

# Chapter 11

## Multidisciplinary Assessment of Nature-Based Strategies to Address Groundwater Overexploitation and Drought Risk in Medina Del Campo Groundwater Body



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### Highlights

- Noticeable improvement in knowledge of the MCGWB geological, geophysical and hydrogeological aspects: aquifer geometry, behaviour and ecosystems-aquifer interactions.
- Assessment of MAR effectiveness in the Trabancos sub-basin.
- Participatory Modelling activities have been used to develop a comprehensive understanding of the scope of the system.

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- The main variable controlling risk in Medina del Campo is human activity.
- Reduction of groundwater abstractions would be the most critical necessary measure to recover GRES and aquifer storage.
- NAS strategy 1 with crop changes and water management measures showed the highest cost-benefit ratio.

## 11.1 Introduction

The Medina del Campo Groundwater Body (MCGWB) is the biggest aquifer system located in the Duero River Basin, in Central Spain. Being a drought prone area, the MCGWB has experienced intense exploitation in the last decades mainly for irrigation (which represents 96% of the total annual extractions), and for drinking water supply and other (industrial) uses. As a result, the sharp decrease in groundwater levels (Fig. 11.1) has induced water quality degradation, severe deterioration of dependent wetlands and streams, and eventual reduction in the delivery of ecosystem services in the area.

The Groundwater Directive 2006/118/EC and the Water Framework Directive 2000/60/EC impose the obligation for the Duero River Basin Authority (DRBA) to assess the impact and damages from existing pressures, and to take measures to restore the good quality status by 2027. In the case of the MCGWB, the main threats identified include lowering piezometric levels, diffuse agricultural pollution ( $\text{NO}_3$  contents up to 190 mg/L), and elevated arsenic contents of lithological origin (up to 240  $\mu\text{g/L}$ ). A first measure established by the DRBA to address these pressures was a water transfer from the neighbouring Adaja River and the Cogotas reservoir to substitute groundwater by surface water for irrigation in the Adaja irrigation district (6000 ha). As a result, a localised recovery on piezometric levels was detected in the surrounding area due to the double effect of stopping groundwater extractions and increased replenishment from surface return flows.

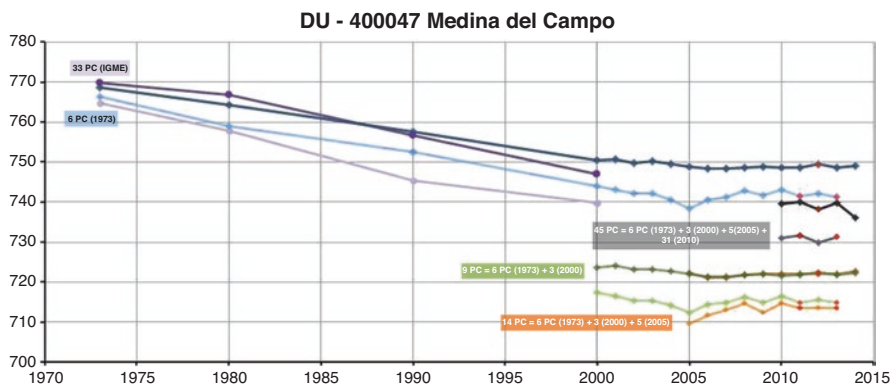
The NAIAD framework was applied in the case study with the aim to contribute in finding and evaluating different nature-based strategies to address these challenges. The study pursued to identify and assess possible Natural Assurance Schemes (NAS) that could help reduce water related risks while restoring the aquifers system status and functions. With this objective, a series of NAS strategies were co-designed with local stakeholders combining NBS and soft measures (Table 11.1). The process followed the iterative steps set by the NAIAD stakeholder protocol described in López-Gunn et al. (2022 – Chap. 2 in this volume). The collaborative approach was combined with an analysis of their legal and technical feasibility by the DRBA.

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**Fig. 11.1** Groundwater level evolution in Medina del Campo Groundwater body (1975–2012) according to river basin management plan. (Source: CHD 2013)

**Table 11.1** NAS strategies considered for reducing vulnerability against drought risk while restoring the aquifer system status and functions in the Medina del Campo Groundwater Body

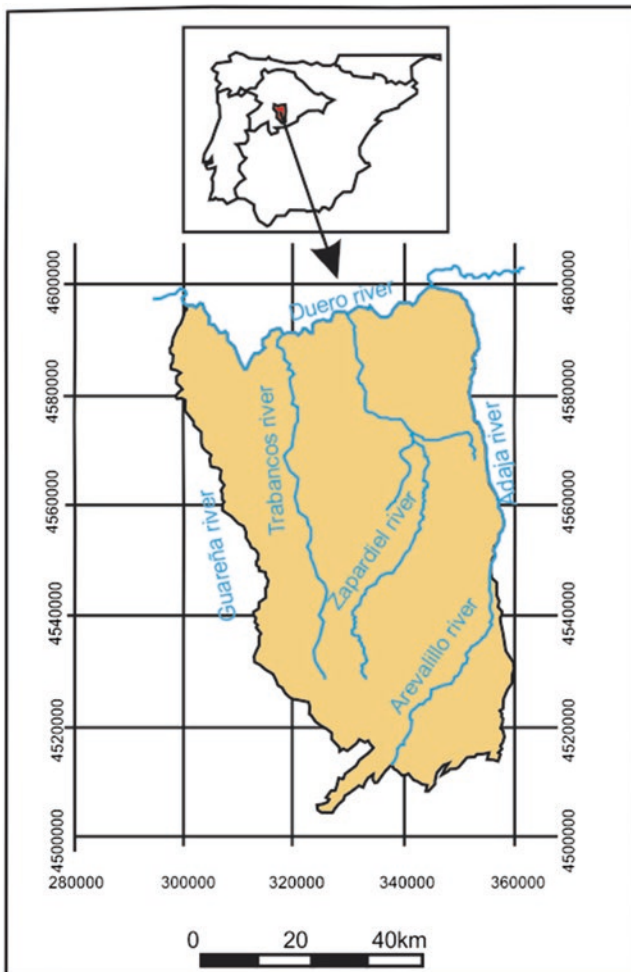
Business as usual	Strategy 1	Strategy 2
<b>Measures</b>		
No measures are applied	<b>NBS:</b>	<b>NBS:</b>
	Crop change towards drought resilient species	Aquifer recharge through the Zapardiel river using the Adaja irrigation infrastructure to restore riverine ecosystems
	Soil and water conservation practices	
	<b>Soft:</b>	<b>Soft:</b>
	Water user associations (WUAs) formation	WUAs formation
Abstractions monitoring and control	Abstractions monitoring and control	
Environmental awareness raising	Environmental awareness raising	

The NAS strategy considered for reducing flood risks was based on an intervention project designed by the DRBA consisting on the removal of dikes, the re-naturalisation of the Zapardiel River banks and the enhancement of floodplains upstream to prevent floods in the town of Medina del Campo. However, the assessment of this strategy could not be performed because it was not technically possible to simulate the potential effects of the measures on reducing the flooding impacts. Therefore, only the drought related NAS strategies were analysed and are discussed hereafter.

