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Tourism and sustainable water supply in Mallorca: a geographical analysis

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Abstract

Problems of sustainability of water supply in tourist resorts are becoming an increasingly common and important issue in applied geography and environmental management. This paper examines the relationships between tourism and water supply on the Mediterranean island of Mallorca, discussing both the scale of the problem and recent measures to find a solution, particularly the proposed Hydrological Plan for the Balearic Islands (published in 1998/9). Since Mallorca lies in an area likely to be seriously affected by future climate change, its potential effects are discussed and evaluated. One of the most critical problems relates to the coarse spatial resolution of general circulation models for predicting precipitation in an area where precipitation regimes grade steeply from semi-arid to humid temperate. However, it is likely that a continuation of the marked inter-annual and decadal-scale variability in precipitation seen during the recent past probably poses a greater threat to Mallorca's water supply than the more gradual, progressive change typically predicted to accompany future global warming. Similarly, continued over-exploitation of coastal aquifers will be more critical to water quality issues than the direct impacts of any future sea level rise, although the latter would undoubtedly exacerbate these effects. The conclusion discusses the controversial new *ecotasa* ('ecotax'), due to be imposed on Mallorca's tourist industry in 2002, which is likely to represent only a partial solution to the long-term water supply problem. As the physical, cultural and economic environments of Mallorca are typical of much of the Mediterranean region, the implications of this issue extend well beyond the island's shores.

Keywords: Balearic islands; Climate change; Ecotax; Environmental management; Groundwater; Hydrology; Mallorca; Mediterranean; Tourism; Water conservation; Water supply

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Introduction

No environmental issue has attracted more popular and political attention in Spain than the critical problem of water shortages. Spain's average national rainfall is not very different from that of the UK, but it is spatially very uneven, as is the demand for water (Bull, 1997; Williams, 1997; Romero, Guijarro, Ramis, & Alonso, 1998). However, the 1990s saw one of the longest and most severe droughts on record (Roberts, 2002). In the early 1990s, average rainfall fluctuated between 30 and 80% of the long-term average in much of southern and eastern Spain (Wheeler, 1995). In addition, predictions of future climate change and the possible impacts that may result in Mediterranean countries are highly variable (Attard, Axiak, Borg, Borg, & Cachia, 1996; Houghton et al., 1996; Birdi, 1997; Houghton, 1997; Corte-Real, Sorani, & Conte, 1998; Goodess, Mariani, Palutikof, Menichini, & Minardi, 1998).

Although 60–80% of water supply in Spain is typically used in agriculture and for irrigation (Smith, 1997), problems have been exacerbated in many parts of the country by the additional demands of the tourist industry (e.g. Roberts, 2002). One of the most concentrated areas of tourist activity is in the Balearic Islands, particularly the island of Mallorca. In the Balearics, tourism accounts for over 60% of GDP (Batle, 2000). Tourists expect water supplies to be both reliable and safe. However, during the spring of 2000, water shortages on Mallorca, combined with problems of water quality, resulted in adverse publicity in the German press (*Das Bild*). Consequently, a significant reduction in the number of German tourists coming to the island was reported in the local Mallorcan press in September 2000. These circumstances were of considerable potential importance to the island's tourist industry, as Germans represent approximately one-third of all tourists arriving on the island (Buswell, 1996). Their response gives a possible early indication of the consequences for both the economy and society of the island if water supplies come under even greater pressure in the future.

The aim of this article is to examine the relationships between tourist demand and water supply on the island of Mallorca and to assess whether the supply of water may ultimately constrain the long-term viability of the island's tourist industry. After describing the physical and human factors behind the current supply of and demand for water, the mixed success of early attempts at managing supply and demand are reviewed, which leads to a discussion of the proposed Hydrological Plan for the Balearics (Conselleria de Medi Ambient, 1998/9). Predictions of climatic change and climate change modelling are ignored completely in the forecasts within the plan, as are climatic changes in the recent past that may prove to be a precursor to future change. Lastly, the implications for the future of the island's water supplies are reviewed and the future long-term sustainability of its tourist industry questioned. In many aspects of its geography, Mallorca is a microcosm of the wider Mediterranean region, although as a comparatively small island, it is perhaps more vulnerable than most to the various environmental and economic pressures that underlie the water quality issue. Nevertheless the island's recent and ongoing experiences should

sound a warning to other areas in the Mediterranean region that are also striving for an expanded tourism economy.

Water in Mallorca

In Mallorca and the other Balearic islands, key aspects of both physical and cultural geography contribute to the water supply problem.

