the interactions and feedback between human and water systems. It aims to analyze the dynamics of socio-hydrologic processes, explain their impact on human well-being, and explore future scenarios. This field integrates the study of multiscale water system structures, human outcomes related to water, and societal goals for water use and sustainability. By formalizing these interactions, socio-hydrology seeks to address water sustainability challenges in the Anthropocene [81].

It differs from resource management approaches such as integrated water resources management (IWRM) or the water–energy–food (WEF) nexus, as these approaches primarily focus on water resource management and their inter-relationships with economic and social sectors but do not explicitly address long-term social dynamics or the co-evolution processes between water and human systems [82]. Socio-hydrology has a more scientific and academic approach based on modeling and analyzing historical and future scenarios that aim to capture how social behaviors, policies, and human actions affect water systems and vice versa.

Aligned with the discussion above, the prevalent approach in the field of socio-hydrology is the development of coupled human–water models. Mostert [83] proposed an alternative: qualitative case study research involving systematic reviews of human activities, key actors, and influencing factors. It presented a case study of the Dommel Basin in Belgium and the Netherlands. Case studies offer a more complete understanding of management levers, while coupled models generate quantitative scenarios. Scholars in socio-hydrology aim to capture the full range of human behaviors in interactions with natural systems, but methodological implementations often reduce these dimensions to fit quantitative models, posing epistemological challenges. Human behavior is influenced by perceptions, preferences, and socio-political contexts, making it difficult to find a single truth [84].

Regarding epistemological challenges, it is true that quantitative modeling in socio-hydrology faces many of the same issues as other approaches, such as the lack of precise data or the difficulty in representing the complexity of hydrological and social systems in predictive models. However, the challenges are deeper in socio-hydrology due to the need to integrate unpredictable social dynamics into traditional models. These dynamics include human behaviors that change based on cultural, economic, or political factors, adding a layer of uncertainty that is not present in purely physical hydrological models.

2.5. Hydro-Social Territories

Hydro-social territories are complex spaces where society, technology, and nature intersect, being shaped by human imagination and social practices. These territories include interactions between water flows, hydraulic infrastructure, and governance structures, where dynamics of inclusion, exclusion, and resource distribution come into play, reflecting a complex network of biophysical, technological, social, and political elements in water management [85]. Water management in these territories reflects a dynamic network of biophysical, technological, social, and political elements, requiring an integrated approach for effective understanding and management.

Dynamic relationships create inconsistent categories, such as those emerging between rural and urban actors, local communities and the state, or private and public actors. These inconsistencies are not just a side effect of interaction but a central feature of how these territories are constructed and negotiated over time. Unlike other management approaches where categories tend to be more static or well defined, hydro-social territories recognize that categories are inherently porous and subject to change due to the fluid nature of relationships between water, technology, and governance structures.

A study conducted by Hommes and others explored Foucault's "arts of government" applied to the management of water transfers from rural to urban areas in cities such as Lima, San Luis Potosí, and Bucaramanga [86]. This analysis included both traditional water transfer schemes and payments for ecosystem services systems, revealing how urban imaginaries about rural areas influence governance decisions, shaping the subjectivities of the actors involved, that is, how rural and urban actors see themselves and how they are perceived by others. These subjectivities are not static; they are in constant negotiation, acceptance, or dispute by the affected communities, providing a deeper understanding of how rural–urban hydro-social territories are configured and how technologies play a fundamental role in transforming rural identities. Traditionally, rural identities have been characterized by their close relationship with agriculture, natural resources, and community lifestyles. However, the introduction of advanced technologies has significantly transformed these dynamics [87,88]. Technologies such as precision agricultural machinery, digital platforms for product marketing, and renewable energy systems like solar panels have profoundly altered traditional practices in rural areas. For example, farmers who once relied on generational knowledge now use technological tools like GPSs and smart sensors to optimize water and nutrient use, turning them into technological managers of their land. This shift has modified rural identities, as traditional roles of "guardians of the land" are transformed into "technological operators", whose knowledge and skills are more aligned with industrial and urban practices [89].

Despite the benefits that emerging technologies can bring to agricultural productivity and access to global markets, they also present significant challenges. One challenge is the digital divide, which may widen between rural communities that have access to these technologies and those that do not. This unequal adoption of technology can affect social dynamics, creating new forms of exclusion or technological dependence, especially in rural areas where digital infrastructure is limited.

Additionally, the integration of technologies in natural resource management can reconfigure power relations between rural communities and the industrial or urban sectors that consume those resources. For example, the use of advanced water monitoring technologies can improve management efficiency but may also concentrate control of these resources in the hands of large corporations or institutions, distancing the local communities that directly depend on water for their livelihoods.

To mitigate these effects, it is crucial that the introduction of new technologies in rural areas is accompanied by inclusive policies. These policies must ensure that all actors, including the most vulnerable, equitably benefit from these technological advances, thus avoiding the creation of new forms of marginalization or dependence. The participation of rural communities in the design and implementation of these technologies is key to democratizing the benefits and reducing inequalities [90].

Although the concept of hydro-social territories is useful for understanding the complexity of water management, it faces limitations in its conceptual and practical application. One of the main difficulties lies in the dynamic and reciprocal nature of the categories "state" and "local community", which are continually reconfigured through hydraulic and conservation projects. These projects change the identities and roles of the actors involved, complicating their representation and understanding.

The negotiation and dispute processes among the actors involved constantly alter their perceptions, making it difficult to maintain consistent categories over time. Although more powerful actors, such as governments and large corporations, often dominate decisions about water management, there is also the possibility that grassroots democratizing discourses can reshape power relations and decision-making processes, potentially leading to the more inclusive and adaptive governance of water resources [85].

Furthermore, while powerful actors, such as governments or large corporations, tend to dominate local communities in terms of water management decisions, there is a possibility that grassroots discourses can democratize water governance. This process can lead to reconfigurations of the actors involved, the decision-making processes, and the spatial scales at which water resources are managed [91].

3. The Role of Policy in Water Management

Water resource decision making can be supported through various technical tools, including both administrative and technological approaches. The administrative tools are part of the legal framework of each territory, and they are generally inserted in government policies [92]. Political decisions regarding water determine who has access to the resource, how it is distributed, and who manages it, which can generate dynamics of inclusion or exclusion within territories. In particular, water management in rural and urban areas is deeply influenced by the policies regulating its use, and these decisions can have drastic effects on the quality of life of the local communities and the sustainability of ecosystems.

In urban areas, water management policies tend to prioritize access for domestic and industrial consumption, often leading to the transfer of resources from rural areas to cities. This process not only reflects an imbalance in the distribution of water resources but also highlights the asymmetry in the decision-making power between urban and rural actors. Urban policies often ignore the needs and rights of rural communities that depend on water for their subsistence, such as agriculture and livestock, generating tensions and conflicts between both regions [93].

In rural areas, water policies are marked by fragmentation and a lack of recognition of the specific needs of rural communities. These policies are often designed in urban centers without a deep understanding of the local conditions. This results in the implementation of policies that do not adequately address the particularities of rural territories, exacerbating problems of access, equitable distribution, and sustainability. Additionally, rural communities, with less political and economic power, are often marginalized in decisions about water management, leaving their needs in the background compared to urban or industrial demands.

Decision-making processes in water management are also deeply affected by power dynamics between different actors. Large corporations, private actors, and government entities often have more influence over water policies than rural communities or small producers. This power asymmetry can lead to policies that favor the more powerful actors, leaving rural communities with limited or lower-quality access to water resources. As a result, water policies may not reflect the interests of all water users but rather prioritize the interests of those with more economic or political power [94].

Therefore, it is crucial that water policies include mechanisms for participation and democratization that allow rural communities and other marginalized actors to have a voice in decision making. Without these mechanisms, water management will continue to reproduce inequalities, both between rural and urban areas and among the different social groups that depend on the resource [85,89]. Participatory governance in water management can offer a way to mitigate these problems by ensuring that policies respond to the needs of all parties involved and promote the equitable and sustainable use of the resource. Finally, effective water governance requires a multi-stakeholder approach, where policies are designed to address both the infrastructure and the socioeconomic and environmental dimensions of water management [95,96].

4. Bourdieu's Framework

Pierre Bourdieu has been one of the most influential sociologists in history, and his theories continue to be extensively used across a wide range of fields to comprehend social dynamics and power relations. His ideas revolve around understanding the dynamics within social fields through the interplay of capital, fields, and habitus. By combining anthropology, sociology, and philosophy, his approach focuses on how different forms of capital—economic, social, cultural, and symbolic—affect social interactions and power structures within distinct social spaces [97]. Power is both the main interest of practice and the engine of field dynamics in Bourdieu's theory. Bourdieu aligns all practices through the logic of domination [98]. Bourdieu defines the field as an arena where conflict arises among the actors seeking access to specific resources that define it; this structure is determined by the relationships between the involved actors [49]. Each field is organized around specific problems and interests, motivating the participants to invest in it. The "field" encompasses two aspects: the social position of the actors, which is influenced by the number of different types of capital, as well as the symbolic positions or attitudes that these individuals adopt. Various forms of capital differ in value and distribution within fields, establishing a hierarchical structure with unequal relations among actors who may not have direct interaction. Dominant figures in the field can enforce both formal and informal rules, primary objectives, and entry criteria that reflect not only a power relationship but also an element of domination [99]. Field theory is pertinent for understanding dominant figures but may be less applicable to the subordinate and peripheral actors who are not as significantly impacted by the influences and dynamics of the field.

