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# Vulnerability assessment of groundwater resources: A modelling-based approach to the Mancha Occidental aquifer, Spain

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**Abstract**

The semiarid Mancha Occidental aquifer represents a paradigmatic case of intensive groundwater use for agriculture. Irrigation has proven a catalyst for welfare in the area over the last three decades, if at a significant environmental cost and while raising concerns as to its mid-term sustainability. This paper describes an interdisciplinary exercise of scenario design and modelling, providing a methodology to couple hard-science numerical modelling approaches with the involvement of key water actors. Given the long-standing conflicts in the area, modelling work largely focuses on carrying out a vulnerability assessment rather than on trying to find solutions. The system's most resilient aspects and its drivers for change are identified, while their potential implications for aquifer sustainability are assessed under the light of the mandatory objectives established by the European Union Water Framework Directive for all Member States. Whereas modelling results imply that such objectives are unlikely to be met, a vulnerability assessment suggests that even adverse scenario pumping patterns could be sustained in the mid- to long-term (two to four decades).


*Keywords:* Groundwater; Participatory modelling; Mancha Occidental; Aquifer; Vulnerability; Water Framework Directive

## 1. Introduction

The Mancha Occidental aquifer, central Spain, spans an area of 5500 km$^2$ and is home to approximately 300,000 people (Fig. 1). The area presents a continental semiarid climate, where long dry periods alternate with short wet sequences, and hot dry summers follow short mild winters. Average rainfall is approximately 415 mm/yr and potential evapotranspiration is on the order of 1200 mm/yr. Temperatures range from an average 5 °C in winter to about 25 °C in summer.

Together with Toledo and its surroundings, the Mancha Occidental aquifer boasts the most dynamic economy of the Castilla-La Mancha state, an otherwise depressed and scarcely populated region (Fornes et al., 2000).

Groundwater is by far the most valuable water resource in the area. Aquifer-based irrigation accounts for 95% of the total uses, corresponding to an irrigated surface in excess of 200,000 ha (Guadiana Water Authority, 2007). Intensive groundwater development began in the 1970s, mostly through the initiative of individual farmers. Since then, irrigation has brought significant social and economic benefits to the region, mainly due to the ready availability of groundwater on demand and to the reliability of aquifers during droughts (Hernández-Mora et al., 2003; Garrido et al., 2006).

However, groundwater development mostly took place in an uncontrolled manner, while Spain's water authorities traditionally focused on building and managing surface water infrastructures (Llamas and Martínez-Santos, 2005). This led to significant management uncertainties, particularly in regard to pumping and irrigation data, an occurrence which, on the other hand, seems commonplace in many semiarid regions of the world (Shah, 2004; Kretsinger and Narasimhan, 2006).

Pumping caused noteworthy water table drawdowns, severely affecting valuable groundwater-dependent wetland ecosystems such as the "Mancha Humeda" UNESCO Biosphere

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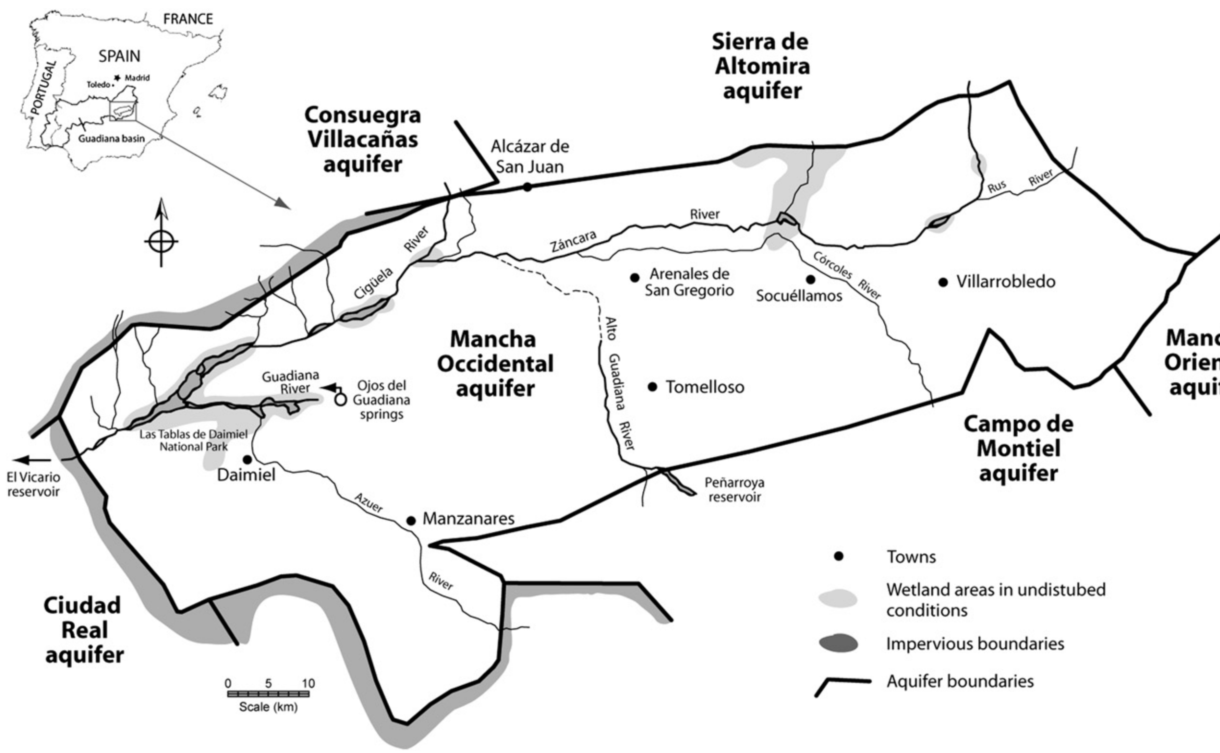


Fig. 1. Geographical setting of the Mancha Occidental aquifer. The aquifer is located within the upper part of the Guadiana basin, one of Spain's driest regions.

Reserve or Ramsar-listed ''Las Tablas de Daimiel'' National Park (Llamas, 1988; Martínez-Alfaro and Castaño, 2001). European subsidies favouring irrigation of water-intensive crops contributed to aggravate these effects during the 1980s and 1990s (Bromley et al., 2001). In recent years, and despite different water-saving initiatives, downward water table trends have not been reversed (IGME, 2004).

This had led to a Significant conflict between environmental conservation groups and farmer collectives have arisen as a result. These are however not the only disputes at the basin scale. Official estimates state that over a half of the existing wells in the area are unlicensed (Guadiana Water Authority, 2005). Unlicensed abstraction not only poses a considerable uncertainty in regard to the area's water uses, but it is also one of the main sources of friction between the Guadiana Water Authority (the agency responsible for groundwater management in the catchment) and farmers (the main groundwater users). Several attempts have been made to correct this situation, ranging from top-down command and control approaches to compensatory payments for farmers to voluntarily cut down on water use (Varela-Ortega et al., 2003). These have traditionally fallen short of potential, largely due to the heterogeneity of views held by the different farmer lobbies, to the existence of illegal pumping and to the lack of coordination between the agencies responsible for implementing water and agricultural policies. Conflicts between farmers and the Water Authority are fuelled by a sense of urgency derived from the EU Water Framework Directive, which establishes an obligation to all Member States to recover a good ecological status of their surface and groundwater bodies by 2015.

A dropping water table (1 m/yr in some areas over the past 30 years) has also raised concerns as to the sustainability of the current situation. Even if agriculture is steadily losing importance as an economic sector, aquifer exhaustion is seen as potentially serious threat in the mid-term (Guadiana Water Authority, 2005). This is because irrigated agriculture still provides an important part of the employment in some municipalities, and also because it is the base for a significant share of the area's industrial sector.

In such a situation, where conflict is commonplace, water data uncertain and sustainability an issue of concern, involvement of the main social actors is perceived as essential in order to devise a sustainable water plan for the future. Within the context of a larger-scale project this paper describes the development of a tool to facilitate the transition to adaptive water management at the basin scale. Adaptive water management is already widely discussed in the literature (Lee, 1999; Stankey et al., 2003; Pahl-Wostl, 2006a). For the purpose of this paper it should suffice to say that public participation is a becoming feature both to adaptive management regimes and to the EU Water Framework Directive (European Commission, 2003; Henriksen et al., 2007). Thus the project seeks to involve stakeholders and water managers from the very outset, asking them what management problems and uncertainties they face and what sort of tools they require to address them.

From the above description it could be inferred that Mancha Occidental water managers and stakeholders currently face a variety of problems. Farmers have significantly depleted the Mancha Occidental aquifer since the 1970s, and

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they now believe groundwater will eventually run out. They wish to know when and where that is more likely to happen, since groundwater is the only water resource they can rely on. On the other hand, the Guadiana Water Authority must ensure a complete recovery of the aquifer and its associated ecosystems within the deadlines established by the EU Water Framework Directive (2015, or ultimately, 2027). In order to comply, they need to factor into pumping plans how much water needs to be saved on a yearly basis. This information is also of interest for farmers and environmental conservation groups, since the former must forfeit the water and the later play an active role as ecosystem restoration advocates.

Controversies therefore boil down to establishing the system limits and evaluating potential tradeoffs between irrigation water demands and environmental flows. As explained later, consultation with Mancha Occidental stakeholders led to the conclusion that these issues could be assessed by means of appropriate decision-support systems, in this case a numerical groundwater flow model.

## 2. Objectives

This paper focuses on the development and participatory application of such a model. The model is in essence a mathematical replica of the physical system, able to dynamically reproduce its behaviour. It is used to simulate aquifer evolution within a series of scenarios, which are drafted according to stakeholder opinion. Modelling work ultimately aims at testing the vulnerability of the system (and hence the stakeholders' own) by considering a range of tradeoff alternatives between agricultural and environmental water demands. This implies that the emphasis was not on finding solutions (probably an unrealistic approach in view of the basin's long-standing conflicts), but to take a step down the right road by letting the stakeholders assess their own vulnerabilities in the face of plausible scenarios.

