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A Framework for the Analysis of Governance Structures Applying to Groundwater Resources and the Requirements for the Sustainable Management of Associated Ecosystem Services

Kathrin Knüppe · Claudia Pahl-Wostl

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Abstract The competing demands placed on groundwater for socio-economic and for ecological benefits, and the resultant tradeoffs, represent a major challenge for the management arena. The governance of groundwater resources and the sustainable management of associated ecosystem services must take into consideration human and biophysical characteristics as intertwined systems. Frameworks and analytical tools are required to help understand complex governance regimes, and the linkages between management and the corresponding effects on ecosystem services. Presented in this paper is a framework for the analysis of groundwater governance based on the adaptive management approach and the ecosystem services concept. Governance can be analyzed on the basis of certain characteristics. One characteristic of a governance regime assumed to be crucial for adaptive and sustainable management is vertical integration, which refers to the connectedness of different administrative levels, including the involvement of non-governmental stakeholders in decision-making and planning processes. The framework was applied in the Upper Guadiana Basin in Spain, where the intensive use of groundwater has led to significant conflicts between farmers, authorities and environmental conservation groups. The analysis showed that conflicts arose from a lack of vertical integration; e.g., one-way communication between official authorities and the exclusion of local stakeholders during planning processes. The framework is deemed to be a strong analytical tool as it provides a basis for organized and context-specific case study assessment and renders complex groundwater management more transparent and comprehensible. The framework will be further applied and enhanced for application in international case studies.

Keywords Groundwater · Ecosystem services · Tradeoffs · Governance · Adaptive management · Vertical integration · Analytical framework · Upper Guadiana Basin

K. Knüppe (✉) · C. Pahl-Wostl
University of Osnabrück, Institute of Environmental Systems Research, Barbarastr. 12, 49069 Osnabrück, Germany
e-mail: kathrin.knueppe@usf.uni-osnabrueck.de

1 Introduction

Groundwater is a pivotal resource in the supply of freshwater in many regions of the world. In addition to goods essential in the context of social and economic development, groundwater also serves numerous environmental functions, such as providing base-flow to rivers and wetlands, and soil and water purification. These goods and functions are termed ecosystem services, which Daily (1997) described as, "*the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life.*"

In recent decades, groundwater ecology–including subterranean organisms, flora and aquifer-dependent ecosystems–have become an important research domain in the hydrogeological field (see Gibert et al. 1994; Gibert and Deharveng 2002; Hancock et al. 2005; Danielopol and Griebler 2008). The fact that groundwater associated ecosystem services (GWaES) play an essential role in human life (e.g., water for drinking, food production, sanitation, poverty reduction and healthcare) is well known. While scientific knowledge of hydrogeology, and the physical and chemical characteristics of groundwater is developing continuously, relatively little is known about how to form the legal basis and policies governing these services, or about the requirements of sensible enforcement (Mukherji and Shah 2005). Water management no longer deals solely with complex ecological and technical systems; rather management itself can become a complex system including a range of socio-economic, institutional, ecological and technical elements (Knieper et al. 2010).

Research is urgently needed to better understand the requirements of groundwater governance, policy strategies and the dynamics of transformation processes in order to be better able to assess the transferability of insights and detect management patterns in different cases with similar contextual conditions. The efforts to develop a framework for the analysis of groundwater governance described in this paper built upon the management and transition framework (MTF) developed by Pahl-Wostl and colleagues (Pahl-Wostl 2009; Pahl-Wostl et al. 2010). The MTF is an interdisciplinary conceptual and methodological framework supporting the analysis of water systems, management processes and multi-level governance regimes[1]. We modified elements of the framework in order to analyze the management of groundwater services and the emerging tradeoffs embedded in complex governance regimes. This novel framework supports an assessment of management processes by identifying complex system linkages, such as cooperation structures and information transfer during the various phases of the water management cycle or the degree of influence of local communities during management processes. The framework highlights GWaES at multiple levels (local, regional and national) and takes into account long-term processes, as these services often have different time lags due to deterioration and recovery processes, as well as management planning and implementation.

The key conceptual pillars of the framework comprise the adaptive management approach and the concept of ecosystem services developed by the Millennium Ecosystem Assessment. These two concepts contribute to an understanding of the relationship between governance regime characteristics and their effects on water management. It is assumed that the sustainable management of groundwater requires a high degree of vertical integration, which implies a need to address the interplay between different administrative authorities, as well as the intensive involvement of non-governmental actors from different levels. In

[1] A regime is here described as *"the whole complex of technologies, institutions, environmental factors and paradigms that are highly connected and* […] *form the base for the functioning of the management system targeted to fulfill a societal function"* (Pahl-Wostl 2009, pp. 354–365).

this way, the management becomes more flexible in adjusting to change and is able to adapt its capacity to respond to diverse user requirements, including short and long-term system alterations (Berkes et al. 2003; Ostrom 2007).

This article is divided into four parts. Following a summary of the conceptual pillars of the framework, vertical integration is introduced as a characteristic of adaptive governance supporting the sustainable management of groundwater services. The modified MTF class diagram. and the policy cycle are then presented. Subsequently, a case study analyzing the degree of vertical integration in the Upper Guadiana Basin in Spain illustrates the potential of the framework.

Presented in the final chapter is a summary of the conclusions with regard to the potential offered by the framework introduced in this paper and prospective future applications.

2 Governance of Groundwater Resources

Many of the challenges in the management of GWaES, and in relation to the responsibility to reduce tradeoffs, are more frequently associated with failures of governance than with the actual resource base (Bakker et al. 2008; Rogers and Hall 2003). According to Turton et al. (2006), governance is "*the process of informed decision-making that enables tradeoffs between competing users of a natural resource so as to balance protection and use in such a way as to mitigate conflicts, enhance security, ensure sustainability and hold government officials accountable for their action*." In general terms, governance needs to take into account the increasing importance of modes of governing, where non-state and private corporate actors participate in policy formulation and implementation, and develop instruments that co-exist alongside government policy processes (Rhodes 1997). In relation to groundwater resources, the definition provided by Foster et al. (2009) appears apt. They stated that governance includes, "*the fulfillment of appropriate authority and promotion of responsible collective action to ensure sustainable and efficient utilization of groundwater for the benefit of humans and dependent ecosystems*."

According to these rather normative descriptions of groundwater governance, it is crucial to highlight the need for integrative and cooperative management at all levels–from local to international–as well as the active involvement of different stakeholders in order to ensure the sustainable utilization of groundwater resources. The definition provided by Foster et al. (2009) makes clear that governance must view human and bio-physical systems as intertwined components by taking into account both human benefits and the maintenance of groundwater dependent ecosystems. For the purposes of our research, we used the lens of governance to analyze the interaction between diverse actors, their conflicting objectives and the instruments chosen to govern social and environmental processes within a particular policy arena.