Pierre Bourdieu's sociological theory emphasizes the central role of capital concepts in understanding social dynamics and power distribution within different social fields. He classifies capital into four main forms: economic, social, cultural, and symbolic. Economic capital encompasses the financial and material resources owned by an individual or group, such as money, properties, and other assets that can be readily converted into cash. This type of capital can be quickly and directly changed into money and may also be formalized through property rights [100]. Social capital refers to the resources that stem from belonging to a network or group of more or less institutionalized relationships characterized by mutual acquaintance and recognition. Members of this network have access to various benefits through their social connections. Social capital comprises social obligations (“connections”), which, under specific conditions, can be converted into economic capital and could even be formalized as a title of nobility [101]. Cultural capital can exist in three forms: embodied, as long-lasting dispositions of the mind and body; objectified, as cultural goods such as books, works of art, or scientific instruments; and institutionalized, in the form of educational qualifications. It is not transferred instantaneously but requires a process of acquisition that involves accumulating knowledge and skills over time [101]. According to Pierre Bourdieu [102], symbolic capital is a form of capital related to perception and recognition within a specific social field. It includes resources such as prestige, honor, and attention that an individual or group possesses due to their cultural, social, or economic capital. Such forms of capital influence how individuals are perceived and treated by others in society and can be utilized to gain additional advantages or maintain one’s social position. In each field, agents use these forms of capital to maintain or improve their position within the hierarchy. The relationship between the types of capital and the field is dynamic; agents can transform one type of capital into another depending on the conditions of the field and their abilities to maneuver within it. For example, a person can use their social capital (connections) to gain access to opportunities that increase their economic capital (wealth) or cultural capital (educational credentials).

Another important concept is habitus. Pierre Bourdieu defines it as the internalized and enduring dispositions that shape individuals’ perceptions, thoughts, and actions. These dispositions result from the inculcation of social and cultural structures and often operate unconsciously, guiding individuals in their everyday interactions across various fields [103]. Thus, habitus not only reflects the social conditions of its production but also actively influences how individuals engage with and respond to those conditions. This interplay between structure and agency is central to understanding the reproduction and transformation of social structures within Bourdieu’s theory.

Within Bourdieu’s theory, space plays a key role in the arrangement of the social field. The spatialization of the analysis is essential to capture the unique socioeconomic and cultural dynamics at play in each area. Through spatialization, it is possible to visualize how access to capital and power relations are distributed geographically, allowing for a deeper analysis of inequalities in resource management.

Bourdieu’s work emphasizes understanding how social positions, dispositions, and choices are relationally defined by individuals’ practices within a system. He argues that direct comparisons of isolated traits can misrepresent structural differences or similarities; therefore, comparisons should be made across entire systems. The idea of “distinction” refers to the relational properties that exist through connections to other properties rather than innate qualities [103]. This highlights the concept of social space, where positions are defined by their relations to others, reflecting proximity, distance, and hierarchy. The social space is organized so that agents or groups are distributed according to their positions in the statistical distributions of economic and cultural capital. Agents have more in common when they are closer in these dimensions. The distances on paper reflect social distances. In the main dimension, those with significant capital, such as entrepreneurs and professors, oppose those without, such as unskilled workers. The structure of capital, meaning the relative weight of economic and cultural capital, also creates opposition, such as between professors and entrepreneurs. These capital differences lead to variations in dispositions and positions, translating into different practices and goods, which form a coherent system of habitus according to the social class position (Figure 2). Elaborating on the social space, which is an abstract reality that structures the practices and representations of social agents, enables the construction of theoretical classes based on the primary factors shaping social practices. This classification not only describes empirical realities but, akin to an effective taxonomic system, also forecasts other properties, clustering similar agents and distinguishing them from others.

Figure 2. The space of social positions and the space of lifestyles [49].

Figure 2 illustrates how different levels of economic and cultural capital influence not only personal preferences but also political tendencies. For example, people with high cultural capital tend to enjoy more intellectual or cultural activities, such as chess, mountaineering, piano, or golf, while those with high economic capital enjoy more exclusive activities like golf, hunting, and consuming luxury products like champagne. Those with low cultural and economic capital tend to engage in more popular and accessible activities, such as soccer and beer consumption, and people with low cultural but high economic capital tend to enjoy more traditional or working-class-related activities, such as fishing and drinking wine. Each of these social groups also has different political tendencies, with a clear division between voting for the left (lower economic capital sectors) and voting for the right (higher economic capital sectors).

5. Engineering Method

Engineering is often viewed with condescension, even among those who recognize the cultural importance of science and technology. This perspective reduces engineering to merely applied science, ignoring the distinct theoretical and epistemological frameworks that differentiate it from the physical sciences. While science seeks universal truths about the natural world, engineering operates within a context-specific, socially driven framework [104]. A clear example is the development of renewable energy infrastructure, where engineers have had to adapt global technologies to local needs and resources. Engineering is often treated in academic programs as a black box, a step in the technological innovation process, or a matter of technical problem solving. However, Science and Technology Studies scholarship has generated a richer understanding of technological innovation as a complex social process. In order to fully appreciate engineering, it is important to understand how engineers enable this process of selective knowledge exploitation, which exemplifies a distinctive form of rationality compared to science [105]. Engineering problems and solutions are inherently context dependent. Engineers generate the knowledge needed to solve the problems they define by selectively appropriating scientific or other knowledge and transforming it into engineering knowledge. Engineering reasoning is highly complex, as it is inseparable from the particularities of intentionality, contingency, voluntariness, and value-laden contexts. This reasoning cannot be uncovered by applying a generic solution methodology; rather, it is through the explicit valuation and the specific process of defining engineering problems and developing solutions that the unique reasoning and method of engineering are manifested [104,105].

In the last century, engineers have commonly assumed that "design" or, more precisely, the ability to design is the fundamental element linking engineering and technological development. Design is a creative and adaptive activity inherent to human abilities, which not only seeks efficient technical solutions but also takes social and cultural factors into account. This process has been observed in green infrastructure projects, where engineers design solutions that respect local ecosystems and social needs. Therefore, design involves adapting the means to achieve a predetermined end. The ability to design demonstrates technological aptitude and successful creations by engineers. This requires combining numerous elements into a carefully crafted whole to achieve a preconceived goal. Essentially, design involves a structure or pattern and a particular arrangement of details or component parts [106]. In other words, design shapes the way in which engineers reason about problems. This mode of thinking is fundamentally at odds with the notions of universality and context-free engineering concepts, which philosophers have promoted as the only valid approaches derived from validations through mathematics and modern physics. Additionally, design is inextricably linked to historical, sociocultural, and personal factors [107].

The objectives of any engineering research project must be grounded in the generation of new knowledge. As previously established, this new knowledge takes the form of "know-how" or, more precisely, "know how to do something". In this proposal, the novelty is inherently tied to a reconceived approach to water management. As will be evident in this paper, previously overlooked elements are incorporated, and engineering-driven technological tools are leveraged. The main aim is to enhance water management, with the new knowledge translating into a more effective and innovative way of addressing this task.

In the framework design, we use a process planning heuristic: "the use of heuristics to find the best solution in a poorly understood situation with the available resources" [108]. This introduces the concept of the state of the art, which refers to a set of heuristics. A heuristic is any approach that provides guidance in solving a problem and can be based on different states of the art. Heuristics, as guiding tools in solving complex problems, allow engineers to progress iteratively, adjusting their solutions as new variables arise. We use various heuristics as a basis to link the social and cultural elements in water management, resulting in a unified model that addresses population phenomena based on individual and institutional behaviors within a social field. The central idea is to incorporate the complexity of human behavior in the water management planning process. The engineering method is based on decision making that guides the process toward a desired final state, using heuristics that engineers select according to their current knowledge and the context in which they operate. This process is dynamic and adaptive, recognizing that both the problem and available resources may change over time. Heuristics, as key elements of the method, not only direct the course of action but also reflect the limitations and possibilities of knowledge at any given moment. As the engineer progresses from an initial state to a final state, continuous evaluations are made to ensure that the chosen direction remains the most appropriate given the changing circumstances and new societal goals that may emerge. The notion of a "best" engineering solution is inherently subjective, as it is shaped by the individual engineer's knowledge, experience, and understanding of the current state of the art. This subjectivity is further compounded by the inherent uncertainty and incomplete information that characterize engineering problems. Consequently, the engineering methodology is closely tied to the subjective determination of the "best" solution, which is influenced by personal and contextual considerations [48].

We propose an approach to water management as a social field, positioning social dynamics, capital structure, and power distribution as the central consideration in the planning process. However, simply stating the habitus and capital as the core elements is insufficient. Rather, the framework must be able to meaningfully connect these with the relevant aspects of water management and provide a means to support planning efforts. Guided by the design principles of engineering, we put forward a framework that integrates the complete cycle of technological development. This framework is intended to facilitate water management by incorporating new elements and employing a participatory approach to generate scenarios, not only to ensure that local communities have a voice in decision making but also to promote sustainable and culturally appropriate solutions. Given the complexity of a social field, uncertainty is inherent in the conceptualization of these systems. There is a significant lack of information about the various elements present in the field, making it impossible to achieve complete knowledge. To address this challenge, an agent-based modeling framework is particularly well suited for water management, as it allows for the simulation of interactions between multiple actors, from individual users to governmental institutions. This approach facilitates the creation of scenarios that reflect the diversity of behaviors and decisions affecting water use, providing a more flexible tool for water management planning. A key aspect of this approach is to avoid oversimplifications that overlook essential elements and instead strive to incorporate the inherent complexity of the field. The goal is to optimize water availability by considering fundamental societal well-being factors that have traditionally been neglected due to their complexity.

6. Water Management as a Social Field

By applying Bourdieu's concept of the social field to water management, we seek to understand how diverse agents interact within a structured space defined by their access and control over various forms of capital [101]. This social field is a dynamic arena where agents, including government, private companies, academic institutions, non-governmental organizations, and the population, navigate their positions based on their capital accumulation. The social field of water management is characterized by the distribution of different forms of capital among its agents [85,109].

Economic capital shapes water management practices and policies, since individuals, communities, and institutions can mobilize financial resources and assets to influence these domains [110]. This form of capital impacts not only the infrastructure and technologies that are developed and deployed but also the power dynamics within water governance. Economic capital significantly shapes investment in water infrastructure, including dams, reservoirs, pipelines, and treatment plants. Wealthier communities or regions are more likely to access advanced water technologies and infrastructure, securing a more reliable and higher-quality water supply, which also heavily influences access to water resources, especially in areas with constrained or privatized water supplies. Affluent individuals and corporations can leverage their financial resources to acquire water rights, invest in private water infrastructure, or engage in legal battles to secure water access, frequently to the detriment of less affluent communities. This can result in policies and practices that prioritize the interests of the wealthy, potentially neglecting the needs and rights of economically disadvantaged populations. In summary, the perspective of Bourdieu's theory suggests that economic capital is a significant force in shaping the distribution of water resources. Acknowledging the influence of economic capital is crucial to address the inequalities it may perpetuate and to formulate more equitable and sustainable strategies for water management.

