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COMPETING DEMANDS FOR IRRIGATION WATER: GOLF AND AGRICULTURE IN SPAIN[‡]

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ABSTRACT

In many countries where water resources are under stress, there is a perception that irrigating golf courses causes significant additional abstraction, and that this has major impacts on the environment and other abstractors, including irrigated agriculture. This paper provides a quantitative assessment of water use within the golf sector in Spain, and compares it with irrigated agriculture. It is based on literature review, a national survey of golf course irrigation practices, and a correlation of reported irrigation consumption against agroclimate. Using a geographical information system (GIS), the water consumption for all golf courses in Spain was modelled and mapped, and the total water consumption estimated.

The results show that the volume of water used for golf irrigation is extremely small compared to agricultural irrigation. Furthermore, a significant portion comes from wastewater reuse (41%) and desalination (7%), rather than direct abstraction, which competes with agriculture. However, it is concentrated in particular tourist areas and could cause local problems. The average economic productivity of the water used for golf, estimated at around 9 € m^{-3} in direct benefits (course fees) and 28 € m^{-3} if including the benefits to the tourist industry, is very much higher than for even high-value agricultural crops. These results suggest that irrigating golf courses for tourism purposes is an economically rational water use in Spain, even though the transfer of resources from agriculture is controversial. Copyright © 2007 John Wiley & Sons, Ltd.

KEY WORDS: agriculture; golf; irrigation; maps; Spain; water resources

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RÉSUMÉ

Dans beaucoup de pays où les ressources d'eau sont très sollicitées, une opinion courante est que l'irrigation des terrains de golf représente un prélèvement additionnel significatif, et que ceci a des effets majeurs sur l'environnement et sur d'autres usages préleveurs, parmi lesquels l'agriculture irriguée. Cet article fournit une évaluation quantitative de l'utilisation de l'eau dans le secteur du golf en Espagne, et le compare à l'agriculture irriguée. Il est basé sur la littérature existante, une enquête sur les pratiques nationales en matière d'irrigation de terrains de golf, et une corrélation entre la consommation d'irrigation et les données de météo agricole. A l'aide d'un système d'information géographique (GIS), la consommation d'eau de tous les cours de golf d'Espagne a été modélisée et représentée, et la consommation totale d'eau a été estimée.

Les résultats prouvent que le volume d'eau utilisé pour l'irrigation des terrains de golf est extrêmement minime par rapport à l'irrigation agricole. En outre, une partie significative vient de la réutilisation des eaux résiduaires (41%) et du dessalement (7%), plutôt que de prélèvements directs qui concurrencent l'agriculture. Cependant, elle

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est concentrée sur des secteurs très touristiques et pourrait poser des problèmes locaux. La productivité économique moyenne de l'eau utilisée pour le golf, estimée à environ 9 € m^{-3} en avantages directs (honoraires de cours) et 28 € m^{-3} en incluant les avantages allant au secteur du tourisme, est beaucoup plus élevée que pour les cultures, même à haute valeur ajoutée. Ces résultats suggèrent que l'irrigation des terrains de golf pour touristes est un usage économiquement raisonnable de l'eau en Espagne, bien que le transfert de ressources à partir de l'agriculture soit controversée.

MOTS CLÉS: agriculture; golf; irrigation; cartes; Espagne; ressources en eau

INTRODUCTION

As in many Mediterranean countries, water resources in Spain are under intense pressure. Many river basins already have major levels of water deficit (García, 2004). Irrigated agriculture uses three-quarters (77%) of all freshwater withdrawals (abstractions), with public water supply (15.5%) and industry (6.8%) accounting for most of the remainder (Spanish National Statistics Institute, 2001). However, in some locations, agricultural water users are now having to compete with a new and highly profitable water use, for irrigating golf courses.