Aside from explicit stakeholder request, four further reasons justify this exercise. In the first place, the very process of developing the model incorporates advances in terms of understanding the area's aquifer system, particularly due to the availability of significantly enhanced geological and hydrogeological data (Esnaola, in press); secondly, a numerical model allows to simulate a wide range of conditions, providing results that are not only unbiased, but also meaningful to stakeholders both in time and space; third, participatory approaches represent in themselves a much-needed opportunity for stakeholder interaction, especially given the conflicts that exist between the main collectives and the lack of a participatory tradition; and fourth, this kind of exercise may provide a pioneering tool for social learning about groundwater. This exercise could also prove a valuable reference to other settings, since groundwater's ‘‘hidden’’ nature is often misunderstood by users and managers. Hence the difficulties that often surround groundwater resources management all over arid and semiarid regions of the world (Llamas and Martínez-Santos, 2005; Villholth and Giordano, 2007).

Thus, the above features are all desirable in a situation where public participation and groundwater education has traditionally been lacking, groundwater resources are becoming increasingly scarce, key data remain uncertain and significant frictions exist among the main stakeholders (Lopez-Gunn, 2003). Within this context, the following pages may also show how scientific approaches can bring together conflicting social actors (Turton et al., 2007; Marín et al., 2007) through providing ad hoc technical tools and developing a sufficiently transparent framework for dialogue.

## 3. Methodology

Research is carried out in three main stages namely: (1) stakeholder analysis and engagement, (2) model development and participatory scenario design, and (3) scenario simulation. The first step essentially consists in ensuring a representative stakeholder base, striving to involve all key water actors in the process. This stage includes both a decision on the part of all participants as to how the participatory process should be run and a explicit definition of the existing research needs.

Given the existing controversies the group agreed that a desirable outcome of the project would be a vulnerability analysis of the aquifer system. This could be addressed by developing a groundwater model, which would in turn be used to simulate a series of scenarios defined according to stakeholder perceptions. Although separately explained in the following sections, model development and scenario building processes ran largely parallel, merging towards the scenario simulation part of the process (Fig. 2).

### *3.1. Stakeholder analysis and engagement*

Stakeholder involvement plays a major role in this research. This is not only due to the philosophy of the project, but also to the fact that active stakeholder involvement is a requisite of the Water Framework Directive (European Commission, 2003). Within a context of uncertainty and fragmented knowledge it also seems like an appropriate way to tackle groundwater management problems in the Mancha Occidental area.

Uncertainties stem from a general lack of reliable water data, particularly in regard to groundwater abstraction patterns. Even if inroads are being made in the field of remote sensing, there are currently no accurate estimates as to yearly pumping or cropping distributions. Besides, this work deals with a complex social and economic system, where significantly different views are upheld even within the main stakeholder collectives. Involving all key actors is thus necessary to first, attain an adequate qualitative overview of the problems, and second, devise realistic modelling scenarios.

For the purpose of this study a stakeholder is broadly defined as any individual or group influenced by—and with the ability to significantly impact (either directly or indirectly)—the topical area of interest (Glicken, 2000; Hare and

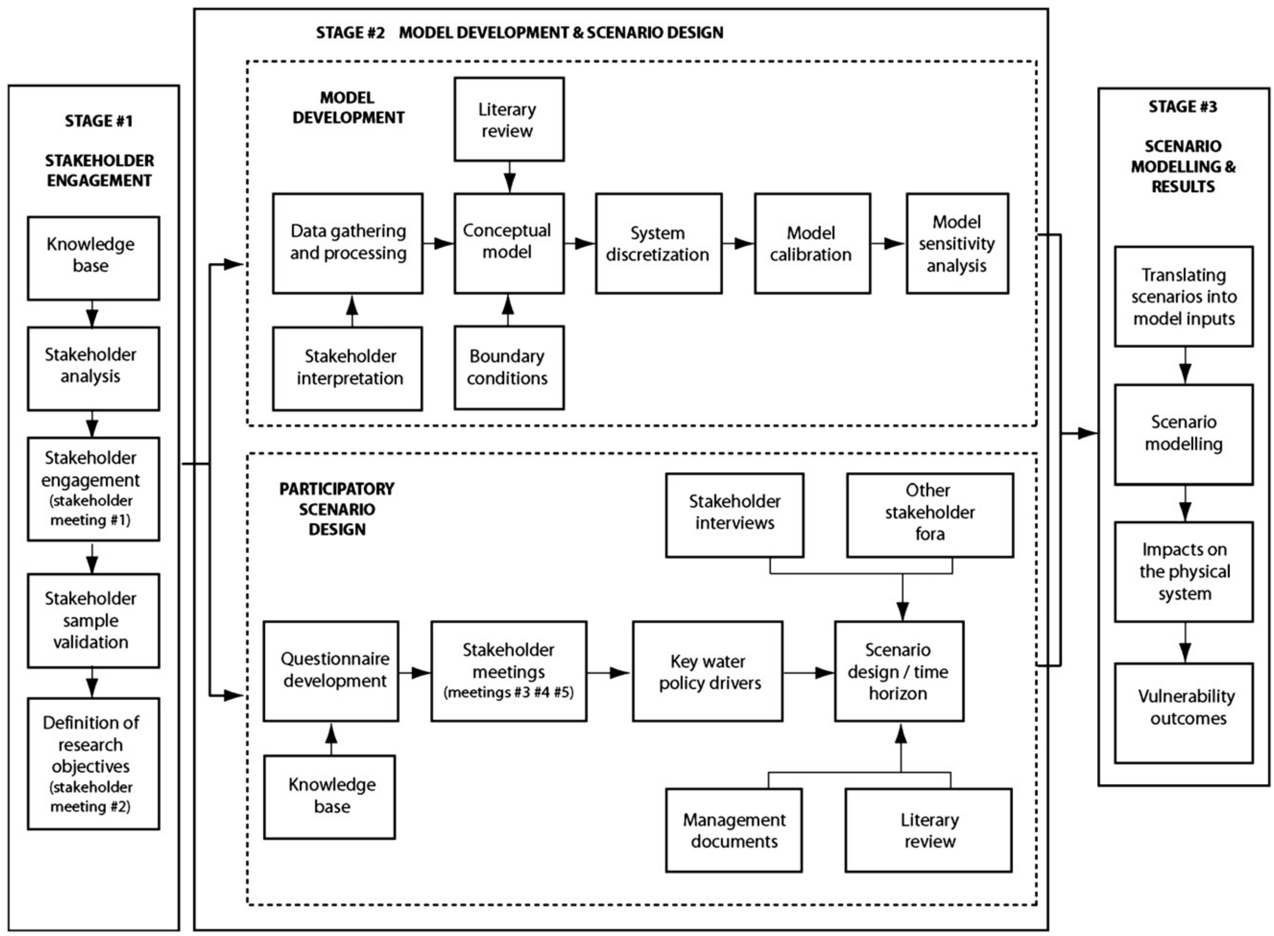


Fig. 2. Methodological overview of the participatory modelling process. The large boxes refer to the three research stages mentioned in the text: stakeholder analysis and engagement, model development and participatory scenario design, and scenario simulation.

Pahl-Wostl, 2002). Stakeholder analysis, understood as the process of identifying the key water actors, was based on the ongoing experience of the research team in the catchment, which spans several decades (Llamas, 1966, 1988; Cruces, 1998; Martínez-Alfaro and Castaño, 2001; Coleto et al., 2003). Selected collectives initially included the Guadiana Water Authority, Spain's Ministry for the Environment, mainstream and local environmental conservation groups, water user associations and farmer unions. This stakeholder cross-section was considered representative on a first-approach basis in view of the controversies and potential vulnerabilities outlined in the first two sections of the paper.

Stakeholder engagement took place via five one-day meetings. These were all held in Madrid between spring 2005 and early 2007 (Fig. 3). Given the conflictive nature of the basin, it was made clear from the beginning that the role of the research team was to provide an unbiased framework for discussion, modelling and social learning, rather than to influence sensitive aspects of decision-making (Martínez-Santos and Llamas, 2007). All meetings were conducted either by an independent facilitator or—whenever this was not possible—by a member of the research team. As shown later on, external observers evaluated the process to ensure its fairness. They also assessed stakeholder satisfaction and evaluated their impression regarding the impartiality of the framework (Correa, 2007a,b).

The first meeting intended to establish contact with the main actors, present the project to them and obtain their willingness to collaborate. It also served the purpose of ensuring a representative stakeholder sample. This was achieved through encouraging the attendants to invite those collectives that they felt might have been missing. Eventually, this led to the inclusion of new stakeholders such as the Agricultural Department of the Castilla-La Mancha regional government (the institution responsible for the implementation of agricultural policies), and the Geological Survey of Spain (responsible for aquifer monitoring).

A second meeting was organised in order to determine needs for research and to decide collectively how to run the participatory process. This meeting led to the implementation of several initiatives, including the modelling exercise that is described in this paper. Besides, it allowed to define how to break down and discuss water issues during the ensuing months. Three thematic reunions followed, focusing respectively on economic, legal-institutional, and hydrological aspects of the area's water policy. As shown later, these provided the basis for scenario design (Varela-Ortega et al., 2006; Hernández-Mora, 2007; Martínez-Santos and Llamas, 2007).