Cultural capital in the water management social field could seem like scientific knowledge, referring to the understanding of hydrological systems, water management technologies, cultural knowledge, and the local customs, traditions, and practices related to water use and conservation, which can vary widely between local communities around the world [110]. Perceptions encompass the beliefs and values associated with water, such as its perceived importance, respect for water bodies, and awareness of conservation needs. Education is the level of formal and informal education related to water management that individuals and institutions possess. Cultural capital is crucial for understanding the social dynamics of water management; it shapes how management strategies are adopted and the effectiveness of interventions. Recognizing and utilizing this cultural capital is vital for developing more inclusive and sustainable water policies that resonate with the target communities.

Social capital in water management, as viewed through Bourdieu's theory, is a vital resource that enhances the capacity of individuals and communities to manage water resources effectively [110]. It facilitates co-operation, information exchange, access to resources, and conflict resolution, all of which are essential for sustainable water management. Communities often rely on social capital to effectively manage their water resources. Strong social connections enable collective action, allowing residents to address water scarcity, maintain local infrastructure, and advocate for improved water services. Such collective efforts are particularly vital in rural or marginalized areas that lack formal institutional support. Effective water management is based on trust and mutual support within a network. In the context of water, trust among community members, between communities and authorities, or across different agents is crucial for successfully implementing water management strategies. This trust enables co-operation, minimizes conflicts over water use, and encourages compliance with agreed water management practices. Social capital can help resolve conflicts over water resources. In areas with water scarcity or competition, strong social ties can enable constructive dialog and negotiation to find mutually agreeable solutions. Social capital can also reduce the risk of escalating conflicts and support long-term peace efforts in water-stressed regions.

Lastly, symbolic capital is a form of power that legitimizes certain actors, practices, and narratives within the field. It plays a crucial role in shaping how water resources are governed, how policies are formulated, and how different agents can assert their interests and values in the management of water. Recognizing the role of symbolic capital is essential for understanding the dynamics of power and influence in water management and for developing more inclusive and equitable approaches to governance. Building on the application of Bourdieu's theoretical concepts to water management, the following section proposes how the social space for water management should be designed.

The scale at which environmental resources are managed plays a crucial role in determining the effectiveness of management strategies [111]. According to Max Neef's Human Scale Development [112], water management as a social field should involve a participatory and decentralized approach, where local communities play a central role. This model emphasizes the active engagement of communities in identifying their water-related needs and developing tailored solutions [94]. By integrating local knowledge and ensuring community participation in decision-making processes, more sustainable water management practices have been observed. This approach not only promotes environmental sustainability but also aligns with fundamental human needs such as participation, identity, and the protection of vital resources [93,113]. Community participation not only strengthens the legitimacy of decisions but also facilitates the implementation of solutions adapted to local conditions, which is essential in a field as complex and diverse as water management [114,115]. Previous studies have shown that management systems involving local communities tend to be more effective and sustainable in the long term compared to centralized or technocratic approaches [94,116,117]. Therefore, the proposed approach is supported by the existing literature and is based on documented experiences in multiple studies [118,119].

This paper builds the social space for water management in the department of Magdalena, Colombia (Figure 3), which is experiencing water scarcity. To gather local insights into water management challenges, the study conducted a series of interviews, surveys, and workshops across the region, engaging a wide range of stakeholders (Figure 4). These engagements took place in five urban areas: Pivijay, Plato, Pueblo Viejo, Fundación, and El Banco; three rural areas of Santa Marta: El Trompito, Buritaca, and 20 de Octubre; one rural area of Pueblo Viejo: Tasajera; one rural area of Ciénaga: Nueva Esperanza; one rural area of Zona Bananera: Sevilla; and the stilt towns of Buenavista and Nueva Venecia. These interactions provided valuable perspectives from diverse stakeholders across the region.

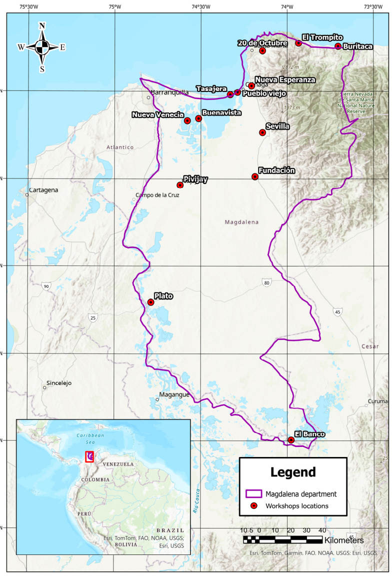

Figure 3. Magdalena department, Colombia.

Figure 4. Magdalena department workshops.

The process included the creation of causal loop diagrams (CLDs) called "Water Scarcity", which was used as a tool to identify the relationships between the variables affecting water scarcity in Magdalena department, Colombia [120]. This approach allowed the participants to visualize how different factors, such as climate, infrastructure, and water usage, interact with the issue, as well as identify the power relationships between the actors involved in water management in the territory [121].

The workshops included 13 sessions in different areas of Magdalena department. The participants represented various rural and urban communities, including community leaders and citizens who are directly affected by water scarcity, as well as some local authorities. The process for each workshop progressed from collecting ideas using sticky notes to the creation of a visual map that integrated the key points identified by the participants. This map was constructed by facilitators using Vensim software Version 10.1.5 [122].

The causal loop diagram (Figure 5) revealed that water scarcity in Magdalena department stems from multiple interconnected factors, including climate change, deforestation, poor water quality, high agricultural and livestock water demands, infrastructure deficiencies, and governance challenges. These factors create reinforcing feedback loops that perpetuate and exacerbate the water scarcity issue. The analysis underscores the need for an interdisciplinary approach that addresses both technical and social factors.

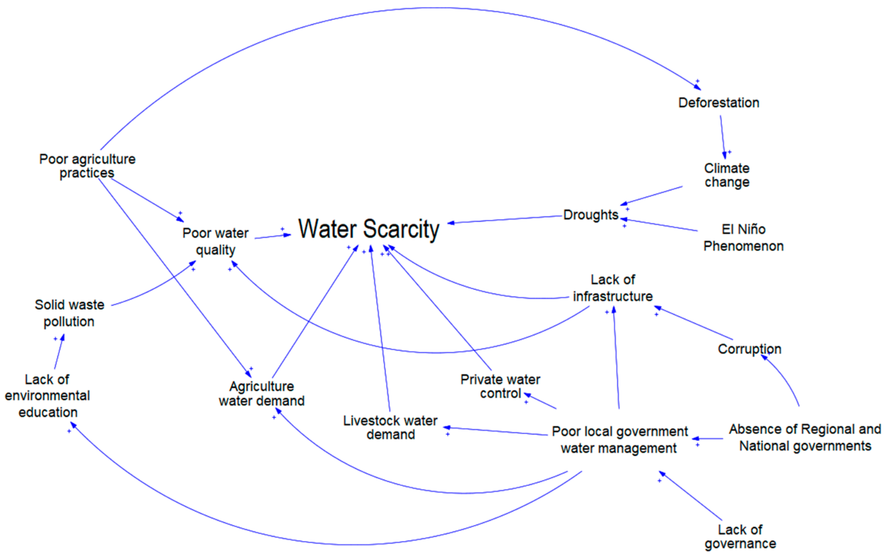

Figure 5. Magdalena department, Colombia, water scarcity causal loop diagram.

Next, a survey was conducted to assess the community's perception of water scarcity, water management, and social capital. A total of 414 surveys were applied, and the questions are available in the Supplementary Materials. Significant differences were found in how urban and rural populations perceive water scarcity and management. Urban residents reported more severe water scarcity, which was attributed to watershed degradation, reduced river flows, decreased rainfall, illegal water extraction, and rapid population growth [123]. In contrast, rural residents living closer to natural water sources exhibited more neutral perceptions, suggesting their proximity buffers them from severe scarcity. Bourdieu's theory of habitus provides a useful lens in terms of understanding the social dynamics shaping these divergent perceptions and responses to water scarcity between urban and rural communities.

Following this, a final workshop was held in the 13 sessions, where Bourdieu's theory of social space was explained. During the workshop, the various actors involved in the social field of water management were identified and collectively positioned within the social space [117]. At the end of each workshop, a social space diagram for water management was produced, which was then compiled into the single diagram shown in Figure 6.

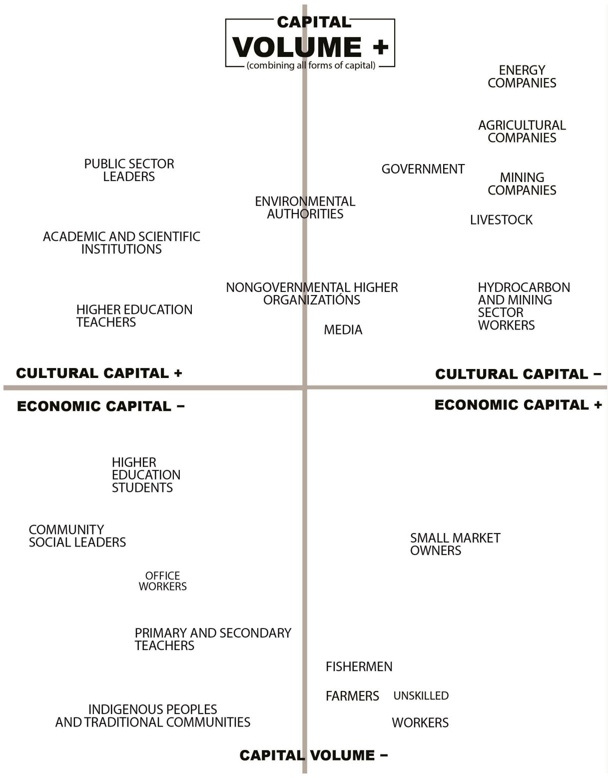

Figure 6. Magdalena department, Colombia, water management social field positions.

It is important to note that although the aim was to achieve the highest possible representativeness, some key actors may have been absent, which could have influenced the collective perceptions captured in the diagrams. Nonetheless, the results accurately reflect the perceptions and experiences of the local communities, although they may not necessarily represent a comprehensive technical view of the issue.

The above diagram reflects the interaction between the different social actors who influence water management in the local context. According to Bourdieu's theory, actors are positioned in the diagram based on their cultural and economic capital.