The precipitation regime of Mallorca

The climate of Mallorca displays marked seasonality, particularly in precipitation, as is typical of the Mediterranean region (Linés Escardó, 1970; Perry, 1997; Allen, 2001; Mayes, 2001). During winter months, the island is affected by the southern part of the belt of mid-latitude westerlies, with associated frontal systems often bringing heavy rainfall. In the summer, the westerly wind belt moves to higher latitudes and Mallorca's weather is strongly influenced by the subtropical belt of high pressure systems, which typically bring dry, hot weather (Sumner, Ramis, & Guijarro, 1993; Sumner, Guijarro, & Ramis, 1995; Lluch Dubon, 1997). As a consequence, virtually all precipitation occurs in the autumn and winter months, with the wettest months typically being October to December (Fig. 1). Exceptional rainfall in October is particularly common (Spellman, 1998; Mayes, 2001).

There is also strong regional differentiation (Fig. 2), particularly of precipitation, due to topography (Wheeler, 1994). Thus annual rainfall may vary from as little as 300 mm in the southeast to $>$1200 mm in the Sierra de Tramuntana, only about 100 km to the north. As a result, the estimated period of soil moisture deficit varies from as long as 10–11 months at Cap de Ses Salines in the southeast to around 3 months at Almallutz, in the Sierra de Tramuntana (Fig. 3). These strong regional and seasonal differences in precipitation and soil moisture characteristics have important implications for water supply, notably the need for transfer and storage of water within the island to match the supply and demand.

Limestone geology and hydrology

The island's geology, which is almost entirely limestone, and its resulting influence on hydrology, has had a profound effect on water supply and management. The combination of a Mediterranean climate and a highly permeable lithology means that surface water flow only occurs in winter months and almost all streams are ephemeral (Lluch Dubon, 1997). Consequently, 75–95% of Mallorca's water is abstracted from groundwater sources (Pons, 1989; Conselleria de Medi Ambient,

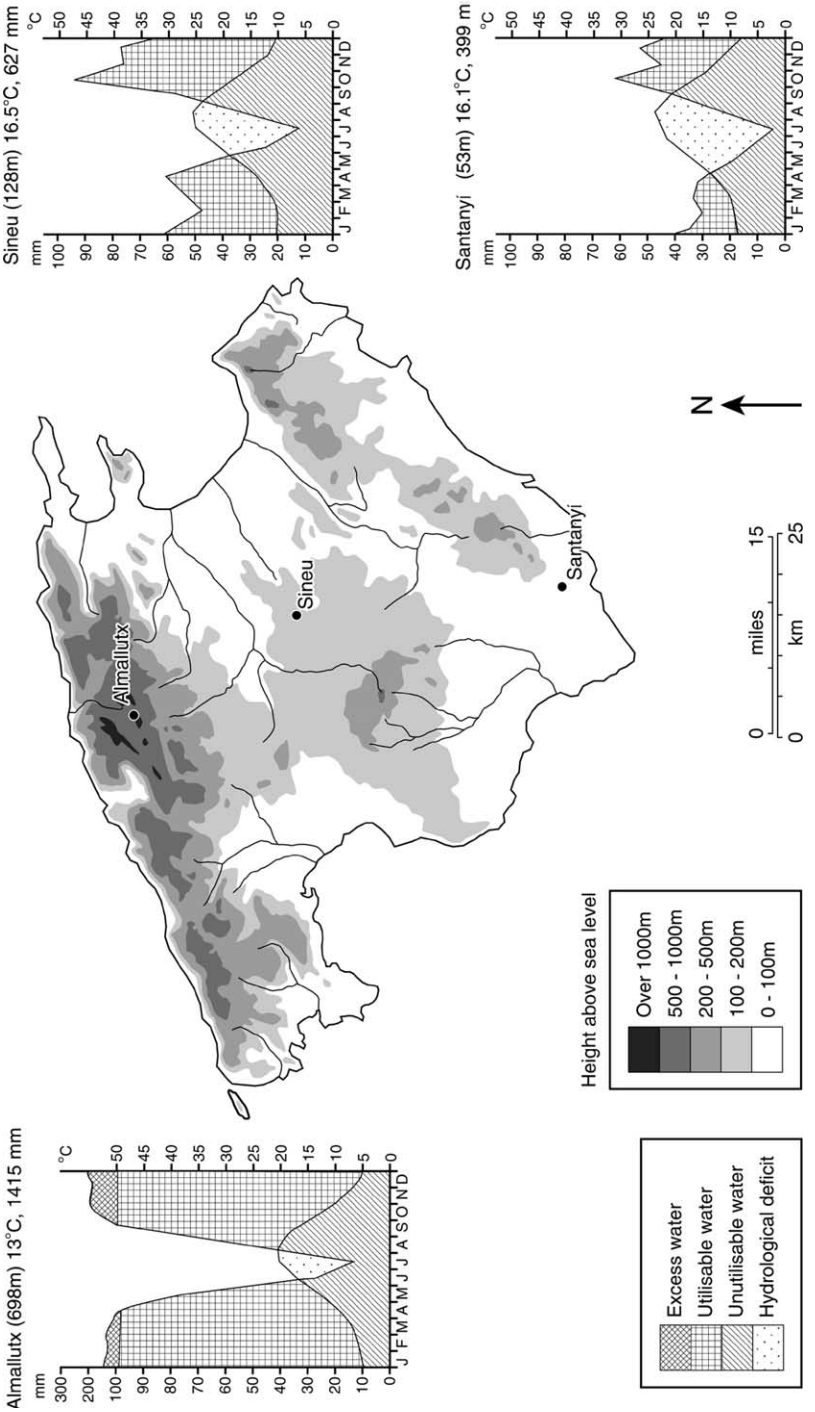

Fig. 1. Summary climate graphs for three locations on Mallorca. *Source*: Govern Balear (1995).

