Pergamon

Phys. Chem. Earth (B), Vol. 25, No. 7-8, pp. 623–627, 2000

1464-1909/00/$ - see front matter

PII: S1464-1909(00)00075-7

Possible Solutions to Avoid Conflicts Between Water Resources Development and Wetland Conservation in the "La Mancha Húmeda" Biosphere Reserve (Spain)

J. Fornés, J. A. Rodríguez, N. Hernández and M. R. Llamas

Dept. Geodynamics, Complutense University, 28040 Madrid, Spain

Received 26 May 1999; accepted 13 January 2000

Correspondence to: Juan Fornés Azcoiti

Abstract. The Upper Guadiana Basin is located in the Central "Meseta" of Spain and has a semiarid climate. About half of the catchment surface is formed by important calcareous aquifers. The hydraulic connection between surface and groundwater is high. In this catchment are located a good number of wetlands of different types that are considered relevant from the ecological point of view. They form the main part of the UNESCO Biosphere Reserve called "La Mancha Húmeda".

In the early seventies began a significant change in land use. The irrigated surface grew from some 200-300 km^2 to 1,300-1,400 km^2 in the early nineties. Pumping of groundwater from the main aquifer of the catchment has done most of this development. This new irrigated agriculture has been a driving force for the region economic development. Nevertheless, it has induced dramatic changes in the catchment hydrology and has caused serious impacts on some wetlands.

1. Introduction

The Upper Guadiana basin is located on the Central Spanish Plateau. It covers an area of 16,130 km^2 from the source of the River Cigüela tributary to its outlet in the reservoir of El Vicario. The climate of the region is typical of a semi-arid area.

This region was rich in wetland ecosystems. The natural wetland area of the entire basin was more than 250 km^2. Nowadays, the wetland surface is about 70 km^2. In 1981, due to their ecological importance, the wetlands were designated as a Biosphere Reserve by UNESCO, and the area became world known by the name "La Mancha Húmeda". Some specific wetlands are also in the Ramsar list and/or have been legally classified as National or Regional Parks, according to the Spanish legislation.

Development of the region since the early seventies has been mainly achieved by expanding irrigated agriculture. The irrigated surface grew from some 200-300 km^2 to 1,300-1,400 km^2 in the early nineties. Pumping groundwater from the main aquifer of the catchment has enabled this development. The intensive use of groundwater, especially during long periods of low rainfall, has led to a dramatic decline in groundwater levels, which has led to degradation of important wetlands such as Las Tablas de Daimiel National Park, the main groundwater discharge area in the catchment.

2. Hydrological and hydrogeological characteristics of the Upper Guadiana Basin

The basin is a part of the Central Spanish Plateau. Its topography is flat to undulating. Ground elevations range from approximately 600 m at El Vicario reservoir to over 1,200 m in the Sierra de la Calderina which lie 10-20 km north of the Las Tablas de Daimiel National Park. The smooth relief of this area, the absence of a clearly defined drainage system, the abundance of aquifers and their complex interconnection with the rivers, result in the existence of numerous wetlands that form the UNESCO Biosphere Reserve (Cruces et al., 1997).

The climate of this region is classified as Mediterranean with a moderate continental tendency to be extreme, semi-arid, with long summers and winters and short springs and autumns. The regional climate of La Mancha exhibits high diurnal and seasonal thermal fluctuations. The mean annual temperature is 15°C and temperatures range between less than 5°C to 45°C. Average annual rainfall of the area is 400-500 mm. Over the past 50 years, distinct wet and dry periods have been recognised. The two decades between 1940 and 1960, and the period from the late 1970's to the 1995 were particularly dry, while the 1960's and 1970's were more humid (Fornés et al., 1998). The potential evapotranspiration ranges is from 800 to 900 mm/year. This area can be classified as semiarid. Evaporation rates from free water bodies vary between 1100-1400 mm/year.