From 1997 to 2005 the total number of golf courses in Spain increased by 83% (Real Federación Española de Golf, 2005a). By 2005 there were reported to be 289 golf courses in Spain (Golf Spain, 2005), and this number is expected to double within the next decade (Schouten, 2003). The majority of these courses are located in the major tourist areas, particularly along the Mediterranean coast (Figure 1). Nearly 13% are around Malaga, with Barcelona and Alicante accounting for a further 7 and 4.6%, respectively. About 9% are located around Madrid. These locations coincide with many of the catchments with the greatest water deficits (Figure 2) (Ministerio de Medio Ambiente, 1998).

On all modern golf courses in arid climates, irrigation is an essential tool, used for controlling the growth and quality of the turf, for maximising playability, and for maintaining the aesthetic conditions demanded by players and spectators (Weatherhead *et al*., 2006). The objectives determining irrigation water use in golf differ markedly from those in agriculture. In contrast to maximising crop yield and/or quality, the main objective of sports-turf irrigation is to control the soil moisture content, which influences bounce and playability, and to produce and maintain a safe, high-quality playing surface. Income is dependent both on the number of rounds the course can withstand per season and the value the players place on playing on that course. In tourist golf developments, the income from rental accommodation, hotels and restaurants can be dramatically influenced by the quality of the golf provided. Since acceptable conditions have to be maintained year-round, the water requirements are significantly higher than those for agricultural crops.

The demand for water for irrigated agriculture in Spain is also growing steadily, driven by consumer demands for high-quality fresh produce, for both domestic consumption and for export. In 2001, the total agricultural irrigated

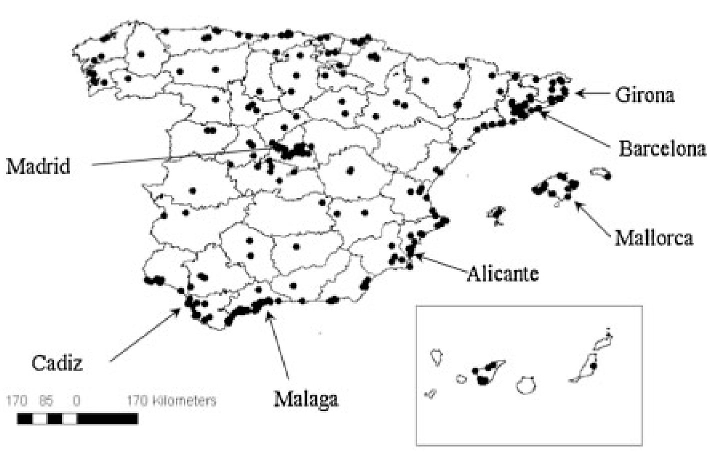

Figure 1. Spatial distribution of golf courses across Spain, and by province, in 2005

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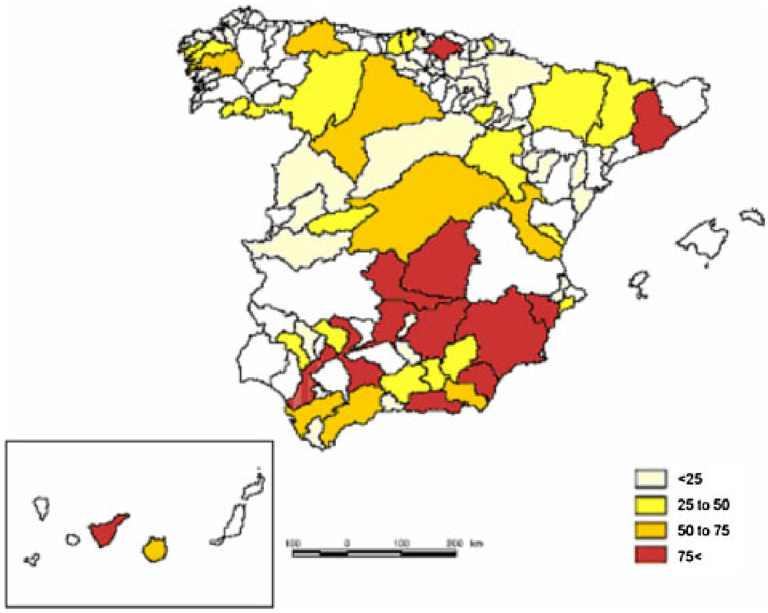