Transferring a certain governance regime from one state to another is often associated with many challenges. One overall challenge is the common pool character of groundwater, including attributes of subtractability and excludability, which makes the protection of GWaES and the effectiveness of governance with respect to the day-to-day livelihoods of people even more difficult. Subtractability refers to the fact that GWaES have a limited capacity, whereby the consumption of groundwater by one user subtracts from the flow of GWaES available to others (Ostrom 2005). The problem of excludability means that it is difficult to prevent water users–especially landowners and farmers–from pumping water from aquifers. The challenges arising from groundwater overuse are highly diverse and require context-sensitive approaches so as to understand governance structures and modes of behavior. In accordance with Ostrom (2007), we would argue that one cannot provide cure-alls to arrive at general solutions to the problem of the overuse of natural resources, but that a diagnostic approach is required in order to address the context-specific attributes of diverse cases. Employing such an approach, it becomes possible to dig deeply into the structure of governance regimes and to evaluate various system characteristics.

Mukherji and Shah (2005) referred to two essential steps towards the successful implementation of groundwater governance. The first step requires adequate and high-quality information concerning hydrogeological and socio-economic properties, and the second step must ensure open access and the willingness of scientists and managers to share their knowledge and information with groundwater users. Often a lack of reliable data creates misconceptions and impedes water managers in taking action.

The Council of Canadian Academies (2009) gave a much broader view of the groundwater governance challenges that politicians must consider. They assumed that these challenges lie in the institutional and political arenas, and include fragmented and overlapping jurisdictions and responsibilities, competing priorities, and inertia in traditional unsustainable management approaches and ways of thinking.

From a global point of view, one can summarize the challenges of current groundwater management towards an adaptive and sustainable governance regime as follows:

- The intensive use of groundwater resources is of relatively recent origin, dating back half a century at most in many countries; consequently there is a lack of experience regarding the effects of unsustainable long-term patterns of use.
- The institutional arena relating to groundwater resources is highly fragmented in many governments and sectoral policies, and planning processes are developed in isolation; there are few structures facilitating cooperation between water managers, scientists, the private sector and public society in place, with most of those that do exist still in the early stages of development.
- Surface water and groundwater are managed separately and are not merged in integrated water management approaches applied within the context of the overall hydrological cycle.
- The invisible character of groundwater makes it difficult to comprehend the characteristics and behavior of the resource in terms of geological and hydrogeological settings; therefore, it requires a lot of sampling, which is costly and cumbersome.
- The contamination of groundwater is difficult to detect (e.g., source of pollution) and can persist for several decades.
- In developing countries groundwater management often lacks sufficient financial and human resources to explore the resource characteristics and functions and hence develop realistic rights, licenses and pricing systems.
- The dynamic nature of both socio-economic development and predictions regarding global climate change make groundwater management complex, uncertain and, therefore, unpredictable.

Empirical data, analytical frameworks and practical experience of the requirements of sustainable groundwater management are often limited, especially with regard to the management under particular groundwater governance regimes and the implementation of the legal basis on the ground. As argued above, we need a complementary approach that embraces complexity and context dependence (Meinzen-Dick 2007; Pahl-Wostl 2007a) rather than defaulting to simplistic, generic recipes. A framework to analyze governance regimes requires substantial and legitimate knowledge of the complexity of the system, including both ecological and socio-economic characteristics.

3 Conceptual Foundations

According to Wilson (2006), many frameworks for managing and understanding natural resources fail to match the diversity of spatial settings and the complexity of people, political arenas and ecosystems. In order to understand and analyze the management of GWaES, we built upon the MTF, which integrates a range of concepts to enable a more coherent understanding of the complexity of water management: adaptive and integrated water management (Folke et al. 2005; Pahl-Wostl 2007), social learning processes and regime transition theory (Pahl-Wostl et al. 2007a, b; Pahl-Wostl et al. in review), as well as the institutional analysis and development (IAD) framework developed by Elinor Ostrom and colleagues to analyze collective choice processes (Ostrom 2005). However, the MTF is not linked to a specific theory, but it provides a flexible language that can be tailored to particular research issues.

Burke and Moench (2000) found that effective approaches to groundwater management cannot depend on a single political mechanism. Rather they should include coordination and cooperation structures within governance regimes, as well as long-term processes and solutions taking into account uncertainties such as global climate change, through which national, regional and local systems can evolve.

The underlying conceptual basis for the development of the framework for sustainable management of GWaES presented here can be summarized under the following general headings:

- adaptive management including vertical integration as an important characteristic of groundwater governance and
- the ecosystem services approach as a concept bridging socio-economic and ecological systems.

It is assumed that these two concepts provide important and valuable underlying principles for sustainable groundwater management, whereby adaptive management can be seen as a concept facilitating an understanding of regime complexity and the requirements of dealing with uncertainties and system alterations. The concept of ecosystem services serves to structure the linkages and dependencies between GWaES and human well-being, whereas adaptive management deals with performance of the governance regime (e.g., involvement of stakeholders, sharing of knowledge and information) and the associated impacts on GWaES.

3.1 Adaptive Management

The concept of adaptive management has existed for quite some time and is generally best known from its long history of application in ecosystem management (Holling 1978; Walters 1986; Pahl-Wostl 1995; Lee 1999). This tradition builds strongly on an experimental approach to management that supports a 'learning by doing' attitude. The overall idea of adaptive management relies on the recognition that ecosystems are complex systems, which are adaptive and self-organizing, and have to be managed in such a way that it is possible to adjust to change, uncertainty and unexpected occurrences (Holling and

Gunderson 2001). The MTF builds on a wider interpretation of adaptive management, defined by Pahl-Wostl et al. (2010 p. 573) as, "*a systematic process for improving management policies and practices by systemic learning from the outcomes of implemented management strategies and by taking into account changes in external factors in a pro-active manner.*" Originally developed as a management concept for ecological systems, adaptive management has more recently evolved into an interdisciplinary field of research and action, as reflected in the broader term adaptive governance (Folke et al. 2005). This interpretation places a stronger emphasis on the general need to increase the adaptive capacity[2] of a management regime to deal with any kind of uncertainty and surprise. As aquifer systems are complex, difficult to understand, and the consequences of human intervention are difficult to predict (Seward et al. 2006), adaptive management is a suitable approach to dealing with these challenges.

Given the historical development of groundwater management under control and centralized regimes, most governance structures do not provide the structural conditions necessary to implement adaptive approaches without changing certain characteristics of management. We assumed the following to be essential for a paradigm shift in favor of adaptive groundwater management:

- a shift towards participatory management and collaborative decision making,
- greater integration of different research issues and interdisciplinary sectors,
- decentralized and more flexible management approaches, which take uncertainties and unexpected events into account,
- incorporation of ecological system properties and mainstream GWaES into management goals at all levels,
- provision of free access to information and the conscious collection of data and monitoring of the state of GWaES.