The rivers of the Upper Guadiana basin are closely interconnected with the aquifers. Their hydrological regime is conditioned by the local hydrogeological characteristics and by climatic and anthropic changes. The main rivers draining the Upper Guadiana basin are the Guadiana itself, and the Záncara, Rus, Saona, Córcoles, Cigüela, Riansares and Azuer rivers (fig. 1). A combination of low rainfall and high evaporation rates, mean that river flows are typically small. Under natural conditions, the total discharge of the Guadiana at El Vicario is 300-400 million m^3/year, equivalent to 20-25 mm/year or about 5% of rainfall. Total surface and groundwater resources in the watershed have been estimated to range between 400-500 million m^3/year. This difference between the average El Vicario streamflow and the total average water resources, is due to evaporation and evapotranspiration from the wetlands (Cruces et al., 1998[a]).

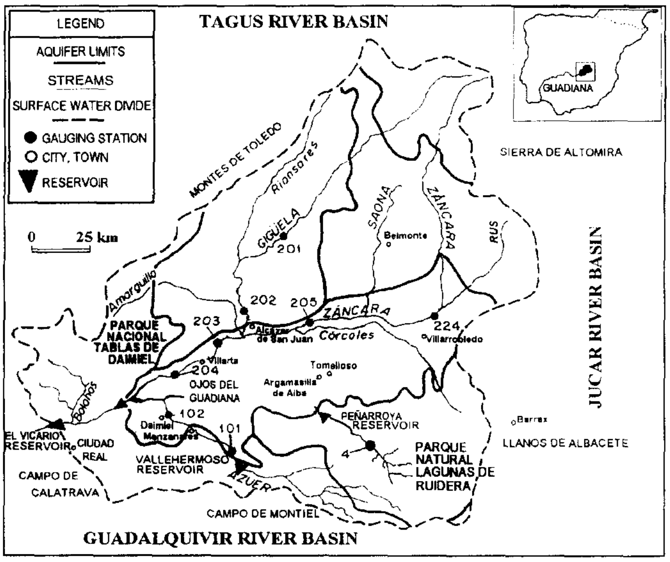

Fig. 1. General map of the Upper Guadiana catchment.

The Upper Guadiana basin is formed by geological materials of different lithologies and ages. The Paleozoic basement is constituted by schists, gneisses and granites. On these materials, there are series of Triassic, Jurassic, Cretaceous and Tertiary detrital and/or carbonated materials. Attending to the different lithologies (Cruces et al., 1998[b]), four major aquifer systems were identified and numbered by the Instituto Tecnológico GeoMinero de España (ITGE) in the early seventies. In the nineties, a slightly different numbering and identifications was done jointly by ITGE and the Dirección General de Obras Hidráulicas (DGOH). The main characteristics of each Hydrogeological Unit follow.

- Sierra de Altomira aquifer (Number 19 or Hydrogeological Unit 04.01): folded Cretaceous and Jurassic limestones and dolomites, and Miocene marls and gypsum. Groundwater development is moderate. The system functions as a free aquifer or semiconfined in depth. The Jurassic materials constitute the principal aquifer. Its area is about 2,600 km^2.

- North La Mancha aquifer (Number 20 that includes the Hydrogeological Units 04.02 and 04.03): Miocene and Pliocene limestones, marly limestones and sands, and Triassic sandstones. Groundwater development is small because of its brackish chemical characteristics. In this aquifer exists one of the greatest concentrations of wetlands of "La Mancha Húmeda", primarily in the confluence of Riansares-Cigüela rivers (Fornés, 1994). This aquifer system covers a surface of 3,550 km^2.

- Campo de Montiel aquifer (Number 24 or Hydrogeological Unit 04.06): horizontal Jurassic limestones and dolomites that present a high karstification. This unit functions as a free aquifer. It is almost undeveloped because of climatic and legal reasons. On this aquifer is located the Lagunas de Ruidera ecosystem. The aquifer covers about 2,600 km^2.

- West La Mancha aquifer (Number 23 or Hydrogeological Unit 04.04): it is also denominated the Llanura Manchega Occidental aquifer. It covers about 5,500 km^2 and constitutes the most important aquifer of the Upper Guadiana basin. The relief is very smooth.

