Conflicts Between Wetland Conservation and Groundwater Exploitation: Two Case Histories in Spain

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ABSTRACT / The problems in two Spanish national parks located on wetlands are analyzed. The hydrogeological and ecological characteristics of the two parks are somewhat different as are their respective degrees of deterioration.

The Tablas de Daimiel National Park is located on the Central Plateau of Spain. It used to consist of a marshy area of about 20 km² around the confluence of two relatively small rivers. The area was marshy mainly because it was the natural discharge zone for a Tertiary aquifer system about 100 m thick extending over an area of some 5,000 km², composed of calcareous and detrital material of continental origin. The average annual recharge has been estimated at approximately 350 hm³/yr. Current groundwater withdrawal is around 450 hm³/yr, mainly used to irrigate a surface area of some 1,000 km². This overdevelopment has led to a continuous depletion of the regional water table and eventually to the drying out of the marshy area. Spontaneous combustion or fires caused by man have occurred in about 10 km² of the desiccated areas since the spring of 1986.

The Doñana National Park is located on the estuary of the River Guadalquivir. The aquifer system of the Lower Guadalquivir estuary consists essentially of a permeable formation of unconsolidated Plioquaternary materials with an area of some 3,000 km². Under the marshy area (about 1,800 km²) the aquifer system is confined below low-permeability estuary deposits which can be over 100 m thick. Around most of the marshland the aquifer crops out and is recharged by rain. The Doñana National Park is over 700 km² in size, part of which is in the marshland and part in the recharge area where the aquifer is phreatic. In the 1970s Spain's largest irrigation project using groundwater, covering a surface area of 240 km², was planned in an area bordering on the national park. The initial project has been scaled down considerably as a result of protests by conservation groups. However, it seems likely that the water table depletion as a result of pumpage for irrigation could cause a large part of the ecotone situated at the contact-line between the marshland and the phreatic aquifer to disappear. This ecotone exists because it is a natural groundwater dischange area.

Introduction

It is usually admitted that concern over protecting the environment only began with any intensity in the 1970s, when serious deterioration was discovered in the enviroment. The cause of some of these problems were significant changes in the hydrological systems involved, caused in turn by anthropogenic action. Thus, for instance, the large-scale drainage of marshlands and the exploitation of groundwater have given rise on occasion to substantial changes in groundwater flow and in the existing wetlands.

Up until recently the marshlands or wetlands were considered unproductive land for agricultural purposes and frequently unhealthy. For this reason almost all governments offered incentives for them to be drained and converted into arable land. In recent decades, however, the particular ecological importance of marshlands or wetlands has been proved. Moreover, they are considerably sensitive to the different anthropogenic actions. Wetlands usually exist as a result of the combined action of ground and surface water (see Llamas 1984; Custodio 1987).

In arid and semiarid countries wetlands, in addition to being relatively small in size, play an even more important role than in temperate or cold zones. At the same time, these countries usually make special demands on groundwater for agricultural use. These extractions of groundwater can cause drastic changes in the wetlands related to the aquifers from where such pumpage is drawn.

This article presents two case histories of wetlands in Spain particularly affected by groundwater extraction (Fig. 1). Several years ago both areas were declared national parks and consequently in theory should be covered by unique protection laws against all unfavorable man-made action. This has not been the case in reality. In fact, one of them, the Tablas de Daimiel Park, has been virtually entirely destroyed, literally calcined. In the second case, Doñana National Park, there is almost enough evidence to suggest that it may undergo a similar process. Both wetlands appear under Class A in the 1965 MAR list that includes 200 wetlands or marshlands of international importance in Europe and North Africa. This list contains ten Spanish wetlands, of which only four are classed as A,

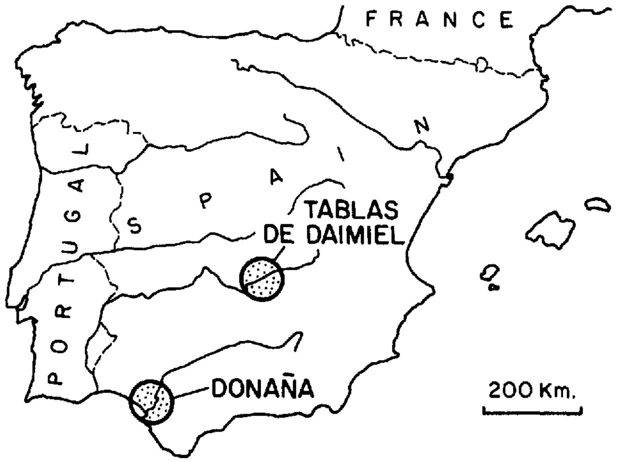

Figure 1. Map of the area.

or of exceptional importance, and the remaining six are classed as B (Llamas 1984).

The basic cause of the deterioration of these important wetlands is perhaps the insufficient attention the Spanish government has paid to groundwater in its water resources policy (Llamas 1983).

The Tablas de Daimiel National Park

General Ecological Characteristics

The Tablas de Daimiel National Park (TDNP) was set up by decree 1874/73 and the successive law 25/1980 that governs the activities inside the national park itself and its surrounding areas. The TDNP covers an area of some 18 km². It is situated at the confluence of two rivers, the Gigüela and the Guadiana (with a joint basin of some 15,000 km²). The western La Mancha region aquifer system, which covers an area of some 5,000 km², also discharges naturally there. However, the majority of this aquifer discharge took place upstream from the TDNP in an area known as the Ojos del Guadiana.