In the upper right quadrant (high economic capital and low cultural capital), there are energy, agricultural, and mining companies that have significant control over resources due to their economic power but possess less cultural capital. In the upper left quadrant (high cultural capital and low economic capital), public sector leaders and academic and scientific institutions stand out, having a high level of knowledge but less direct economic influence. In the lower left quadrant (low economic and high cultural capital), actors such as Indigenous Peoples and traditional communities are positioned, having limited access to economic resources but a high level of local and cultural knowledge. In the lower right quadrant (low cultural and high economic capital), small market owners and unskilled workers are found, having limited access to both technical knowledge and economic resources.

The diagram reflects Bourdieu's theory, showing how access to resources and power in water management is unequally distributed among actors based on their economic and cultural capital. According to Bourdieu's theory, positions in the social field are determined by the accumulation of different forms of capital, and those with greater economic capital have more decision-making power, while those with more cultural capital have deep local knowledge, but their influence is limited by their lack of economic resources. The results reinforce previous studies that emphasize the importance of participatory water management. It is essential to place local communities at the center of decision making to achieve equitable and sustainable distribution of water resources. These approaches allow communities to identify their needs and develop solutions tailored to their specific conditions, especially in contexts of water scarcity [69,94,124].

Participatory modeling enables local communities, even with less economic capital, to significantly contribute to water management by leveraging their cultural and contextual knowledge. This process not only promotes equity in water resource distribution but also greater legitimacy in decision making. Involving communities in identifying problems and designing tailored solutions ensures more sustainable and just management, which is essential for effectively and durably addressing the challenges of water scarcity [125–127].

During the workshops held in Magdalena department, an analysis approach based on spatialization was used to ensure that the specific social, economic, and cultural dynamics of each area were adequately captured. It is important to emphasize that this spatialization process should be carried out for each specific study area, as social, economic, and cultural dynamics vary significantly depending on the context. In the workshops, this translated into identifying unique factors that affect water management in rural and urban communities, such as differences in the access, distribution, and governance of water resources. It is recommended that this spatialization be carried out at the most local level possible, considering the region's habitus, as this ensures a more precise and relevant understanding of the interactions and power relations that influence water management. For example, in rural areas, local knowledge of watershed management and sustainable water use can be a valuable resource, but it is often subordinated to political decisions that prioritize urban needs. Bourdieu's theory offers a valuable framework for analyzing these dynamics, including how power and resources are distributed among different actors based on their economic and cultural capital.

Applying this approach to specific contexts, such as Magdalena department in Colombia, can provide valuable insights to inform more equitable and effective policies and strategies for water management. However, it is crucial to adapt this methodology to other geographic and social settings to ensure that the proposed solutions are relevant and sustainable for each situation. By applying this territorial analysis in the workshops, it was possible to reflect how regional inequalities in access to water depend not only on infrastructure but also on the power dynamics that cut across different communities.

7. Agent-Based Modeling of Social Fields

Agent-based modeling (ABM) is well suited for simulating complex social systems, as it can capture emergent phenomena from the interactions among individual agents. Unlike traditional top–down approaches, ABM allows for a bottom–up perspective, where the global behavior of a system arises from the local interactions of its components. This is crucial for accurately representing inherently complex social systems characterized by nonlinear interactions, adaptation, and self-organization. The flexibility of ABM in modeling individual behaviors, social interactions, and environmental influences makes it an ideal tool for exploring the dynamics of social fields and understanding the mechanisms that drive social change. Through ABM, researchers can simulate and analyze how individual actions aggregate to influence the overall system dynamics, providing valuable insights that are difficult to achieve using more traditional modeling techniques [128]. The reviewed literature highlights how ABM has bridged theoretical frameworks with practical scenarios, ranging from opinion dynamics to environmental management, disaster risk reduction, and economic decision making [129–137]. These studies collectively demonstrate the capacity of ABM to simulate intricate interactions within systems, providing a valuable tool for both predictive analysis and policy development. By connecting these findings with the broader discourse on social field modeling, this study establishes a foundation for integrating ABM with Bourdieu's theoretical constructs, ultimately improving our understanding of social dynamics in water management. It is important to note that this study proposes the use of Bourdieu's theory as a conceptual tool to design models that more accurately reflect the dynamic interactions within the social field of water management. Through these concepts of cultural, economic, and social capital, the aim is to create a more robust framework that allows for a better understanding of how power positions and social relationships influence decision making regarding the use of water resources.

ABM has become increasingly important in water management research; the models have been integrated with traditional water distribution models to simulate the interactions between various agents, such as governing bodies, operational managers, and water consumers, under different stress scenarios, such as climate change or infrastructure failures [138–140]. This approach has proven effective in exploring the long-term impacts on system sustainability and resilience [141]. Additionally, agent-based models have been used to understand public perceptions and behaviors regarding water reuse, revealing how factors such as market conditions, quality assessments, and environmental awareness shape decision making within a community context [142]. These models enable a more comprehensive analysis of water systems by incorporating dynamic and often nonlinear interactions between social, economic, and environmental components, thereby offering valuable insights for policy development and system optimization. ABM has also been used to explore how Bourdieu's concepts of social and cultural capital influence social dynamics in educational and institutional settings, simulating how individuals and groups interact within specific social fields. Henrickson (2002) [143] analyzed how cultural and social capital affects college choice processes, demonstrating that these forms of capital can significantly impact outcomes in ways that are consistent with Bourdieu's theory, gaining deeper insights into the mechanisms driving the reproduction or transformation of social inequalities.

ABM could be integrated with hydrological simulations to enhance water management strategies. These integrated models provide a more comprehensive understanding of how social factors, such as public awareness and expert influence, interact with hydrological processes, such as groundwater flow and contaminant transport [144–146]. This approach enables the development of more robust and adaptive water management strategies that account for both environmental and social complexities, leading to more sustainable and equitable outcomes. Integrating agent-based models with hydrological simulations provides a powerful approach to understanding the complex dynamics of water management. This integrated modeling framework offers insights into the intricate relationships between human behavior, water resource utilization, and environmental consequences.

In summary, an agent-based model based on Bourdieu's theory can effectively integrate social dynamics, capital structures, and power distributions as central elements in water management research. This model leverages engineering heuristics to navigate the complex and context-dependent nature of social fields, ensuring that the generated solutions are tailored to the specific sociocultural and economic contexts. By incorporating Bourdieu's concepts of habitus and capital, the methodology can address the intricacies of human behavior, social interactions, and power relations in water management. This approach aligns with the engineering emphasis on practical problem solving and adaptive design while also enriching the planning process by considering the broader social implications and the dynamic nature of the social field. Overall, this method, which is rooted in the subjective determination of the "best" solution, offers a robust tool for creating innovative and context-sensitive water management strategies that are better suited to the challenges of contemporary society.

ABM is a powerful tool, but it faces challenges similar to other integrative approaches, such as hydrological models and top–down approaches, which also struggle to accurately capture the nonlinear interactions often determined by social, cultural, and environmental factors, as well as the system's complex dynamics. While ABM is effective in simulating emergent interactions at the local level, it encounters difficulties when scaling these models to broader dynamics [147–151]. In contrast, top–down approaches, although better suited to handle larger spatial and temporal scales, fail to integrate social and cultural factors that are key to comprehensive resource management [119]. This scaling problem is particularly evident when attempting to integrate ABM with traditional models, such as hydrological simulations, which operate on different temporal and spatial scales [152–157].

Finally, there is the issue of data availability and validation. ABM requires detailed data on individual behaviors, social networks, and environmental conditions, which are often difficult to obtain. Furthermore, validating the results of an ABM model in the context of social fields is challenging due to the unpredictability of human behavior and the influence of external, unmodeled factors [158,159]. Despite these challenges, ABM remains a valuable tool for exploring social dynamics and developing water management strategies, especially when combined with other modeling techniques and theoretical frameworks [160–162].

8. Conclusions

This study examined how Pierre Bourdieu's sociological theory on social fields, capital, and habitus can be applied to understand the dynamics of power and resource distribution among different actors in Colombia's water management sector. By visualizing the social field, the analysis revealed how various agents, from government institutions to local communities, navigate their positions based on their access to economic, cultural, social, and symbolic forms of capital. Spatializing the analysis is essential to capture the unique socioeconomic and cultural dynamics at play in a given area.

Integrating agent-based modeling into this approach further improves our ability to simulate and understand these complex social systems. This modeling technique enables the detailed exploration of how individual behaviors and interactions shape the broader dynamics of the social field. When combined with Bourdieu's theoretical framework, agent-based modeling provides a powerful tool for developing more equitable and effective water management strategies tailored to the specific needs and conditions of each community.

Our analysis indicates that integrating Bourdieu's sociological theory with engineering methods, emphasizing context-specific problem solving and adaptive design, provides a robust approach to addressing contemporary water management challenges by accounting for the complexities of human behavior, social interactions, and power dynamics in the planning process. The proposed interdisciplinary model does not aim to provide a complete solution to the complexities of human behavior and social interactions. However, this approach is essential for addressing the complexity of water management systems, which involve technical, social, and ecological aspects. By bringing together knowledge from various disciplines, such as engineering, sociology, economics, and environmental sciences, a more comprehensive perspective is created. This allows for a better understanding of the interactions between human behavior, power dynamics, and technical factors, which is crucial for developing solutions that are not only technically feasible but also socially acceptable and environmentally sustainable. This approach comes closer to achieving this goal than traditional approaches. The interdisciplinary model is key in this approach because water management cannot be understood solely from a technical or social perspective. This approach differentiates itself from the more one-dimensional approaches, as it promises to facilitate the development of innovative water management strategies that are tailored to the diverse and changing needs of today's society.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w16192842/s1.

Author Contributions: Conceptualization, M.A.D.L.-V. and M.G.-M.; writing—original draft preparation, M.A.D.L.-V. and M.G.-M.; writing—review and editing, M.G.-M.; visualization, M.A.D.L.-V.; supervision, M.G.-M. All authors have read and agreed to the published version of the manuscript.