Recharge to this aquifer comes from river infiltration, directly from rainfall and by groundwater flow from adjacent aquifers, particularly from the Jurassic and Cretaceous limestones of the Campo de Montiel to the south. Under natural conditions, discharge took place mainly as outflow into the rivers, into the wetlands of the Las Tablas de Daimiel National Park close of the catchment outlet and into many other smaller wetlands. However, over the past 25-30 years, development of the irrigation has meant that borehole abstraction for irrigation has accounted for an ever-increasing proportion of discharge.

3.- "La Mancha Húmeda" Biosphere Reserve

In 1967 there were in this region about 25.000 ha of wetlands (Llamas, 1988). Nowadays, wetlands cover only 7,000 ha in the Upper Guadiana basin. This means that about 70% of the surface of wetlands has disappeared.

Most wetlands of this region, were located in discharge areas of the aquifers. Some of them were riverine wetlands and their hydrological functioning was related to both surface and groundwater hydrological conditions. Nevertheless, there are almost 80 saline wetlands that are located in closed basins, mainly on the aquifer systems nº19 and nº 20 (Fornés et al., 1995). These wetlands are playa-lake type.

The most important wetlands group was the one included in Las Tablas de Daimiel National Park, with a maximum flooded area of 15-20 km^2. This group was the main discharge area of the West La Mancha aquifer and the flagship wetland of "La Mancha Húmeda". It was declared National Park in 1973. This is the maximum legal protection for a natural space accorded by Spanish law. In spite of this legal protection, this wetland is seriously degraded due to water depletion produced by intensive groundwater abstraction. During the last 30 years, irrigated lands increased from less than 200-300 km^2 in the seventies, to more than 1,300-1,400 km^2 about ten years ago. All this irrigation is done with groundwater, with the only exception of 50-60 km^2 which used waters of the Peñarroya Reservoir located in the middle Guadiana river, just upstream of La Llanura Manchega (Cruces et al., 1998[b]).

4. Socio-economic frame

The Upper Guadiana basin is located mainly in the Ciudad Real province. The statistical data of this province will be presented as an acceptable first approximation of the catchment situation. The population in the catchment is almost 500,000 persons, which are distributed in rather large villages with typical sizes from 5,000 to 15,000 inhabitants each. Population density is about 25 persons/km^2 which is lower than average density of Spain (78 persons/km^2). In summary, Ciudad Real province and the whole Castilla-La Mancha Autonomous Region is a poorly populated region in Spain and the trend is to diminish its population mainly because of emigration from rural areas to more industrialized zones.

The distribution of the Gross Revenue in Ciudad Real (1987) was Agriculture (13%), Industry (mainly Agro-Industry) (41%) and Services (46%). In the whole Spain the corresponding proportions are 6%, 33% and 61%. This shows the great importance that agriculture has in Ciudad Real. As a matter of fact this catchment is one of the few zones in Castilla-La Mancha in which the population has not decreased during the last 20-30 years. There is a certain agreement that population stability in this zone is due to the development of irrigated agriculture and the related industrial activities (irrigation devices, fertilizers, wineries,...etc).

5. Hydrological and ecological impacts

This intensive pumpage on La Mancha Occidental aquifer and the relative scarcity of rainfall during the last decade caused a continuous depletion of the water table in the aquifer of La Mancha Occidental. In many places this drawdown was 40-50 m and the depletion trend seemed to continue steadily, nevertheless the humid period that began in 1995/96 until nowadays, has induced a water table recovery of 10-15 m in many places.

The drawdown of the water table has had several impacts:

1) The Guadiana, Zancara and Cigüela Rivers have ceased flowing during dry periods when they reached La Llanura Manchega Occidental, although they usually flow in their upstream reaches. The main river, Guadiana, was dry between Peñarroya and El Vicario reservoirs for the last 15 years, until the 1995/96 hydrological year; the water table was frequently 30-40 m deep below its thalweg during the dry period. Practically all corridor or riparian forests have dried up.

2) The "Ojos del Guadiana", area of springs (fig. 1) has been not only dry since the early eighties, but the peat formed there during the last 8 to 10 thousand years now underwent spontaneous combustion and almost all the peatland has been already burnt.