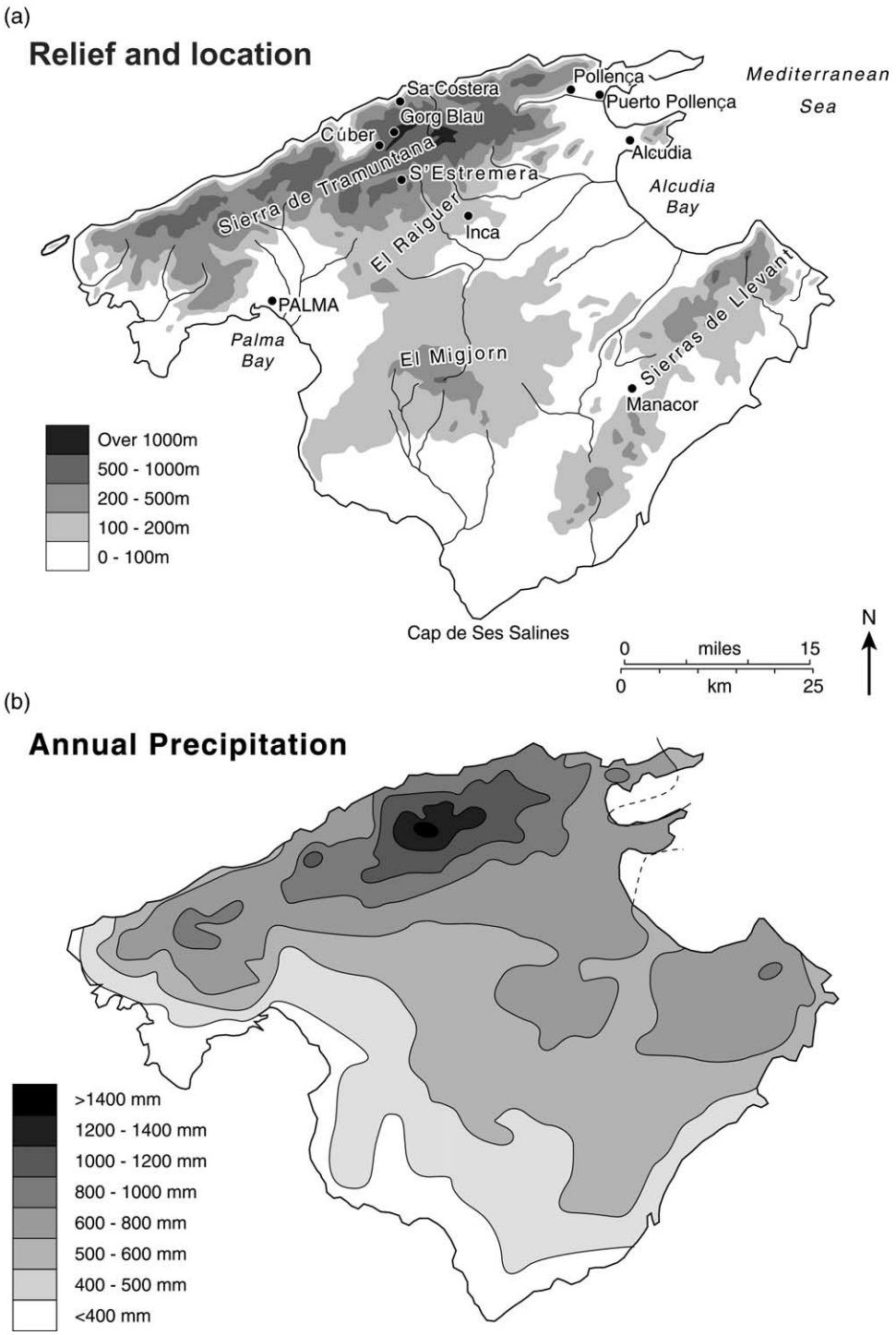

Fig. 2. (a) Relief and location map of Mallorca; (b) annual precipitation on Mallorca (mm). *Source*: Govern Balear (1995).