Figure 2. Reported water deficits in Spain, by sub-catchment (million $m^3 yr^{-1}$) (Ministerio de Medio Ambiente, 1998). This figure is available in colour online at www.interscience.wiley.com/journal/ird

area in Spain was estimated to be 3.3 million ha, spread across more than 1 million irrigated farms (del Campo, 2002). This is the largest irrigated area in Europe, ahead of Italy (3.1 million ha), Turkey (2.2 million ha), Greece (1.2 million ha) and France (1.1 million ha) (Federación Nacional de Comunidades de Regantes, 2005). The irrigated agricultural land in Spain represents 13% of the total cropped area but accounts for 60% of the total value of agricultural production. In terms of contribution to gross value of production the most important irrigated crops, by percentage of the total irrigated surface, are fruit trees and citrus (15.6%), vegetables (10.2%), potatoes (5.5%) and ornamental and flower crops (3%), though there is a great variability between individual regions. Some 17.7 billion m^3 of water were consumed by agriculture nationally in 1999 (Spanish National Statistics Institute, 2001). In some coastal provinces (principally in the south-east) there are already recurrent problems in water supply, especially during the summer months when the peak demand for tourism coincides with that for agricultural and golf irrigation (Kent *et al.*, 2002; De Stefano, 2004). Clearly, in a country where water resources are already constrained, the rising demand for irrigation for golf course developments in conjunction with the continued expansion of the tourism sector will increase pressure on already limited supplies and have implications on water allocations for irrigated agriculture. The transfer of water from agriculture to golf developments is already a political issue, in Spain and elsewhere (e.g. Rego, 2005). The longer-term threat of climate change with the likelihood of much drier summers and more frequent droughts (Moreno, 2005) would only exacerbate the current situation.

This paper provides a quantitative assessment of irrigation demand within the golf sector in Spain, and compares the nature and composition of golf course irrigation water use with that of irrigated agriculture.

METHODOLOGY AND RESULTS

A three-stage methodology was used:

1. A national postal survey was conducted to derive a baseline dataset on the nature and composition of golf course irrigation water use in Spain. The data relate to 2004;
2. A GIS was used to model and map the spatial variation in agroclimate across Spain, using the variable maximum potential soil moisture deficit ($PSMD_{max}$) as a climatic indicator;

3. A correlation was established between reported water use on golf courses and $PSMD_{max}$. The correlation and the agroclimatic map were then used to estimate water use at the other courses and in total.

The survey findings and modelling outputs were then used in a comparative assessment of irrigation water use within the golf and agricultural sectors, including the areas irrigated, the volumes applied, and the costs and benefits of using the water. This approach is applicable to other Mediterranean countries where appropriate datasets can be obtained. A brief description of each stage is provided below.

Spanish golf irrigation survey

In contrast to irrigated agriculture in Spain (e.g. del Campo, 2002; Federación Nacional de Comunidades de Regantes, 2005), there was virtually no published information relating to irrigation water use within the golf sector in Spain. A national postal survey was therefore undertaken to provide a baseline dataset. The survey collected information on aspects including the areas irrigated, the equipment used, water consumption, irrigation management, water sources, water costs and options for adapting to changing water availability (for example, due to climate change). The survey was targeted to 283 golf courses spread across Spain, as identified by the Royal Spanish Federation of Golf (Real Federación Española de Golf, RFEG) and the Spanish Greenkeepers' Association (Asociación Española de Greenkeepers). In all, 30 completed forms were returned, representing a 12% response rate.

Agroclimatic mapping

As with agriculture, the climatic drivers of irrigation demand for sports turf relate primarily to the balance between rainfall and evapotranspiration (ET) and their consequent impacts on soil moisture and turf growth. The particular crop water requirements of golf can mean, however, that simple crop water balance models such as CROPWAT do not directly provide the full water requirements, and the efficiencies attained would have to be assumed. The actual water use data reported by each course in the survey were therefore correlated to a simple agroclimatic indicator, allowing the actual water use at the other courses to be estimated, assuming they were similarly irrigated.