3) Some waterwells, mainly those located near to the border of the La Mancha Occidental aquifer, have become dry and other wells had to be drilled deeper in order to maintain their yield. Thus far, these waterlevel declines not caused yet significant decrease in the agricultural yield on the area.

4) The flooded wetlands area in the National Park of Las Tablas de Daimiel dramatically decreased from 15-20 km^2 to less than 1 km^2. Some authors consider that the situation of the National Park can be described as "ecological coma" or "state of agony" (Llamas, 1994). Since the beginning of the last wet period (1995/96), the amount of flooded area has almost reached the pristine condition. Nevertheless, the hydrological functioning of the wetland has been seriously modified. The wetlands instead of being a groundwater discharge area have become a gigantic artificial recharge area. Many small wetlands located on La Mancha Occidental aquifer, have dried-up and are now farming land.

5) Nevertheless, most wetlands included in the "La Mancha Húmeda Biosphere Reserve" have not been impacted by groundwater abstraction because they are located on aquifers in which groundwater abstraction has been small. Most of them suffered the "natural impact" of the last long drought (about ten years). This dry spell finished in 1995 Fall and most of these wetlands are now recovering their normal hydrological functioning except when other anthropic activities have impacted them (e.g. water pollution by sewage or filling by urban solid wastes). An special case is the degradation of the Cigüela river riverine wetlands caused by the so called Regeneration Plan of the Tablas de Daimiel National Park, that is commented below.

6. Solutions taken by the Water Administration

For at least seventeen years, there has existed a serious social concern about the ecological impact caused by such intensive pumpage, and about the sustainability of pumping amounts of water in excess of the average renewable water resources.

In order to cope with these problems the following main actions were taken by the Water Administration (Cruces et al., 1998*):

- According to the Spanish Water Code of 1985, the West La Mancha aquifer (Hydrogeological Unit 04.04) was declared "provisionally overexploited" in February 1987 and "definitively overexploited" in December 1994. The farmers did not agree with this decision and they only accepted it when a significant program for economic compensation has been approved.

- The Campo de Montiel aquifer (Hydrogeological Unit 04.06) was declared "provisionally overexploited" in April 1988 and "definitively overexploited" in June 1989, although groundwater abstractions were only quite a small fraction (25%) of the official estimation of the natural recharge, and the assumed ecological impact on Las Lagunas de Ruidera Regional Park was far from hydrologically evident (Llamas, 1994). This legal declaration of overexploitation was contested by the farmers who brought this decision to the Court.

- In 1993, the Spanish Government began a 5-year plan to compensate the farmers who stop or reduce pumping for irrigation (about 75% of such payments is money coming from Brussels), in West La Mancha and Campo de Montiel aquifers. These Spanish-European subsidies (about 100 million ECUs) are intended to recover Las Tablas de Daimiel National Park. According to the Guadiana Water Authority, pumping has been reduced to about 300 Mm^3/year or less (see Esnaola et al., 1995, and Almagro, 1995). Nevertheless, the water table depletion trend seemed to continue although since the 1995/96 hydrological year, the water table has risen 10-20 m in many places. In December 1997, the European Commission extended the Program for the period 1998-2001 (about 150 million ECUs). In this case, Sierra de Altomira and North La Mancha aquifer systems, have also been included in the program, although pumpage in them is small.

- Between 1987 and 1995, were constituted 21 communities of groundwater users in the West La Mancha aquifer, and 1 in Campo de Montiel aquifer. These associations are intermediate institutions between the groundwater users and the Water Authority. The existence of these communities is considered a must for a good water management (Aragonés et al., 1996). The functioning of these institutions depends on the good public relations between the communities and the Water Authority; in this case, up to now, these relations are not the best.

- Between 1988 and 1999, also in order to restore the degraded Tablas de Daimiel National Park, something more than 100 Mm^3 of water from the so called Tagus-Segura Aqueduct, have been diverted to the Cigüela river in order to supply water to the "agonising" National Park. The results of such diversion of water through the Cigüela river seems rather poor for the restoration of the National Park.