This chapter presents the different methods and tools developed to assess the impacts and effectiveness of the selected NAS strategies in biophysical, economic and social terms, following the approaches presented in Chaps. 4, 5 and 6 of this volume. It also summarizes the approaches for integrating all these assessments, as well as the main conclusions and lessons learnt with views to the design and implementation on NAS for adaptation to droughts in the study area.

## 11.2 Biophysical Characterization and Assessment of the MCGWB

The MCGWB is the central part of the former so-called Los Arenales Aquifer System (Fig. 11.2), currently divided into three Groundwater Bodies. It is a semi-arid region, with average precipitation around 450 mm/year and high dependency on groundwater for agriculture and urban demands. The MCGWB belongs to the Duero river basin, administratively encompassed within the Castilla and Leon region (Spain). The MCGWB covers an area of 3700 km<sup>2</sup> (see Fig. 11.2) and is crossed from West to East by four main rivers – Guareña, Trabancos, Zapardiel and Adaja – and one tributary of the Adaja river by the left margin – Arevalillo.



**Fig. 11.2** Location of Medina del Campo groundwater body within the Duero basin. (Source: modified from de la Hera-Portillo 2020a)

Intensive groundwater exploitation since the early 1970s, mainly for agriculture, induced a decline of groundwater levels up to 30 m in 40 years between 1972 and 2012. The sustainability indicator defined by the WFD, the Exploitation Index (ratio between groundwater recharge and abstractions), has passed the threshold value of 0.80 for the mentioned period (1972–2012) and is currently established in 1.65, according to the DRBA (DRBA, oral communication).

The overall aim of the analyses included in this section was to improve the understanding of the aquifer system structure and functioning, including the aquifer-rivers-wetlands relationships, as a basis to support simulation of the potential physical effects of the NAS strategies on the evolution trends of groundwater quantity and quality under different climate scenarios.

### ***11.2.1 Improvement of Geological, Geophysical and Hydrogeological Knowledge***

The first step was to check that most part of the hydrogeological knowledge of the MCGWB came from the former recognition of Los Arenales Aquifer System. The previously existing geological, geophysical and hydrogeological knowledge was compiled and reviewed as a baseline to build a conceptual model of the MCGWB.

The study has detected an important knowledge gap with regard to the geometry of the aquifer, which was estimated around 500 m deep based on the level of the existing wells. The existing geological and geophysical information has been integrated into a 3D geological model that allowed to reproduce the geometry of the whole aquifer system, showing that the real depth can go down to 2000 m in the area of Arevalo (De la Hera-Portillo et al. 2020b). This finding is key to understanding the response of the aquifer to groundwater management actions. The long period of high water pumping rates has caused the upper unconfined aquifer to act as a perched aquifer which recharges the deep regional aquifer, being the latter the most intensively exploited over the last 50 years. Under natural conditions, the rivers and wetlands played as discharge zones for the entire aquifer system, whereas in the current conditions they are solely connected to the upper layer (perched aquifer), receiving discharges from the unconfined aquifer only in wet periods. Under natural conditions (i.e. before the increase in water pumping that started in the 1970s), there were over two thousand wetlands and surface water bodies associated to the MCGWB, of which only a few remain today (de la Hera-Portillo et al. 2020a).

A second analysis consisted in a review of historical information about one of the most representative wetlands of the MCGWB: Lagunas Reales wetland. They are located 5 km southwest of Medina del Campo town (Fig. 11.2). There are references reporting the use of these ponds for fishing of tench and eels along 1500–1800, although water transfers from the Zapardiel River were also a frequent practice in order to keep the appropriate water level. The sedimentological analysis shows that these ponds should have been permanent before 1700, seasonal between 1700 and 1983, and fed by groundwater after 1983. From that date onwards, the system became disconnected from the regional aquifer (De la Hera-Portillo et al. 2020a), as

a result of the piezometric drop caused by increasing pumping for irrigation. The sediments also show that the salinity of the waters has changed over time and there are markers of human activity (Mediavilla et al. 2020).

A set of facts called our attention when studying the aquifer-rivers historical relationship: concerning the four rivers crossing the MCGWB: (1) All these rivers are currently dry; (2) the existence of gauging stations in these rivers was anecdotal; (3) the available information on gauging measurements points out that some base-flow occurred mainly in the middle and lower sections of these rivers some decades ago (De la Hera-Portillo et al. 2020a); (4) The historical data available on the IGME databases show that the groundwater levels of the regional aquifer in the 1970s (considered the reference for natural conditions) were slightly lower than the water table of the upper unconfined aquifer.

The previous results allow us to conclude that the current conceptual model of the MCGWB presents a perched unconfined aquifer recharging the regional deep aquifer, which has been intensively exploited. The consequences are seen in the damage caused to the surface water ecosystems (rivers and wetlands) and terrestrial ecosystems that relied on groundwater (woods and riverine vegetation) today disappeared.

### ***11.2.2 Assessment of Groundwater-Related Ecosystem Services***

Due to the above mentioned pressures, the flow to humans of groundwater-related ecosystem services (GRES) in MCGWB has been reduced. To improve understanding of the aquifer-rivers-wetlands system and support simulation of the impact of particular NBS on the system, the current and potential future trends of the following set of Provisioning Services (PS) and Regulating & Maintenance Services (RM) related to GRES have been assessed: (i) Provision of fresh groundwater for irrigation (PS1); (ii) Provision of good-quality groundwater for human supply (PS2); (iii) Capacity of maintaining base-flow to streams (RM1); (iv) Capacity of maintaining riverine forests (RM2); (v) Capacity of maintaining wetlands (RM3).

The assessment of PS1 and PS2 current trends faced a main problem: the lack of data representativity with respect to particular aquifer depths. Many monitoring boreholes have long screened intervals, thus providing averaged data from large aquifer thicknesses. With respect to PS1, the statistical analysis of 169 piezometers with data records from 1985 to 2018 (and with at least ten continuous years of data) showed two periods with different behaviour (Borowiecka et al. 2019a, b): (1) between 1985 and 2001 there was a generalised tendency to lowering levels across the MCGWB pointing to intensive groundwater exploitation. (2) Between 2002 and 2018, only 25% of the observation points, mostly to the SE and E of MCGWB, showed clear increasing piezometric trends, while the rest showed weak and unclear tendencies. This points to diverse and localised causes, most probably abandonment of dried and expensive exploitations and replacement of groundwater for surface

water for irrigation from the Cogotas reservoir (see above). Thus, the regional piezometric drawdown since 1985 reduced discharge from groundwater bodies to surface ecosystems and induced fast decrease of the Provisioning and Regulating & Maintenance Services PS1, RM1, RM2 and RM3 flows. Meanwhile, local reduction of groundwater exploitation just induced slow and localised recovery of groundwater levels over the last two decades.