Funding: This research and the APC were funded by SERUANS ENVIRONMENT S.A.S. and Pontificia Universidad Javeriana.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Tao, Y.; Tao, Q.; Qiu, J.; Pueppke, S.G.; Gao, G.; Ou, W. Integrating Water Quantity- and Quality-Related Ecosystem Services into Water Scarcity Assessment: A Multi-Scenario Analysis in the Taihu Basin of China. *Appl. Geogr.* **2023**, *160*, 103101. [CrossRef]
2. Li, M.; Yang, X.; Wang, K.; Di, C.; Xiang, W.; Zhang, J. Exploring China's Water Scarcity Incorporating Surface Water Quality and Multiple Existing Solutions. *Environ. Res.* **2024**, *246*, 118191. [CrossRef] [PubMed]
3. Zhong, R.; Chen, A.; Zhao, D.; Mao, G.; Zhao, X.; Huang, H.; Liu, J. Impact of International Trade on Water Scarcity: An Assessment by Improving the Falkenmark Indicator. *J. Clean. Prod.* **2023**, *385*, 135740. [CrossRef]
4. Kolahi, M.; Davary, K.; Omranian Khorasani, H. Integrated Approach to Water Resource Management in Mashhad Plain, Iran: Actor Analysis, Cognitive Mapping, and Roadmap Development. *Sci. Rep.* **2024**, *14*, 162. [CrossRef]
5. Vichete, W.D.; Méllo Júnior, A.V.; Soares, G.A.d.S. A Water Allocation Model for Multiple Uses Based on a Proposed Hydro-Economic Method. *Water* **2023**, *15*, 1170. [CrossRef]
6. Echogdali, F.Z.; Boutaleb, S.; Abioui, M.; Aadraoui, M.; Bendarma, A.; Kpan, R.B.; Ikirri, M.; El Mekkaoui, M.; Essoussi, S.; El Ayady, H.; et al. Spatial Mapping of Groundwater Potentiality Applying Geometric Average and Fractal Models: A Sustainable Approach. *Water* **2023**, *15*, 336. [CrossRef]
7. Dai, Y.; Liu, Z. Spatiotemporal Heterogeneity of Urban and Rural Water Scarcity and Its Influencing Factors across the World. *Ecol. Indic.* **2023**, *153*, 110386. [CrossRef]
8. Al-Addous, M.; Bdour, M.; Alnaief, M.; Rabaiah, S.; Schweimanns, N. Water Resources in Jordan: A Review of Current Challenges and Future Opportunities. *Water* **2023**, *15*, 3729. [CrossRef]
9. Karimi, M.; Tabiee, M.; Karami, S.; Karimi, V.; Karamidehkordi, E. Climate Change and Water Scarcity Impacts on Sustainability in Semi-Arid Areas: Lessons from the South of Iran. *Groundw. Sustain. Dev.* **2024**, *24*, 101075. [CrossRef]
10. Wardropper, C.; Brookfield, A. Decision-Support Systems for Water Management. *J. Hydrol.* **2022**, *610*, 127928. [CrossRef]
11. Baudoin, L.; Arenas, D. From Raindrops to a Common Stream: Using the Social-Ecological Systems Framework for Research on Sustainable Water Management. *Organ. Environ.* **2020**, *33*, 126–148. [CrossRef]
12. Lazaro, L.L.B.; Abram, S.; Giatti, L.L.; Sinisgalli, P.; Jacobi, P.R. Assessing Water Scarcity Narratives in Brazil—Challenges for Urban Governance. *Environ. Dev.* **2023**, *47*, 100885. [CrossRef]
13. Jiang, T.J.; Kumar, P.; Chien, H.; Saito, O. Socio-Hydrological Approach for Water Resource Management and Human Well-Being in Pinglin District, Taiwan. *Water* **2023**, *15*, 3302. [CrossRef]
14. Acosta-Vega, R.K.; Algaba, E.; Sánchez-Soriano, J. Design of Water Quality Policies Based on Proportionality in Multi-Issue Problems with Crossed Claims. *Eur. J. Oper. Res.* **2023**, *311*, 777–788. [CrossRef]
15. Bo, Y.; Zhou, F.; Zhao, J.; Liu, J.; Liu, J.; Ciais, P.; Chang, J.; Chen, L. Additional Surface-Water Deficit to Meet Global Universal Water Accessibility by 2030. *J. Clean. Prod.* **2021**, *320*, 128829. [CrossRef]
16. Xu, L.; Tu, Z.; Yang, J.; Zhang, C.; Chen, X.; Gu, Y.; Yu, G. A Water Pricing Model for Urban Areas Based on Water Accessibility. *J. Environ. Manag.* **2023**, *327*, 116880. [CrossRef]
17. Bandala, E.R.; McCarthy, M.I.; Brune, N. Water Security in Native American Communities of Nevada. *Environ. Sci. Policy* **2022**, *136*, 520–529. [CrossRef]
18. Gray, E. Tropical Forests and Water Security in South America: Deforestation Trends, Drivers, and Solutions for Water Suppliers and Regulators. *Imperiled Encycl. Conserv.* **2022**, *1–3*, 145–156. [CrossRef]
19. Falkenmark, M.; Wang-Erlandsson, L. A Water-Function-Based Framework for Understanding and Governing Water Resilience in the Anthropocene. *One Earth* **2021**, *4*, 213–225. [CrossRef]
20. Howell, C.L.; Cortado, A.P.; Ünver, O. Stakeholder Engagement and Perceptions on Water Governance and Water Management in Azerbaijan. *Water* **2023**, *15*, 2201. [CrossRef]
21. Ganoulis, J. The Dialectics of Nature-Human Conflicts for Sustainable Water Security. *Sustainability* **2024**, *16*, 3055. [CrossRef]
22. Chunga, B.A.; Graves, A.; Knox, J.W. Evaluating Barriers to Effective Rural Stakeholder Engagement in Catchment Management in Malawi. *Environ. Sci. Policy* **2023**, *147*, 138–146. [CrossRef]
23. Sheng, B.; Cushing, D.; Satherley, S.; Ozgun, K. Green Infrastructure in Water Management: Stakeholder Perceptions from South East Queensland, Australia. *Cities* **2023**, *137*, 104346. [CrossRef]
24. Lee, M.; Yoon, J.H.; Yang, J.E.; Namkoong, S.; Kim, H. Stakeholder Analysis for Effective Implementation of Water Management System: Case of Groundwater Charge in South Korea. *Heliyon* **2024**, *10*, e24699. [CrossRef]
25. D'Agostino, D.; Borg, M.; Hallett, S.H.; Sakrabani, R.S.; Thompson, A.; Papadimitriou, L.; Knox, J.W. Multi-Stakeholder Analysis to Improve Agricultural Water Management Policy and Practice in Malta. *Agric. Water Manag.* **2020**, *229*, 105920. [CrossRef]
26. Hasan, N.; Pushpalatha, R.; Manivasagam, V.S.; Arlikatti, S.; Cibin, R. Global Sustainable Water Management: A Systematic Qualitative Review. *Water Resour. Manag.* **2023**, *37*, 5255–5272. [CrossRef]
27. Delozier, J.L.; Burbach, M.E. Boundary Spanning: Its Role in Trust Development between Stakeholders in Integrated Water Resource Management. *Curr. Res. Environ. Sustain.* **2021**, *3*, 100027. [CrossRef]
28. Poupeau, F.; O'Neill, B.F.; Muñoz, J.C.; Coeurdray, M.; Benites-Gambirazio, E. *The Field of Water Policy: Power and Scarcity in the American Southwest*; Taylor and Francis Inc.: Abingdon, UK, 2019; ISBN 9780429201394.
29. Khan, H.F.; Arshad, S.A. Beyond Water Scarcity: Water (in)Security and Social Justice in Karachi. *J. Hydrol. Reg. Stud.* **2022**, *42*, 101140. [CrossRef]