The ability to implement adaptive management and to integrate it within the overall management of groundwater resources depends on a number of structural characteristics (Pahl-Wostl et al. 2010). One of these characteristics is vertical integration, which is better known as a sub-theme under the overall umbrella of multilevel governance. Due to space restrictions, only the analysis of vertical integration is presented in this paper. We are aware, however, that complex adaptive systems are framed by many different structural governance conditions.

3.1.1 Vertical Integration

The significance of the term vertical integration here is twofold. First, it refers to the connectedness of different administrative levels (from local to international; including the natural boundaries of a basin or sub-basin) and second, it includes the active involvement of stakeholders, both governmental and non-governmental actors, at various administrative levels. Stakeholders in this case are individuals or entities with a stake in groundwater resources. We defined participation as a process that actively involves the public, private enterprises, farmers and NGOs during the development of policy options and in implementing programs. The overall goal of participation is to make people responsible for the decision-making process and for their behavior, which often has a significant impact on how they use their natural water resources, in contrast to a top-down allocation of a

[2] Adaptive capacity is described as being the ability of a regime to change management goals and practices in order to be more flexible in dealing with uncertainties and unpredicted occurrences at diverse administrative levels and across different time-scales (Pahl-Wostl 2009).

clearly defined natural resource. Foster et al. (2009) named some general reasons why stakeholder participation is a critical instrument in groundwater governance: (1) management decisions taken unilaterally by a regulatory agency without social consensus are often impossible to implement and (2) essential management activities (e.g., monitoring, fee collection) can be carried out more effectively through cooperation, integration and consultation. Although the participation of stakeholders is essential for sustainable management, this generally also requires a local official agency (e.g., basin authority) acting as an overall facilitator to support communication between groundwater users and governmental authorities, and to assist in the operational implementation and enforcement of legal restraints.

Vertical integration is crucial where rigid and hierarchical forms of management dominate. In the absence of collaboration and coordination, these tend to lead to fragmented responses and are not suited to dealing with complex problems (MEA 2005). Summarized in Table 1 is a set of working assumptions related to vertical integration as a crucial characteristic of sustainable and adaptive groundwater management.

While the concept of adaptive management emphasizes the need to change certain structural conditions of governance regimes, we also make use of the ecosystem services concept to highlight the linkages between the socio-economic and ecological systems, and the tradeoffs between provisioning, regulating, supporting and cultural GWaES.

Table 1 Definition of vertical integration and related assumptions to support adaptive and sustainable management of GWaES

Regime characteristic	Definition	Assumptions
Vertical integration	Vertical integration refers to the interconnectedness (or interplay) of different administrative levels (from local to international) and includes the active involvement of stakeholders at various administrative levels during management performances (including decision, planning, implementation and monitoring phases).	It is assumed that a lack of vertical integration leads to policy failures due to disconnection of administrative levels and gaps between policy processes and operational implementation. As GWaES cross political boundaries and operate at different spatial scales, it is crucial that governance bodies have the capacity to work and interact at multiple levels. (source: Pahl-Wostl 2009; Irwin and Ranganathan 2008) Sustainable management of GWaES depends on decisions of numerous actors who have individual goals and values of GWaES; sustainable groundwater management needs inter alia a broad integration of bottom-up approaches by including a wide array of diverse stakeholders. It is most likely to sustain GWaES in the long-term when communities themselves set up rules and regulate natural resources. (source: Burke and Moench 2000; Ostrom 2005; Irwin and Ranganathan 2008; Agboola and Braimoh 2009)

3.2 Ecosystem Services Concept

The concept of ecosystem services has been developing for over a century as a means to recognize the dependence of human societies on natural systems (Daily 1997). This concept integrates ecology and economics in an attempt to explain the effects of human policies and actions on natural systems and on human welfare (Foster et al. 2003; Farber et al. 2006). The services provided by groundwater ecosystems furnish a wide range of beneficiaries. These include extractive services, where groundwater is pumped from aquifers and utilized for a variety of human needs (e.g., drinking supply, food production), and non-extractive services, where the water is left in the ground or in dependent ecosystems to provide soil moisture, base flow to streams and wetlands and recreational opportunities. Cork et al. (2001) perceived ecosystem services as "*transformations of natural assets into products that are important to humans.*" For example, discharge of groundwater into streams and rivers provides nutrients essential to aquatic life and supports downstream users in the form of water for drinking and irrigation (NRC 1997).

A benchmark definition of ecosystem services research was provided by the Millennium Ecosystem Assessment (MEA), a formal international scientific effort (Brauman et al. 2007). The MEA framework was developed within an internationally acknowledged study and designed to capture how groups of people interact with and rely on ecosystems, and how changes to these ecosystems influence individual and community well-being (MEA 2005).

The MEA categorized ecosystem services according to four classes: provisioning, regulating, supporting and cultural services. The four categories—including examples of GWaES–were defined by the MEA (2005) as follows:

- Provisioning services are '*products obtained from ecosystems*' (e.g., aquifer storage and retention for domestic, industrial and agriculture uses)
- Regulating services are '*benefits obtained from the regulation of ecosystem processes*' (e.g., water regulation, water purification and waste treatment, erosion regulation and flood control)
- Supporting services are '*services which are necessary for the production of all other ecosystem services*' (e.g., water and nutrient cycling)
- Cultural services are '*non-material benefits that people obtain from ecosystems*' (e.g., spiritual and religious values, recreation and aesthetic experiences).

This categorization serves as a functional abstraction from ecological resources to 'ecosystem services' that highlights the linkages and dependencies between these services and human well-being (Loring et al. 2008).

The ecosystem services framework not only makes the complex linkages explicit, but also the tradeoffs between ecosystem services and their users. Tradeoffs arise when the provision of one service is optimized at the cost of another service (Raudsepp-Hearne et al. 2010). Examples of groundwater-related tradeoffs include those between industrial and domestic usage (e.g., irrigation, sanitation) and water quality, as well as between land use patterns and biodiversity. The MEA revealed that there is a tendency when making tradeoff decisions to favor provisioning services over regulating, and regulating services over cultural. One cannot expect to find cure-alls in the management of tradeoffs because they are always related to space, time and cultural and political aspects of society (Hein et al. 2006).

Both of the concepts presented above are well recognized in the scientific world and have found their way onto many political agenda. Unfortunately, their efficient implementation on the ground still poses a big challenge worldwide.

One of the central themes related to these challenges is the failure of governance, including a lack of vertical integration, which in turn is crucial for sustainable and adaptive groundwater management. To explore vertical integration we made use of an analytical framework that bridges the gap between highly complex management, groundwater tradeoffs and the overall context in which a case study is embedded. The ecosystem services concept and the MEA framework proved a useful analytical lens for the classification of different GWaES and to understand the linkages between these services and human well-being. The concept of adaptive management lends analytical strength of the framework by making complex governance characteristics more transparent and understandable, and by providing insights into vertical integration.