With respect to PS2 assessment, elevated ionic balance errors in a number of analysis, and mixing of water from different flowlines in long-screened boreholes led to uncertain chemical representativity of  $\text{NO}_3$  data and non-conclusive statistical results. To gain some insight about the current trends of PS2, two maps of  $\text{NO}_3$  were drawn for two different moments, 1978–85 (99 data points) and 2018 (62 data points). Three zones were mapped: (A) with  $\text{NO}_3 < 10$  mg/L, representing unpolluted groundwater; (B) with  $\text{NO}_3 = 10\text{--}49$  mg/L, representing polluted groundwater but complying with the legal requirements on water quality, and (C) with  $\text{NO}_3 \geq 50$  mg/L, representing polluted groundwater not complying with legal requirements. Comparing both maps, it seems that the surface area of zone A could have decreased around 3–4%, the surface of zone B could have decreased around 22%, and the surface of zone C could have increased some 25% between both periods. This would mean that a general improvement of PS2 is being produced. However, the assessment is weak for many reasons, most notably the mixing of data from different depths.

With the aim of understanding the present trends of Regulating & Maintenance Services RM1, RM2 and RM3, a geographical analysis was performed by comparing orthophotos of the study area from 1956 to 1957 (close to natural conditions) and 2017 (strongly modified regimes) years combined with spatial data from the Copernicus programme, with a shapefile of riparian zones, and a DRBA shapefile on wetlands and lakes (Poirée 2019). Concerning RM1, the length of streams receiving base-flow has decreased dramatically in three of the four main rivers: Guareña, Zapardiel and Trabancos, while it seems not to have changed significantly in the Adaja river. Thus, the partial piezometric recovery detected is not yet having an impact on the base-flow to rivers. Concerning RM2, the surface of riparian vegetation has decreased between 9% and 42%, most significantly for the Trabancos (36%) and Zapardiel (42%) rivers. Together with the lowering of the water table, land use changes, mostly for agricultural and urban uses, have also played an important role in the lowering of piezometric levels. With respect to RM3, the proportion of wetlands surface from 1956–57 to 2017 is just around 0.5%.

The hypothetical future trends of PS1, RM1, and RM3 GRES have been assessed through groundwater flow modelling. The numerical model, (using MODFLOW software) covers the MCGWB and the bordering groundwater bodies to the East (Los Arenales) and West (Tierra del Vino). The geometry, hydraulics, recharge, and exploitation functions were based on a sound review of all the available geological and hydrogeological data. The PS2 (potential evolution of  $\text{NO}_3$  trends) is underway. After an acceptable calibration, groundwater flow was simulated for three different climate scenarios: (a) no change in current precipitation, (b) 3% increase in

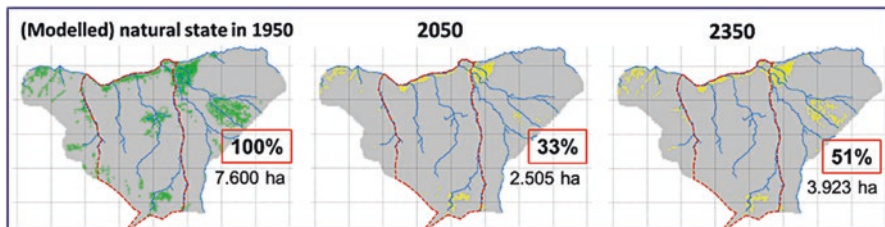


precipitation, (c) 8% decrease in precipitation (CEDEX 2012); and three different groundwater management scenarios: (1) Business as usual (BAU) (current exploitation index  $-EI = 1.65$ ), (2) a reduction of EI to 0.85 by year 2050 and beyond, and (3) a reduction of EI to 0.8 by 2050 (DRBA goal) and beyond. The last two models aimed to provide sensibility on the impact of small groundwater management changes. The main results are presented in García-Alcaraz et al. (2019) and summarized hereafter: no changes in the piezometric level with  $EI = 0.8$  by 2050, and 1 m lower ( $-1$  m) with  $EI = 0.85$ , for whatever climate scenario. By year 2350, the recovery of the piezometric level would be 2 m higher with  $EI = 0.8$  than with  $EI = 0.85$  for whatever climate scenario. For  $EI = 0.8$ , the piezometric recovery rate between years 2018 and 2350 would be 0.012 m/year if the precipitation decreases 8%, 0.021 m/year if the precipitation increases 3%, and 0.018 m/year if there are no changes. Thus, groundwater management (through reducing the EI) has a much larger impact on piezometric recovery than climate change (through modified aquifer recharge).

Given the small impact and high uncertainty of climate projections, the assessment of wetland surface evolution relied mainly on the effect of groundwater management. Assuming a wetland area of 7000 ha in year 1950 as the reference for natural conditions, the best recovery trend is produced by management scenario 2 above: wetland surface recovery will be around 33% by year 2050 and 51% by year 2350 (Fig. 11.3).

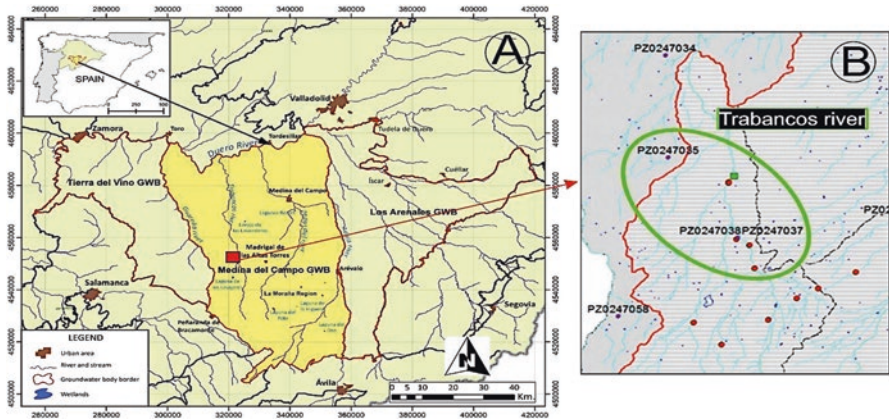
### 11.2.3 Assessment of Managed Artificial Recharge (MAR)

One of the potential NBS considered as identified by stakeholders was Managed Artificial Recharge (MAR) through river-bed infiltration using the Trabancos River channel as infrastructure (Fig. 11.5). Its potential impact was assessed through modelling and simulation of the recharge conditions (see location in Fig. 11.4).