30. Pedro-Monzonís, M.; Solera, A.; Ferrer, J.; Estrela, T.; Paredes-Arquiola, J. A Review of Water Scarcity and Drought Indexes in Water Resources Planning and Management. *J. Hydrol.* **2015**, *527*, 482–493. [CrossRef]
31. Sturla, G.; Ciulla, L.; Rocchi, B. Natural and Social Scarcity in Water Footprint: A Multiregional Input–Output Analysis for Italy. *Ecol. Indic.* **2023**, *147*, 109981. [CrossRef]
32. Nhim, T.; Richter, A.; Zhu, X. The Resilience of Social Norms of Cooperation under Resource Scarcity and Inequality—An Agent-Based Model on Sharing Water over Two Harvesting Seasons. *Ecol. Complex.* **2019**, *40*, 100709. [CrossRef]
33. Otero, I.; Kallis, G.; Aguilar, R.; Ruiz, V. Water Scarcity, Social Power and the Production of an Elite Suburb. The Political Ecology of Water in Matadepera, Catalonia. *Ecol. Econ.* **2011**, *70*, 1297–1308. [CrossRef]
34. Ohlsson, L. Water Conflicts and Social Resource Scarcity. *Phys. Chem. Earth (B)* **2000**, *25*, 213–220. [CrossRef]
35. Bréthaut, C.; Gallagher, L.; Dalton, J.; Allouche, J. Power Dynamics and Integration in the Water-Energy-Food Nexus: Learning Lessons for Transdisciplinary Research in Cambodia. *Environ. Sci. Policy* **2019**, *94*, 153–162. [CrossRef]
36. Warner, J.; de Man, R. Powering Hydrodiplomacy: How a Broader Power Palette Can Deepen Our Understanding of Water Conflict Dynamics. *Environ. Sci. Policy* **2020**, *114*, 283–294. [CrossRef]
37. McIlwain, L.; Holzer, J.M.; Baird, J.; Baldwin, C.L. Power Research in Adaptive Water Governance and beyond: A Review. *Ecol. Soc.* **2023**, *28*, 22. [CrossRef]
38. Peixoto, F.d.S.; Soares, J.A.; Ribeiro, V.S. Conflicts over Water in Brazil. *Soc. Nat.* **2021**, *34*, e59410. [CrossRef]
39. Helga, G.; Joost, D.; Paul, B.J.; Marijke, D. Power Relations in the Co-Creation of Water Policy in Bolivia: Beyond the Tyranny of Participation. *Water Policy* **2022**, *24*, 569–587. [CrossRef]
40. McIlwain, L.; Baird, J.; Baldwin, C.; Pickering, G.; Manathunga, C. Structural Power Dynamics in Polycentric Water Governance Networks. *Soc. Nat. Resour.* **2024**, *37*, 402–427. [CrossRef]
41. Yudiatmaja, W.E.; Yudithia; Samnuzulsari, T.; Suyito; Edison. Social Capital of Local Communities in the Water Resources Management: An Insight from Kepulauan Riau. In Proceedings of the IOP Conference Series: Materials Science and Engineering, Wuhan, China, 22–23 January 2020; Institute of Physics Publishing: Bristol, UK, 2020; Volume 771.
42. Chiang, H.H.; Basu, M.; Sianipar, C.P.M.; Onitsuka, K.; Hoshino, S. Capital and Symbolic Power in Water Quality Governance: Stakeholder Dynamics in Managing Nonpoint Sources Pollution. *J. Environ. Manag.* **2021**, *290*, 112587. [CrossRef]
43. Fekete, B.M.; Bogárdi, J.J. Role of Engineering in Sustainable Water Management. *Earth Perspect.* **2015**, *2*, 2. [CrossRef]
44. Gain, A.K.; Hossain, S.; Benson, D.; Di Baldassarre, G.; Giupponi, C.; Huq, N. Social-Ecological System Approaches for Water Resources Management. *Int. J. Sustain. Dev. World Ecol.* **2021**, *28*, 109–124. [CrossRef]
45. Brelsford, C.; Dumas, M.; Schlager, E.; Dermody, B.J.; Aiuvalasit, M.; Allen-Dumas, M.R.; Beecher, J.; Bhatia, U.; D'odorico, P.; Garcia, M.; et al. Developing a Sustainability Science Approach for Water Systems. *Ecol. Soc.* **2020**, *25*, 1–6. [CrossRef]
46. George-Williams, H.E.M.; Hunt, D.V.L.; Rogers, C.D.F. Sustainable Water Infrastructure: Visions and Options for Sub-Saharan Africa. *Sustainability* **2024**, *16*, 1592. [CrossRef]
47. Bogardi, J.J.; Fekete, B.M.; Vörösmarty, C.J. Planetary Boundaries Revisited: A View through the "Water Lens". *Curr. Opin. Environ. Sustain.* **2013**, *5*, 581–589. [CrossRef]
48. Koen, B.V. Discussion of the Method: Conducting the Engineer's Approach to Problem Solving. Available online: https://books.google.hu/books/about/Discussion_of_the_Method.html?id=xLfTi2dpYTcC&redir_esc=y (accessed on 31 August 2024).
49. Bourdieu, P. *Practical Reason on the Theory of Action*; Stanford University Press: Stanford, CA, USA, 1998; ISBN 9780804733632.
50. Global Water Partnership. *Integrated Water Resources Management*; TAC BACKGROUND PAPERS 4, Ed.; Global Water Partnership: Stockholm, Sweden, 2000; ISBN 9163092298.
51. Biswas, A.K. Integrated Water Resources Management: A Reassessment: A Water Forum Contribution. *Water Int.* **2004**, *29*, 248–256. [CrossRef]
52. Cardwell, H.E.; Cole, R.A.; Cartwright, L.A.; Martin, L.A. Integrated Water Resources Management: Definitions and Conceptual Musings. *J. Contemp. Water Res. Educ.* **2006**, *135*, 8–18. [CrossRef]
53. Ako, A.A.; Eyong, G.E.T.; Nkeng, G.E. Water Resources Management and Integrated Water Resources Management (IWRM) in Cameroon. *Water Resour. Manag.* **2010**, *24*, 871–888. [CrossRef]
54. Ngene, B.U.; Nwafor, C.O.; Bamigboye, G.O.; Ogbiye, A.S.; Ogundare, J.O.; Akpan, V.E. Assessment of Water Resources Development and Exploitation in Nigeria: A Review of Integrated Water Resources Management Approach. *Heliyon* **2021**, *7*, e05955. [CrossRef]
55. Katusiime, J.; Schütt, B. Integrated Water Resources Management Approaches to Improve Water Resources Governance. *Water* **2020**, *12*, 3424. [CrossRef]
56. Dirwai, T.L.; Kanda, E.K.; Senzanje, A.; Busari, T.I. Water Resource Management: Iwrm Strategies for Improved Water Management. A Systematic Review of Case Studies of East, West and Southern Africa. *PLoS ONE* **2021**, *16*, e0236903. [CrossRef] [PubMed]
57. Goyal, V.C.; Garg, A.; Patil, J.P.; Thomas, T. Formulation of Integrated Water Resources Management (IWRM) Plan at District Level: A Case Study from Bundelkhand Region of India. *Water Policy* **2020**, *22*, 52–99. [CrossRef]
58. Ben-Daoud, M.; El Mahrad, B.; Elhassnaoui, I.; Moumen, A.; Sayad, A.; ELbouhadioui, M.; Moroșanu, G.A.; Mezouary, L.E.; Essahlaoui, A.; Eljaafari, S. Integrated Water Resources Management: An Indicator Framework for Water Management System Assessment in the R'Dom Sub-Basin, Morocco. *Environ. Chall.* **2021**, *3*, 100062. [CrossRef]

59. De Luque-Villa, M.A.; González-Méndez, M. Water Management in Colombia from the Socio-Ecological Systems Framework. *WIT Trans. Ecol. Environ.* **2022**, *259*, 111–122. [CrossRef]
60. Saravanan, V.S.; Mcdonald, G.T.; Mollinga, P.P. Critical Review of Integrated Water Resources Management: Moving beyond Polarised Discourse. *Nat. Resour. Forum* **2009**, *33*, 76–86. [CrossRef]
61. Metz, F.; Glaus, A. Integrated Water Resources Management and Policy Integration: Lessons from 169 Years of Flood Policies in Switzerland. *Water* **2019**, *11*, 1173. [CrossRef]
62. Hoff, H. *Understanding the Nexus. Background Paper for the Bonn 2011 Conference: The Water, Energy and Food Security Nexus*; Stockholm Environment Institute: Stockholm, Sweden, 2011.
63. Simpson, G.B.; Jewitt, G.P.W. The Development of the Water-Energy-Food Nexus as a Framework for Achieving Resource Security: A Review. *Front. Environ. Sci.* **2019**, *7*, 8. [CrossRef]
64. Purwanto, A.; Sušnik, J.; Suryadi, F.X.; de Fraiture, C. Water-Energy-Food Nexus: Critical Review, Practical Applications, and Prospects for Future Research. *Sustainability* **2021**, *13*, 1919. [CrossRef]
65. Zhang, J.; Campana, P.E.; Yao, T.; Zhang, Y.; Lundblad, A.; Melton, F.; Yan, J. The Water-Food-Energy Nexus Optimization Approach to Combat Agricultural Drought: A Case Study in the United States. *Appl. Energy* **2018**, *227*, 449–464. [CrossRef]
66. Sadeghi, S.H.; Sharifi Moghadam, E.; Delavar, M.; Zarghami, M. Application of Water-Energy-Food Nexus Approach for Designating Optimal Agricultural Management Pattern at a Watershed Scale. *Agric. Water Manag.* **2020**, *233*, 106071. [CrossRef]
67. Wicaksono, A.; Jeong, G.; Kang, D. Water-Energy-Food Nexus Simulation: An Optimization Approach for Resource Security. *Water* **2019**, *11*, 667. [CrossRef]
68. Torres, C.; Gitau, M.; Lara-Borrero, J.; Paredes-Cuervo, D. Framework for Water Management in the Food- Energy-water (FEW) Nexus in Mixed Land-use Watersheds in Colombia. *Sustainability* **2020**, *12*, 10332. [CrossRef]
69. Locke, K.A. Integrated Water Resources Management and the Land-water Nexus: A South African Perspective. *World Water Policy* **2024**, *10*, 755–779. [CrossRef]
70. O'Hogain, S.; McCarton, L. *A Technology Portfolio of Nature Based Solutions: Innovations in Water Management*; Springer: Berlin/Heidelberg, Germany, 2018; ISBN 9783319732817.
71. Qi, Y.; Chan, F.K.S.; Thorne, C.; O'donnell, E.; Quagliolo, C.; Comino, E.; Pezzoli, A.; Li, L.; Griffiths, J.; Sang, Y.; et al. Addressing Challenges of Urban Water Management in Chinese Sponge Cities via Nature-Based Solutions. *Water* **2020**, *12*, 2788. [CrossRef]
72. Souliotis, I.; Voulvoulis, N. Operationalising Nature-Based Solutions for the Design of Water Management Interventions. *Nat.-Based Solut.* **2022**, *2*, 100015. [CrossRef]
73. Pistocchi, A. *Nature-Based Solutions for Agricultural Water Management Characteristics and Enabling Factors for a Broader Adoption*; European Commission, Joint Research Centre (JRC): Luxembourg, 2022.
74. Cohen-Shacham, E.; Walters, G.; Janzen, C.; Maginnis, S. Nature-Based Solutions to Address Global Societal Challenges. *IUCN Gland Switz.* **2016**, *97*, 2016–2036.
75. Raymond, C.M.; Frantzeskaki, N.; Kabisch, N.; Berry, P.; Breil, M.; Nita, M.R.; Geneletti, D.; Calfapietra, C. A Framework for Assessing and Implementing the Co-Benefits of Nature-Based Solutions in Urban Areas. *Environ. Sci. Policy* **2017**, *77*, 15–24. [CrossRef]
76. Pauleit, S.; Zölch, T.; Hansen, R.; Randrup, T.B.; Konijnendijk van den Bosch, C. Nature-Based Solutions and Climate Change–Four Shades of Green. In *Nature-Based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy and Practice*; Springer Nature: Cham, Switzerland, 2017; pp. 29–49.
77. Seddon, N.; Chausson, A.; Berry, P.; Girardin, C.A.J.; Smith, A.; Turner, B. Understanding the Value and Limits of Nature-Based Solutions to Climate Change and Other Global Challenges. *Philos. Trans. R. Soc. B* **2020**, *375*, 20190120. [CrossRef]
78. Faivre, N.; Fritz, M.; Freitas, T.; De Boissezon, B.; Vandewoestijne, S. Nature-Based Solutions in the EU: Innovating with Nature to Address Social, Economic and Environmental Challenges. *Environ. Res.* **2017**, *159*, 509–518. [CrossRef]
79. Ryfisch, S.; Seeger, I.; McDonald, H.; Lago, M.; Blicharska, M. Opportunities and Limitations for Nature-Based Solutions in EU Policies—Assessed with a Focus on Ponds and Pondscapes. *Land Use Policy* **2023**, *135*, 106957. [CrossRef]
80. Eggermont, H.; Balian, E.; Azevedo, J.M.N.; Beumer, V.; Brodin, T.; Claudet, J.; Fady, B.; Grube, M.; Keune, H.; Lamarque, P. Nature-Based Solutions: New Influence for Environmental Management and Research in Europe. *GAIA-Ecol. Perspect. Sci. Soc.* **2015**, *24*, 243–248. [CrossRef]
81. Sivapalan, M.; Konar, M.; Srinivasan, V.; Chhatre, A.; Wutich, A.; Scott, C.A.; Wescoat, J.L.; Rodríguez-Iturbe, I. Socio-hydrology: Use-inspired Water Sustainability Science for the Anthropocene. *Earths Future* **2014**, *2*, 225–230. [CrossRef]
82. Troy, T.J.; Konar, M.; Srinivasan, V.; Thompson, S. Moving Sociohydrology Forward: A Synthesis across Studies. *Hydrol. Earth Syst. Sci.* **2015**, *19*, 3667–3679. [CrossRef]
83. Mostert, E. An Alternative Approach for Socio-Hydrology: Case Study Research. *Hydrol. Earth Syst. Sci.* **2018**, *22*, 317–329. [CrossRef]
84. Wesselink, A.; Kooy, M.; Warner, J. Socio-Hydrology and Hydrosocial Analysis: Toward Dialogues across Disciplines. *Wiley Interdiscip. Rev. Water* **2017**, *4*, e1196. [CrossRef]
85. Boelens, R.; Hoogesteger, J.; Swyngedouw, E.; Vos, J.; Wester, P. Hydrosocial Territories: A Political Ecology Perspective. *Water Int.* **2016**, *41*, 1–14. [CrossRef]