4 An Analytical Framework for the Assessment of Groundwater Governance

The framework introduced here consists of a *static representation* (see section 4.1) and a *process* or *dynamic view* (see section 4.2). The former is presented by the class diagram, which provides an ontology of the important elements within a water system, including their specific attributes and relations. The latter consists among other things of a policy cycle containing different phases of a stylized management process.

4.1 Structural Foundation: The Class Diagram

The diagram presented in Fig. 1 is based upon the original MTF class diagram, which addresses various elements in a water system and their relationships, including basic structural conditions (e.g., aquifer system characteristics, GWaES, institutions) and elements that interact in the management of the system (e.g., actors, action situations, action arenas).

The framework enables scholars to organize and structure class linkages in a systematic fashion and so to understand the management of and alterations to groundwater systems.

The diagram is limited to specific classes involved in assessing and understanding groundwater governance regimes and system linkages. These classes were chosen to address the following research questions: Which management activities and governance characteristics support a transformation towards adaptive and sustainable groundwater management? How does the governance structure influence the management process and how does this process lead to alterations of GWaES? The framework can be adapted to address additional research questions.

The central class is the 'water system,' which frames the overarching boundaries of the whole groundwater governance regime, including the 'ecological system' and the 'socio-economic system.' The 'water system' takes into account case study specific attributes such as the location, hydrological characteristics, population density and climatic conditions. The 'ecological system' comprises abiotic and biotic components of the groundwater body and related ecosystems such as floodplains, swamps, springs and sloughs. In very large aquifer systems there is likely to be more than one ecological system. Important attributes of the 'ecological system' are *hydrogeological characteristics* (e.g., related to geology, lithology, permeability), *biodiversity*, *degree of human influence*, *water availability*, *water quality* and *natural storage capacity*. The 'socio-economic system' is shaped by cultural, political, historical, religious and spiritual context-specific attributes. The interface between the 'ecological system' and 'socio-economic system' is established by 'GWaES,' which may be a public, private or collective good, depending on the ease of exclusion and their subtractability (Ostrom 2005, see section 2). Further attributes of 'GWaES' are the

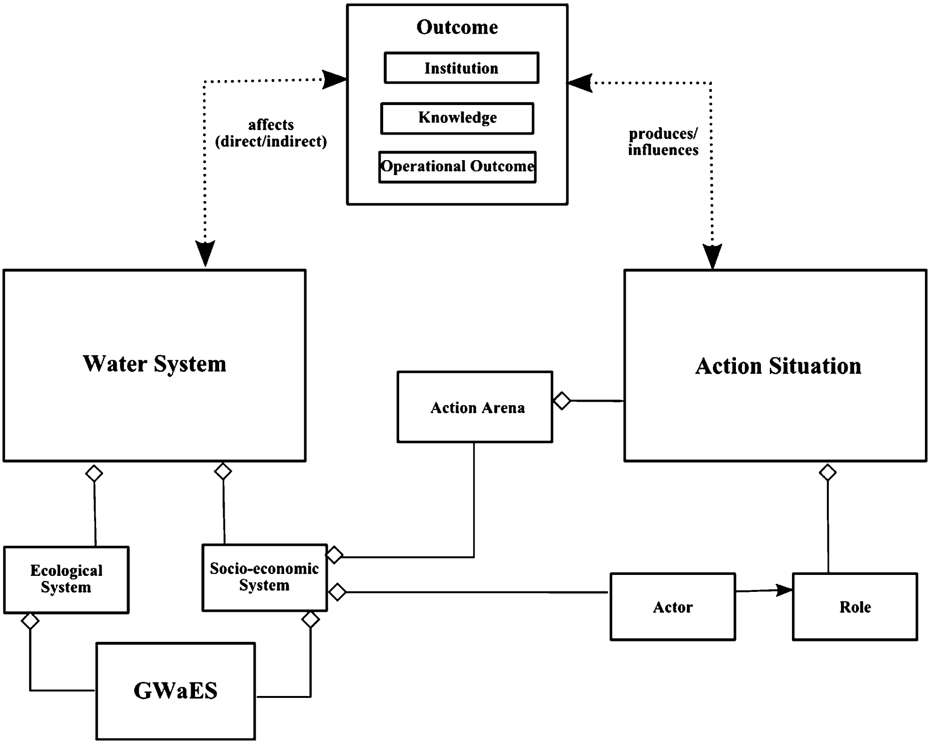

Fig. 1 Representation of all class elements and their linkages. In order to simplify the illustration, the attributes of the classes are not shown. The *diamond symbol* denotes a link; e.g., an ecological system has a GWaES. The *broken line* indicates dependencies between an action situation and an outcome (e.g., implementation of a new water act) and between an outcome and a water system (e.g., a new water act reduces groundwater abstraction rates). The *arrow* highlights the direction of the relationship between objects of classes (here actor/role)

economic v*alue* and the degree of *variability,* which indicate that 'GWaES' may not always be available due to irregularities in the system and non-linear system behavior (e.g., discharge year, drought periods).

The process of management of 'GWaES' essentially occurs within a certain 'action arena' and includes several 'action situations' and 'actors.' The 'action arena' is embedded in a 'socio-economic system' and refers to different policy sectors and contexts related to the management of 'GWaES;' e.g., wetland management or agricultural planning and development. An 'action situation' is a structured social interaction that leads to a specific 'outcome' that influences the elements in the 'water system' and vice versa. 'Outcome' is divided into three categories: 'knowledge,' 'operational outcome' and 'institutions.' 'Institutions' are the *rules of the game* (North 1990) in which 'actors' operate and have been devised to manage GWaES. They include formal laws and regulations, which are legally binding rules, and informal norms and organizations, which are not legally binding, but exist as real written documents and have a confirmed status in the corresponding 'action situation.' 'Knowledge' refers to meaningful information and experience (e.g., knowledge of water availability during summer periods and crop profitability), whereas 'operational outcome' is a concrete physical, measurable effect of groundwater management (e.g., land use change, composition of water chemistry, groundwater table drop). 'Action situations' are connected by their 'outcomes,' e.g., action situation A results in a formal document to reduce groundwater abstraction, which in turn influences the implementation processes in action situation B. A sequence of different 'action situations' frames a chain of related management steps, which is embedded in the governance regime.

The attributes of an 'action situation' are its *kind*, according to Ostrom's IAD framework (constitutional, collective choice, or operational); the *phase*, which refers to a stage in the policy cycle (see section 3.2) and its *level*, which refers to different spatial scales and could be based on traditional administrative boundaries (e.g., international, national, regional or local) or those defined by natural hydrological units (e.g., basin, sub-basin, aquifer unit). The 'action situation' is influenced and steered by '**actors**,' who are part of the 'socio-economic system' and characterized as *individuals*, *organizations* or *aggregated collectives*, or according to whether they are *governmental* or *non-governmental* actors. Further attributes of an 'actor' are specific *goals* (e.g., increase crop production and social welfare for farmers or protect endangered species) and *values* (e.g., social, economic or ecological) of 'GWaES.' Many tradeoffs arise from management processes in an 'action situation.' These can change the type and mixture of 'GWaES.'