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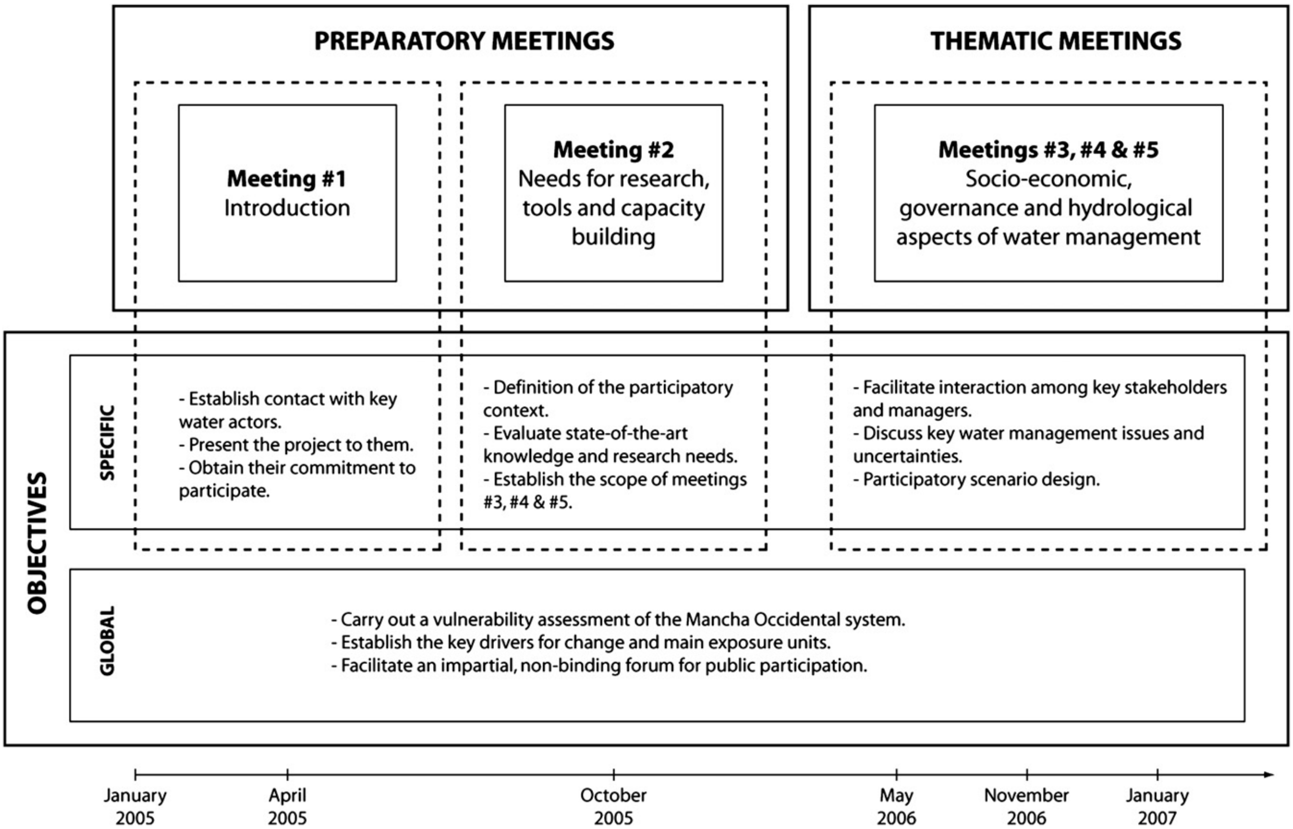


Fig. 3. Schematic overview of the objectives of the stakeholder involvement process.

Table 1 gives an overview of those collectives represented in the process. As shown, solid stakeholder commitment ensured that all conflicting views could be upheld in nearly every one of the meetings. The sample of participants ranged from high-level representatives to individual stakeholders. Among several others, these included the president and the chief planning engineer of the Guadiana Water Authority, the Director of the Rural Development Office of the Castilla-La Mancha Autonomous Government or the president of the Mancha Occidental Groundwater User Association, as well as representatives from environmental conservation groups and individual farmers. Between 20 and 30 people attended each of the meetings, researchers included.

Stakeholders defined the research objectives. They also provided and contributed to interpret model data, and participated to a large extent in devising the modelling scenarios. On the other hand, researchers focused on facilitating stakeholder meetings and putting in the data-entry work to develop the model. This task also included shaping the final version of the scenarios. As explained later on, this obeys to the need to translate scenarios into numerical model inputs.

### 3.2. Model development

Numerical groundwater modelling is a tedious and time-consuming task, which is simply not very well suited to active stakeholder participation. Stakeholders were thus spared the

Table 1
Stakeholder attendance to project meetings

| Collective | Meeting attendance | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| General Water Directorate (Spain's Ministry for the Environment, national administration) | X | X | X | X | X |
| Guadiana Water Authority (Spain's Ministry for the Environment, national administration) | X | X | X | X | X |
| Community of Water Users of the Mancha Occidental Aquifer (water user association, national administration) | X | X | X | X | X |
| Geological Survey of Spain (Spain's Ministry for Education and Science, national administration) | X | X | X | X | X |
| Agriculture Department (Castilla la Mancha Autonomous Government, regional administration) | | | X | X | X |
| Daimiel Centre for Wetlands (Daimiel, municipal administration) | X | | X | | X |
| Association of Groundwater Users of Spain (water user association, civil society) | X | | X | | X |
| World Wildlife Fund Spain (environmental conservation group) | X | X | X | X | X |
| Ecologistas en Acción Ciudad Real (environmental conservation group) | X | X | | | X |
| Coordinadora de Agricultores y Ganaderos—Iniciativa Rural (farmer union) | X | X | X | X | |
| Asociación Jóvenes Agricultores (farmer union) | X | X | X | X | |

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data entry work associated to model development. They did however contribute to the implementation of the model in terms of providing and interpreting data. Each of the stakeholders contributed information in a different way: from the Water Authority and the Geological Survey of Spain, who provided most aquifer-wide hydrological data, to the users, who for instance helped to refine the crop water demand information at the farm scale. Such data was necessary both for model calibration and scenario building purposes.

Following stakeholder request, the groundwater model was developed from scratch. The model is based on a finite-difference code (Processing Modflow 5.3) whose reliability and robustness has been tested in a wide variety of conditions (Chiang and Kinzelbach, 2001). While the modelling methodology is standard (Anderson and Woessner, 1992; Refsgaard et al., 2007) the following paragraphs briefly dwell on how the model was developed. This is a relevant addition to the paper in so much as it provides an overview of the model structure and capabilities. Besides, the model itself is important for two main reasons: first, it is necessary to simulate the scenarios; and second, its very development has contributed to enhance the hydrological knowledge of the system (Martínez-Santos, 2007).

Model development takes place in two steps, which ultimately aim at reproducing the behaviour of the Mancha Occidental aquifer in the computer. The first step (model implementation) consists in replicating the geological and hydrogeological conditions of the aquifer, while the second (model calibration) is used to evaluate how well the prototype is able to reproduce the evolution of the water table over a long period of time. This period must cater for wet and dry weather conditions, so as to ensure that the model responds correctly under a sufficiently wide range of circumstances. Once these steps have been successfully implemented, the model is considered a reasonably faithful clone of the physical reality, and it is ready to simulate scenarios.

### 3.2.1. Model implementation

The first step is in developing the numerical tool is to define the conceptual model of the system, that is, how the hydrological system works in reality (Fig. 4). This includes establishing the system's boundary conditions.

Under natural conditions, Mancha Occidental aquifer recharge takes place mostly through rainfall, lateral inflows from neighbouring aquifer units and infiltration from surface water courses. The latter may also be considered a system outflow, since rivers present a gaining or losing behaviour at different stages along their courses, depending on the season and on whether the climatic sequence is wet or dry. Other natural system outputs are evapotranspiration from the water table and discharges through groundwater-dependent wetlands (Martínez-Cortina and Cruces, 2005).

Intensive pumping has significantly altered the system over the past three decades, practically becoming the sole aquifer output under current conditions. A dropping water table has reduced evapotranspiration dramatically, while also causing the disappearance of most wetland ecosystems. Rivers have become net losers and run completely dry most of the time (Bromley et al., 2001; Martínez-Santos, 2007). Table 2 provides a general estimate of the changes experienced by the system since 1970 in terms of average water budget values.

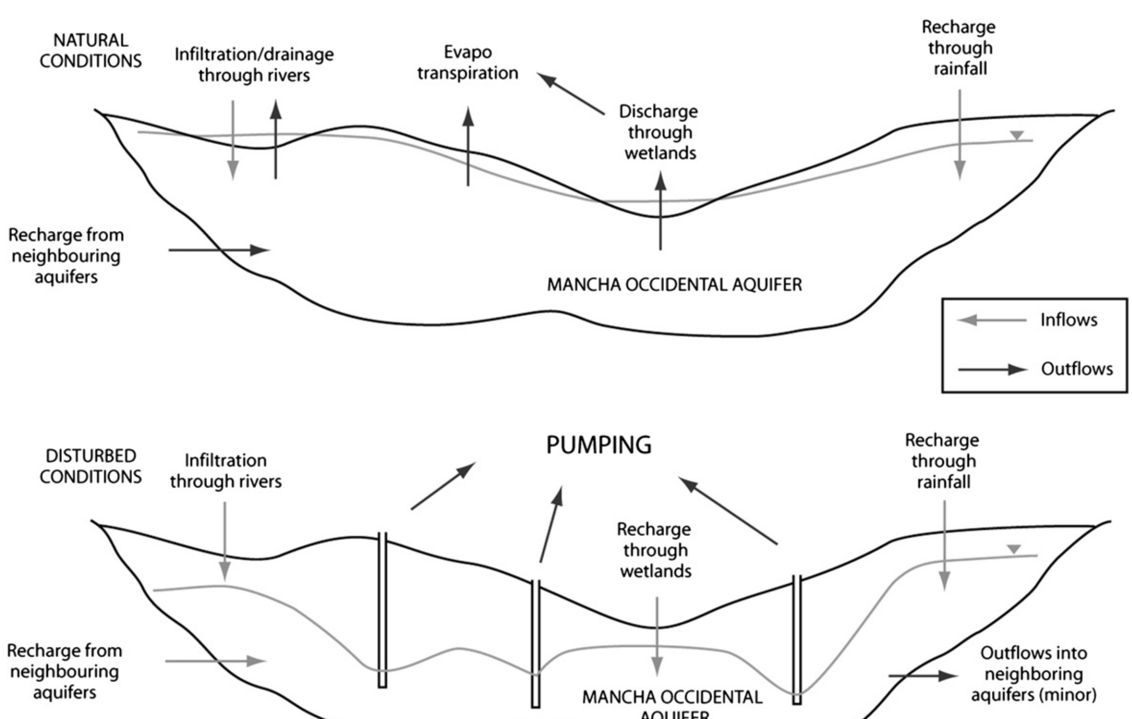


Fig. 4. Conceptual model of the Mancha Occidental aquifer. The figure provides an overview as to how the physical system works under natural (former) and disturbed (current) conditions.