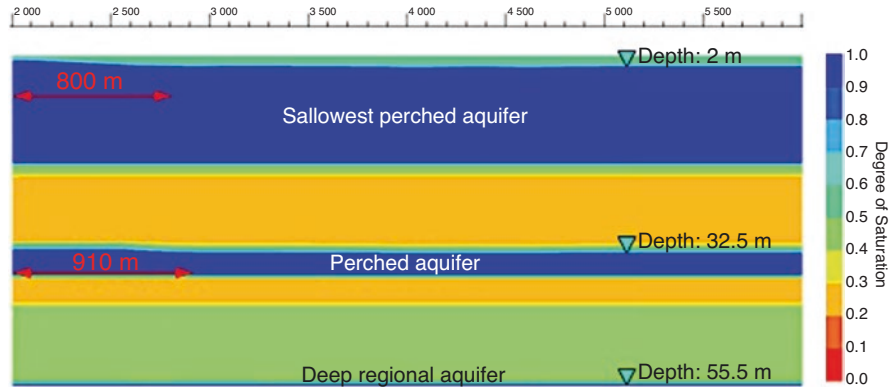


**Fig. 11.3** Modelled evolution of wetlands surface area with no precipitation changes and Exploitation Index = 0.8. (Modified from García-Alcaraz et al. 2019)





**Fig. 11.4** (a) Location of the MCGWB in the Duero Basin (Spain) (modified from De la Hera-Portillo 2020a, b). (b) Detail of the Managed Artificial Recharge area in the Trabancos River



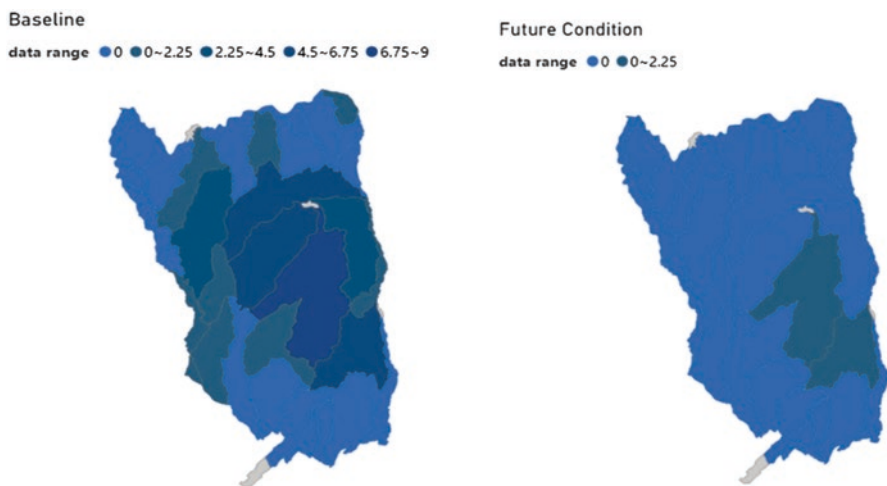
**Fig. 11.5** MAR impact in MCGWB considering an average-type decade: 3 wet years +5 average years +2 dry years,  $t = 3650$  days. The x axis represents the distance from the river where the recharge would take place (Aguilera et al. 2019)

MAR as an action to increase the renewable water resources in the system has been analysed by an unsaturated-saturated flow model (Valle et al. 2018; Aguilera et al. 2019) using VS2DTi code (Hsieh et al. 2000). The area selected to simulate this MAR was the Trabancos River (Fig. 11.4). The results show that simulated MAR, with a recharge volume estimated in  $3 \text{ Mm}^3$  in an average year, has no impact on the deep regional aquifer after 10 years of artificial recharge. It only increases the level of the perched isolated aquifers in the river surroundings (Fig. 11.5). A new groundwater model is under construction to test the potential effects on the Zapardiel basin. A simulation of the impact of the MAR on the deep aquifer was also performed, showing only a slight impact in the long term (after 10 years).

### 11.2.4 Hydrological and Water Allocation Assessment

Understanding the hydrology of the MCGWB (and its associated sub-basins) is essential for understanding the water demanded by the existing water users in comparison with the water availability. This section assessed the potential impact on the MCGWB water balance of the NBS in Medina NAS strategy 2, i.e. crop changes towards more drought resilient species as well as crop rotation. The hydrological and water allocation assessment was carried out using the RIBASIM model. The analysis conducted shows significant impacts when changing the status quo (Fig. 11.6).

The system is under pressure in the present situation. Today most irrigated areas are dependent on groundwater. However, over abstraction of groundwater for irrigation purposes is depleting groundwater dramatically as aforementioned. Agricultural practices are not being carried out considering this water stress situation. Therefore, a change of public subsidies towards support of the use of drought-resilient crops and more efficient technologies, in combination with technical and capacity support, would be advisable. According to the hydrological and water allocation assessment, the water demand is drastically reduced when farmers change their cropping plan. The model shows that this results in an improvement of the present situation, with high increases in the water level. A more sustainable system that is also more resilient to uncertain possible futures is possible when changing the existing farming practices with the new proposed measures. Moreover, it is recommended to conduct a detailed study of possible measures that improve and expand the current infrastructure for supplying surface water beyond the existing intervention, as the hydrological analysis shows considerable opportunities and co-benefits particularly in those sub-basins linked to Adaja and Duero rivers.



**Fig. 11.6** Results for the transient regime for the baseline current situation and the future condition with the application of NBS in NAS strategy 2. (Source: own elaboration)

### 11.3 Risk Assessment of Natural Hazards in MCGWB

The assessment of hazards has proven that the MCGWB is located in an inflexion point with regard to global and regional climate models. This means no significant changes in the main studied variables, i.e. temperature, rainfall, floods and droughts, can be expected due to climate change. In technical terms, this is proven by the fact that the maximum average variations in such parameters are still less than a quarter of the standard deviation (approx). Hence, the current situation with regard to risk should be considered as the starting point towards any societal, economic or land use planning changes, and these changes will bear responsibility for any increase or decrease in risk.

With regard to floods, a rainfall-runoff to flood model was followed as a first approach for the Zapardiel River, aiming at providing an estimate of floods in Medina del Campo Town. The first step was to analyse the precipitation, which showed extremely variable with no significant trends. The model was calibrated at the entry point of the Zapardiel into Medina del Campo town. A coupled 1D and 2D approach would have been ideal to fully model the Zapardiel flow through Medina del Campo, given the river has been channelized. The river was modelled without any obstacles due to specific characteristics of the study. Nevertheless, an approach to test the impact of those elements is highly advised. Therefore, the most similar to natural conditions was modelled, excluding the channel, which is in fact designed with legal bindings regarding floods. The concluding remark is that, under natural conditions, the Zapardiel River can overflow within a return period of 50 years (that is a 2% chance each year) with very limited impact, if any. An event with a 1% chance a year will already cause several areas to become flooded, and an event with a 0.2% chance a year (matching the legal limit to consider flood prone zones) will provide a flood that could reach the Town Hall. Meanwhile, any action upstream focused on retaining flood waters could reduce the peak of the flow, hence it would contribute to lessen the impact to a degree still to be estimated. Given the low slope of the area, a very large amount of water should be retained in the basin in order to minimize the impact of floods in Medina del Campo. River restoration measures could help in order to attain this goal. Nevertheless, further analyses considering the obstruction structures should be performed. In fact, a coupled groundwater model and a distributed rainfall-runoff model with a mixture of 1D/2D approaches would be the best way to proceed.

Overall, the main variable controlling risk in Medina del Campo is human activity. It is on the choice of the inhabitants to give the river its natural space and carry out activities compatible with the scarce rainfall, allowing for manageable risk; or to continue a model that adds pressure to the ongoing physical situation, which would build in increased risk.