The relationship between 'actor'–'action situation' is described by means of the '**role**' an 'actor' plays in a specific 'action situation.' It can shift from one 'action situation' to the next. The corresponding attributes–*lead*, *active* or *passive* participant–enable researchers to identify the role characteristics with respect to the influence of actors on the processes in an 'action situation.'

The choice of the level of detail and the amount of data relating to each class element and their attributes depends on the degree of information required to understand and analyze a certain problem and to answer a certain research question. This allows researchers a high level of freedom.

4.2 Dynamic View: The Policy Cycle

The dynamic feature of the framework is represented by the policy cycle, which is applied here as an analytical guideline. It helps to structure complex policy performances by identifying different steps during a management process. Where possible, each action situation is assigned to a phase in the policy cycle (see Table 2). For example, the implementation of groundwater protection zones refers to the 'implementation' phase. The policy phases may overlap or run parallel. This approach helps researchers to structure the analysis and to render influencing factors transparent by illustrating outcomes in a structured manner. The first phase of the policy cycle–'strategic goal setting'–is particularly important, as this phase is influenced by the state of GWaES as perceived by the various actors. Ideally, the goals and values are multifaceted so as to support both ecological and socio-economic goals and developments.

This process is iterative, and phases of the policy cycle are revisited and reviewed–or, in other words, the policy cycle promotes a steady 'learning by doing' approach and thus supports the adaptive management approach.

5 Application of the Framework

The novel framework introduced in the previous chapter was applied in the Upper Guadiana Basin (UGB) in Spain's autonomous Castilla La Mancha region. The UGB was chosen because of the reputed hopelessness of the conflict between farmers' intensive use

Table 2 Process or dynamic view (formalized generic management process) of the framework

Phases of the policy cycle	
1. Strategic goal setting	The strategic goals for the management process are set to determine a desirable state of the entire water system, including both socio-economic and environmental goals and values (social, economic or ecological). The strategic goals are formally binding for all actors.
2. Assess the current state	The current state of the water system is assessed to estimate the distance of the current state from the desired goal state. Hence it is possible to determine satisfaction and the need for change.
Note: After a first comparison of the current system state; the strategic goals allow determining the degree of deviation from the desired state and estimating the need for action. At this stage it is already possible to adjust strategic and more promising or important goals according to the current state.	
3. Policy formulation	Policies are developed that represent coherent approaches how and in which time frame improvement of the current state of the water system is initiated. This phase may include an interpretation and refinement of the strategic goals and it can be expected to involve different stakeholders, who pursuing their goals and try to influence the policy process.
4. Developing operational goals	Operational goals are defined that allow assessing efficiency and effectiveness of measures and that are the basis for monitoring.
5. Developing measures	A plan with specific measures including an assessment of their costs and expected effectiveness is developed.
Note: Take into account' Best Practice Examples' from other cases to learn from failure or success stories. Before implementing measures inform and educate the local community to achieve a successful implementation process; e.g. organize workshops and public events, communicate via internet or newspaper, etc.	
6. Implementation	In this phase the measures are implemented on the ground at the appropriate level e.g. improvement of infrastructure to save water, introduction of new water pricing policies.
7. Monitoring	Monitoring means reviewing the implemented measures as to achievement of the strategic goals. Therefore it is possible to detect potential unexpected and undesired consequences.
Note: At this state the process may go back to the first phase (or any other phase) and strategic goals may come under scrutiny.	

of provisioning GWaES on the one hand and the prevailing ecological requirements on the other. Our analysis focused on the process of elaboration of the Special Plan for the Upper Guadiana Basin[3] (SPUGB), which was developed to find solutions accommodating different actors and governing tradeoffs between competing user requirements. The framework was applied to help provide an understanding of the vertical interplay of the diverse actors at various administrative levels and how tradeoffs were captured during the drafting of the SPUGB.

The study benefitted from the considerable amount of research carried out in the UGB to date (see, for example, López-Sanz 1999; López-Gunn and Martínez-Cortina 2006; Varela-Ortega 2007; Martínez-Santos et al. 2008b; Ross and Martínez-Santos 2009; Aldaya et al. 2009; van der Keur et al. 2010; Zorrilla et al. 2009). Our framework has been tailored to focus explicitly on the complex governance characteristics and on the management. The exploration of GWaES tradeoffs and the linkages to management performance represented a novel contribution. The following overview of the application of the framework in the UGB serves to demonstrate to researchers how it can be used to assess vertical integration and its

[3] Plan Especial del Alto Guadiana

effects on groundwater management. To apply the framework it was first necessary to characterize the important class elements and their attributes, then to identify action situations and the associated outcomes and, finally, to test assumptions related to vertical integration (see Table 1).

5.1 Case Study of the Upper Guadiana Basin

The UGB is a semi-arid region where the intensive use of GWaES for irrigation has helped to transform a previously poor rural region into a prosperous agricultural and industrial center, triggering abundant social and economic benefits for a predominantly rural population (Brugnach et al. 2011). The governance regime in the UGB is characterized by an enduring lack of integration and mismatching agricultural and water policies. Major problems have arisen in the region as a result of uncontrolled groundwater development (Varela-Ortega et al. 2011). The tradeoffs associated with groundwater pumping are a dropping of aquifer levels and the degradation of the wetlands of the *Las Tablas de Daimiel* National Park; a *Ramsar* site and UNESCO Biosphere Reserve (Martínez-Santos et al. 2008a). Since 1998, the wetlands have been surviving artificially, in an 'ecological coma,' due to the intra-basin transfer of water from the Tagus-Segura Aqueduct (Hernández-Mora et al. 2003). Many aquifers and ecological interfaces between aquatic and terrestrial ecosystems are either altered or diminished, and many GWaES have been traded off. This situation has led to conflicts between the socio-economic goals of farmers and the goals of environmental conservation groups and governmental officials.

The SPUGB was developed–over a time period of 7 years (2001–2008)—in order to find solutions to the conflicts and to conserve *Las Tablas de Daimiel*. The deeply rooted social conflicts pose challenges to the water administration, which seeks to meet two overall objectives, namely to achieve a good ecological status of all aquatic bodies according to the goals of the EU Water Framework Directive and to satisfy the water demands necessary to maintain rural livelihoods. The issue of vertical integration during the drafting of the SPUGB was investigated, as an important characteristic in the context of improving the adaptive capacity of the governance regime in the UGB.