86. Hommes, L.; Boelens, R.; Bleeker, S.; Duarte-Abadía, B.; Stoltenborg, D.; Vos, J. Water Governmentalities: The Shaping of Hydrosocial Territories, Water Transfers and Rural–Urban Subjects in Latin America. *Environ. Plan. E Nat. Space* **2020**, *3*, 399–422. [CrossRef]
87. Carolan, M. Publicising Food: Big Data, Precision Agriculture, and Co-experimental Techniques of Addition. *Sociol. Rural.* **2017**, *57*, 135–154. [CrossRef]
88. Rotz, S.; Gravely, E.; Mosby, I.; Duncan, E.; Finnis, E.; Horgan, M.; LeBlanc, J.; Martin, R.; Neufeld, H.T.; Nixon, A. Automated Pastures and the Digital Divide: How Agricultural Technologies Are Shaping Labour and Rural Communities. *J. Rural Stud.* **2019**, *68*, 112–122. [CrossRef]
89. Scholz, R.W.; Steiner, G. The Real Type and Ideal Type of Transdisciplinary Processes: Part II—What Constraints and Obstacles Do We Meet in Practice? *Sustain. Sci.* **2015**, *10*, 653–671. [CrossRef]
90. Pfeiffer, L.; Lin, C.C. The Effects of Energy Prices on Agricultural Groundwater Extraction from the High Plains Aquifer. *Am. J. Agric. Econ.* **2014**, *96*, 1349–1362. [CrossRef]
91. Flaminio, S.; Rouillé-Kielo, G.; Le Visage, S. Waterscapes and Hydrosocial Territories: Thinking Space in Political Ecologies of Water. *Prog. Environ. Geogr.* **2022**, *1*, 33–57. [CrossRef]
92. Dill, J.; Dagios, R.N.; Barros, V.G. Public Policies on Water Resource Management and Its Impacts on the Context of Climatic Changes and Alterations in Land Use and Land Cover in Small and Protected Rainforest River Basins. *Environ. Sci. Policy* **2022**, *137*, 191–204. [CrossRef]
93. Boelens, R. Cultural Politics and the Hydrosocial Cycle: Water, Power and Identity in the Andean Highlands. *Geoforum* **2014**, *57*, 234–247. [CrossRef]
94. Zeitouna, M.; Allan, J.A. Applying Hegemony and Power Theory to Transboundary Water Analysis. *Water Policy* **2008**, *10*, 3–12. [CrossRef]
95. Chen, Y.; Vardon, M. Accounting for Water-Related Ecosystem Services to Provide Information for Water Policy and Management: An Australian Case Study. *Ecosyst. Serv.* **2024**, *69*, 101658. [CrossRef]
96. Dombrowsky, I.; Lenschow, A.; Meergans, F.; Schütze, N.; Lukat, E.; Stein, U.; Yousefi, A. Effects of Policy and Functional (in)Coherence on Coordination—A Comparative Analysis of Cross-Sectoral Water Management Problems. *Environ. Sci. Policy* **2022**, *131*, 118–127. [CrossRef]
97. Schirone, M. Field, Capital, and Habitus: The Impact of Pierre Bourdieu on Bibliometrics. *Quant. Sci. Stud.* **2023**, *4*, 186–208. [CrossRef]
98. Friedland, R. The Endless Fields of Pierre Bourdieu. *Organization* **2009**, *16*, 887–917. [CrossRef]
99. Ancelovici, M. Bourdieu in Movement: Toward a Field Theory of Contentious Politics. *Soc. Mov. Stud.* **2021**, *20*, 155–173. [CrossRef]
100. Bourdieu, P. *Poder, Derecho y Clases Sociales*, 2nd ed.; Editorial Desclée de Brouwer S.A.: Bilbao, Spain, 2001; ISBN 8433014951.
101. Bourdieu, P. The Forms of Capital. In *The Sociology of Economic Life*; Routledge: London, UK, 2018; pp. 78–92. [CrossRef]
102. Bourdieu, P. *The Rules of Art: Genesis and Structure of the Literary Field*; Stanford University Press: Stanford, CA, USA, 1996; ISBN 9780804725682.
103. Bourdieu, P. *Distinction A Social Critique of the Judgement of Taste*; Harvard University Press: Cambridge, MA, USA, 1984; ISBN 9780674212770.
104. Goldman, S.L. Philosophy, Engineering, and Western Culture. In *Broad and Narrow Interpretations of Philosophy of Technology*; Springer: Berlin/Heidelberg, Germany, 1990; pp. 125–152. [CrossRef]
105. Goldman, S.L. Why We Need a Philosophy of Engineering: A Work in Progress. *Interdiscip. Sci. Rev.* **2004**, *29*, 163–176. [CrossRef]
106. Layton, E.T. Science and Engineering Design. *Ann. N. Y Acad. Sci.* **1984**, *424*, 173–181. [CrossRef]
107. Poel, I.; Goldberg, D. (Eds.) *Philosophy and Engineering: An Emerging Agenda*; Springer: Dordrecht, The Netherlands, 2010; p. 361. ISBN 978-94-007-3103-5.
108. Koen, B.V. The Engineering Method and Its Implications for Scientific, Philosophical, and Universal Methods. *Monist* **2009**, *92*, 357–386. [CrossRef]
109. Swatuk, L.A.; Cash, C. *Water, Energy, Food and People across the Global South: 'The Nexus' in an Era of Climate Change*; Springer: Berlin/Heidelberg, Germany, 2017; ISBN 3319640240.
110. Whaley, L. Water Governance Research in a Messy World: A Review. *Water Altern.* **2022**, *15*, 218–250.
111. Cash, D.W.; Moser, S.C. Linking Global and Local Scales: Designing Dynamic Assessment and Management Processes. *Glob. Environ. Chang.* **2000**, *10*, 109–120. [CrossRef]
112. Max-Neef, M.A.; Elizalde, A.; Hopenhayn, M. *Desarrollo a Escala Humana Conceptos, Aplicaciones y Algunas Reflexiones*; Icaria Editorial, Ed.; Romanyà Valls: Barcelona, Spain, 2006; ISBN 8474262178.
113. Ostrom, E. *Governing the Commons: The Evolution of Institutions for Collective Action*; Cambridge University Press: Cambridge, UK, 1990; ISBN 0521405998.
114. Agrawal, A. Common Property Institutions and Sustainable Governance of Resources. *World Dev.* **2001**, *29*, 1649–1672. [CrossRef]
115. Armitage, D.; De Loë, R.C.; Morris, M.; Edwards, T.W.D.; Gerlak, A.K.; Hall, R.I.; Huitema, D.; Ison, R.; Livingstone, D.; MacDonald, G. Science–Policy Processes for Transboundary Water Governance. *Ambio* **2015**, *44*, 353–366. [CrossRef]
116. Cleaver, F. *Development through Bricolage: Rethinking Institutions for Natural Resource Management*; Routledge: London, UK, 2017; ISBN 1315094916.