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Table 2
Pumping-induced changes in the Mancha Occidental aquifer water budget: general estimates

| Aquifer budget components | | Prior to 1970 ($Mm^3$/yr) | Disturbed conditions ($Mm^3$/yr) |
|---|---|---|---|
| Recharge | Infiltration (rain and surface water courses) | 200–400 | 200–400 |
| | Inflows from neighbouring aquifers | 40–60 | 40–60 |
| Discharge | Rivers and wetlands | 150–300 | <25 |
| | Evapotranspiration from the water table | 100–130 | <25 |
| | Pumping | <100 | 260–600 |

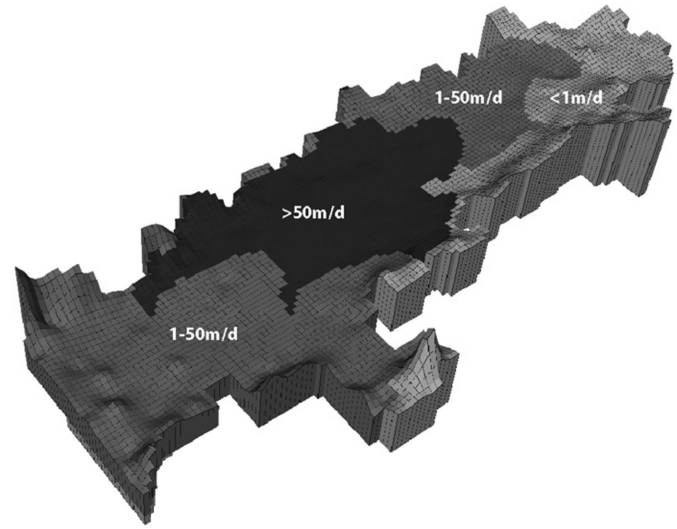


Fig. 5. The numerical model caters for geological and hydrogeological heterogeneities. This figure represents the distribution of time-independent hydrogeological parameters for the topmost model layer (horizontal hydraulic conductivity).

Note the variability in some of the figures, which partly stems from the wide fluctuations proper to the area's semiarid climate.

On the other hand, aquifer geometry is defined throughout by the interpretation of over 400 borehole records (Esnaola, in press; Martínez-Santos, 2007). These incorporate significantly enhanced geological data, leading to an accurate spatial distribution of the three main geological units that constitute the Mancha Occidental system.

From top to bottom, these comprise a Miocene aquifer, whose average thickness is approximately 200 m, a low permeability Cretacic aquitard (50 m) and a deep Jurassic aquifer (100 m). The Miocene unit behaves in an unconfined manner, while the Cretacic aquitard acts as a semi-confining unit for the Jurassic aquifer. The latter units outcrop towards the eastern side of the system.

For modelling purposes, these units have been discretised in five layers, whose horizontal extension varies with depth. Average layer thickness is approximately 130 m for the top layer and 50 m for the other four. Layers do not correspond to the system's geological elements, but rather adapt to the geometrical peculiarities of each unit. This is achieved by establishing specific hydrogeological parameters for each cell, according to the unit to which they geologically belong. Cells are defined at $1 \times 1$ $km^2$ in the horizontal dimension.

Hydrogeological parameters present an irregular areal and in-depth distribution (Fig. 5). Hydraulic conductivity values range from below 1m/d near the system boundaries to nearly 100 m/day in its central areas. The same occurs with specific yield values, which roughly vary between 0.01 and 0.06.

While hydrological data is available, and reasonably accurate estimates exist as to most elements of the water budget (Estrela et al., 2000), others remain difficult to quantify. These must be dealt with on an approximate basis.

Take for instance pumping data, which are far from appropriate. This is largely due to the existence of about 20,000 illegal wells in the area (Guadiana Water Authority, 2005). Moreover, there is little control as to the spatial distribution of cropping patterns, and estimates of the average crop water requirements vary widely. As a matter of fact, an indirect calculation by means of geostatistical methods suggests that official figures may undervalue actual pumping by an average 15% (Martínez-Santos, 2007). This seems roughly consistent with stakeholder and Water Authority perceptions, who state that the number of illegal wells currently operational is probably a little below one third of the figure quoted above. Besides, most of the unlicensed pumping seems to irrigate water-efficient crops, namely vineyards (Guadiana Water Authority, 2007; Martínez-Santos and Llamas, 2007).

Evapotranspiration from the water table is difficult to quantify for the system's undisturbed state, due to the lack of recorded experiences prior to the 1970s. As a consequence, this element of the budget can only be calculated approximately. An average potential evapotranspiration rate of 1000 mm/yr and an extinction depth of 3m were assumed for this purpose. These values, admittedly general, seem consistent with existing estimates (Montero, 1994; Martínez-Cortina and Cruces, 2005).

Finally, there is some uncertainty as to potential exchange flows between the system and neighbouring Mancha Oriental aquifer. This latter unit is located immediately to the east of the Mancha Occidental system, and presents a similar degree of groundwater-based irrigation development. For model calibration purposes, this uncertainty was dealt with through defining a time-variant specified-head boundary. Fluctuations correspond to water table measurements carried out from 1970s to recent times (Sanz, 2005).

### *3.2.2. Model calibration*

Model calibration takes place in two phases, namely, permanent and transient regime conditions. The former refers to reproducing the system's natural (equilibrium) state, and is taken as a starting point for the latter, which in turn aims at reproducing the historical evolution of the aquifer. Once both are satisfactory, the model can be considered calibrated, that is, able to reproduce the behaviour of the physical system. It is then ready for simulating scenarios.

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The water table level measured at 35 piezometres (approximately 1 per 150 km$^2$) is taken as the benchmark to evaluate how well the model is able to replicate the aquifer's actual evolution. The longest available piezometric records go back to the early 1970s, with only a few of the series spanning fewer than ten years. Fig. 6 shows how the model seems to replicate reasonably faithfully the historical water table trends. There are however some local exceptions to the rule in border areas. These may be justified by the geological heterogeneities proper to transition materials, and do not seem to have a significant effect on regional flow patterns. Fig. 6 also suggests that the spatial distribution of calibration points can be considered adequate, even if benchmark data is lacking in some areas.

Note also that there are deviations between observed and simulated water table levels from 1996 onwards. These stem from a lack of reliable irrigation data for that period. In particular, no reliable estimates of areal crop distribution were available between 1996 and 2006. The reason seems to be that in the absence of groundwater metering devices, the Water Authority has largely relied on remote sensing methods. Remote sensing technology is apparently limited in terms of telling apart irrigation and rainfed vineyards. This introduces large errors in the cropping data. Such errors cannot be ignored, the reason being that irrigated vineyards experienced a significant increase from the mid-1990s, becoming one of the area's mainstream irrigated crops.

However, these uncertainties do not necessarily deter from the reliability of the model. Before reaching that point the tool is already calibrated for a period lasting over 20 years (1974–1996), which is considered enough in view that water table records do not often exceed that length (IGME, 1999). Besides, the software allows for the actual water table levels measured in 2006 to be entered as the starting point for scenario simulation, which implies that it is not necessary to model the whole historical sequence before being able to simulate scenarios. Thus the calibration was considered satisfactory.