Our analysis built upon two different types of data. Firstly, we incorporated the results of the EU NeWater project,[4] wherein the Guadiana river basin was just one of seven case studies. Secondly, we conducted expert interviews during January 2011. To guide the interviews we developed a catalogue of action situations based on the results of a literature review, including the linkages between them. Taken together these action situations shaped the overall management process in the UGB. Ten experts were selected to participate in the interviews. The interviewees provided expertise and knowledge from different sectors: politics and administration, consulting, agriculture, research and practical nature conservation. The experts were interviewed by telephone or during face-to-face sessions of 60–120 min by a person trained in the underlying concepts and structures of the framework. All information and data were transferred to an *MS Access* database–based upon the MTF–and represented in a formalized way describing dynamic water governance and management processes as well as the context (socio-economic and ecological conditions) of the UGB. For further explanations of the underlying conceptual and methodological foundations of the MTF database refer to Knieper et al. (2010).

[4] New Approaches to Adaptive Water Management under Uncertainty, supported by the European Commission under the 6th Framework Programme, PRIORITY 6.3 'Global Change and Ecosystems' 2005–09

To reiterate, the purpose of highlighting the UGB example in this paper is less to provide holistic and in-depth analytical results, but rather to demonstrate the potential application of the framework.

5.2 Framework Classes

It is first necessary to introduce the class elements incorporated in the analysis of the UGB according to their relevance for the assessment of vertical integration. One of the most important elements in this respect is the actors. For this reason, a brief description of the main actor groups follows. Presented in Table 3 are the additional classes and their pertinent attributes.

5.2.1 Actors

The main factors involved in the drafting of the SPUGB could be grouped according to three broad categories: administration/officials, farmers and irrigating communities, and environmental conservation groups. The actors were chosen on the basis of the NeWater research results and, where necessary, we extended the list of actors according to recommendations made during the expert interviews.

1) Administrative/official actors responsible for water, environment and agriculture policies

   Ministry of the Environment: responsible for water resource management, through the RBAs
   Ministry of Agriculture: traditionally played an important role in the UGB and promoted the transformation from rain-fed to irrigation agriculture
   Guadiana River Basin Authority: under the Ministry of the Environment, in charge of planning, constructing and operating major water infrastructural developments (e.g., dams); formulating basin plans; setting water quality targets, including monitoring and control; granting permits to use water; etc.
   Castilla La Mancha Regional Government: by law, local governments are responsible for water and sanitation services in urban areas. They are responsible for various water issues but do not provide the water services themselves.
   Members of the Water Board: constitute an advisory body to the UGB, incorporating representatives of the national and regional government, water users and social organizations from within the basin.

2) Farmers and irrigating communities who account for approximately 95% of the total groundwater withdrawal in the catchment

   ASAJA[5] *(union of large farmers)*: biggest and most professional farmer organization in Spain. Promotes the economic development of family farms and agricultural businesses. Amongst the ASAJA farmers are those owning the largest farms in the basin
   COAG[6] *(union of small farmers):* supports the developments of farmers' cooperatives and aims to prevent population decline in rural areas and to promote sustainable agriculture

[5] Asociación Agraria de Jóvenes Agricultores
[6] Coordinadora de Organizaciones de Agricultores y Ganaderos

Table 3 Important class elements assumed to be important during the elaboration process of the SPUGB

Class element	Description	Attributes
Water system	Upper Guadiana Basin	Basin size: 16,000 km²
		Climate: semiarid
		Rainfall: 400 mm/year
		Evapotranspiration: 1,200 mm/year
		(source: Hernández-Mora et al. 2003)
Socioeconomic system	Castilla La Mancha (CLM)	Population total: 2,095,855
		Population density: 26.4/km^2
		Gross domestic product: €33,077,484,000
		(source: Instituto Nacional de Estadística 2011)
Ecological system	Mancha Occidental Aquifer	Aquifer size: 5,500 km²
	Interrelated ecosystem: *Las Tablas de Daimiel* National Park	Declaration of overexploitation in 1987
		Water availability: medium
		Natural storage capacity: high
		Biodiversity classification: low
		Protection status: high
		Degree of human influence: high
		(source: Hernández-Mora et al. 2003; expert interviews (anonymous) 2011)
GWaES	MEA Categories	
	Provisioning: drinking supply, sanitation, irrigation, livestock watering	Exclusion: no
		Subtractability: yes
		Economic value: yes
		Degree of variability: high
	Regulating: base flow to wetlands, erosion and flood control, drought buffer	Exclusion: no
		Subtractability: yes
		Economic value: no
		Degree of variability: high
	Supporting: water/nutrient cycling	Exclusion: no
		Subtractability: yes
		Economic value: no
		Degree of variability: high
	Cultural: recreation and tourism, aesthetic beauty, knowledge and education	Exclusion: no
		Subtractability: yes
		Economic value: no
		Degree of variability: medium
		(source: expert interviews (anonymous) 2011)
Action arena	Agriculture management and nature protection	
Actors	Ministry of the Environment	Spatial unit: Spain
		Admin. level: national
		Value: ecologic
	Ministry of the Agriculture	Spatial unit: Spain
		Admin. level: national
		Value: economic
	CLM Regional Government	Spatial unit: Castilla La Mancha

Table 3 (continued)

Class element	Description	Attributes
		Admin. level: regional Value: no dominant value orientation
	Guadiana River Basin Authority	Spatial unit: Spanish Guadiana Basin Admin. level: sub-basin Value: no dominant value orientation
	Members of the Water Board	Spatial unit: Spanish Guadiana Basin Admin. level: sub-basin Value: no dominant value orientation
	Environmental conservation groups	Spatial unit: Spanish Guadiana Basin Admin. level: sub-basin Value: ecologic
	National Park administration	Spatial unit: UGB Admin. level: sub-basin Value: ecologic
	Farmer and irrigation communities	Spatial unit: Farms in the UGB Admin. level: local Value: economic
	Diverse research experts	Spatial unit: Spain Admin. level: national Value: no dominant value orientation

(source: NeWater project 2005–2009, expert interviews (anonymous) 2011)

General User Community of Aquifer 23: the creation of groundwater user communities–encompassing all individual communities in the aquifer–is required under the Spanish Water Law of 1985 (declaration of overexploitation)

3) Environmental conservation groups whose overall aim is to protect the wetlands and to ensure the services provided by groundwater ecosystems remain intact. They oppose the construction of dams and other hydraulic works and the spread of economic activities with high water demands in areas where there are water shortages. (Included here are the following organizations: WWF/Adena, Ojos del Guadiana Vivos, SEO/Birdlife, and Ecologistas en Acción.)

Also included are researchers. These have not been assigned to a particular group of stakeholders, however, as they merely provide technical advice and expertise regarding hydrogeological flow patterns.

Table 3 contains further classes deemed to have been important for the analysis. However, the main focus was on highlighting the interactions between the actors, and how the interplay between them steered the development of the SPUGB. As highlighted in section two, a holistic and integrative governance regime requires diverse geo-physical, hydrological, hydrogeological and economic models in order to provide data for water managers and stakeholders (e.g., water consumption, crop patterns, irrigation and pumping costs). This information is not included here as it would exceed the scope of this paper. Interested readers should refer to the following for more detail: Martínez-Cortina and Cruces 2005; Martínez-Santos et al. 2008b; Blanco-Gutiérrez et al. 2011.