117. Pahl-Wostl, C. The Implications of Complexity for Integrated Resources Management. *Environ. Model. Softw.* **2007**, *22*, 561–569. [CrossRef]
118. Voinov, A.; Bousquet, F. Modelling with Stakeholders. *Environ. Model. Softw.* **2010**, *25*, 1268–1281. [CrossRef]
119. Voinov, A.; Kolagani, N.; McCall, M.K.; Glynn, P.D.; Kragt, M.E.; Ostermann, F.O.; Pierce, S.A.; Ramu, P. Modelling with Stakeholders—Next Generation. *Environ. Model. Softw.* **2016**, *77*, 196–220. [CrossRef]
120. Biggs, R.; de Vos, A.; Preiser, R.; Clements, H.; Maciejewski, K.; Schlüter, M. *The Routledge Handbook of Research Methods for Social-Ecological Systems*, 1st ed.; Routledge: London, UK; New York, NY, USA, 2022.
121. Peck, S. Group Model Building: Facilitating Team Learning Using System Dynamics. *J. Oper. Res. Soc.* **1998**, *49*, 766–767. [CrossRef]
122. Ventana Systems Inc. User Guide—Vensim Introduction & Tutorials. Available online: https://vensim.com/documentation/users_guide.html (accessed on 19 July 2024).
123. Amorocho-Daza, H.; Cabrales, S.; Santos, R.; Saldarriaga, J. A New Multi-Criteria Decision Analysis Methodology for the Selection of New Water Supply Infrastructure. *Water* **2019**, *11*, 805. [CrossRef]
124. Akamani, K. The Roles of Adaptive Water Governance in Enhancing the Transition towards Ecosystem-Based Adaptation. *Water* **2023**, *15*, 2341. [CrossRef]
125. Walker, D.W.; Smigaj, M.; Tani, M. The Benefits and Negative Impacts of Citizen Science Applications to Water as Experienced by Participants and Communities. *Wiley Interdiscip. Rev. Water* **2021**, *8*, e1488. [CrossRef]
126. Adams, E.A.; Zulu, L.; Ouellette-Kray, Q. Community Water Governance for Urban Water Security in the Global South: Status, Lessons, and Prospects. *Wiley Interdiscip. Rev. Water* **2020**, *7*, e1466. [CrossRef]
127. Zarei, Z.; Karami, E.; Keshavarz, M. Co-Production of Knowledge and Adaptation to Water Scarcity in Developing Countries. *J. Environ. Manag.* **2020**, *262*, 110283. [CrossRef]
128. Remondino, M. *Analysis of Agent Based Paradigms for Complex Social Systems Simulation*; Universita di Torino: Turin, Italy, 2004.
129. Nugent, A.; Gomes, S.N.; Wolfram, M.-T. Bridging the Gap between Agent Based Models and Continuous Opinion Dynamics. *Phys. A Stat. Mech. Its Appl.* **2024**, *651*, 129886. [CrossRef]
130. Kammer-Kerwick, M.; Yundt-Pacheco, M.; Vashisht, N.; Takasaki, K.; Busch-Armendariz, N. A Framework to Develop Interventions to Address Labor Exploitation and Trafficking: Integration of Behavioral and Decision Science within a Case Study of Day Laborers. *Societies* **2023**, *13*, 96. [CrossRef]
131. Han, X.; Koliou, M. Assessing the Impact of Seismic Scenarios and Retrofits on Community Resilience Using Agent-Based Models. *Int. J. Disaster Risk Reduct.* **2024**, *111*, 104678. [CrossRef]
132. Flache, A. Between Monoculture and Cultural Polarization: Agent-Based Models of the Interplay of Social Influence and Cultural Diversity. *J. Archaeol. Method. Theory* **2018**, *25*, 996–1023. [CrossRef]
133. Rizzati, M.; Landoni, M. A Systematic Review of Agent-Based Modelling in the Circular Economy: Insights towards a General Model. *Struct. Change Econ. Dyn.* **2024**, *69*, 617–631. [CrossRef]
134. Abrams, M. A Moderate Role for Cognitive Models in Agent-Based Modeling of Cultural Change. *Complex Adapt. Syst. Model.* **2013**, *1*, 16. [CrossRef]
135. Templeton, A.; Xie, H.; Gwynne, S.; Hunt, A.; Thompson, P.; Köster, G. Agent-Based Models of Social Behaviour and Communication in Evacuations: A Systematic Review. *Saf. Sci.* **2024**, *176*, 106520. [CrossRef]
136. Baier, K.; Mataré, V.; Liebenberg, M.; Lakemeyer, G. Towards Integrated Intentional Agent Simulation and Semantic Geodata Management in Complex Urban Systems Modeling. *Comput. Environ. Urban. Syst.* **2015**, *51*, 47–58. [CrossRef]
137. Daly, A.J.; De Visscher, L.; Baetens, J.M.; De Baets, B. Quo Vadis, Agent-Based Modelling Tools? *Environ. Model. Softw.* **2022**, *157*, 105514. [CrossRef]
138. Harik, G.; Alameddine, I.; Zurayk, R.; El-Fadel, M. An Integrated Socio-Economic Agent-Based Modeling Framework towards Assessing Farmers' Decision Making under Water Scarcity and Varying Utility Functions. *J. Environ. Manag.* **2023**, *329*, 117055. [CrossRef]
139. Zhang, Q.; Hu, T.; Zeng, X.; Yang, P.; Wang, X. Exploring the Effects of Physical and Social Networks on Urban Water System's Supply-Demand Dynamics through a Hybrid Agent-Based Modeling Framework. *J. Hydrol.* **2023**, *617*, 129108. [CrossRef]
140. Canales, M.; Castilla-Rho, J.; Rojas, R.; Vicuña, S.; Ball, J. Agent-Based Models of Groundwater Systems: A Review of an Emerging Approach to Simulate the Interactions between Groundwater and Society. *Environ. Model. Softw.* **2024**, *175*, 105980. [CrossRef]
141. Ormsbee, L.; Byrne, D.; Magliocca, N. The Need for Integrating Governance, Operations, and Social Dynamics into Water Supply/Distribution Modelling. *Eng. Proc.* **2024**, *69*, 12. [CrossRef]
142. Fu, H.; Zhang, H.; Zhang, M.; Hou, C. Modeling and Dynamic Simulation of the Public's Intention to Reuse Recycled Water Based on Eye Movement Data. *Water* **2023**, *15*, 114. [CrossRef]
143. Henrickson, L. Old Wine in a New Wineskin: College Choice, College Access Using Agent-Based Modeling. *Soc. Sci. Comput. Rev.* **2002**, *20*, 400–419. [CrossRef]
144. Jaxa-Rozen, M.; Kwakkel, J.H.; Bloemendal, M. A Coupled Simulation Architecture for Agent-Based/Geohydrological Modelling with NetLogo and MODFLOW. *Environ. Model. Softw.* **2019**, *115*, 19–37. [CrossRef]
145. Bakarji, J.; O'Malley, D.; Vesselinov, V.V. Agent-Based Socio-Hydrological Hybrid Modeling for Water Resource Management. *Water Resour. Manag.* **2017**, *31*, 3881–3898. [CrossRef]

146. Simmonds, J.; Gómez, J.A.; Ledezma, A. Testing the Feasibility of an Agent-Based Model for Hydrologic Flow Simulation. *Information* **2024**, *15*, 448. [CrossRef]
147. Yu, Z.; Song, C.; Liu, Y.; Wang, D.; Li, B. A Bottom-up Approach for Community Load Prediction Based on Multi-Agent Model. *Sustain. Cities Soc.* **2023**, *97*, 104774. [CrossRef]
148. Magliocca, N.R. Agent-Based Modeling for Integrating Human Behavior into the Food–Energy–Water Nexus. *Land* **2020**, *9*, 519. [CrossRef]
149. Guo, N.; Shi, C.; Yan, M.; Gao, X.; Wu, F. Modeling Agricultural Water-Saving Compensation Policy: An ABM Approach and Application. *J. Clean. Prod.* **2022**, *344*, 131035. [CrossRef]
150. Koutiva, I.; Makropoulos, C. On the Use of Agent Based Modelling for Addressing the Social Component of Urban Water Management in Europe. *Comput. Water Energy Environ. Eng.* **2021**, *10*, 140–154. [CrossRef]
151. Agha-Hoseinali-Shirazi, M.; Bozorg-Haddad, O.; Laituri, M.; DeAngelis, D. Application of Agent Base Modeling in Water Resources Management and Planning. In *Essential Tools for Water Resources Analysis, Planning, and Management*; Springer: Singapore, 2021; pp. 177–216. [CrossRef]
152. Xu, S.; Hsu, S.C.; Du, E.; Song, L.; Lam, C.M.; Liu, X.; Zheng, C. Agent-Based Modeling in Water Science: From Macroscale to Microscale. *ACS ES T Water* **2024**, *4*, 1206–1219. [CrossRef]
153. Costabile, P.; Costanzo, C. A 2D-SWEs Framework for Efficient Catchment-Scale Simulations: Hydrodynamic Scaling Properties of River Networks and Implications for Non-Uniform Grids Generation. *J. Hydrol.* **2021**, *599*, 126306. [CrossRef]
154. De Bruijn, J.A.; Smilovic, M.; Burek, P.; Guillaumot, L.; Wada, Y.; Aerts, J.C.J.H. GEB v0.1: A Large-Scale Agent-Based Socio-Hydrological Model—Simulating 10 Million Individual Farming Households in a Fully Distributed Hydrological Model. *Geosci. Model. Dev.* **2023**, *16*, 2437–2454. [CrossRef]
155. Sidle, R.C. Strategies for Smarter Catchment Hydrology Models: Incorporating Scaling and Better Process Representation. *Geosci. Lett.* **2021**, *8*, 24. [CrossRef]
156. Ponnambalam, K.; Mousavi, S.J. CHNS Modeling for Study and Management of Human-Water Interactions at Multiple Scales. *Water* **2020**, *12*, 1699. [CrossRef]
157. Ghorbanidehno, H.; Kokkinaki, A.; Lee, J.; Darve, E. Recent Developments in Fast and Scalable Inverse Modeling and Data Assimilation Methods in Hydrology. *J. Hydrol.* **2020**, *591*, 125266. [CrossRef]
158. An, L.; Grimm, V.; Sullivan, A.; TurnerII, B.L.; Malleson, N.; Heppenstall, A.; Vincenot, C.; Robinson, D.; Ye, X.; Liu, J.; et al. Challenges, Tasks, and Opportunities in Modeling Agent-Based Complex Systems. *Ecol. Model.* **2021**, *457*, 109685. [CrossRef]
159. Banks, D.L.; Hooten, M.B. Statistical Challenges in Agent-Based Modeling. *Am. Stat.* **2021**, *75*, 235–242. [CrossRef]
160. Hung, F.; Yang, Y.C.E. Assessing Adaptive Irrigation Impacts on Water Scarcity in Nonstationary Environments—A Multi-Agent Reinforcement Learning Approach. *Water Resour. Res.* **2021**, *57*, e2020WR029262. [CrossRef]
161. Bourceret, A.; Amblard, L.; Mathias, J.D. Governance in Social-Ecological Agent-Based Models: A Review. *Ecol. Soc.* **2021**, *26*, 1. [CrossRef]
162. Vidal-Lamolla, P.; Molinos-Senante, M.; Oliva-Felipe, L.; Alvarez-Napagao, S.; Cortés, U.; Martínez-Gomariz, E.; Noriega, P.; Olsson, G.; Poch, M. Assessing Urban Water Demand-Side Management Policies before Their Implementation: An Agent-Based Model Approach. *Sustain. Cities Soc.* **2024**, *107*, 105435. [CrossRef]