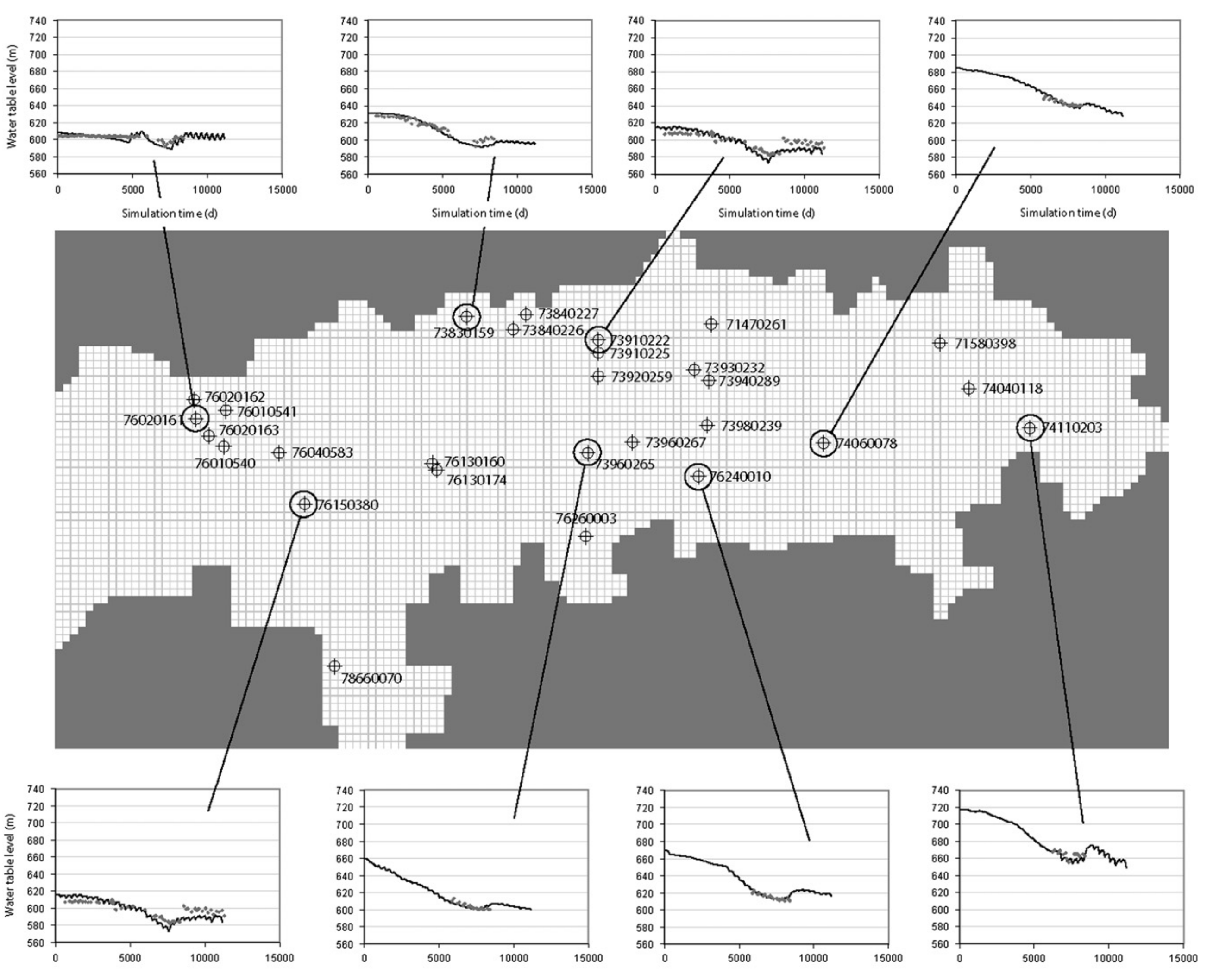


Fig. 6. Overview of the model calibration (i.e. the model ability to replicate the aquifer behaviour for the 1974–2006 period). Dots correspond to field records and continuous lines are numerical model outputs.

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### 3.3. Participatory scenario design

Since rapid change has become an inherent feature of the modern time, vulnerability assessments are increasingly acquiring significance as indicators of risk and of a system's ability to cope with uncertainty. Thus, scenario design is often recognised as a valuable tool within the water policy framework, not only in regard to potential climate hazards, but also to political and legal constraints (Berkhout et al., 2002; Nguyen et al., 2007). Involving stakeholders is a desirable component of such studies, as it can contribute to bridge the gap that often exists between water managers and the field. It may also allow to obtain valuable data at a reasonable cost (Lee, 1999; Pahl-Wostl, 2006b).

Scenarios are useful instruments to think about the future, and to build storylines about how it may unfold (Caille et al., 2007). Scenario building is neither a predictive tool nor a forecast, but rather a way to assess the potential outcomes of current actions. Whether qualitative or quantitative, scenarios may thus provide insights regarding current strategies (Ledoux et al., 2005).

Different authors perceive scenario design in slightly different ways. These, however, share some common procedural stages (Nguyen et al., 2007). The process generally starts by establishing a scenario building team and defining the goals of the scenario design exercise. Data analysis ensues, leading to specify the driving forces and the mechanisms that are likely to induce change. Finally, scenarios are put into a narrative form and tested for internal consistency before the simulation process takes place.

#### 3.3.1. Overview of the scenario-building process

As stated earlier, the scenario building process is undertaken during the third, fourth and fifth stakeholder meetings (Fig. 3). These focused on discussing economic, hydrological and institutional aspects of groundwater management in the basin.

Meetings were divided into several sessions to deal separately with specific aspects of the main theme. Each session consisted in an introduction made by a member of the research team, a discussion in small groups and a plenary debate around the conclusions reached by each one of them. An attempt was made to ensure all the key stakeholders were represented in each of the groups. Note that this was not always possible because there was sometimes an imbalance in the number of representatives from each collective.

Questionnaires developed by the research team provided a starting point for discussion, but did not necessarily constrain the debate (Llamas and Martinez-Santos, 2006). Discussions focused mostly on establishing the key drivers for future change and discussing the different effects these might have upon the Mancha Occidental aquifer system. The outcomes of each meeting were compiled into a report that included the outcomes of the discussions and the anonymous answers to questionnaires (Varela-Ortega et al., 2006; Hernández-Mora, 2007; Martínez-Santos and Llamas, 2007). All such reports were made available to the stakeholders for validation.

In order to ensure that no viewpoint dominated the results a facilitator conducted all three thematic meetings. Anonymous individual answers to questionnaires were also collected to complement discussion outcomes. Some of the absentees cared to mail their responses to questionnaires, which suggests that the sample of results is sufficiently representative. Members of the research team also conducted several one-to-one interviews outside the meetings.

Prior to simulation the scenarios were put to representatives from all stakeholder collectives for their agreement. Scenarios were largely uncontested for two main reasons. First, because a broad enough envelope of potential alternatives was considered; and second, because it was made clear that subsequent runs of the model could be made at anybody's request. How discussion outcomes found their way into scenarios is explained in the following sections.

#### 3.3.2. Driver identification and discussion

Scenario building is first tackled through getting the stakeholders to identify and discuss the system's main drivers for change. According to stakeholder opinion these include the potential effects of the European Union Common Agricultural Policy (CAP) reforms on the Mancha Occidental cropping patterns, the upcoming Upper Guadiana Water Plan (UGWP), the potential reallocation of the existing Tajo–Segura water transfer to the area, reforms of Spain's Water Law and their implications on the issue of illegal wells, and the risks associated to eventual effects of climate change (Varela-Ortega et al., 2006; Hernández-Mora, 2007; Martínez-Santos and Llamas, 2007).

Stakeholder-based diagnoses were confirmed through a series of trend analyses, including a literary review of nearly 200 scientific papers and management documents, as well as several interviews with representatives from national and regional government agencies and other collectives (Martínez-Santos, 2007). Rather than to influence the outcomes of the exercise, the purpose of this parallel work was to bring about elements that might have been left out in the debate, thus contributing to provide more meaningful questionnaires for discussion.

The following headings briefly describe each of the drivers, explaining their significance for scenario building purposes.

*3.3.2.1. Driver #1. Reforms of the Common Agricultural Policy and Upper Guadiana Water Plan.* CAP reforms and the UGWP are two theoretically independent drivers which nevertheless form a tight-knit unit. As irrigation is the area's main groundwater consumer (over 90%) and there is traditionally little control over groundwater pumping, water issues in the Mancha Occidental aquifer are decisively constrained by agricultural policy. This often poses an additional difficulty to water management in the area, because water is the competence of Spain's central administration whereas agriculture depends on the Castilla-La Mancha state government. Take for instance the late 1980s and early 1990s, when CAP subsidies favouring water-intensive crops managed to offset water-saving policies implemented by the Water Authority.

It is no wonder, then, that aquifer recovery hypotheses considered by the UGWP are largely based on potential redistributions of current crop patterns, which are in turn drafted by the Water Authority in accordance with the Castilla-La Mancha state government. Whether these will be achieved obviously depends on the incentives farmers receive to switch to more water-effective practices, and on whether these are compatible with the provisions made by the CAP.

Current EU-level agricultural policy reforms are an issue of concern. Consider for instance the current negotiations within the wine sector. While these are still not over, Brussels seems headed to increase competitiveness through cutting down on the Union's total vineyard surface (European Commission, 2006). Whatever agreement is reached on this point will almost necessarily have a significant impact on the Mancha Occidental aquifer, since vineyards currently amount to about one half of the area's irrigated land.

Besides, vineyards are traditionally considered a reasonably profitable water-efficient crop, and thus a pivotal element in devising aquifer-friendly cropping patterns. Take as an example the "sustainable agricultural model" proposed by the UGWP. This measure aims to reduce the total irrigated surface from over 200,000 ha to 125,000 ha (Guadiana Water Authority, 2006, 2007). Out of these, approximately 50,000 ha would be tree crops (mostly vineyards with some room for olive trees) with approximately the same amount of land dedicated to water-efficient bioenergetic crops (cardoon, rape, sunflower). The remaining 25,000 ha would go to horticultural crops like melons or paprika. Though these crops are comparatively high water consumers, their subsistence is justified by the fact that they generate significant revenues and employment. Not many more economically feasible alternatives seem to exist among the water-efficient crops.

On the other hand, the Water Framework Directive (WFD) seems to have comparatively little bargaining power at the user level. In actual fact, the Water Authority's groundwater management potential is largely restricted to its offer to purchase pumping rights from farmers in order to set up a water market. As stated later, this presents one major inconvenience, as there is relatively little use in considering the possibility of a water market so long as illegal wells are rampant and abstraction monitoring remains practically non-existent.

The above discussion suggests that there are three aspects that the CAP/UGWP part of scenario building should deal with (Table 3). First, there is a question as to whether the CAP and the UGWP will be fully compatible. This is because CAP provisions are set at the European Union level, whereas the UGWP is a basin-scale water management initiative. The sustainable agriculture model proposed by the UGWP attempts to reduce pumping from the current estimation of 400 $Mm^3$/yr to approximately 200 $Mm^3$/yr, largely through favouring water-efficient crops such as vineyards (Guadiana Water Authority, 2005, 2006). Scenario-wise this could be considered the most aquifer-friendly possibility. However, CAP reforms may also result in a significant reduction of vineyard surface, thus offsetting UGWP provisions. Farmers could then switch to profitable horticultural crops (water-intensive). Depending on the overall magnitude of such shift, total pumping could actually increase rather than decrease.