5.3 The Process of Drafting the SPUGB for the UGB

Depicted in Table 4 are the most important action situations arising during the process of drafting the SPUGB between 2001 and 2008. Action situations are connected via their outcomes (institutions, knowledge and operational outcomes; see section 4.1) and related to a specific policy phase. For the purposes of this paper, the management process is represented as a simplified summary. The actual network of action situations, the relationships between actors and the implications was considerably more complex than is indicated in Table 4.

The process of formulating the SPUGB could be divided into two periods, namely the period from 2001 to 2004 and the period from 2004 to 2008. The bullet points below provide a summary of the process of formulating the plan for the region.

Period 2001–2004:

- The formulation of the plan took place at the sub-basin level.
- The lead during the official development process (action situation 1–3) was taken by the RBA. The RBA is answerable to the Ministry of the Environment, which is responsible for approving the plan.
- Actors from lower levels (e.g., environmental NGOs, farmers and the national park administration) were neither involved nor consulted during the identification of the strategic goals of the plan.
- Information was not circulated from the RBA to regional or local stakeholders and consultation opportunities were strictly limited to farmers and irrigating communities (basically ASAJA).
- The operational outcome consisted essentially of opposition to and claims made against the plan (action situation 2 and 3).

Period 2004–2008:

- The process of formulating the plan was very much contested by stakeholders from the local and regional levels (action situation 3 and 4); they criticized the lack of participation during the initial phase and in the identification of strategic goals (action situation 1).
- Local stakeholders were able to influence the process at a higher level by submitting claims against the plan and the planning process. Consequently, the process stopped (outcome action situation 4) and the development of new guidelines (action situation 5) encompassing a much broader stakeholder approach and the incorporation of local knowledge (outcome of action situation 4) was considered by the RBA at sub-basin level.
- The lead during the formulation of new guidelines was again restricted to the RBA supported by scientific research experts. Local actors were actively involved, however, and could influence the contents.
- The main goal of the plan is to restore the wetlands of the national park without any negative impacts on the livelihoods of local farmers.
- The informal approval of the plan (action situation 7) met with a high level of agreement, and different kinds of management tools were chosen for the restoration of *Las Tablas de Daimiel*.
- The SPUGB clearly indicates the need to protect and maintain groundwater resources and ecosystem services for both ecological and socio-economic requirements.
- The implementation of the plan is currently in an initial stage and faces many challenges (e.g., financial resources).

Table 4 Sequence of action situations related to the elaboration of the Special Plan of the Upper Guadiana Basin from 2001 to 2008. The table includes the administrative level of the respective action situations, the related policy phase, actors involved, produced outcome, and additional information

Action situation	Admin. level	Policy phase	Actor (lead, active or passive)	Outcomes	Additional information
1. Elaboration of SPUGB proposal (2001/02)	Sub-basin	Policy formulation, developing operational goals	Lead: RBA Active: Ministry of the Environment, Ministry of Agriculture, main farmer and irrigation communities	Institution: Proposal draft	The initial elaboration process was limited to the RBA, Ministry of the Environment and main farmer and irrigation communities. Neither municipalities, the National Park nor NGOs were informed or consulted during this process.
2. Presentation of SPUGB to members of the water board (2003)	Sub-basin	Policy formulation	Lead: RBA Active: Members of the Water Board Passive: Farmer and irrigation communities, NGOs, CLM Regional Government, National Park administration	Institution: Opposition against the proposal Operational outcome: Mistrust	In addition to the formal information process, informal meetings created new associations and open debates A major conference was organized to produce alternatives to the proposal. Many stakeholders claim that only a few actors were consulted for the proposal draft, and no information was provided to most of them.
3. Public information process (2004)	Sub-basin	Policy formulation	Lead: RBA Active: Framer and irrigation communities, NGOs, CLM Regional Government, National Park administration	Institution: Allegations against the proposal	Allegations: many stakeholders criticize that no true participatory process during the elaboration of SPUGB took place–as required by the European Water Framework Directive.
4. Seminar on SPUGB proposal (2004)	Local	Strategic goal setting	Lead: NGOs, CLM Regional Government Active: National Park administration, farmer and irrigation communities, research experts Passive: RBA, Ministry of the Environment, Ministry of Agriculture	Institution: Agreement to ask the development process to stop Knowledge: Local knowledge	The Seminar was an unofficial discussion forum initiated as a reaction to the proposal presented by the RBA. The seminar mainly comprised stakeholders not involved in the development of the initial proposal. The participants of the seminar demand a new development process of the Plan including all stakeholders.
5. Elaboration of guidelines for a	Sub-basin	Developing operational goals	Lead: RBA, research experts Active: CLM Regional Government,	Institution: Guidelines for the elaboration of a new	Turning point in 2004 due to new elections of the government making management

Table 4 (continued)

Action situation	Admin. level	Policy phase	Actor (lead, active or passive)	Outcomes	Additional information
new SPUGB (2004)			farmer and irrigation communities, NGOs, National Park administration	SPUGB	processes more open and visible. The new elected Guadiana RBA starts bilateral meetings to inform stakeholders and invite them to participate in the design process of the new SPUGB.
6. Development of new SPUGB proposal (2005)	Sub-basin	Developing operational goals	Lead: RBA Active: Ministry of the Environment, Ministry of Agriculture, CLM Regional Government, farmer and irrigation communities	Institution: Proposal of the new SPUGB	It took almost 3 years for the new proposal to be finalized. The plan includes different types of measures: purchasing water rights, legalization of illegal wells, closing-up of unlicensed boreholes, re-forestation plan and the support of rainfed farming.
7. Informal approval of SPUGB (2007)	Sub-basin	Policy formulation, developing measures	Lead: RBA Active: CLM Regional Government, farmer and irrigation communities, NGOs	Institution: Agreement on the plan	A high level of agreement was achieved. The overall goal of the plan was to restore the wetlands without negatively impacting the local economy.
8. Formal approval of SPUGB (2008)	National	Policy formulation	Lead: Ministry of the Environment Active: RBA, CLM Regional Government	Institution: SPUGB (formal rules and legally binding) Operational outcome: Implementation challenges	The SPUGB for the period 2008–2027 was approved with a budget of €5.5 million. The implementation of the plan is facing many challenges and difficulties.

5.4 Discussion of the Results

Table 4 shows that the process of formulating the SPUGB was rooted at the sub-basin level. Under the 1985 Spanish Water Act, and the European Water Framework Directive, the decentralization of water management is a requirement. Hence, groundwater is managed within the natural boundaries of the UGB. Traditionally, the decision-making process on water management issues in the UGB was controlled mainly by the RBA operating under the Ministry of the Environment.