To a great extent the 1973 decree owed its existence to the government's reaction to pressure from conservation groups which opposed the surface drainage works. These were carried out in several wetlands in the La Mancha region by farmers, backed by government aid, and began in 1965. These drainage works reduced the extent of the wetlands or marshes in La Mancha from the 250 km² that existed in 1967 to 90 km² in 1981 and to a lower figure still at the present time (López Camacho 1987). The conservation groups were concerned only about these surface drainage works. They successfully managed to have them virtually stopped. The government even went so far as to fill in many of the drainage channels and to build a small dam designed to try to cancel out or at least reduce the effects of these drainage works in the area close to Las Tablas National Park.

However, the major negative impact suffered by the TDNP and which it continues to suffer increasingly does not come from these surface drainage works but from the exploitation of the goundwater from the La Mancha aquifer system. This deterioration was denounced some years previously in several scientific studies which went virtually unheeded, first as a result of the traditional neglect of the importance of groundwater by the hydraulic engineers of the Guadiana Water Authority, and second as a result of the economic and social development that the groundwater exploitation implied in that region. The regeneration of these wetlands at this moment represents an arduous task.

Hydrogeological Characteristics

The upper basin of the River Guadiana (15,000 km²) is characterised by its low relief. It has a continental Mediterranean climate with an average annual rainfall in the order of 400–500 mm/yr and an average annual temperature of around 14–15°C. Several aquifer systems exist in this upper basin but only one of them has direct and significant importance on the ecosystem of the TDNP–the western La Mancha aquifer which covers a surface area of some 5,000 km² (Fig. 2). It has an average thickness of about 100 m. It mainly consists of Tertiary continental formations. The lithology of the permeable mass consists mainly of limestones. Tertiary clays or gypsum or Paleozoic schists form its lower confinement (IGME 1985). The Miocene limestone forms an unconfined aquifer, which is connected to the rivers and to other aquifers in its eastern and southern zones. The recharge of this aquifer in undisturbed regime has been estimated by the Spanish Geological and Mining Institute (IGME) (1985) and by the Servicio Geológico de Obras Públicas (SGOP) (1983), giving the following figures, respectively: (1) rain infiltration (235 and 180 hm³/yr; (2) underground flow from other neighboring aquifers (60 hm³/yr, both), and (3) river infiltration (15 and 80 hm³/yr). The natural regime discharge occurred at its outflow into rivers and small lakes (among these the Tablas de Daimiel). The IGME (1985) estimates the volume of fresh water stored in the system at some 12,000 hm³, in other words 30–40 times greater than that of the average annual recharge.

Figure 3a shows a diagram of the water balance in the area surrounding the Tablas de Daimiel parkland in the hydrological year 1973/4, a year in which the