## 11.4 Social Assessment: Risk Perception and Selection of NAS Strategies

The methodologies developed by Giordano et al. (2022 – Chap. 5 in this volume) were applied in Medina case study to undertake a social analysis of risk perception and support the selection of NAS strategies, while detecting implementation barriers and leveraging actions. This section focuses on the barriers due to lack of effective interactions among different decision-makers and stakeholders. The work assumes that effective NAS require cooperative actions from stakeholders, since individuals do not make decisions in a vacuum.

The process involved three main steps. First, a participatory mapping exercise with local stakeholders was carried out to identify the network of stakeholder interactions, the information flows between them and the tasks developed by each of them to address risk reduction. This exercise was part of the second stakeholders workshop aimed to co-design the NAS strategies, in line with the stakeholder engagement protocol described in Chap. 2 (López-Gunn et al. 2022 – this volume). Second, the research team analysed the map in order to detect the main vulnerabilities and barriers, as well as key elements in the network. The obtained maps detected four key barriers, as well as several interventions that could be implemented to overcome them. The identified barriers were the following:

First, the **role of water user associations (or WUAs)**, which is strongly affected by the farmers' willingness to associate, depending on the farmers' risk awareness. The lack of WUAs involvement in the NAS process would very importantly reduce the effectiveness of controlling individual water abstractions.

Second, the **low level of acceptance of the water rights allocation**. Most of the involved farmers considered the process unfair and not fully transparent. More effective implementation of the water rights would have led to a reduction in aquifer exploitation.

Third, the **technical support to farmers for enabling crop change toward less water-demanding crops**. The lack of WUA involvement affected the sharing of this technical information and, thus, the farmers' behavioural change towards more sustainable water consumption.

Fourth, the **low level of accessibility of information concerning the groundwater state**, mainly due to the low level of availability and reliability of data on the groundwater level (i.e. groundwater metering). This information would have an impact on the farmers' risk awareness and, consequently, the formation of WUAs and the implementation of the crop change strategy (NAS strategy 2).

The exercise showed that, in order to facilitate the cooperative work of decision-makers and stakeholders for NAS co-design and implementation, actors need to be better involved in the process. Information should flow within the network and tasks should be carried out cooperatively. In the third and final step, a simulation model was used to identify the most effective interventions, as described in Giordano et al. (2022 – Chap. 5 in this volume). The list of identified interventions to address these barriers and a comparison of their effectiveness at tackling those barriers is shown in Fig. 11.7.

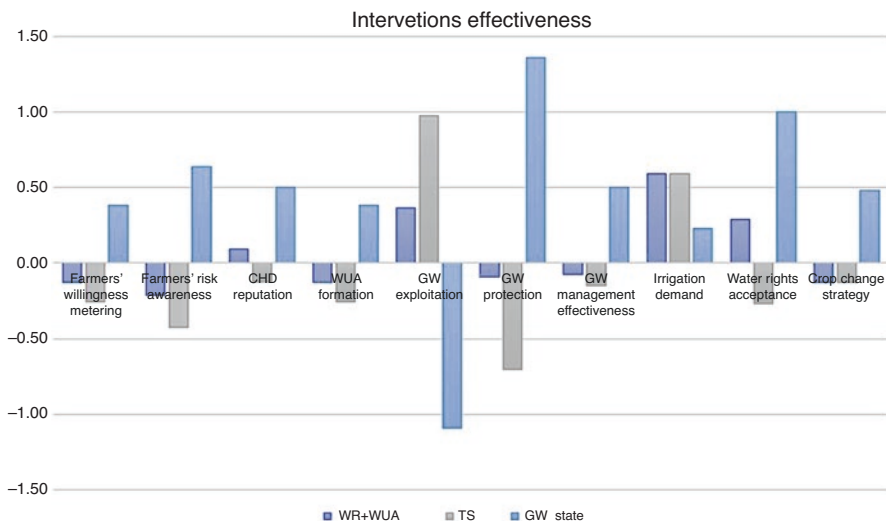


Fig. 11.7 Comparison among the three intervention scenarios. (Source: own elaboration)

Figure 11.7 shows that the most effective interventions are those aiming at enhancing the availability, reliability and accessibility of the information related to the groundwater state. These interventions could have a twofold positive impact. On the one hand, they could lead to an increase in the farmers’ risk awareness and, in doing so, they could contribute to enable the shift towards less water-demanding crops. On the other hand, the availability of reliable information on the groundwater state could allow the DRBA to enhance the effectiveness of the territory control and the groundwater management. This, in turn, could have a positive impact on the farmers’ perception of the DRBA role and, consequently, could lead to a higher acceptance of the water rights management process.

### 11.5 Economic Assessment of NAS Effectiveness

The two NAS strategies proposed for coping with drought hazard risks in the MCGWB (see Table 11.1) were economically evaluated under different scenarios following the economic cost-benefit analysis framework presented in LeCoen et al. (2022 – Chap. 6 in this volume). The aim was to assess whether the NAS strategies can help to increase the provision level of groundwater-related ecosystem services while reducing the economic impacts of hydrological risks.

The soft measures in both strategies would reduce water availability for farmers by restricting groundwater abstractions. In addition, the MAR in strategy 2 would not result in increased water availability for irrigation and thus would not reduce drought damages, whereas strategy 1 would reduce drought economic risk through

the introduction of alternative crops and soil conservation practices. It must be noted that reducing groundwater extractions is a must rather than an option. Therefore, the “Business as usual” (BAU) strategy was redefined as the BAU with the restriction of groundwater abstractions, and both strategies were compared with this redefined BAU scenario. The climatic and socio-economic/regulatory scenarios considered were also selected using a combination of expert-based and participatory co-development approaches. The evolution of the Common Agricultural Policy (CAP) subsidies was identified by stakeholders as a critical driver of land use change. Consequently, both a current CAP scenario and a more environmentally-oriented CAP scenario were considered. Regarding climatic scenarios, a preliminary assessment of trends in average and maximum precipitation using the RPC 4.5 and RPC 8.5 IPCC projections (CEDEX 2012) showed that no significant trends existed in any of the rainfall series to the project time horizon (2050), in line with the risk assessment results previously mentioned (Llorente et al. 2018). Consequently, only one climate scenario, based on the historical trends, was simulated (Calatrava et al. 2019).

The economic impacts of the NAS strategies in terms of reducing drought risk have been assessed using an agro-economic model calibrated to the technical, economical and hydrological characteristics of the study area. This model simulates land and water allocation among cropping alternatives to improve the aquifer’s conditions and reduce drought risk in irrigated agriculture, under the different climatic and socio-economic scenarios considered, and computes several economic, social and resources use indicators. The method and results of the economic assessment of the impact of NAS strategies on the avoided damages is detailed in Calatrava et al. (2019). The impact of the CAP scenarios on the results for both strategies is negligible. The insurance value of the NAS strategies, calculated as the difference in the mean annual avoided damage between each strategy and the BAU + control of groundwater abstractions case, is 12 M€/year for strategy 1 and 0 for strategy 2, as the recharge has no effect on the agricultural irrigation capacity (see Chap. 6). The largest share of the costs for both strategies corresponds to the soft measures, especially to the creation of Water Users’ Associations.