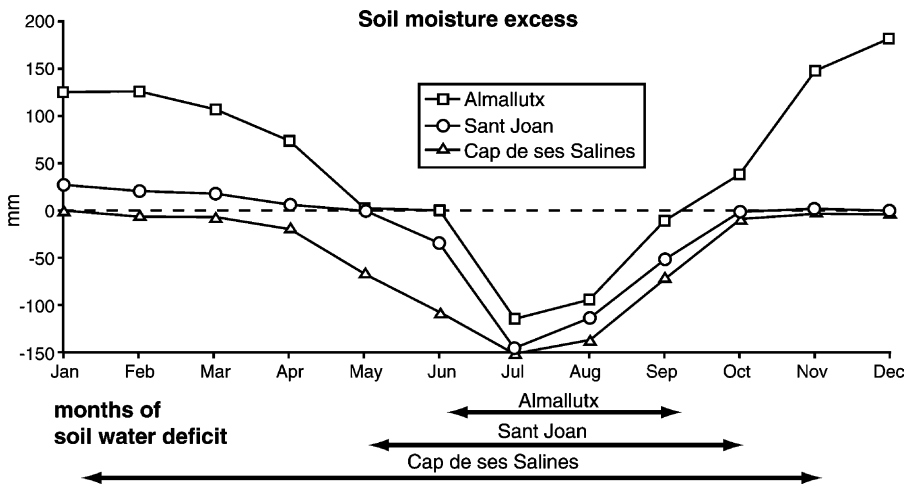

Fig. 3. Estimated soil moisture excess and deficiency by month at three sites in Mallorca: Almallutx (Sierra de Tramuntana); Sant Joan (Central Plains) and Cap de Ses Salinas (South-eastern coast). *Source*: Govern Balear (1995).

1998/9; Wheeler, 1995; Smith, 1997), which is highly unusual in the Spanish context, where on average less than 5% of supplies are derived from groundwater.

The nature of tourism demand

Tourists typically utilize more water on a per capita basis than do local inhabitants (Salem, 1995; Holden, 2000) and this pattern of demand is almost certainly true of Mallorca. Since tourist areas are concentrated on the coastal fringe, while supply areas are principally inland, there is spatial separation of supply and demand (Bull, 1997; Gössling, 2001). In addition to obvious primary uses of water for drinking, washing and bathing, the quantities required have been greatly increased by secondary demand, principally for irrigation in agriculture and the market gardening sector that services the tourist trade. Like tourism demand, these supplies are required during the main holiday season, which coincides with the driest weather. Irrigation water is widely applied and wastage is common, although water re-use is also increasingly practised. Most, if not all, hotels, villas and apartment complexes also use water for swimming pools.

Further increase in demand for water is also associated with the much greater area of landscaping within most of the coastal resorts, stimulated by tourism rejuvenation programmes in the 1990s. In the 1980s, the island had gained a bad image, particularly because of the influx of large numbers of anti-social visitors from Britain and Germany at the lower end of the market, but also because a great deal of the original 1960s tourism infrastructure had become dilapidated and worn out (Morgan, 1991). In the simplistic terms of tourist destination life-cycle dynamics, Mallorca

had reached the 'stagnation stage' of Butler's resort life-cycle model (Butler, 1980) and faced either a phase of 'decline', if no improvements were initiated, or a phase of 'rejuvenation', if appropriate interventions to reinvigorate international tourist demand to the island were implemented successfully.

Stricter planning controls, introduced in the 1980s and 1990s, have removed the lower sector of the market and encouraged rebuilding and landscaping of resorts, which have in turn increased water demand. As an example, in 1995, the Pla de Ordenació de l'Oferta Turística (POOT) was introduced, which stipulated ratios for green open areas and gardens within newly urbanized areas (Batle, 2000). The tourism revitalization programmes have also created new demand through attempts to diversify the tourism product and appeal to a higher-spending clientele. One of the most controversial issues on Mallorca has been the proliferation of new golf courses (Royle, 1996). Prior to 1986, there were only four; by 2000, this number had increased to 13, many being constructed away from the resorts in more rural locations. Very large quantities of water (3.5–5.0 mm m^{-2}) are required to maintain them (Aramburu & Escribano, 1993; Marwick, 2000). Diversification of the tourism market has also involved the emergence of more selective and upmarket niches, including those dependent on water-based environmental features, such as bird-watching holidays around the island's wetland sites at the Albufera.

As well as fuelling demand for more water, tourists also expect high standards of water quality; yet these are not always attainable on Mallorca because of physical environmental factors (Mader, 1988; Mieczlowski, 1995). In terms of water management, priority is normally given to the provision of clean, piped water, but perhaps the area of greatest neglect has been sewage and effluent treatment and disposal from resorts and other urban areas. In the European Mediterranean as a whole, only 30% of municipal wastewater from coastal towns receives any treatment before discharge (Smith, 1997). Grenon and Batisse (1989) estimated that across the Mediterranean Basin, the solid waste generated by tourists alone would increase from 2.9×10^6 t y^{-1} to $8.7–12.1 \times 10^6$ t y^{-1}, and waste water from 0.3×10^9 m^3 to $0.9–1.5 \times 10^9$ m^3 by 2020. These three- to five-fold increases are likely to be realistic scenarios for Mallorca, with associated consequences for water quality in the medium to long term.