7. Is it possible wetland conservation and agricultural development in the Upper Guadiana Basin?

The irrigated agriculture has been the main economic drive in this region but it seems clear that the previous rate of pumpage (600 Mm^3/year) could not be maintained for many years. Conceptual and numerical models can provide important information about what objectives can be achieved. Despite the level of uncertainty of all prediction exercises, models can set important guidelines for management as well as quantify the effects of different hydrological processes that are only qualitatively understood. In fact, numerical models like MODFLOW have been useful to model the complex behaviour of Upper Guadiana basin aquifer. A MODFLOW was used to estimate the impacts of changing abstraction rates. The water management scenarios, have been the following according to the groundwater reduction: no reduction (600 Mm^3/y), 1/3 reduction (400 Mm^3/y), 2/3 reduction (200 Mm^3/y) and zero option (this option set up the hypothesis of no pumpages at all) (Cruces et Martínez, 1999).

The figure 2 presents the model prediction cell in the central part of the main aquifer (10 km east of Los Ojos del Guadiana, 15 km north of Manzanares village, as we can see in figure 1). The figure clearly shows that for pumping rate above 2/3 of the maximum historical rate (400 Mm^3/year), the situation seems to be unsustainable, while for water abstraction below this value, the system could maintain an acceptable groundwater situation similar to the one at 1995 while different degrees of recovery are possible with lower rates. The average drawdown is not linear with water abstraction (Cruces et Martínez, 1999).

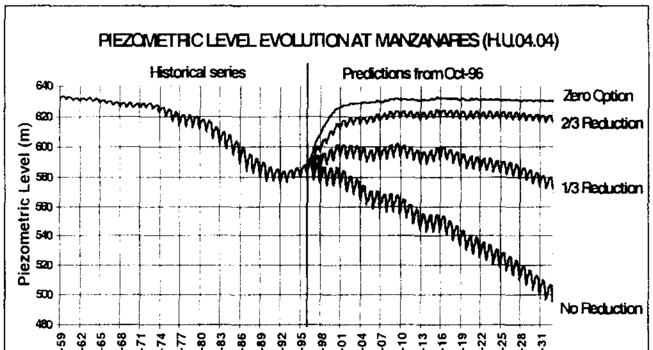

Fig. 2. Model results for calibration period and water management scenarios.

8. Conclusions and recommendations

The irrigated agriculture has been the main economic drive in the Upper Guadiana basin. To get a sustainable development, some factors should be taken into consideration:

- In order to develop sustainable water management, it is necessary to estimate more accurately the renewable groundwater resources. These seem to oscillate between 200-500 Mm^3/year, in dry and humid periods respectively. To improve hydrological knowledge, it is crucial to improve the corresponding instruments. In the West La Mancha aquifer, there isn't one limnigraph in 5,500 km^2!

- Development of water management plans, require the good relation between the Communities of Groundwater Users and the Guadiana Water Authority. The influence of these communities is still small, because of their recent establishment and internal fights among the twenty-one existing communities. The goal is to try to go from "confrontation" between farmers, Guadiana Water Authority and Conservation Groups, to "collaboration", in order to achieve sustainable development in abstraction, competitive agriculture and wetlands conservation.

- To change the agricultural practices in order to get the same economic yield from crops which use less water. Crops, which use a lot of water, should bed changed to crops which are more water efficient. The use of more efficient irrigation system (such as drip irrigation), have contributed to the decrease of groundwater abstraction in West La Mancha aquifer.

- The agricultural subsidies in West La Mancha and Campo de Montiel aquifers, have contributed to reduce the groundwater abstraction. The principal objective of these subsidies was to save the wetlands by promoting the improvement of agricultural technology.- Pumping rate above 2/3 of the maximum historical rate (400 Mm^3/year) seems to be unsustainable but for water abstraction below this value, the system seems maintain an acceptable groundwater situation from the agricultural development point of view, but the recovery of the wetlands located on the West La Mancha aquifer seem difficult.

- In summary, the water table depletion degrades the wetlands but increases the water resources available due to the "water saved" from evapotranspiration in wetlands and rivers, the increase in the indirect recharge from streams in wet years and the induced lateral flows from contiguous aquifers.