Although the strategies’ co-benefits have not been monetarily evaluated, the combination of the different analysis performed allowed for the qualitative and/or quantitative assessment of major expected co-benefits, as summarised in Table 11.2.

Identified co-benefits include an increase in water productivity, job generation and the profitability of agricultural employments, suggesting a greater potential for higher agricultural wages. Regarding the environmental co-benefits, both strategies would have similar impacts on the improvement of the aquifer’s quantitative and qualitative status, although the artificial recharge in strategy 2 would accelerate the aquifer’s improvement and would positively impact on some riverine ecosystems. Lastly, strategy 1 implies a less intensive farming than strategy 2, as crop rotations and less water-demanding crops are fostered, resulting in an environmental improvement of agricultural systems.

The results of the economic assessment show that the second strategy does not reduce drought risks but improves local riverine ecosystems, while the benefits of



**Table 11.2** Co-benefits assessment for each strategy with respect to the BAU situation

Item	CO-benefit	BAU + GW control	Strategy 1	Strategy 2
Aquifer quantitative status	Reduced extractions	-50.50%	-50.50%	-50.50%
	Aquifer exploitation index	1.00	1.00	1.00
	Changes in piezometric levels	No effect on the deep aquifer	No effect on the deep aquifer	No effect on the deep aquifer
Aquifer qualitative status	Changes in water quality	Compliance with standards	Compliance with standards	Compliance with standards
Groundwater-dependent ecosystems	Generation of, and support to, ecosystems	-	-	Local ecosystems improvement
Environmental status of agricultural systems	Irrigated area with permanent crops (%)	19.49	23.95	19.49
	Irrigated area under crop rotation (%)	-	78.50	-
Water use	Water use efficiency (m <sup>3</sup> /ha)	5629	5303	5629
	Average water productivity (€/m <sup>3</sup> )	0.88	0.97	0.88
	Social profitability of water (jobs/Mm <sup>3</sup> )	15.76	16.18	15.76
Agricultural employment	Employments in agriculture (jobs/ha)	0.0887	0.0858	0.0887
	Profitability per employment (€/job)	€28,240	€32,687	€28,240
	Minimum area to grant an average salary (ha)	11.95	10.65	11.95

Source: Calatrava et al. (2019). Average values for the two CAP scenarios considered

strategy 1 largely outweigh its costs, with a 3.17 benefit/cost ratio, even if the existing co-benefits were not considered (see Calatrava et al. 2019). However, strategies 1 and 2 are not conflictive but highly complementary and should be ideally combined to accelerate the aquifer's recovery and increase other environmental co-benefits.

An exercise to develop business models for the analysed strategies was carried out collaboratively with the stakeholders during workshop 3 of the stakeholders engagement protocol (López-Gunn 2022 – Chap. 2 in this volume), following the methodology of the NAS canvas framework (Mayor et al. 2022, Chap. 8 in this volume). The results showed the required actors, roles and elements required for the implementation of the strategies, and the possible funding instruments that could help the implementors face the upfront and maintenance costs. The resulting NAS canvases for Medina strategies can be found in Mayor et al. (2019, 2021).



## 11.6 Integration of Results from the Biophysical, Social and Economic Assessments

### 11.6.1 Qualitative Integration of Results in Medina Del Campo-Drought

The first approach for integration of results was the construction of a Systems Dynamic Model to understand the qualitative relations, in line with the methodological approach described by Basco et al. (2022 – Chap. 7 in this volume). The results of the qualitative system dynamic model developed for Medina case study can be seen in Fig. 11.8. The conceptual map describes the complex interconnections of the MCGWB according to stakeholder’s perception. The system dynamics qualitative model (SDQM) aggregates knowledge coming from different stakeholders with different degrees of expertise. It represents the dynamic hypotheses and participant’s views on the cause-effect relationships underlying social, economic and environmental factors. It reveals the complexity of the interactions composing the system. In this SDQM, 82 feedback loops are responsible for the underlying behaviour of the system. In order to facilitate the comprehension of the diagram and

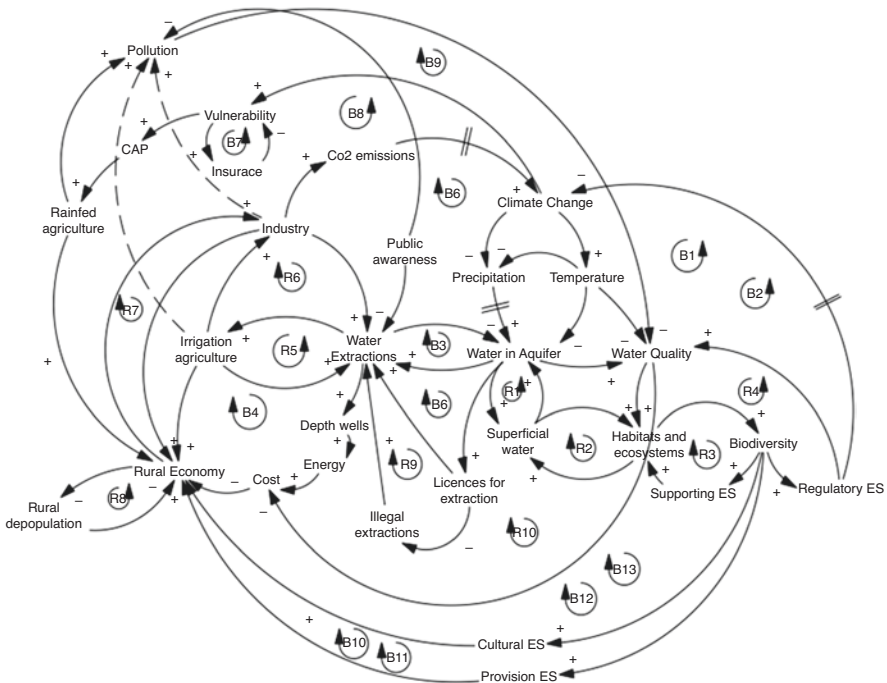


Fig. 11.8 System Dynamic Model of the Medina aquifer. (Source: Own elaboration)

to easily find strong leverage points, the most important loops are highlighted. We identified 9 positive loops indicating self-reinforcement of a given change within the loop and 13 balancing loops indicating self-regulation of a given change within the loop (Fig. 11.8). The stakeholders selected the variable ‘water in the aquifer’ as the core variable of the system.

According to stakeholder’s view, the underlying causes of the aquifer water level decrease are driven by the dominance of reinforcing loop R5 and R9, which are reinforced by loops R6 and R7. This means that the main factors affecting the aquifer are water extractions that are induced by a need of perpetuating an economic system based on agriculture and agriculture-based industry. A dominance of loop R5 would weaken loops R1, R2, R3, R4, which are responsible for the delivery of the main ecosystem services associated with the aquifer.