During the first period (2001–2004), actors from the regional and the local level were not actively involved or consulted. Most actors had no previous information about the plan until the first proposal had been drafted and released to the public. This first proposal was basically a technical legal text that, according to the local NGOs and the national park administration, lacked the environmental measures needed to protect the wetlands and GWaES. Prior to the elections in 2004, the water management regime was characterized by rigid, bureaucratic structures and a lack of transparency (e.g., circulation of information), and participation occurred only in the context of legal requirements.

Furthermore, the analysis showed that the role of actors during policy formulation and development was dominated by the RBA. Under the Water Act, the RBA is responsible for the management of public groundwater resources and for granting permits for all kinds of use (Hernández-Mora et al. 2003).

The second period (2004–2008) of the process and development of new guidelines revealed a broader understanding of participation and of the need for communication. The newly elected government and the new RBA were characterized by a different stance with respect to communication, information sharing and public participation. The reframing of actors' positions seems to be heading in the direction of a more adaptive and cooperative governance regime. Environmental NGOs, the National Park Administration, the regional government and farmers have evolved from their radical opposition to the plan towards a more moderate position. They want to achieve an integrative plan that includes different types of measurements taking into account both environmental aspects and socio-economic development.

With regard to the issue of the connectivity of different levels, it has already been stated that the SPUGB was essentially developed at sub-basin level. The main actor and leader in the process was the RBA, which is situated at sub-basin level. During the initial phase, actors from the national level were actively involved (Ministries of the Environment and Agriculture). This resulted in many conflicts and opposition to the plan from actors located at the local and regional level, who felt excluded from the process. After the elections in 2004, actors from lower levels were granted the opportunity to shape a new planning process in cooperation with the RBA. At this point it became possible for all actors to express their ideas and hopes for the plan.

The case of the UGB illustrates an example of how problems in water management can arise when important actors are excluded. The shift toward a more participative groundwater regime makes it possible to include the different goals and values of various stakeholders. Groundwater-associated tradeoffs can then be considered in a broader context as actors with diverse water demands and ecological requirements are involved in the management process. It is open to debate whether the elections in 2004 or the claims made against the plan triggered the shift towards participation.

In accordance with our assumption (see Table 1), we conclude from the case study of the UGB that vertical integration is a crucial characteristic of adaptive governance regimes as the management of GWaES depends on decisions made by numerous actors who have individual goals. The formulation of the plan achieved a higher level of agreement after local stakeholders were involved in setting up rules and regulating the natural resources upon which they depend.

The implementation of the plan faces many challenges and difficulties: (1) the lack of an appropriate network for groundwater monitoring, (2) an insufficient information system to circulate data to stakeholders in the UGB, (3) the existence of a huge number of illegal wells, and (4) uncertainties relating to the impacts of forecast climate change (e.g., longer droughts, variations to rainfall patterns). Furthermore, implementation has been hindered by budgetary problems arising from the financial crisis in 2008. In light of these challenges, the RBA has highlighted the following issues as being crucial for successful implementation: a reform of the agriculture sector in the UGB, including sustainable irrigation management (including both the socio-economic and ecological aspects); restrictions on groundwater abstraction and an agreement between water users (personal communication, RBA 2011).

The long duration of the planning process was shaped by a slow improvement to the actors' understanding of many specific issues; e.g., dynamics of the aquifer, flora and fauna of the wetlands, various EU and national agriculture and water policies. The lack of communication between actors in the UGB has often led to mistrust and is deemed to be one of the main challenges facing the water management regime.

The second period in the formulation of the SPUGB supported cooperation between stakeholders in the UGB and resulted in wider acceptance of the plan.

6 Conclusions and Further Research

The sustainable and adaptive management of services provided by groundwater ecosystems requires the consideration of diverse elements of socio-economic and ecological systems, and also of the corresponding policy base, which governs the allocation and protection of natural resources. Analyzing the success or failure of complex governance structures in highly diverse contexts is a challenge facing researchers. Our understanding of the characteristics influencing the adaptive capacity of governance regime is still limited. A diagnostic approach supports context-specific analysis and helps to provide an understanding of various groundwater governance characteristics. This paper presents a complementary tool–based on the management and transition framework–to assess multi-level groundwater governance regimes, so as to make the management of GWaES more transparent, by drawing on the principles of adaptive groundwater management and the ecosystem services concept. The analysis is based on the assumption that the adaptive capacity of a governance regime increases where there is a high level of vertical integration with greater connectivity between different administrative levels and an active involvement of non-governmental stakeholders. Poor integration of local stakeholders in planning and decision-making processes often leads to difficulties in the implementation of new tools and approaches on the ground. By examining these assumptions researchers can identify linkages between characteristics of a groundwater governance regime and the overall integration of the case-specific context. The process of formulating the *Special Plan for the Upper Guadiana Basin* was chosen as an opportunity to analyze vertical integration during a groundwater management planning process. The plan was developed in order to protect regulating and cultural ecosystem services within the *Las Tablas de Daimiel* National Park without diminishing the provisioning services required to maintain rural livelihoods. The results underlined the assumption that a low level of vertical integration and the exclusion of stakeholders tends to promote conflict. During the first period of the planning process, the prevailing management of the UGB constituted a barrier to adaptive and sustainable management, as it was characterized by poor communication between the administrative levels and a rather rigid bureaucratic system. During the second period the whole process changed in favor of a more integrative and holistic management, including different actors from lower levels.

The framework offers a powerful analytical tool for comparative analysis of diverse cases where similar conditions or challenges exist; e.g., groundwater overexploitation, climate change, irrigation schemes and fragmented groundwater governance systems. An analysis and comparison of experiences over time and across sectors and regions is beneficial and instructive for water managers as it facilitates a transfer of knowledge and information from one case to another, in both developed and developing countries.

One challenge to the application of the framework is the availability and accessibility of information. Firstly, the collection of specific actor-related data depends on cooperation and openness between researchers and experts, which often requires some time to evolve. Secondly, much information is subjective and may not represent a neutral assessment of management processes, and thirdly, scholars need to gather a huge amount of qualitative data in order to arrive at comprehensive conclusions and identify patterns of adaptive and sustainable groundwater management.

The novel framework presented here requires further investigation through application in highly diverse case studies in order to enhance and establish it as a tool, test its robustness and to assess its potential and its limitations. Ongoing research is exploring groundwater governance regimes and the sustainable management of GWaES in diverse geo-climatic regions across Europe and Africa. The overall goal of the comparative case study analysis is to derive patterns and linkages between groundwater management systems, governance characteristics and performance, and the resulting impacts on GWaES.

We encourage readers to apply the framework in their own research, to test it and to enhance it. The development of shared frameworks and knowledge constitutes an important step towards the sustainable management of groundwater resources and the services it provides in terms of human well-being and ecological processes and functions.

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