Previous studies have used the variable "maximum potential soil moisture deficit" ($PSMD_{max}$) as an agroclimatic indicator to assess the impacts of climate variability on irrigation need (e.g. Knox *et al*., 1997, 2006; Downing *et al*., 2003; Weatherhead *et al*., 2006). In this study, a similar approach was applied to Spain using mean monthly data. For a given site, the PSMD in each month is calculated from:

$$PSMD_i = PSMD_{i-1} + ET_i - P_i \quad (1)$$

where

$PSMD_i$ = potential soil moisture deficit in month i, mm
$PSMD_{i-1}$ = potential soil moisture deficit in month $i-1$, mm
ET_i = potential evapotranspiration of short grass in month i, mm
P_i = rainfall in month i, mm

The initial $PSMD_i$, for January is assumed at 0 (for an irrigated site). When $P_i > PSMD_{i-1} + ET_i$, (e.g. following heavy rain) any existing deficit is assumed to have been replenished, with excess water draining or running off, and $PSMD_i$ is again reset to 0. The highest $PSMD_i$ over the year is then the $PSMD_{max}$ for that site.

For this study, the gridded climatic datasets developed by the International Water Management Institute (IWMI) were used. These are at a $10' \times 10'$ (approximately 50 km × 50 km) grid resolution and contain mean monthly climate data for a range of variables relating to 1961 to 1990 (New *et al*., 2002). The IWMI gridded dataset contains rainfall data and the variables needed to estimate ET_o based on the FAO Penman-Monteith equation (namely, mean air temperature, solar radiation, wind speed and humidity). Using an approach developed by Hess and Knox (2006), the IWMI datasets were used to generate a gridded dataset of mean monthly ET_o across Spain. This derived ET_o

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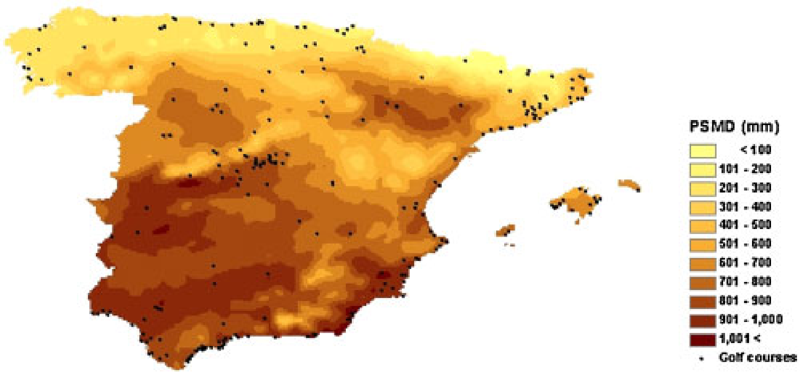

Figure 3. Location of golf courses in Spain relative to the spatial distribution of potential soil moisture deficit ($PSMD_{max}$). This figure is available in colour online at www.interscience.wiley.com/journal/ird

dataset and the IWMI rainfall dataset were then combined (Equation 1) to generate a gridded $PSMD_{max}$ dataset across Spain. This was imported into a GIS and, using a contouring function, a map showing the spatial variation in $PSMD_{max}$ across Spain was produced (Figure 3).