The dominance of balancing loop B3 regulates the system. This means that when the water level is reduced to a certain point, the strength of R1 is also reduced (water extractions decrease).

### ***11.6.2 Quantitative Integration of Results: Effectiveness of NBS for Strategic Adaptive Planning in Medina Del Campo***

The effectiveness of NAS strategies for MCGWB requires the integration of the results from the previously described studies in a manner that is understandable, acceptable and sufficiently accurate for decision-makers and end users. The meta-model developed in the final phase of the project allows assisting the Medina case study in the multi-criteria decision making and evaluation of the NAS strategies considering possible futures. Overall, the meta-model allows the combination of biophysical, economic and social indicators resulting from the groundwater and water allocation models and carrying out a type of multi-criteria analysis. With this meta-model, users can access the results of different models in a fast-integrated systems model. Meta modelling enables relevant stakeholders to be involved in the whole modelling chain using a collaborative modelling approach. The interactive visualization of the integrated results and the resulting integrated indicators enables a rapid and comprehensive assessment of the effectiveness of NBS and soft measures in terms of direct benefits and co-benefits. An overview of the indicators used for assessing the effectiveness of NBS for Medina del Campo are presented in Fig. 11.9.

The current prototype, already including the stakeholder’s views and understandings, can be accessed at: <https://app.powerbi.com/view?r=eyJrIjoiMDYzOThmYzAtZWYxZi00NWFiLTk4OGUtYmU2MmVhZDAzZWZhIiwidCI6IjE1ZjNmZT-BILWQ3MTItNdk4MSIiYzdkLWZlOTQ5YWYyMTViYiIsImMiOiJh9>

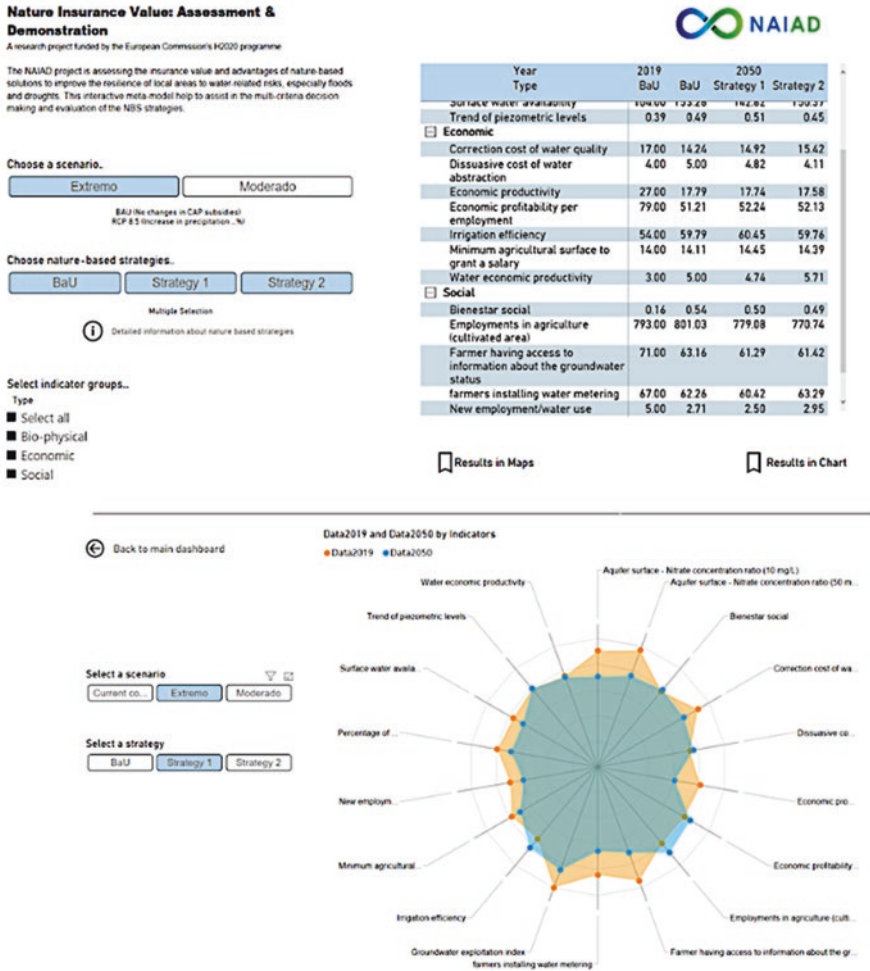


Fig. 11.9 Visualization of meta-model dashboard. (Source: NAIAD website. <https://app.powerbi.com/view?r=eyJrJoiMDYxOTMwYzAtZmYxZi00NWFiLTk4OGUxYmU2MmVhZDZAZWFlbiwiCi6IjE1ZjNmZTBiLWQ3MTItNDk4MS1iYzdlLWZlOTQ5YWYyMTViYiY1ImMiOjIh9>)

The main elements of the meta-model are:

- *Main dashboard* which summarizes and qualitatively compares the valuation of indicators based on the selection of two scenarios (extreme and moderate) and three strategies (Business as usual, strategy 1 and strategy 2). The user can select what scenario, strategy, and indicators to evaluate by clicking on the appropriate boxes;
- *Spatially distributed results* for each indicator can be accessed through the indicator table in the main dashboard;
- *Description* of strategies that are included in the models. This also includes the strategies that are monitored and modelled separately (groundwater recharge and floods).

The meta-model should not only be considered as a tool, rather as a collaborative modelling process that facilitates the conveyance of ideas, working outputs and mental models. The development of trust, acceptance of other's perspectives and shared sense of ownership is indispensable for creating partnerships that allow participatory adaptive planning and management.

## 11.7 Conclusions and Lessons Learnt

The work performed in the Medina del Campo case study has entailed important progress in the understanding and description of the MCGWB from many disciplines. Furthermore, several models and tools with high performance levels have been generated and made available for use by the DRBA, which will inform the current and upcoming River Basin Planning stages.

Some of the main conclusions and lessons derived from the biophysical, risk, social and economic assessments above presented, as well as from their integration to assess the effectiveness of the co-developed NAS strategies, are summarised below.

- Identification of the main changes (stages) that occurred in the MCGWB at space-time scale: a previous unperturbed stage (before 1970) with groundwater levels close to ground surface and discharge of groundwater into the rivers and wetlands; a transition period characterized by an increasing and intensive groundwater pumping (between 1970 and 2010); and a stage with shy and slow signs of recovery at the local level from 2010.
- Between years 1956 and 2017, the surface of riparian vegetation in the streams has decreased between 9% and 42%, most significantly in the Trabancos (36%) and Zapardiel (42%) rivers. The proportion of wetlands surface from 1956–57 to 2017 is just around 0.5% of the 7600 ha identified. Even though the piezometric levels are recovering in part of the MCGWB, this is not yet having impact neither on the capacity of the aquifer to maintain riparian forest, nor to generate base-flow to rivers and discharge to wetlands.
- Reducing groundwater exploitation at a regional scale is the most effective measure to produce a widespread recovery of the groundwater levels, and thus increase water supply and resilience against droughts. Given that the rivers, wetlands and riverine forests are linked to the water table, recovering GRES related to regulation and maintenance of surface ecosystems would require to increase the groundwater stored in the aquifer system, and thus a reduction of the exploitation index.
- Improving the representativity of the monitoring networks is a main and paramount need to allow improved assessments of the current and future trends of groundwater quantity and quality in the MCGWB.
- The implementation of MAR to the unconfined aquifer could improve to some extent the riparian conditions of the Trabancos river water in the short term. Nevertheless, the simulated impacts on the deep aquifer are almost imperceptible in the long term.