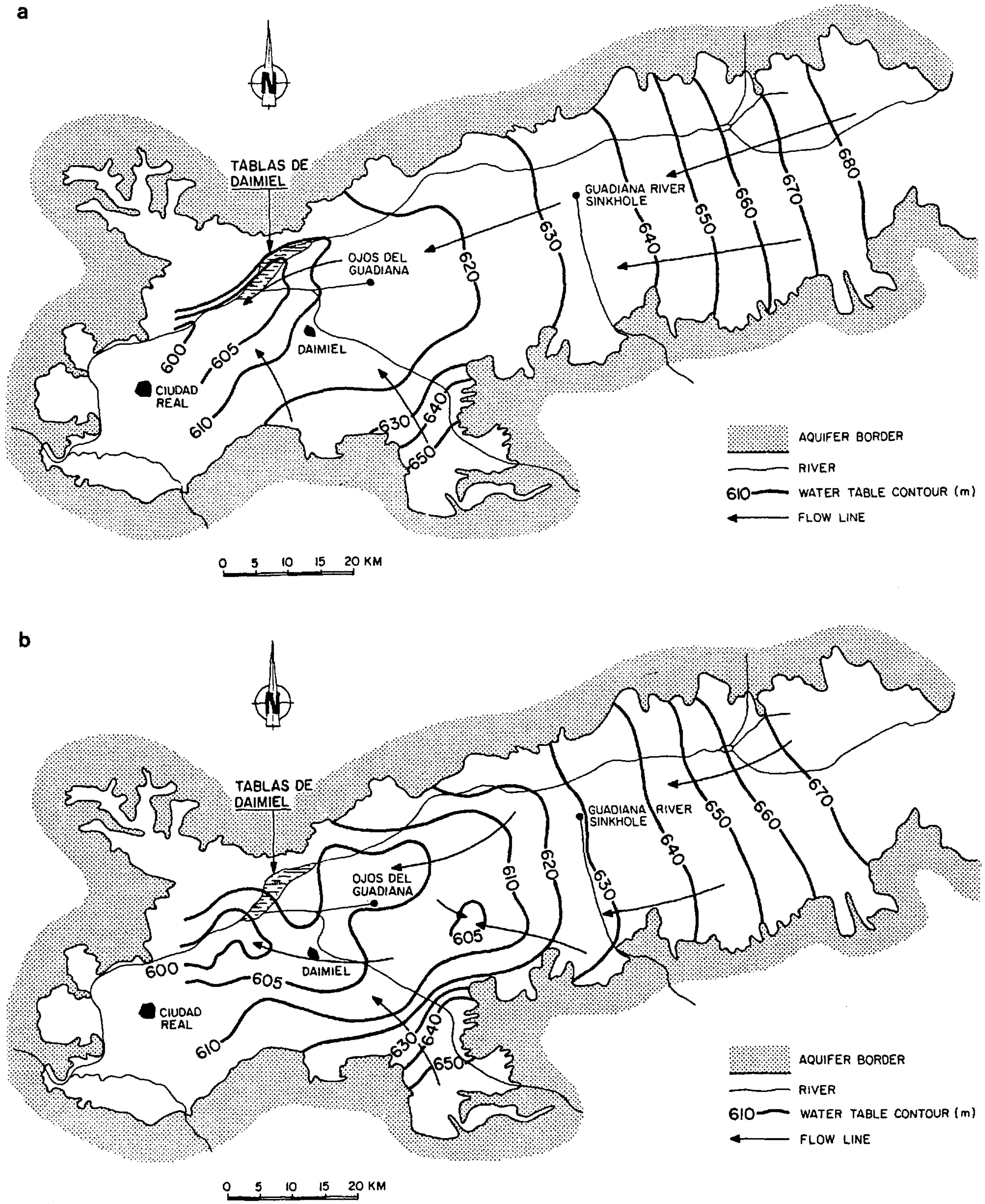

Figure 2. Water table of the La Mancha aquifer: **a.** September 1980. **b.** September 1984 (modified from López Camacho 1986).

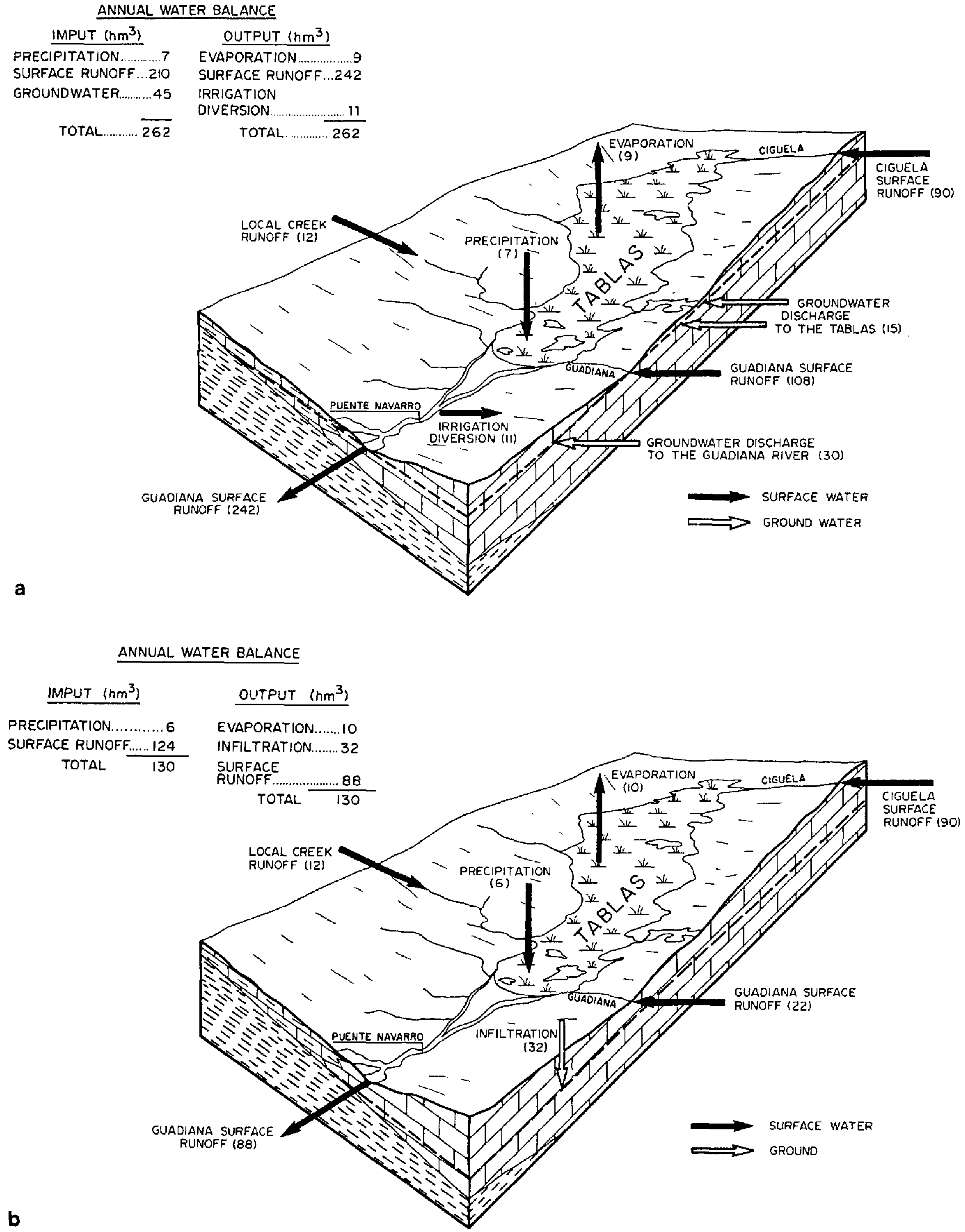

Figure 3. Water balance of Las Tablas de Daimiel National Park: **a.** Natural situation, year 1973/74. **b.** Disturbed by irrigation pumpage (modified from SGOP 1983).

effect of the pumping was still small. Under these circumstances it was assumed that the Tablas de Daimiel Park received a groundwater supply of some 15 hm^3/yr plus a surface supply from the River Guadiana of something over 100 hm^3/yr. It must be pointed out that this water supply from the River Guadiana was primarily groundwater which entered the river at the Ojos del Guadiana resurgences, located some 201 km upstream from the Tablas de Daimiel area.

Groundwater Exploitation

The La Mancha region was predominantly one of dryland farming until a few decades ago, when the existence of an important underlying aquifer began to be known. Generally speaking it is easy to drill wells of under 100 m depth in this aquifer to obtain sufficient water to irrigate 50–100 ha.