Correlating agroclimate to water use

The next stage involved assessing the relationship between $PSMD_{max}$ and irrigation water consumption on golf. The $PSMD_{max}$ value for each of the golf courses that responded to the survey (excluding those in the Canary Islands) was extracted from the map and correlated to their reported water consumption. The derived linear regression is shown in Figure 4, where:

$$\text{Water consumption (mm)} = 0.619\ \text{PSMD max(mm)} + 404 \tag{2}$$

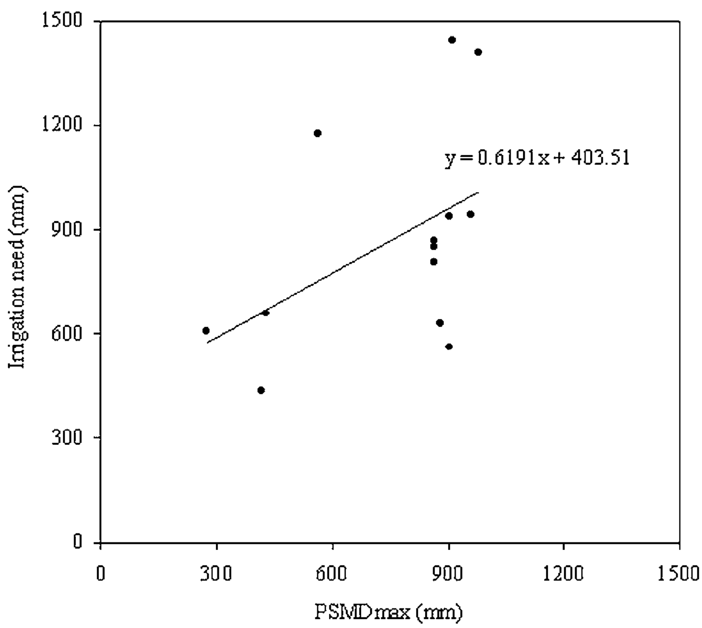

Figure 4. Linear regression between $PSMD_{max}$ and reported water consumption for selected golf courses in Spain

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The final step was to extract the $PSMD_{max}$ values corresponding to the grid pixel location for all known golf courses and, using the above linear regression correlation and the average irrigated surface, to estimate the total water consumption (m^3) of all golf courses in Spain. The correlation was not applied to the Canary Islands because of the very different climate pattern.

RESULTS AND DISCUSSION

Irrigated areas

Golf courses typically comprise 18 holes, though other multiples of 9 can occur. On each hole, five areas can be differentiated, namely tees, fairways, approaches, greens and (surrounding the other four) rough. The survey data suggested that in Spain most courses irrigate all five constituent parts. This is in contrast to the practice in more temperate countries such as England, where typically only the tees and greens are irrigated (Weatherhead *et al.*, 2006). Although there were large observed differences between individual courses, the average irrigated area per course was estimated to be 34.2 ha. Greens and tees represented only 11% of the total irrigated surface. Assuming 289 fully irrigated golf courses (Golf Spain, 2005), the total area irrigated for golf in Spain is thus estimated to be 9890 ha. This is negligible compared with irrigated agriculture, which covers more than 3.3 million ha (del Campo, 2002).

Irrigation water demand

Although most golf courses are concentrated along the Mediterranean coast where the climate does not vary greatly, the survey data show that there is a great variability in irrigation water consumption, fluctuating between 2000 and 17 000 $m^3\,ha^{-1}$. Excluding the Canary Islands, courses reported an average consumption of 280 440 m^3, implying a water demand of 8200 $m^3\,ha^{-1}$. This is consistent with estimates by Sanz Magallón (2005) and Morell (2002), of 7563 and 8000 $m^3\,ha^{-1}$, respectively.

In comparison, the average irrigation water consumption in agriculture in Spain is less than 5400 $m^3\,ha^{-1}$. This is significantly lower than the average water consumption for golf. However, in the older traditional agricultural systems, where water is conveyed via open channels, water consumption has been reported to vary between 7000 and 9000 $m^3\,ha^{-1}$ (Rodriguez Diaz *et al.*, 2005).

From the GIS modelling, the total water consumption for all golf courses in Spain, excluding the Canary Islands, was estimated to be 76.5 million m^3. However, the variation between provinces is quite high (Figure 5). In most provinces, total demands are lower than 1 million m^3. The high demands are in provinces with most courses, such as Malaga (11.8 million m^3), Madrid (8 million m^3), Cadiz (5.5 million m^3), Mallorca (4.9 million m^3) and Barcelona (4.6 million m^3). Most of these provinces with high demand are located on the coast, and already have problems in water availability especially during the summer tourism season.