- The most effective NAS strategy in terms of economic impacts and co-benefits would be strategy 1, although a combination of both would provide the highest impact. However, these measures would need involvement of the farmers. They are aware of the aquifer value and recognise their reliance on groundwater for the future, but they would also need support to address the implementation and opportunity costs in a joint effort between public and private investments.
- Open communication and awareness raising for farmers about the situation, as well as the collaboration between the DRBA and all affected stakeholders in an iterative process to find suitable solutions, can contribute to tear down some of the barriers for the acceptance and adoption of the proposed nature based strategies chosen by the stakeholders. An open and direct provision of high quality information about the evolution of groundwater quantity and quality would improve confidence and awareness among stakeholders.

## References

- Aguilera H, Heredia J, De la Orden JA, De la Hera A, Del Barrio Beato V (2019) Assessing the feasibility of managed aquifer recharge through unsaturated zone modeling with V<sup>2</sup>DTI in a multilayer system. In: 46th IAH Congress, Málaga, Spain, pp 450
- Borowiecka M, García-Alcaraz MM, Manzano M. (2019a) Analysis of piezometric trends in the Medina del Campo Groundwater Body to understand the status and drivers of changes of groundwater-related ecosystem services. NAIAD EU Project. In: Proceedings of IAHR2019, the 46th Annual Congress of the International Association of Hydrogeologists, Málaga (Spain). J. Jaime Gómez Hernández and Bartolomé Andreo Navarro (eds.) Electronic Ed. [www.aih-ge.org](http://www.aih-ge.org); pp 296
- Borowiecka M, García-Alcaraz MM, Manzano M. (2019b) Analysis of piezometric trends in the Medina del Campo Groundwater Body to understand the status and drivers of changes of groundwater-related ecosystem services. NAIAD EU Project. Proceedings of the 46th International Association of Hydrogeologists, Málaga, Spain, 22–27 September 2019
- Calatrava J, Mayor B, Martínez-Granados D (2019) DELIVERABLE 6.3 DEMO Insurance value assessment report- Part 1: Spain – Medina del Campo. EU Horizon 2020 NAIAD Project, Grant Agreement N°730497
- CEDEX (2012) Evaluación del impacto del cambio climático en los recursos hídricos en régimen natural [Assessment of the impact of climate change on natural regime water resources]. Centro de Estudios y Experimentación de Obras Públicas. 268 pp
- CHD (2013) Informe sobre zonificación de las masas de agua subterránea Tordesillas, Los Arenales, Medina del Campo y Tierra del Vino y propuesta de otorgamiento de concesiones y autorizaciones en dichas masas. 46 pp
- De la Hera-Portillo A, López-Gutiérrez J, Llorente M, Mayor B, Mediavilla R, Heredia J, López-Gunn E (2020a) Reconstruction of the river-aquifer interaction in Medina del Campo groundwater body (Duero basin, Spain) as base knowledge to restore aquatic ecosystems. In: 6th IAHR Europe Congress. 14th–17th September 2020. Warsaw (Poland)
- De la Hera-Portillo A, Marín-Lechado C, López-Gutiérrez J, Ruíz-Constán A, Rubio F, Bohoyo F, Orozco T, Llorente M (2020b) First geophysical-based assessment of the groundwater storage in an intensively exploited multilayer aquifer. Results obtained in NAIAD Project for the Medina del Campo groundwater body. 10 Asamblea Hispano-Portuguesa de Geodesia y Geofísica. Toledo

- García-Alcaraz M, Manzano M, Faneca M, Trambauer P, Pescimoro E, Altamirano M (2019) Understanding the potential of nature based solutions to recover the natural ecosystem services of the Medina del Campo Groundwater Body in the NAIAD EU project. In: Proceedings of IA2019, the 46th annual congress of the international association of hydrogeologists, Málaga (Spain). J. Jaime Gómez Hernández and Bartolomé Andreo Navarro (eds.); pp 156
- Hsieh P, Wingle W, Healy RW (2000) VS2DI—A Graphical Software package for simulating fluid flow and solute or energy transport in variably saturated porous media, Water-Resources Investigations Report 9-4130. U.S. Geological Survey, Lakewood
- Llorente M, De la Hera A, Manzano M (2018) “DELIVERABLE 6.2 From hazard to risk: models for the DEMOs. Report Part 1: Spain – Medina del Campo”. EU Horizon 2020 NAIAD Project, Grant Agreement N°730497
- Mayor B, López Gunn E, Zorrilla P, Nanu F, Groza I, Schrieu A, Marchal R, Le Coent P, Graveline N, Piton G, Biffin T, Daartée K, Pengal P, Krauze K, Douglas C, van der Keur P, Jørgensen ME, Calatrava J, Manzano M (2019) Deliverable 7.2: From Bankability to Suitability report: value capture and business models to catalyse implementation of NAIAD demo’s NAS strategies. H2020 NAIAD project. Grant Agreement No 730497
- Mayor B, Zorrilla-Miras P, Le Coent P, Biffin T, Dartée K, Peña K, Graveline N, Marchal R, Nanu F, Scrieu A, Calatrava J, Manzano M, Lopez-Gunn E (2021) Natural assurance schemes canvas: a framework to develop business models for nature-based solutions aimed at disaster risk reduction. Sustainability 13:1291. <https://doi.org/10.3390/su13031291>
- Mediavilla R, Santisteban JI, López-Cilla I, Galán de Frutos L, de la Hera-Portillo Á (2020) Climate-dependent groundwater discharge on semi-arid inland ephemeral wetlands: lessons from Holocene sediments of Lagunas Reales in Central Spain. Water 12(7):1911
- Poirée L (2019) Evolución de las zonas riparias de los ríos Trabancos, Zapardiel, Adaja y Guareña (cuenca del Duero) entre 1956 y la actualidad. (Evolution of the Trabancos, Zapardiel, Adaja and Guareña rivers riparian areas (Duero River basin) between 1956 and present). Master Thesis. Water and Terrain Science and Technology Master, Universidad Politécnica de Cartagena, Spain. Supervisors: Marisol Manzano and Virginia Robles
- Valle P, Aguilera H, Heredia J, De la Orden JA, De la Hera A, Del Barrio Beato V (2018) Evaluación del impacto de la recarga artificial en la zona no saturada (ZNS) mediante modelización numérica: masa de agua subterránea de Medina del Campo. Congreso Ibérico AIH-GE, 2018, pp 145–154. 015

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