Over the last 20 yr it is estimated that some 100 km^2 of land have been coverted to irrigated land, that is, 20% of the entire extent of the aquifer. López Camacho (1987) estimates that current pumpage for all purposes is in the region of 450 hm^3/yr and that this figure exceeds the average annual recharge level by 100 hm^3/yr. As a result, what is being produced is a progressive and generalized depletion of the water table, which has gone as low as 20 m in broad stretches. This has meant that several wells have stopped being used and others have been deepened, but on the whole the increase in irrigated land continues at a rate of some 6,000 ha/yr. Figure 2b shows the changes already observed in the general flow pattern in September 1984.

The Impact on the Ecosystem

López Camacho (1987) points out how the forecasts already made in a study carried out by the SGOP (1979) on the need to restrict groundwater extractions were received skeptically. In a later study the SGOP (1983) insisted on the matter and it predicted that the water balance and the ecosystem of the TDNP was going to be seriously affected by the pumping (Fig. 3b). The water table would remain permanently below the bottom of the marshlands, which will not only fail to receive any groundwater supply but will be converted into a large recharge basin from which surface water reaching the TDNP from the Rivers Gigüela and Guadiana would filter down into the aquifer. The TDNP would contain water only when the River Gigüela is at full flood and this only occurs during some months in wet years. In short, the majority of the year the TDNP would remain without water.

These forecasts of four years back are now reality. Today the situation is critical, and deterioration has occured which is virtually irreversible. In fact, during 1986 not only did the TDNP virtually remain dry but also several fires occurred that affected some 8 km^2 of land. These fires particularly affected the dry beds of the former marshland, which has a high content of organic material, and others will inevitably occur if urgent steps are not taken. The truth is that in March 1987 a fire did occur which affected some 3 km^2.

Through the ICONA (National Institute for the Conservation of Nature in Spain) the government is studying a plan to regenerate the former hydrologic conditions in the Tablas de Daimiel area. This plan appears to contain several options that are not incompatible and basically fit into the following three solutions: (1) to reduce pumpage, (2) to import water from other neighboring basins, and (3) to use to the full the resources within the upper basin of the Guadiana itself. The first two solutions will probably meet with decided opposition from the current users of the aquifer itself or from the current and potential users of the waters intended to be diverted to the TDNP. The third solution is the most viable but it is doubtful whether it will be sufficient to solve the problem. An emergency measure has also been proposed consisting of pumping water from the aquifer itself to keep the TDNP wet. For the moment this solution has encountered strong opposition and has not been implemented.

In any case and almost independently of the ecological problem of the TDNP, the La Mancha aquifer has just been declared an overexploited aquifer. According to the new Spanish Water Law passed in 1985, this requires that a community of groundwater users be set up for the management of the aquifer. This is one of the first cases where this legal requisite has been applied since the new Water Law came into force. It is too early to form an opinion on how effective the fact of having declared this an overexploited aquifer is going to be in terms of protecting the ecosystem of the Tablas de Daimiel National Park.

The Doñana National Park

General Ecological Characteristics

The Doñana National Park (DNP) is probably the most important national park in Spain and one of the principal ones in southern Europe. It covers some 730 km^2. As already mentioned, it was classed an A wetland in the well-known MAR list in 1965. The DNP was created as a national park in 1969 by the Spanish government, and currently it is governed by special legislation enacted in 1978.

In the 1960s the FAO and the IGME carried out a hydrogeological survey of the River Gaudalquivir basin; its main consequence was to propose the development of what in principle was to be the most important irrigation project using groundwater in Spain: 24,000 ha with a pumpage of 145 hm^3/yr (FAO 1972). This project was named Plan de Transformación Agraria de Almonte-Marismas (PTAAM) and was passed by the government in 1979, in other words only a short while after the law governing the Doñana National Park came into force. The state-run Institute for Agricultural Development and Reform (IRYDA), dependent on the Ministry of Agriculture, was commissioned to develop this scheme. Subsequently in 1985 the management of the scheme was transferred to a body belonging to the Autonomous Government of Andalusia, the IARA.

Both the Doñana National Park and the PTAAM are located on the extensive geomorphological unit formed by the 3,000 km^2 of the lower Guadalquivir valley. This area was originally an estuary now filled in with Plioquaternary sediments. The area has been undergoing intensive agrarian transformation since the beginning of the century. This has essentially consisted of building channeling levels and closing dikes and surface drainage. Nowadays only 300 km^2 remain of the 1,800 km^2 of marshland or wetlands that existed at the turn of the century. They were included in the DNP.

The hydrological regime of the marshy area of the DNP has been considerably affected by the agricultural development works in the vicinity. Pressure from several conservation groups led the government in 1984 to pass a plan known as the Water Regeneration Plan, which endeavors to reduce the negative impact this agricultural development has had on the surface hydrology of the park. However, the concern shown by the conservation groups and, consequently, by the government over the likely serious ecological impact because of groundwater flow modifications has been and continues to be very small.

Three major ecosystems in the Doñana area can be identified: (1) the stabilized eolian sands, (2) the moving dunes, and (3) the marshland or swamps (Fig. 4). The stabilized sands are old dunes, the majority now flattened, although they still have a certain undulation, which means that the water table occurs at unequal distances from the surface of the ground. Scrub tends to abound on the upper parts consisting of different plants depending on the depth of the saturated zone. Tiny lagoons or seepage zones exist on the downs where the water table rises above the surface.

Doñana's system of moving dunes is one of the most spectacular landscapes in Spain. They appear in four or five rows parallel to the coast. Vegetation grows in the dips between the dunes as a result of the proximity of the water table. The dunes advance from the coast inland at a speed of 4 to 6 m/yr, and as they advance they bury and destroy the vegetation. A new biocenosis is set up after the passage of the dune.