Initial signs of a potential crisis

Initial indications of a potential crisis in water supply, caused partly by the increasing demands of the tourist industry, emerged during the 1970s and 1980s. Pons (1989) illustrated how water demand on Mallorca in 1981 represented only 92.3% of available supply but would increase to 112.4% by 2010. The severity of this issue might ultimately interrupt or even terminate attempts to diversify and enhance Mallorca's tourism product. First, the available supply of water may not be of sufficient quantity or quality to service the needs of the tourists. Significant reductions in visitor numbers would be required to match the changed environmental capacity,

which could cause major economic restructuring and serious social implications. Second, reduced water availability in the environment will almost certainly degrade the value of natural sites of interest, such as wetlands, which have emerged as tourism resources as part of the diversification of the island's tourist attractions. The overall appeal and viability of the island for tourists and tour operators will be considerably reduced by the water shortages. In the context of the tourism destination life-cycle model (Butler, 1980), the problem has the potential to interrupt the island's present rejuvenation trajectory and send the tourism economy into a period of stagnation or even decline. Environmental limitations, in this case water supply shortages, are a potentially significant factor in the success of tourist resort revitalization strategies and therefore represent an important potential variant on the tourism life-cycle model. Indeed, the influence of such an 'environmental crisis' could disturb a resort life-cycle at any time.

The main responses to these deteriorating conditions on Mallorca have been to increase abstraction from inland aquifers, build water treatment plants, campaign for water conservation and search for new aquifers (Smith, 1997). From the 1970s onwards, evidence began to emerge of the effects of saline intrusion (caused by the over-abstraction of groundwater) into the important aquifers and wells that underlie Mallorca's coastal plains, in particular the Bay of Palma. Around Palma, the water table has fallen by about 100 m since 1973 and a water table drop of 4–6 m was recorded for some aquifers between 1993 and 1994 alone (Wheeler, 1995). This problem is accentuated where groundwater reservoirs have connections with the sea via coastal and submarine springs that can activate saltwater intrusion. These salt-contaminated wells are extremely difficult to renovate (Price & Herman, 1991; Custodio, 1992; Lindh, 1992).

A further partial solution to the problem involved the construction of the two main reservoirs on Mallorca at Gorg Blau and Pla de Cúber, in the highest part of the Sierra de Tramuntana (see Fig. 2) during the 1970s, to supplement the groundwater supply, particularly in summer months. Although initially successful, both reservoirs experienced serious problems during the 1990s, caused by the combined effects of lower rainfall, a reduction in winter snow cover (and thus spring meltwater) and increased demand (Fig. 4). A sequence of dry years resulted in further concerns about water shortages; in the hydrological years 1991–2 and 1992–3, only 75 and 62% respectively of annual rainfall was recorded in Palma (Wheeler, 1995), which was reflected in lower rainfall in the Gorg Blau and Cúber catchments. In the mid-1990s, the two reservoirs were at 35% capacity (1994). This pattern of unpredictability continued into the late 1990s.

A further abortive attempt to augment supplies involved shipping fresh water by tanker from the Ebro catchment on mainland Spain for pumping into the main network between 1995 and 1998. Various problems were associated with this initiative, most notably the serious contamination of the first shipments by residual wastes in the ship's tanks and also strong protest and resistance from both local political parties and ecological groups in the Ebro catchment and delta (Wheeler, 1995). The project eventually proved uneconomic and was abandoned.