In the Canary Islands, the much higher temperatures that typically occur throughout the year result in higher figures for irrigation water consumption. In this study, average irrigation water consumption was reported to be 16 700 $m^3\,ha^{-1}$, giving an average consumption per course of 571 140 m^3 spread over an irrigated area of 34.2 ha. Golf courses in the Canary Islands thus appear to be applying about twice as much water as those in the rest of Spain. For the 15 golf courses in the islands, this gives a total estimated water consumption of 8.6 million m^3.

Adding the Canary Islands to the rest of Spain gives an estimated total of 85.1 million m^3 of irrigation water consumed by golf courses. Compared with the 17.7 billion m^3 of water consumed by irrigated agriculture nationally in 1999 (Spanish National Statistics Institute, 2001) this figure is again very low ($\sim$0.5%).

However in provinces such as Malaga, where water is already a scarce resource (Figure 2), and with courses concentrated in particular local areas, there could still be real conflicts.

Water sources

The survey results showed that most courses (41%) reuse wastewater for their irrigation, while surface water and groundwater each account for approximately 26%. In contrast, 68% of water used in agriculture is surface water,

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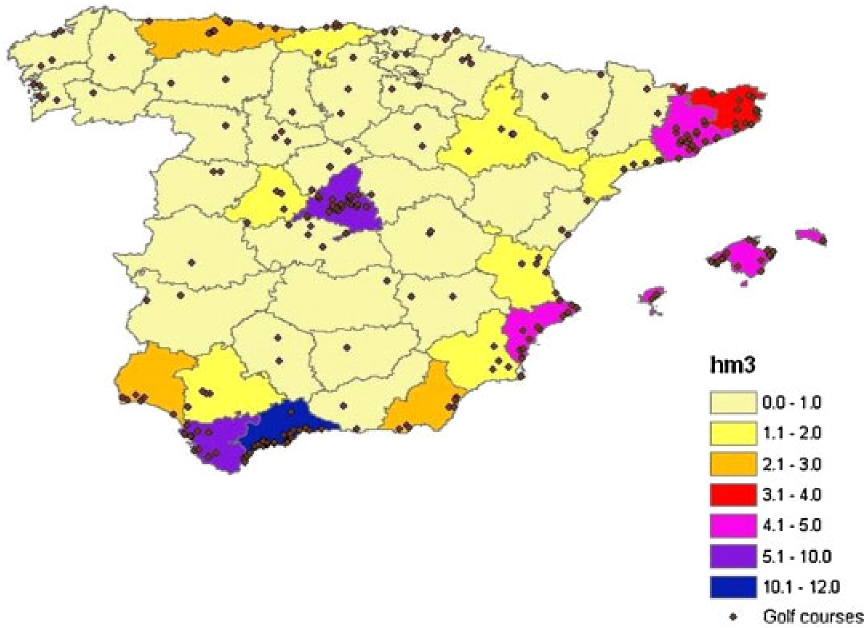

Figure 5. GIS modelled irrigation water demand, by province in Spain (million $m^3 yr^{-1}$). This figure is available in colour online at www.interscience.wiley.com/journal/ird

followed by groundwater (28%), with only 4% being abstracted from non-conventional sources such as wastewater or desalination (Federación Nacional de Comunidades de Regantes, 2005).

Spanish water law sets an order of preference between uses of water. The most important is urban water supply, followed by agriculture, power plants, industry and then recreational purposes. However, this priority can be changed by the catchment regulators (Confederaciones Hidrográficas) although urban water supply must always be allocated first (Texto Refundido de la Ley de Aguas, 2001). Spanish law does allow water markets as a tool to improve water allocation. However, transfers of water to users at lower levels in this hierarchy are not permitted (Sanz Magallón, 2005). With these legal restrictions in force, the only alternative options of water for golf course irrigation are non-conventional sources.