The marshland covers the vast delta formed behind the littoral dunes. What is most impressive from the scenic point of view is how horizontal it is. However, on a microrelief scale, small differences in altitude of a few centimeters control the duration of the inundation, the quality of the water, and the plant and animal biocenoses. In winter almost the entire marshland is under a layer of water of an average depth of 30 cm. In summer virtually the whole of it dries out and presents a typical steppe landscape with saline beds and halophitic and xerophitic plants growing.

The ecotone or area of contact between the marsh and the moving or stabilized sands is the most fertile and productive zone of Doñana as a result of its permanent humidity and of the fertilization it receives from the animals either living there or permanently crossing it. It is because this is an important area of groundwater discharge that it is permanently damp, and this unique ecotone is the area that will suffer the greatest impact from the extraction of groundwater.

General Hydrogeological Characteristics

As mentioned earlier, beneath the lower Guadalquivir valley there is an extensive detritic aquifer some 3,000 km^2 in area. Approximately half of this aquifer is unconfined and receives direct recharge from rainfall. The other half remains confined beneath the muds and clays of the marshlands. Figure 5a gives a diagram of the hydrogeological profile considered representative of the system.

The bed of the aquifer consists of Miocene marls of marine origin considered to be impermeable. The materials above these clays are Plioquaternary and tidal in origin. As is to be expected in a coastal area subjected to several important eustatic oscillations throughout the Quaternary period, the materials have a fairly heterogeneous distribution individually but as a group can be considered a large aquifer the center of which is covered by a layer of estuarine and marshy clayey muds of low permeability with thicknesses of up to 100 m. The aquifer transmissivity ranges from 10 and 20 m^2/d in the peripheral areas (thin olian sands) up to over 2,000 m^2/d in the central area (gravels and sands 150 m thick).

Figure 5b is an idealized diagram of the flow system in the same profile as Figure 5a. The aquifer is

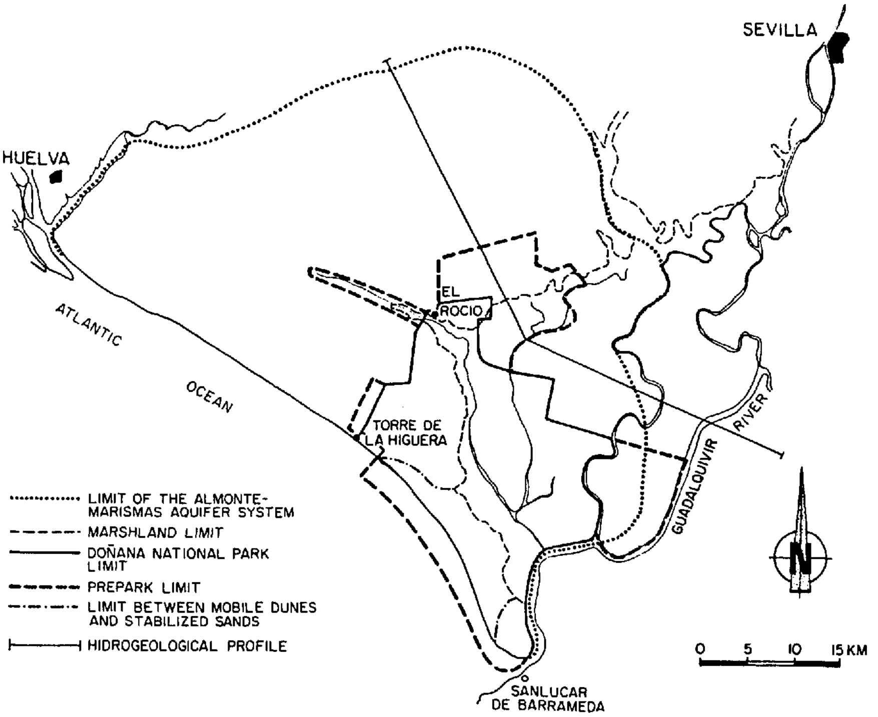

Figure 4. General map of the Doñana National Park.