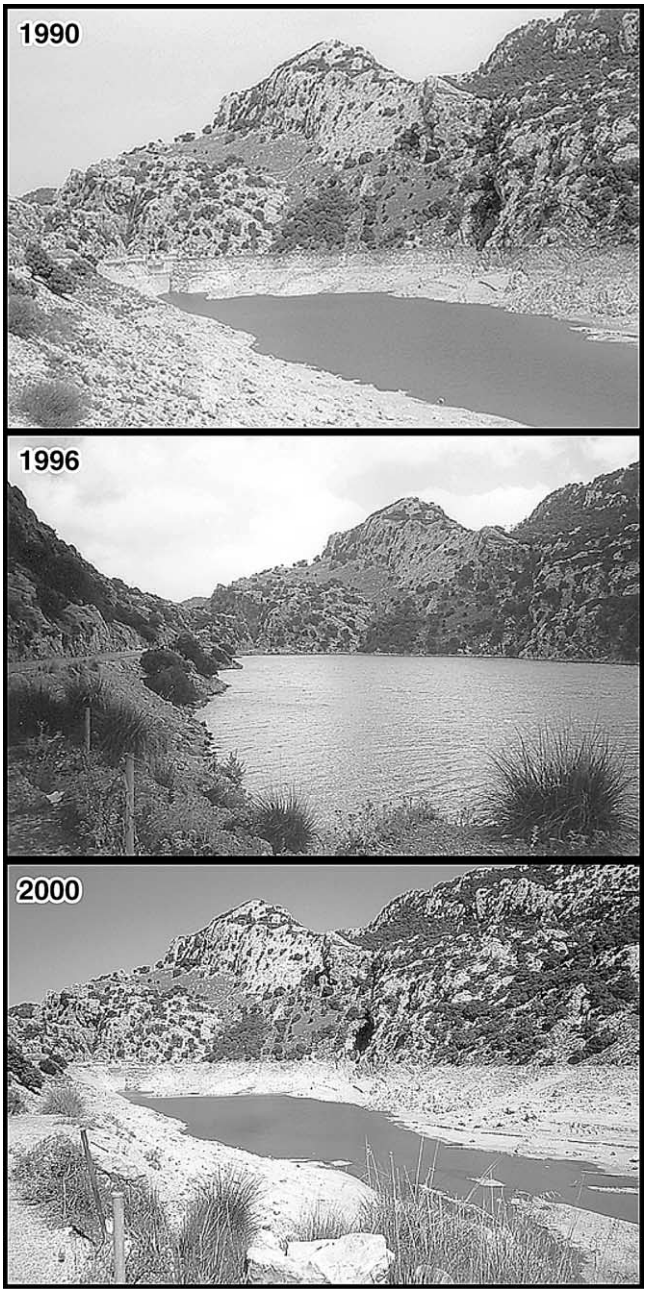

Fig. 4. Water levels in the reservoir at Gorg Blau in the Sierra de Tramuntana: (a) September 1990; (b) September 1996; (c) September 2000.

Table 1
The objectives of the 'Proposed Hydrological Plan for the Balearic Islands'

- Identify available water resources for sustainable exploitation
- Ensure the quantity and quality of water supplied to urban regions
- Provide sufficient supplies to meet the demands and allow development of each economic sector
- Introduce technical measures and policies that encourage sensible use of water and which penalize wasteful and extravagant use by consumers
- Ensure protection of natural hydrological resources that are of high quality and reserve zones specifically for urban supply
- Make maximum re-use of waste and treated water within the limits of economic rationality and health standards
- Plan and justify the exploitation of hydrological systems and define the criteria for the exploitation of hydrogeological units
- Increase supply within the limits of management
- Define the rules or norms of action and work to prevent and reduce damage caused by drought and floods
- Define the rules of action necessary for the conservation of the environment in relation to all interactions with hydrological regimes

Source: Summarized from Conselleria de Medi Ambient, Ordenació del Territori I Litoral Direcció General de Règim Hydràulic Junta d'Aigües de Balears (1998/9).

The proposed Hydrological Plan for the Balearic Islands

In 1998, the regional government (the Govern Balear) produced the 'Proposal for a Hydrological Plan for the Balearic Islands'. This three-volume report (Conselleria de Medi Ambient, 1998/9) set the targets for water supply and management for the 21st century. Its stated objectives are summarized in Table 1. The plan is based on 21 hydrogeological units within Mallorca and predictions are made for two future points in time – 2006 and 2016 – using data available in 1996. Of the 21 hydrological

Table 2
Overall projections of water demand on Mallorca ($hm^3\ y^{-1}$)[a]

Demand and supply	1996	2006	2016
Demand			
Households	87.60	91.96	95.60
Irrigation	150.20	150.20	150.20
Industrial	0.55	0.60	0.67
Golf	3.22	5.31	5.31
Other	1.80	2.00	2.20
TOTAL	243.40	250.10	254.00
Total supply	226.40	220.00	223.50

Source: Conselleria de Medi Ambient, Ordenació del Territori I Litoral Direcció General de Règim Hydràulic Junta d'Aigües de Balears (1998/9).
[a] $1hm^3 = 1 \times 10^6 m^3$.

units on Mallorca, two are classified as over-exploited in terms of groundwater abstraction and six are described as both over-exploited and suffering from saline intrusion. The plan predicts that supply resources will stay more or less constant over the 20-year period, while overall demand will increase only slightly (Table 2). The future predictions for human consumption are given in Table 3. The figures for tourism demand appear to assume no significant increase in visitor numbers.

The plan proposes various ways of making up the difference between supply and demand:

- increased use of recycled and treated waters;
- introducing further desalination plants to add to the one already in service;
- encouraging less wasteful use of water, particularly for irrigation and also by both local residents and tourists;
- exploiting some new aquifers, notably the one at Sa Costera in the Sierra de Tramuntana, and
- cutting losses due to leakage from the municipal network. The targets for acceptable losses from the network are 1996: 30%; 2006: 20%; 2016: 15%.