At present, desalinated water represents only 7% of water used for golf, but with 80% of all golf courses in Spain located less than 10 km from the sea, increased dependence on this source is feasible if cheaper sources are unavailable, particularly if desalination costs fall. However, reuse of wastewater, particularly from the tourist developments associated with many courses, is most widely used; this water is of course first abstracted as urban water supply, at the highest priority.

Water costs and benefits

Data from the survey were analysed to estimate the average costs of water for irrigation. As expected, the non-conventional sources were the most expensive; courses that rely on desalinated water reported average costs of 0.85 € m^{-3}; this is very high compared to the costs of surface or groundwater, which only incur pumping costs. The costs of using wastewater were reported to be between 0.06 and 0.38 € m^{-3}. In agriculture, the water costs vary significantly depending on the source, the crops irrigated and local water allocation rights, but typically range between 0.03 and 0.24 € m^{-3} (Federación Nacional de Comunidades de Regantes, 2005).

The Royal Spanish Federation of Golf estimates that golf in Spain annually generates 2375 million € (Real Federación Española de Golf, 2005b) and is one of the most important elements of the Spanish tourism sector. Applying this value to the 85.1 million $m^3 yr^{-1}$ suggests that the golf productivity per unit of water is

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28 € m^{-3}. This includes both the direct income from course fees and the indirect benefit due to its positive impact on the tourism sector. Sanz Magallón (2005) estimated that only one-third of the total benefits of golf are accounted for through course fees in Spain. Applying this ratio to the 28 € m^{-3} suggests 9.3 € m^{-3} of direct benefits. This value is much higher (threefold) than even the most profitable agricultural crops, such as strawberries in the south-west which typically produce around 3 € m^{-3} (Rodríguez Díaz, 2004).

Regulatory and environmental impacts

In the future, water abstraction for golf will be more heavily regulated through the national policy implementation of the European Water Framework Directive (European Union, 2000). The principle of cost recovery will inevitably raise water prices, which should encourage all water abstractors to become more efficient. However, the high profitability of golf course irrigation makes it unlikely that this would necessarily lead to a reduction in the volumes of water currently being applied.

Golf courses may have scope to improve their water efficiency. Despite the fact that most of the irrigation systems are less than five years old and 50% of golf courses have their own weather station, more than 50% of greenkeepers are reported to be scheduling their irrigation applications using only visual inspection. Most other courses are reported to be using some form of soil water balance, while only 2% were estimated to be using *in situ* soil moisture measurement.

Finally, climate change is also likely to exacerbate the problem. Current predictions for Spain suggest an increase in the average temperatures and an altered distribution of precipitation. Rainfall is predicted to be reduced during summer months, although conversely winter rainfall is likely to increase, including the intensity of storm events. This could cause both a reduction in water resources (supply) for irrigation (Iglesias *et al*., 2005), and an increase in irrigation demand.

CONCLUSIONS

A quantitative comparative assessment of irrigation water use within the golf and agricultural sectors in Spain has been undertaken. This study confirms that golf course irrigation constitutes a very high-value and important use of water, particularly in coastal areas.

The results suggest that in terms of both irrigated area and total volume of water applied, golf course irrigation constitutes a minor abstraction when compared to irrigated agriculture. Furthermore, a significant component of golf course irrigation water is derived from wastewater reuse (41%) and desalination (7%) sources, rather than via direct abstraction, which competes with agriculture. However, golf courses are concentrated in particular tourist areas and are contributing to local environmental and hydrological problems.

The average economic productivity of the water used for golf, estimated at around 9 € m^{-3} in direct benefits (course fees) and 28 € m^{-3} (overall benefits to the tourist industry), is very much higher than for even high-value agricultural crops. These results suggest that irrigating golf courses for tourism purposes is an economically rational water use in Spain, even though the transfer of resources from agriculture is controversial. Improving the efficiency of water use within the golf sector, and promoting the use of non-conventional water sources for golf course irrigation, would, therefore, from a societal perspective, be considered preferable than transferring existing water allocations from agriculture.

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