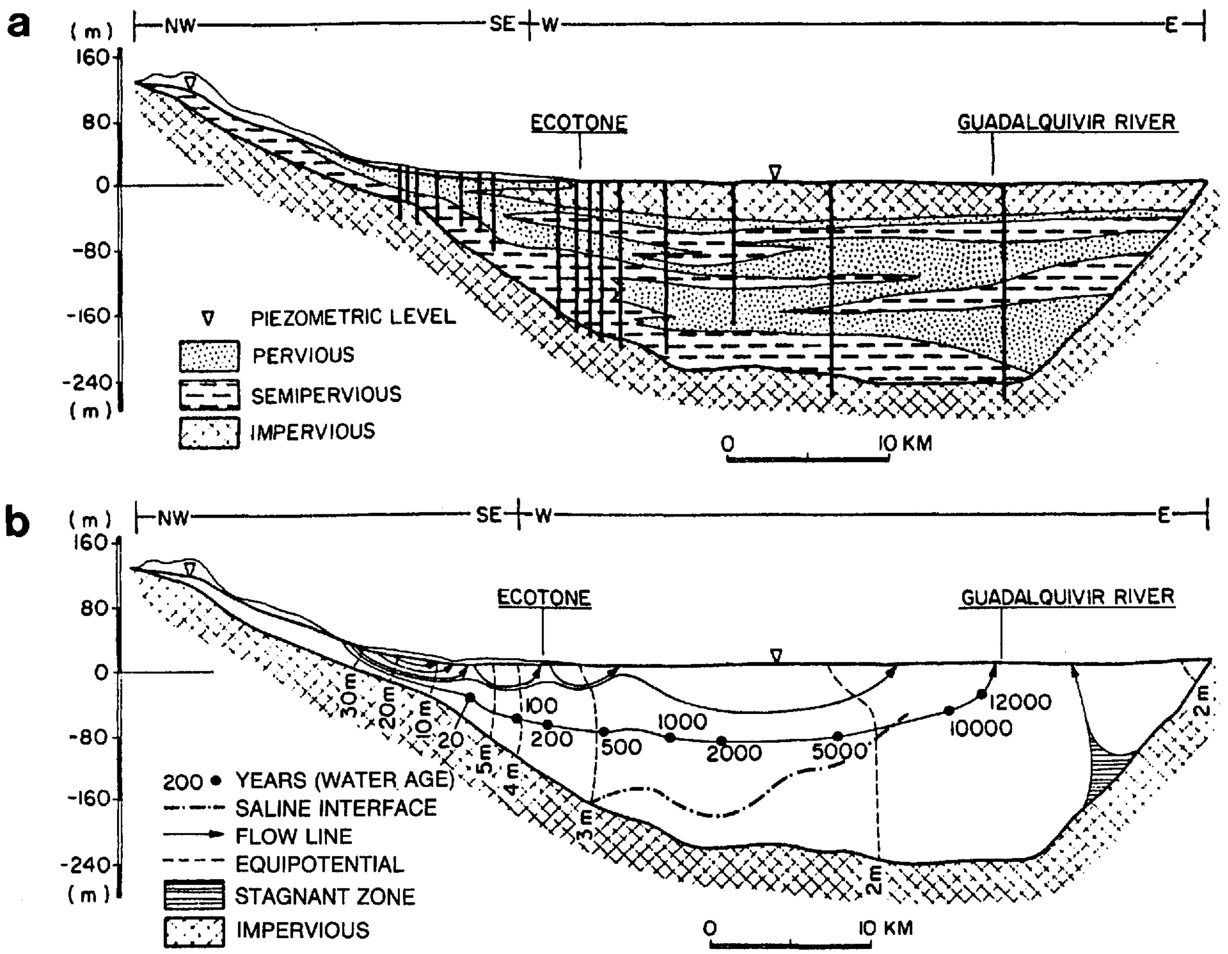

Figure 5. a. Representative hydrogeological profile. **b.** Simplified flow net. Location of the profile in Figure 4 (modified from Yagüe and Llamas, 1984).

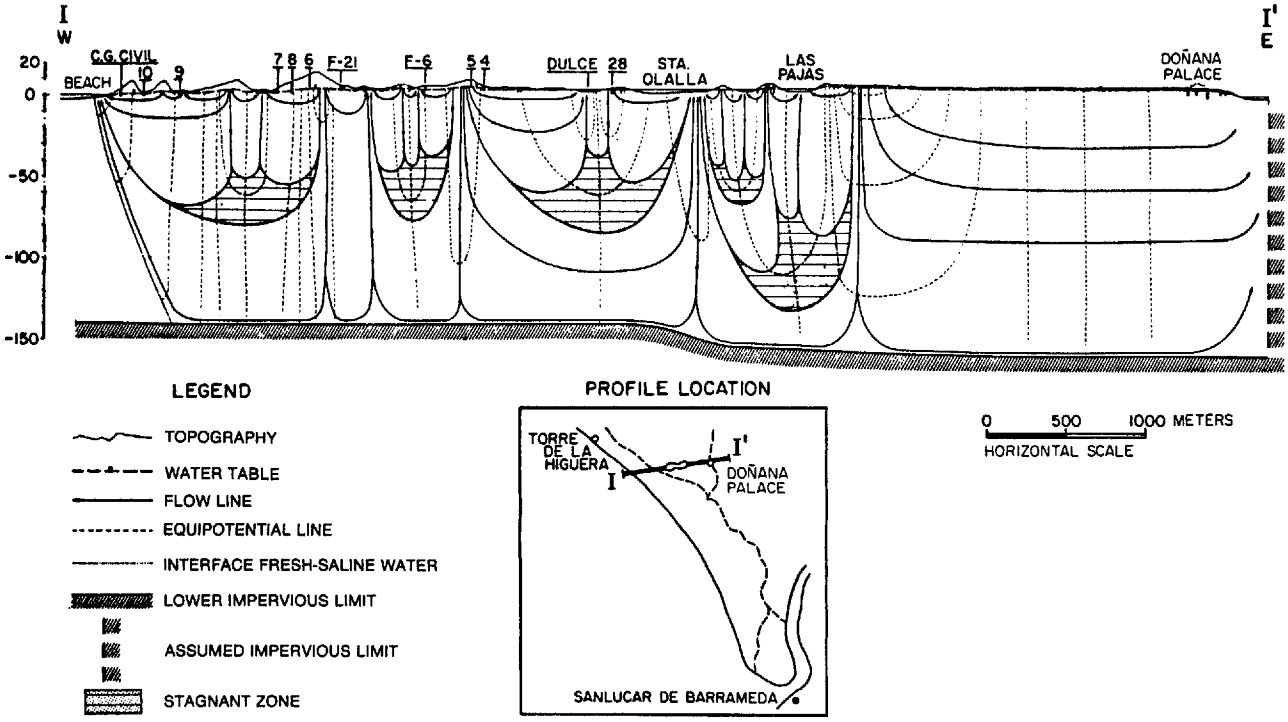

Figure 6. Flow system in a representative hydrogeological profile in the dunes (after Vela and Llamas, 1986).

recharged fundamentally by rainwater infiltration. The discharge occurs essentially as a result of the following phenomena: (1) base flow to the main streams and the sea (in the coastal dunes), (2) evapotraspiration (mostly in the eucalyptus groves), (3) seepage and evapotranspiration in the ecotone, and (4) slow and diffuse flow through the aquitard of the marshes. On the edges of this aquitard some small and localized more permeable zones may exist. These zones give rise to quicksand sites that are known as the marshland eyes.