A second issue to consider is whether the initiative of the Water Authority to purchase groundwater rights will be sufficiently attractive to farmers. If so, up to a further 200 $Mm^3$/yr could be saved, thus reducing pumping in the system to a bare minimum. On the other hand, an unattractive offer may result no water savings whatsoever.

Finally, it is obvious that the effectiveness of both measures depends on whether appropriate monitoring devices are installed and pumping limitations can be enforced. This brings about a new constrain, pumping control, which is considered under the next heading.

*3.3.2.2. Driver #2. Water Law reforms and the problem of illegal wells*. Since the late 1980s, the aquifer is subject to a "declaration of overexploitation", a three-fold legal consideration which essentially implies that no new wells can be drilled, that farmers should adjust to yearly pumping restrictions, and that they should all join the different water user associations.

Due to the constrains outlined before, notably the traditional lack of human and economic means on the part of the Water Authority, these obligations have largely been ignored by water users. Pumping restrictions provide a good example. Restrictions vary from crop to crop, and often allocate water amounts which may seem too low to grow certain crops adequately. Take for instance paprika, whose established water allocation according to pumping plans amounts to about 4300 $m^3$/ha/yr, and which may actually require up to 7500 $m^3$/ha/yr; another example is vineyards, which have recently been limited to 800 $m^3$/ha/yr but may need two or three times as much water (Martínez-Santos, 2007). Given that farmers are able to exceed their current allocation, an important point in devising plausible scenarios is to consider whether the established irrigation volumes will be such that can be respected.

A possibility to control pumping would obviously be to enforce vigilance measures. While this is openly mentioned in current discussions, historical evidence shows that control has been far from appropriate to this date (Fornes et al., 2000; Lopez-Gunn, 2003). Attempts on the part of the Water Authority to prosecute illegal pumping have ultimately ended up in several thousand lawsuits, most of which are yet to be settled in court (Guadiana Water Authority, 2007). Besides, water is often a sensitive issue for politicians, who feel they may anger a share of their own constituency by urging the Water Authority to act.

Though potentially complex, this driver is fairly simple to consider from a scenario-wise viewpoint. This is because it essentially boils down to how effective the solution to the problem of illegal wells may be, and to whether this will enable the Water Authority to attain some degree of control over pumping. In other words, the outcome of this driver in terms of scenario design is "pumping control is achieved" or "pumping control

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Table 3
Participatory scenario definition

| Scenario | #1. CAP Reforms/UGWP | #2. Legal reforms | #3. Climate change | #4. Reallocation of Tajo–Segura transfer | Translation into model inputs |
|---|---|---|---|---|---|
| A1 | – CAP and UGWP fully compatible<br>– Redistribution of cropping patterns achieved<br>– Pumping respects limitations<br>– 200 $Mm^3$ worth of pumping rights are purchased by the Water Authority | – Legal reforms stop illegal pumping<br>– High degree of control over total pumping | – Climate change does not have a significant effect during simulation time<br>– Wet climatic sequence (average 450 mm/yr) | – Reallocation of 160 $Mm^3$/yr (urban supply, wetland conservation and pumping substitution)<br>– No new irrigation surface<br>– Cost recovery principle of the WFD is compatible with transfer | **Total pumping = 0 $Mm^3$/yr**<br>**Average aquifer recharge (rainfall) = 328 $Mm^3$/yr** |
| A2 | – CAP and UGWP fully compatible<br>– Redistribution of cropping patterns achieved<br>– Pumping does not respect limitations (more "realistic" crop water needs applied)<br>– 100 $Mm^3$ worth of pumping rights are purchased by the Water Authority | – Legal reforms stop illegal pumping<br>– Low degree of control over total pumping | – Climate change does not have a significant effect during simulation time<br>– Medium climatic sequence (average 415 mm/yr) | – Reallocation of 160 $Mm^3$/yr (urban supply, wetland conservation and pumping substitution)<br>– No new irrigation surface<br>– Cost recovery principle of the WFD is compatible with transfer | **Total pumping = 100 $Mm^3$/yr**<br>**Average aquifer recharge (rainfall) = 265 $Mm^3$/yr** |
| B | – CAP and UGWP fully compatible<br>– Redistribution of cropping patterns achieved<br>– Pumping does not respect limitations (more "realistic" crop water needs applied)<br>– Pumping over Water Authority limitations offsets purchase of pumping rights | – Legal reforms do not stop illegal pumping<br>– No control over total pumping (UGWP limitations not enforced) | – Climate change does not have a significant effect during simulation time<br>– Medium climatic sequence (average 415 mm/yr) | – Reallocation of 50 $Mm^3$/yr (urban supply only)<br>– No new irrigation surface<br>– Cost recovery principle of the WFD is compatible with transfer | **Total pumping = 200 $Mm^3$/yr**<br>**Average aquifer recharge (rainfall) = 265 $Mm^3$/yr** |
| C1 | – CAP and UGWP fully compatible<br>– Redistribution of cropping patterns not achieved<br>– Pumping does not respect limitations (more "realistic" crop water needs applied)<br>– Pumping over Water Authority limitations offsets purchase of pumping rights | – Legal reforms do not stop illegal pumping<br>– No control over total pumping (UGWP limitations not enforced) | – Climate change has an effect during simulation time<br>– Average rainfall decreases by 5% | – Reallocation of 50 $Mm^3$/yr (urban supply only)<br>– No new irrigation surface<br>– Cost recovery principle of the WFD is compatible with transfer | **Total pumping = 350 $Mm^3$/yr**<br>**Average aquifer recharge (rainfall) = 233 $Mm^3$/yr** |
| C2 | – Incompatibilities between CAP and UGWP<br>– Redistribution of cropping patterns not achieved. Horticultural crops (water intensive) grow at the expense of vineyards (water effective)<br>– Pumping does not respect limitations (more "realistic" crop water needs applied)<br>– Pumping over Water Authority limitations offsets purchase of pumping rights | – Legal reforms do not stop illegal pumping<br>– No control over total pumping (UGWP limitations not enforced) | – Climate change has a major effect during simulation time<br>– Average rainfall decreases by 15% | – Reallocation of 160 $Mm^3$/yr (urban supply, wetland conservation and pumping substitution)<br>– New irrigation surface due to the new availability of resources<br>– New irrigation surface results in extra pressure on the aquifer during dry years (100 $Mm^3$/yr) | **Total pumping = 500 $Mm^3$/yr**<br>**Average aquifer recharge (rainfall) = 155 $Mm^3$/yr** |

is not achieved'' (Table 3). Scenarios considering the first case adopt the water requirements per crop outlined by the Water Authority's pumping limitation plans. Scenarios considering the second option assume a greater crop water consumption, which is estimated according to farmer opinions. Both alternatives are in turn interpreted in coordination with driver #1.

*3.3.2.3. Driver #3. Climate change.* Climate change was identified as another driver to consider. A temperature and rainfall trend analysis has been carried out for the 1904–2003 period (Martínez-Santos et al., 2004). While some of its findings could be interpreted as early signs of climate change, the results are mostly inconclusive. Therefore, climate change was dealt with on an approximate basis, taking into account the official forecasts available from Spain's Ministry for the Environment (MMA, 2005).

As shown in Table 3, climate change essentially influences aquifer recharge, since it has a direct impact on the average rainfall. Other impacts could be attributed to this particular driver (likelihood of extreme events, effects on crop yields), but the current lack of thorough studies suggest that state-of-the-art official predictions can be considered sufficient on a first-approach basis. Interestingly, climate change does not seem to feature as high as the other drivers in stakeholder minds. This is largely because they only perceive it as a long-term threat (Martínez-Santos and Llamas, 2007).

*3.3.2.4. Driver #4. Reallocation of the Tajo–Segura transfer.* A potential reallocation of the existing Tajo–Segura transfer may bring a significant amount of external water resources into the area. The transfer, operational since the late 1970s, is a 300 km canal that links the Tajo and Segura basins through Guadiana territory. It presents an average conveyance of approximately 350 $Mm^3$/yr.

Whether this should remain the case is subject to controversy. Guadiana farmers, mostly based within the Mancha Occidental boundaries, believe they should have preferential rights to the transfer. Their claim is based on an administrative premise, since both the transfer uptake and the upper Guadiana basin are located within the Castilla-La Mancha region. Thus, they feel that transferred water should supply the region before being sent beyond its borders. On the other hand, the Segura basin flags its ''historical rights'' as current recipient of the water, arguing that the social and economic dependence born from the transfer cannot simply be overlooked. Segura and Guadiana lobbies often accuse each other of tolerating uncontrolled water use within their respective jurisdictions.

The upper Guadiana lobby is slowly gaining ground in this dispute, securing two diversions from the mainstream transfer since the late 1980s. The first corresponds to an environmental flow to maintain some ecosystem functionality at the wetlands known as Las Tablas de Daimiel National Park, while the second corresponds to a 50 $Mm^3$/yr transfer for drinking supply. The former has been in place for two decades and the latter is currently under implementation. Further reallocations into the Upper Guadiana are however likely to meet with mounting opposition, particularly if the water is to be used for irrigation purposes. In the view of the stakeholders, it seems unlikely that anything over 160 $Mm^3$/yr may be reallocated to the Guadiana area. This is largely because the remaining flows seem to support long-standing developments in the Segura basin.

Additional flows could substitute pumping in the Mancha area. Nevertheless, an issue of concern with external water resources is always whether these could also result in transforming rain fed areas into new irrigation farms (Garrido et al., 2006). Should this happen, the transfer may not only fail to mitigate current pressure on the Mancha Occidental aquifer, but it could actually contribute to increase it during dry years. This is because transfer-dependent farmers would then resort to groundwater in order to salvage their crops.