Significant sums are to be spent on infrastructural improvements to the water distribution network. One desalination plant in the Bay of Palma opened in 1995 and is capable of treating 30 000 m^3 of contaminated groundwater a day. In September 2000, approval was granted for the construction of another, partly funded by the national government in Madrid, and others are also proposed. The Hydrological Plan gives future estimates for daily provision from desalination plants as 42 000–60 000 m^3. However, the existing plant has proved extremely unreliable, with regular breakdowns reported in the local press. Despite the commitment to new investment,

Table 3
Predicted future water demand for human consumption in Mallorca

Date	Resident population[a]	Visitor population[b]	Total population	Demand (hm^3 y^{-1})[c]	Demand (m^3 per person y^{-1})	Demand (l per person d^{-1})
1996	609 150	210 373	819 523	87.60	107.0	293
2006	671 587	210 373	881 960	91.96	100.3	275
2016	740 125	210 373	950 798	95.60	105.0	288

Source: Conselleria de Medi Ambient, Ordenació del Territori I Litoral Direcció General de Règim Hydràulic Junta d'Aigües de Balears (1998/9).

[a] Resident population predictions for 2006 and 2016 are the medium projections/figures (2006: low 646,247, medium 671,587, high 697,415–2016: low 685,604, medium 740,425, high 798,471).

[b] Visitor predictions for 2006 and 2016 are the medium projections/figures (1996: max. 404,563; median 210,373). Visitor population figures are reworked to give equivalent residential figures from annual tourist/visitor data

[c] $1hm^3 = 1 \times 10^6 m^3$.

and quite apart from the technical problems, the future of desalination still remains questionable because of its high energy costs.

The Hydrological Plan lays great emphasis on treatment, reuse and recycling of water, with such recycled water playing a significant part in irrigation and in watering of parks, urban landscaping and golf courses. Problems of saline intrusion of aquifers are acknowledged and various suggestions are made for artificial recharge of selected aquifers in all six of the salinized hydrological units.

The plan also stresses conservation and education in the sensible use of water and wider introduction of water metering is proposed. Many parts of the island (e.g. Pollensa) already have progressive water charging based on rates of consumption. Efforts to educate both residents and particularly tourists in careful water use are also being increased, with suitable publicity material available in hotels and in advertisements in local newspapers. Problems can occur, however. Not all tourists are happy when confronted with advice on the need to conserve water at the start of their holiday and many hoteliers prefer to ignore the problem for the present. For some there is a perception that publicizing the water supply issue will tarnish the image of the island as a tourist destination.

In terms of future water supply, however, the report makes no mention whatsoever of the possible threats posed by climate change, including both reduced precipitation and increased temperatures, leading to raised evapotranspiration and losses to natural groundwater recharge. From the point of view of hydrological prediction, a major obstacle to the acknowledgement of climate change scenarios is the serious difficulty of accurately predicting exactly what any future impacts may be.

Climatic change: past and present

The most difficult area for the future management of water supplies in Mallorca is that of prediction and planning in relation to potential climatic change, particularly the possible implications of global warming on the future patterns of both precipitation and temperature.

Climatic change in the recent past

Examination of inter-annual and decadal-scale changes in precipitation should also be a consideration for any planning of the future provision of water on the island, although extrapolation from these patterns is always fraught with difficulties. The precipitation regime, in particular, can vary markedly from one year to the next, or in intervals spanning several years, not just in Mallorca, but throughout the Mediterranean region (Perry, 1981, 1997; Birdi, 1997). An examination of the c. 130-year meteorological record of Palma observatory, the longest instrumental record for Mallorca, reveals some interesting precipitation trends (Fig. 5). First, decadal-scale oscillations between comparatively high and low precipitation periods are apparent, with

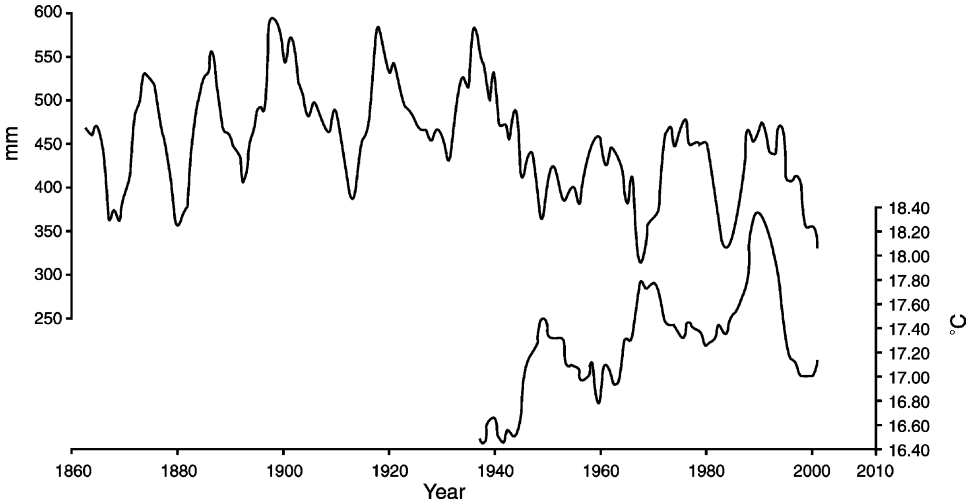

Fig. 5. Medium-term rainfall (top) and temperature (bottom) trends for Palma. *Sources*: Guijarro (1995); National Climate Data Center (2002).