The proportion between these discharges and even the estimate of the total recharge varies considerably from author to author (Yagüe and Llamas 1984). However, it is generally admitted that only a small fraction of the total recharge manages to reach the confined zone of the aquifer system. The following average annual figures serve as a general guide: precipitation: 0.6 m; potential evapotranspiration: 0.9 m; free surface evaporation: 1.5 m; temperature: 18°C.

The ecotone occurs at the contact between the eolian Quaternary deposits and the marshland. Here the aquifer ceases to be unconfined because it is covered by the mud-clay deposits of the Guadalquivir marshes. Figures 5a and 5b indicate that the surface hydrological manifestations observed in the area (seeping slopes, lagoons, and small streams) are the expression of a natural discharge area of groundwater.

Several groundwater flow digital models have been made. The most recent was done by the IGME and their findings were summarized by Virgós and others (1983). These authors reached the conclusion that the natural regime discharge in the ecotone strip was in the order of 12 hm^3/yr. Rodríguez Arévalo and Llamas (1986a, 1986b) reached similar figures by independent procedures.

In the coastal dune system with a more pronounced relief the groundwater flow system is more complex. Vela and Llamas (1986) in a preliminary study came to the conclusion that the groundwater residence time in this aquifer is shorter than the general aquifer of Doñana; the natural discharge principally occurs in the dips between the dunes, either in small lagoons or by evapotranspiration where the water table is close to the surface (Fig. 6).

Groundwater Exploitation

The PTAAM initially contemplated converting 240 km^2 into irrigated land at a pumping rate of 145 hm^3/yr. The irrigable areas were and continue to be primarily situated close to the ecotone (see Fig. 7). In the 1970s IRYDA had already drilled some 500 pumping wells for the PTAAM. The investment made by the government in this scheme amounts to some 15,000 million pesetas (US$ 120 million). To this must be added, at the least, a further 1,500 million pesetas

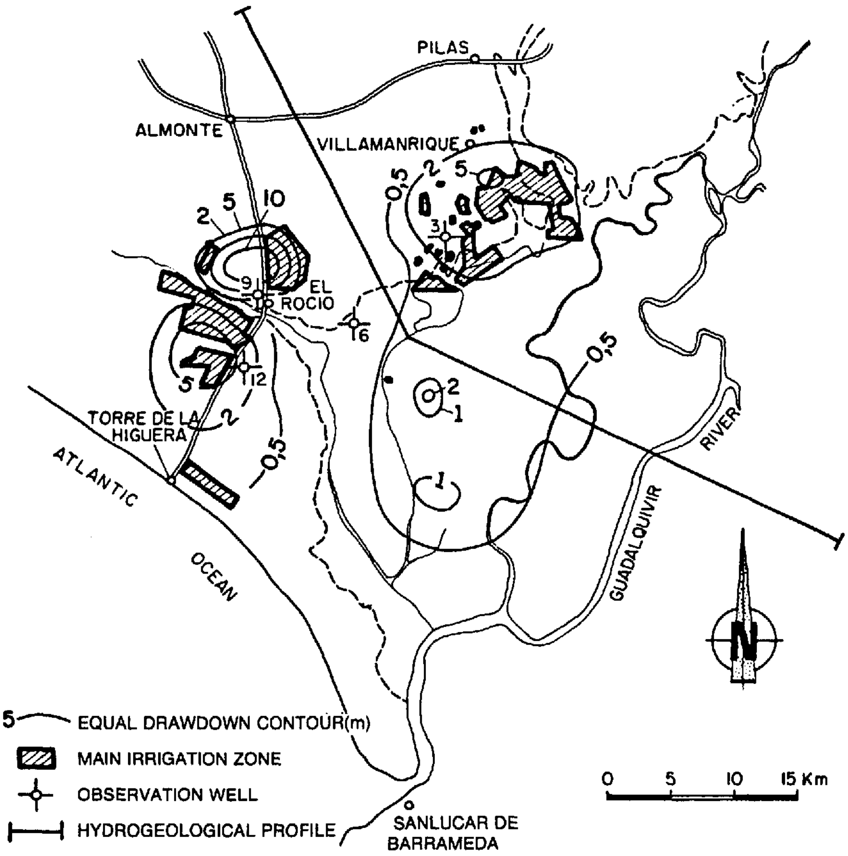

Figure 7. Irrigation areas in 1982 and computed equal drawdown contours after 40 yr of a constant pumpage of 45 hm^3/yr (modified from Rodríguez Arévalo and Llamas, 1986b).

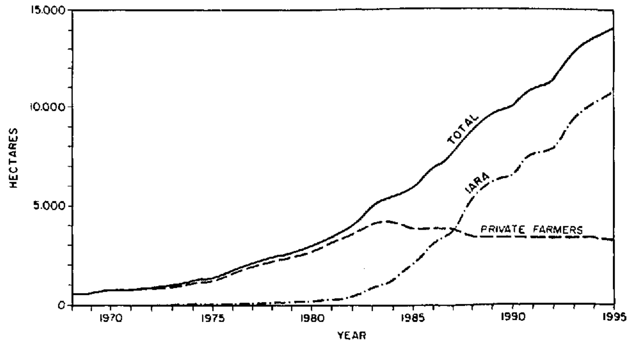

Figure 8. Historic and projected evolution of the area under irrigation (after Llamas and others 1987).