Acknowledgements. The CICYT (Spanish Interdepartmental Committee for Science and Technology) Project HID96-1298-C03-01, titled "Conservation and Restoration of the wetlands of the La Mancha Húmeda Biosphere Reserve. Hydrologic, Economic and Legal Aspects", and the GRAPES (Groundwater and River Resources Action Programme on a European Scale) Project, Contract ENV4-CT95-0186, have provided the necessary resources and support for the preparation of this article. The GRAPES Project, designed by DGXII, is a research programme supported by the European Community Framework Programme for Research and Technical Development, Environment and Climate Work Programme.

References

Almagro, J. (1995). "Algunos aspectos de la aplicación de la Ley de Aguas en los Acuíferos de La Mancha Occidental y del Campo de Montiel". Las Aguas Subterráneas en la Ley de Aguas Española: un decenio de experiencia. Asociación Internacional de Hidrogeólogos-Grupo Español, Tomo II, pp. 157-162.

Aragonés, J.M., Codina, J. and Llamas, M:R. (1996): " Importancia de las Comunidades de Usuarios de Aguas Subterráneas (CUAS)". *Revista de Obras Públicas*, nº 3355 (junio), pp. 77-78.

Cruces, J. and Martínez, L. (1999). "Contribution of models to the assessment of alternative catchment management plans". Final report of the European Commission GRAPES Project. Contract ENV4-CT95-0186, (pre-print).

Cruces, J., Casado, M., Llamas, M.R., de la Hera, A. and Martínez. L. (1997). "El desarrollo sostenible de la cuenca alta del río Guadiana: aspectos hidrológicos". *Revista de Obras Públicas*, nº 3362, pp. 7-18.

Cruces, J., Fornés, J., de la Hera, A., Llamas, M.R. and Martínez, L. (1998[a]). "Hydrogeology of the Upper Guadiana Basin". *Hydrogeologie*, Orleans, France. 51 pp. (pre-print).

Cruces, J., Hernández, J.M., López, G. and Rosell, J. (Coord.) (1998[b]). "De la noria a la bomba. Conflictos sociales y ambientales en la cuenca alta del río Guadiana". Ed. Bakeaz. Bilbao, Spain. 343 pp.

Esnaola, J.M., Martínez Alfaro, P.E., Montero, E. and Luna, E. (1995). "Evaluación hidrológica, regadíos y sobreexplotación de la unidad hidrogeológica 04.04 –La Mancha Occidental- en el marco legislativo de las aguas subterráneas". Las Aguas Subterráneas en la Ley de Aguas Española: un decenio de experiencia. Asociación Internacional de Hidrogeólogos-Grupo Español, Tomo II, pp. 141-150.

Fornés, J. (1994). "Hidrología de algunas lagunas de Castilla-La Mancha". Tesis Doctoral. Facultad de Ciencias Geológicas. Universidad Complutense de Madrid. 315 pp. and annexes.

Fornés, J., de la Hera, A., Cruces, J. and Llamas, M.R. (1995). "Funcionamiento hidrológico de un humedal ribereño, El Masegar, en el conjunto de humedales de La Mancha Húmeda de la cuenca alta del río Cigüela". *Estudios Geológicos*, nº 51, pp. 259-276.

Fornés, J., de la Hera, A. and Llamas, M.R. (1998). "Landscape changes and ecological impacts caused by groundwater abstraction in the Upper Guadiana Basin, (Spain)". Gambling with Groundwater-Physical, Chemical and Biological Aspects of Aquifer- Stream Relations. Brahana et al., (eds.), International Association of Hydrogeologists, pp. 137-142.

Llamas, M.R. (1988). "Conflicts between wetland conservation and groundwater exploitation: two case histories inSpain". *Environmental Geology*, 11, nº 3, pp. 241-251.

Llamas, M.R. (1994). "Four case histories of real or pretended conflicts between groundwater exploitation and wetlands conservation". Water Down Under'94. Adelaide (Australia), International Association of Hydrogeologists, Vol I, pp.493-497.