Moreover, since surface water is heavily subsidised in Spain, most farmers claiming for a reallocation of the transfer seem to assume they will get the water for free. This seems in open contradiction with the WFD, which establishes a cost-recovery principle for water infrastructures. Whether or not tariffs will be sufficiently attractive in the eyes of farmers is yet to be seen. Groundwater remains fairly cheap despite a continuously dropping water table (0.06 €/$m^3$ to 0.12 €/$m^3$ for an average drawdown of 25 m). This basically means that if transferred water results more expensive than groundwater farmers will simply continue to pump.

Therefore this driver presents a three-fold consideration. First, whether there will be a reallocation to the Mancha Occidental area (and how much extra water that would bring into the system); second, whether new flows will result in new land plots coming under irrigation; and third, whether the cost-recovery principle will be applied in practice. Their quantitative significance on the aquifer system is outlined in Table 3.

Finally, it should be stressed that Segura stakeholders were not present in these discussions. One reason for this is that involving people from other basins is beyond the scope and resources of the project. Furthermore, it would also be difficult to involve representative Segura stakeholders just to discuss one of the drivers (particularly since this would be a small part of a broader exercise focused on a ''foreign'' basin). Moreover a potential reallocation of the transfer is already sufficiently controversial within the Upper Guadiana basin itself. Some stakeholders (mostly farmers) think the transfer is necessary, while others (environmental conservation organisations) think that it would basically be a waste of public funds that would only exacerbate the area's water management problems. Therefore it could be argued that there was a sufficient diversity of opinions represented in this participatory exercise, including a frontal opposition to the reallocation of the transfer.

*3.3.3. Scenario design*

The scenario building process requires first an explanation as to how each of the drivers can be expressed in terms of model inputs. The model is essentially a hydrological tool that can only handle variables such as pumping rates or rainfall series. Therefore, for each scenario it is necessary to translate the influence of each driver into datasets such as pumping rates and climatic variables. Sometimes this can be done directly. It is the case of climate change estimates, which can be expected to have a future impact on the average yearly rainfall (in itself a modelling input). On the other hand, translating the effects of other drivers into modelling outputs requires a more indirect approach. Take as an example agricultural policy, which operates on non-hydrological variables such as subsidies, irrigation systems or crop yields. These cannot be handled directly by a groundwater model. It is nevertheless possible to estimate how much groundwater needs to be pumped from the aquifer (a valid model input) based on the amount of water each crop needs and the cropping pattern that a given policy alternative is likely to generate. Other drivers, such as legal reforms, also influence groundwater extraction rates, since these depend on whether pumping restrictions can be effectively enforced.

In terms of modelling inputs, most of the drivers fit under either aquifer recharge or groundwater extraction. In turn, these may indirectly affect other elements of the water budget, such as evapotranspiration or stream flows.

As shown in Table 3, a coherent interpretation of the drivers led to defining an envelope of five water management scenarios, including best-case (A1) and worst-case (C2) hypotheses. Favourable scenarios (A1 and A2) initially referred to a situation that could lead to fulfilling WFD objectives in regard to aquifer recovery. In turn, scenario B corresponds to an intermediate alternative. Hypotheses C1 and C2 refer to cases where current pumping trends would not be reversed.

A baseline scenario is finally provided as a benchmark for comparison (Fig. 7). This essentially entails a "business-as-usual" perspective whereby current pumping would be maintained. In the absence of a more accurate figure, a more or less generally accepted 400 $Mm^3$/yr estimate is adopted. The baseline scenario assumes an average rainfall sequence (415 mm/yr).

### 3.4. Simulation results and vulnerability assessment

Numerous conceptualisations of vulnerability exist in scientific literature, often in contraposition with the concept of resilience (Holling, 2001; Brooks et al., 2005). One widely accepted definition is "the differential exposure to stress experienced by different exposure units" (Henriksen and Barlebo, 2007). The notion of vulnerability has however been subject to many different assessments and has been matched to a wide variety of concepts (Gunderson and Holling, 2002; Luers et al., 2003; Füssel, 2007). As a consequence, vulnerability has sometimes been considered "a rhetorical indicator of areas of greatest concern" (Timmermann, 1981). This is partly why some authors advocate the need to establish a concise conceptualisation of the term, particularly when there is

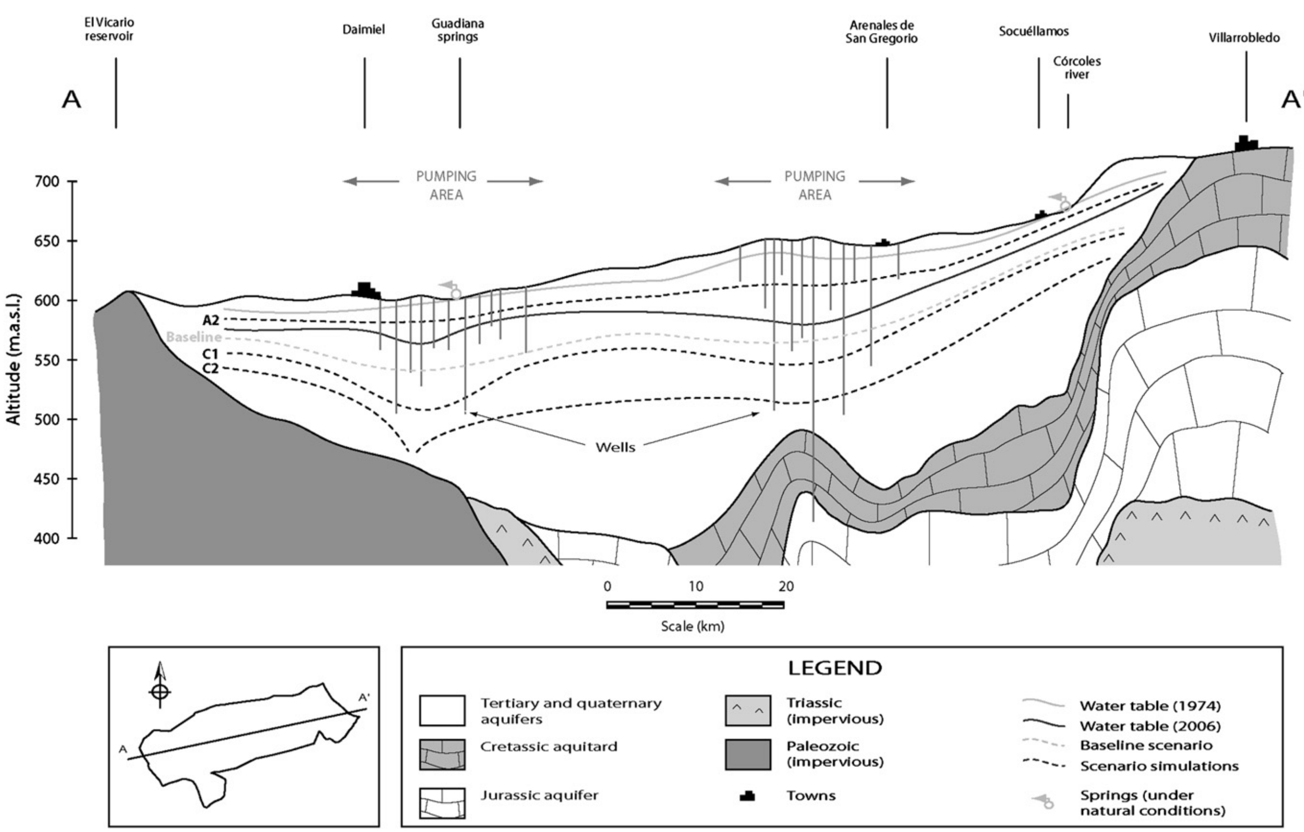


Fig. 7. Scenario modelling results. These correspond to the simulated water table depth for some of the scenarios (A2, C1, C2) versus the natural and current depths of the water table. Results refer to the 2027 horizon, corresponding to the deadline established by the EU Water Framework Directive to recover a good qualitative and quantitative state of all groundwater bodies (including two 6-year extension periods from 2015). A baseline scenario is included for reference.

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a need to assess it at a practical level (Luers, 2005; Füssel, 2007).

The primary objective of vulnerability assessments is to identify people or places that are most susceptible to harm and to identify vulnerability-reducing actions (Stephen and Downing, 2001; Luers, 2005). Following in this intent, the present analysis deals with vulnerability in an ad-hoc manner, suited to the peculiarities of the system. In other words, vulnerability is assessed through applying the model to simulate the scenarios defined in previous sections. This allows for an evaluation of the potential consequences that the system, i.e. the aquifer and its dependent wetlands, would experience under each scenario. In turn, these impacts are likely to cause different stresses on the different stakeholder collectives. From this point of view it could be argued that vulnerability means "running out of groundwater" to farmers, "not complying with the EU deadlines" to water managers and "not recovering wetlands" to environmental conservation groups.

Model outputs are expressed in terms of water table levels. The model predicts what is likely to happen with the aquifer within each scenario. This allows the stakeholders to evaluate how their interests would fare in terms of the available groundwater resources. Farmers are able to see which areas may be more vulnerable to groundwater exhaustion and when this may happen. The Water Authority and the conservation groups are more interested in how modelling outputs represent a potential aquifer recovery.

Simulation considers a double time horizon, 2015 and 2027, consistent with the deadlines established by the WFD for the recovery of a good quantitative status of surface and groundwater bodies (European Commission, 2000).

Fig. 7 presents a geological cross section where model outputs for some of the simulation hypotheses (A2, C1, C2) are plotted against the natural and current states of the system. The figure represents modelling outcomes for the 2027 horizon. In terms of complying with the WFD deadlines, modelling results suggest that full system recovery is unlikely. Only the most favourable hypothesis (A1) would ensure a nearly complete restoration of the system, while more realistic hypotheses (A2, B) yield encouraging yet insufficient results. Scenario B also suggests that pumping could be sustained indefinitely, while in turn attaining a slow recovering the system. This, however, would by no means comply with WFD requirements, as it would probably take several decades to restore the aquifer.