(US$ 12 million) spent on engineering and hydrogeological surveys.

The area irrigated in 1986 covered some 70 km^2 at a yearly pumping rate of some 50 hm^3, and IARA forecasts are for 100 km^2 in 1990 and 150 km^2 in 1995 at a rate of 80–90 hm^3/yr of pumpage (Fig. 8) "if no unfavorable ecological effects are discovered" (Llamas and others, 1987). To these figures must be added the pumping carried out for urban supply, mainly in the tourist complex of Matalascañas. The amount pumped for this purpose was estimated at less than one hm^3/yr by the IGME (1983). Llamas and others (1987) consider that the amount pumped in the Matalascañas area is considerably higher than the figure given by the IGME and that this may possibly lead to the desiccation of some of the lagoons in the nearby eolian sands area. Plans exist to increase tourism to a considerable extent in the vicinity of Matalascañas.

The Groundwater Exploitation Impact

The results of the various digital models made by the IGME and IRYDA to simulate the evolution of the water table or piezometric surface in the aquifer system of Almonte-Marismas were summarized by Rodríguez and Llamas (1986b). These models include simplified hypotheses on the pumping rate and climatology involved. All of them were done from the point of view of the technological feasibility of the pumping scheme, in other words, without paying any heed to the possible ecological impact. Figure 7 gives the equal drawdown curves after 40 yr of a constant pumpage of 45 m^3/yr according to an IGME model (Virgós and others 1983). It can be seen that the depletion in the

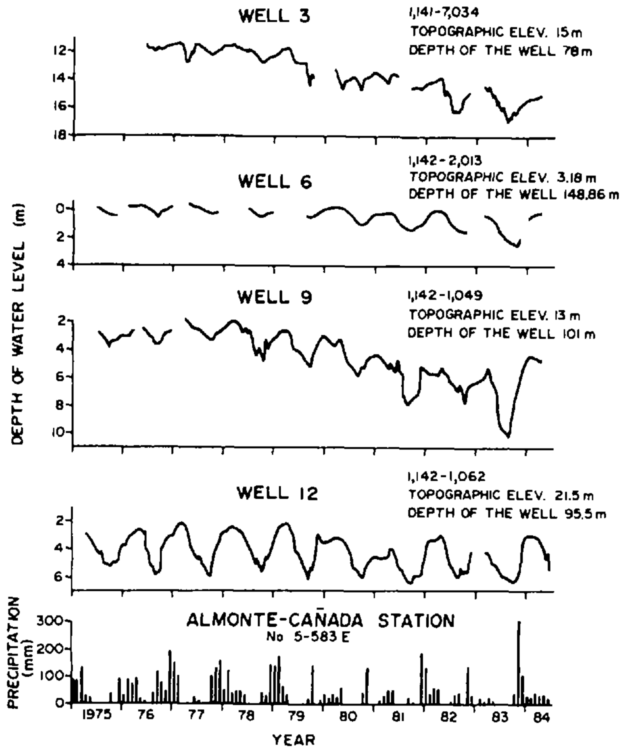

Figure 9. Precipitation and water table evolution (after Rodríguez Arévalo and Llamas 1986a).

water table will be greater than 5 m in extensive areas of the ecotone.

In the opinion of ecologists this depletion will produce a dramatic change in the ecotone. Spontaneous combustion or fires caused by man could even take place as in the case of the Tablas de Daimiel National Park if it is confirmed that the soils contain abundant organic matter. It must be warned that the pumping theory assumed by Virgós and others (1983) is lower than the one actually in progress and a good deal lower than the ceiling rate forecast by IARA (80–90 hm^3/yr for irrigation purposes, i.e., without including any urban supply figures). Naturally these drops will only occur once the irrigated land is fully under cultivation. To judge by the precedent of the Tablas de Daimiel National Park, it does not seem likely that it will be easy to find solutions at that stage.

Figure 9 shows the real depletion that occurred in the piezometric level in several piezometers between 1978 and 1984. Rodríguez Arévalo and Llamas (1986a, 1986b) came to the conclusion that the progressive depletion observed is not the result of a dry climate sequence but the consequence of pumpage.

In synthesis, it seems that from studies carried out and data available there is certain evidence that the current amounts of groundwater extraction in the Almonte-Marismas aquifer will have a serious ecological impact on the ecotone of the Doñana National Park. However, plans implemented in spring 1987 by the Andalusian government apparently consist of duplicating the present extraction rates.

Conclusion

There is now general awareness of the fact that wetlands constitute areas of particular ecological interest that need to be specially protected owing to their great sensitivity.

The majority of wetlands exist because of the joint action of ground and surface water.

The impact of anthropogenic action is usually more easily identified and corrected on surface water. But the changes introduced in the groundwater regime, as a result of the slowness involved, can easily pass unheeded over many years, and when warnings are issued about them it is very difficult indeed to solve the problem.

Thus, in the case of the Tablas de Daimiel National Park it can definitely be stated that the ecosystem has undergone such a degree of deterioration, including fires in one-third of its extent, that its regeneration is virtually impossible because of the economic and social implications involved. In the case of the ecotone of the Doñana National Park, where pumping activity is more recent, the direct ecological impact is not yet so obvious. Perhaps, as a result of this, the government is carrying on with its plan to increase pumping activity.

Both cases described point to the need not only to know more about the role groundwater plays in the existence and conservation of wetlands, but also to convey this knowledge and awareness to those responsible for the management of such ecosystems and to the public in general.

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