On the other hand, only worst-case scenario simulation (C2) yields signs of groundwater exhaustion. The model suggests that severe effects are unlikely to become apparent within the next twenty years. Even then, these would probably be restricted to the Daimiel and Villarrobledo areas, as well as to the aquifer boundaries. Under C2 conditions, farmers from these regions would be the most immediately vulnerable to water scarcity. In contrast, intensive pumping (C1) could seemingly continue for several decades throughout the most part of the system. This appears more evident in the case of its central and south-eastern sectors, where permeable Jurassic formations over one hundred meters thick underlie the Miocene aquifer (Fig. 7). Both C1 and C2 alternatives imply a further depletion of the water table below the baseline conditions.

### 3.5. Model limitations

Whereas numerical modelling provides the best approximation available to deal dynamically with complex groundwater systems, this kind of tool is obviously a simplified approximation to reality. This implies that results should always be taken as general estimates and handled with a healthy degree of care, particularly in instances where these are put to stakeholders or the general public.

In addition, this study deals only with quantitative aspects of the system, thus ignoring groundwater quality issues. While the latter stem mostly from irrigated agriculture (and have already been assessed by other sources (IGME, 2004)), it is necessary to note that water quantity has traditionally been perceived by the participants as a more pressing concern than water quality—even more so given that external water resources will soon replace groundwater in meeting the area's urban supply demands.

Moreover, the present assessment is one-sided in the sense that it only refers to the hydrological aspects of the problem. Obviously, these are in themselves of the utmost importance, but it is also evident that the economic and social aspects of the problem need to be considered. These are currently being studied and in time will be integrated with the results of the present exercise. In addition, scenario design is carried out by means of a perception-based methodology. While the practical limitations of such an endeavour are obvious, these are partly addressed by involving a highly representative sample of stakeholders, as well as by devising a wide envelope of management scenarios.

Finally, future water policy in the area may be constrained by other factors beyond current consideration. Take for instance the provisions of the World Trade Organisation, the preferential food-trade agreements between the EU and the Magreb countries or a potential entrance of Turkey in the Union, all of which are likely to affect Spain's agriculture in the mid-term. While these have not explicitly been dealt with here, current trends suggest that their outcomes are unlikely to either aggravate the worst-case hypothesis or improve the most favourable scenario. Thus, these are tentatively assumed to fall under the envelope of conditions that has been provided.

## 4. Discussion

Stakeholder involvement within the project was evaluated externally in order to ensure a fair process and outcome (Table 4). Stakeholder perceptions were compiled in two different reports which provide the basis for most of the following paragraphs (Correa, 2007a,b).

From an overall point of view, the stakeholders consider the methodology to be an innovative and welcome addition to the basin. They also see this exercise as something useful in the sense that it has helped them to gain a better understanding

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Table 4
Summary of the evaluation of the participatory process (Correa, 2007a)

| Question ("In my opinion…") | n | SA | A | N | D | SD |
|---|---|---|---|---|---|---|
| 1. The participants in this process fairly represent the members of the public who will be affected by the issues raised | 18 | 49% | 39% | 6% | 6% | 0% |
| 2. The process has been run in an unbiased way | 17 | 41% | 41% | 12% | 6% | 0% |
| 3. This process has taken place at a sufficiently early stage to allow participants to have some genuine influence | 17 | 18% | 35% | 29% | 18% | 0% |
| 4. The recommendations that arise from participants in this process will be implemented by the water managers and other decision makers | 18 | 0% | 17% | 38% | 39% | 6% |
| 5. The process has been transparent | 18 | 39% | 50% | 11% | 0% | 0% |
| 6. The process provided me with sufficient resources to take part in it effectively | 17 | 47% | 35% | 18% | 0% | 0% |
| 7. The nature and scope of the task was well defined | 18 | 28% | 60% | 6% | 6% | 0% |
| 8. The process was well organised and managed on a practical level | 18 | 28% | 49% | 11% | 6% | 6% |

Columns: *n*, number of replies; SA, strongly agree; A, agree; N, neither agree or disagree; D, disagree; SD, strongly disagree.

about the hydrological system, how vulnerable they may be in the face of different scenarios and the chances they stand in terms of achieving their own objectives. It could therefore be argued that the model has proved a valuable social learning tool. Moreover, the impartiality of the participatory framework has contributed to cultivate personal relations among key players, who have been able to discuss frankly and freely about water management issues. Given the conflictive nature of the basin, this is also perceived as a positive contribution. The model has also helped to develop a greater understanding of the uncertainties associated to groundwater management in the region.

External evaluation has also shown some weaknesses in the participatory process. An evident one in the eyes of participants—particularly given the current prominence of water issues in the area's political scene—is the absence of first-order political personalities. Even if the key water actors were represented, this hampers a potential translation of the process results into policy outcomes. A reason that explain this is that the 5000 M€ Upper Guadiana Water Plan is still being negotiated, and with such an amount of funding at stake it is only reasonable to expect that decisions will be made only at the highest political level.

Besides, the modelling exercise has shown that win–win solutions are unlikely, thus failing to yield unanimous recommendations to address the area's water woes. While this is something that can be partly attributed to the limitations of the tool (which can only address the water resources side of vulnerability), it is most importantly the result of a situation that has been out of hand for too long. In any case, given the area's long-standing conflicts, win–win solutions looked unlikely from the outset. The purpose of the work therefore was to take steps down the right road, letting the stakeholders address their own vulnerability under different scenarios rather than to provide a solution to the problem.

Stakeholders did neither contest the geological and hydrogeological assumptions underlying the model, nor the results from scenario simulation. One possible explanation is that they saw the research team as sufficiently impartial (Table 4). In addition, the nature of the exercise allowed for individual stakeholders to come up with their own scenarios and get the researchers to model them (in actual fact, representatives from the Water Authority requested some more runs around the intermediate scenarios). One final reason why modelling results were uncontested may have been the fact that the details of the tool were still too technical for the stakeholders. Thus, even if they all seemed to understand its outcomes sufficiently, they would have felt uneasy about challenging them. Be as it may, from the very outset the research team was quick to point out the deficiencies in hydrological and hydrogeological input data (Martínez-Santos and Llamas, 2007). This may provide another explanation as to why the stakeholders generally perceived the process as transparent.

Notwithstanding the above, and the relatively recent implementation of the model, this exercise has seemingly found some echo in stakeholder behaviour. Take for instance the case of environmental conservation organisations. These have partially relied on the model results to voice their views about the latest version of the Upper Guadiana Water Plan (A. Fernández-Lop, Department of Continental Waters of the World Wildlife Fund in Spain, personal communication, September 2007). Another example is the president of the Community of Water Users of the Mancha Occidental aquifer, who arranged for the modelling results to be presented openly to farmers at a one-day meeting with the president of the Water Authority and a high representative of the Agriculture Department of the Castilla-La Mancha state government (A. Apio, President of the Community of Water Users of the Mancha Occidental Aquifer, personal communication, October 2007). Yet another interesting outcome is that members of the research team have been on national and regional media at the request of different stakeholders.

Time will tell whether there this exercise will eventually result in concrete policy outcomes after all. Nevertheless, the above suggest that participatory modelling has succeeded in enhancing stakeholder knowledge about their own aquifer system, identifying the main exposure units and narrowing down some of the key uncertainties that hamper groundwater management in the area.

## 5. Conclusions

In a world of rapid change, water policy is frequently constrained by growing management uncertainties. These may not

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only stem from the hydrological systems under consideration but also from exogenous decisions or hazards. While it is unrealistic to pretend that these uncertainties can be completely dispelled, this participatory exercise shows that inclusive stakeholder processes and adequate technical tools may prove a beneficial in narrowing down and improving stakeholder understanding about the difficulties associated to groundwater management.

This paper presents the methodology and main outcomes of an interdisciplinary modelling exercise focused on the Mancha Occidental aquifer, Spain. Research incorporates a vulnerability analysis of the study area, based on coupling hard-science modelling approaches with the involvement of key water actors. From the environmental modelling point of view this approach has proven a valuable social-learning tool, providing a transparent framework for stakeholder interaction in a traditionally conflict-prone area. This is particularly relevant given the uncertainties that exist in regard to groundwater resources. Scenario modelling serves the purpose of establishing the system limits, while also considering potential tradeoffs between agricultural and environmental water demands that may lead to its recovery.

Modelling results show the system to be more vulnerable to resource exhaustion along its boundaries, as well as in the Daimiel and Villarrobledo areas. Worst-case scenario outcomes suggest that some of these places may experience significant water shortages by approximately 2030. On the other hand, pumping could continue for several decades in the central and south eastern sectors of the aquifer. More balanced simulation hypotheses point at pumping patterns that may be sustained throughout the whole system over the next 40 or 50 years. Aquifer recovery and wetland restoration seems however unlikely. Modelling results suggest that the area will not comply with the 2015 Water Framework Directive deadline for the recovery of a good quantitative status of groundwater bodies. Even if agricultural policies lead to dramatic changes in the area's current cropping patterns full system recovery will almost certainly require the maximum extension (two 6-year periods) allowed by the Directive.

This modelling exercise provides a pioneering public participation initiative in a basin where such schemes have traditionally been lacking. Even though no win–win solutions were found, it can still be considered a step down the right road in as much as it helped stakeholders realise their own vulnerability under different scenarios. Moreover, it is probably a positive contribution to the area's water management practices, particularly in view of the participation demands established by the Water Framework Directive and the degree of reported stakeholder satisfaction. Finally, it could also provide a valuable methodology to inform policy within contexts where conflicts are not so deeply ingrained.

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