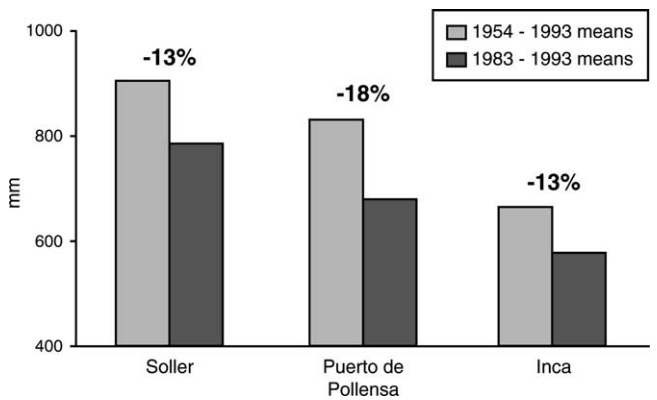

Fig. 6. Annual rainfall for three Mallorcan localities, averaged for the period 1983–93, compared with the mean for 1954–93. *Source*: Govern Balear (1995).

nine well-defined ‘wet’ periods of 10–15 years interrupted by generally shorter ‘dry’ intervals. Second, since 1940, although these decadal-scale oscillations have continued, there has been a significant fall in precipitation levels generally, during both ‘wet’ and ‘dry’ phases. The same decline in precipitation is evident at other localities on Mallorca (Fig. 6) and a similar trend has been reported for other sites in the western-central Mediterranean (Corte-Real et al., 1998; Mayes, 2001) throughout the 1990s. At the same time, observed annual temperatures in Palma, whilst also showing an oscillatory pattern, have risen throughout this period by c. 2°C.

Periodicity in weather patterns over the historical period due to natural factors is now widely acknowledged (Lamb, 1995) and the results of the first research into

this area of historical climatology have recently been published for parts of nearby Catalonia, with a study of catastrophic flood patterns (Vallve & Martin-Vide, 1998) and drought (using 'pro-pluvia' rogations) (Martin-Vide & Vallve, 1998). Both periodicity and extreme events appear to have been characteristic of Catalonian and Mallorcan climates throughout the historical period and into the present day (Wheeler, 1991, 1995).

Global warming

Changes in global climate during the 21st century are likely to be dominated by the influence of the greenhouse effect caused by increasing concentrations of carbon dioxide, methane, nitrous oxide, ozone and halocarbons (Houghton et al., 1996; Houghton, 1997). These changes may already have begun; at the global scale temperatures have increased by about 0.5°C during the past century, in parallel with the increases in greenhouse gases. The temperature rise of 2°C at Palma since 1940 is much greater than this global average and perhaps reflects, to some extent, a progressive urban heat island effect (Barry & Chorley, 1998; Chandler, 1965). However, the marked fluctuations in the temperature record and a strong negative relationship with the precipitation record ($r^2 = -0.292$; $p > 0.05$) indicate that other factors are also involved. As the most marked global warming of the past century has occurred during the second half of the 20th century, it is reasonable to postulate that this global trend has underpinned the temperature rise at Palma since 1940. If so, then further temperature rise during the 21st century may well be accompanied by further decline in precipitation in Mallorca.

Future climate change scenarios for Mallorca

Substantial global warming is now considered to be virtually certain, but the attendant changes in climate at the regional level are highly uncertain. Indeed, for precipitation even the signs of regional changes cannot yet be specified with any reliability by climate change models (Palutikof & Wigley, 1996). The most widely used method of obtaining regional-scale information on possible future climates is through atmospheric general circulation models (GCM). However, because of deficiencies in current GCMs (Wigley, 1992), and because of their generally coarse resolution (Wilby & Wigley, 1997), their outputs should be considered only as possible scenarios for future climate change rather than predictions. This uncertainty is particularly pertinent to precipitation in Mallorca, where steep topographic gradients occur, because GCMs are unable to simulate the way orographic effects interact with atmospheric circulation in controlling precipitation patterns. This problem is accentuated by the highly seasonal and inter-annual variability of Mallorca's precipitation regime. In addition, its location between semi-arid North Africa and humid

Western Europe places it in a particularly sensitive climatic zone. For example, Bradley et al. (1987) reported an upward trend in northern hemisphere land-based precipitation records from 1920 to the present in mid–high latitudes (35–70°N) and a marked downward trend in tropical-to-subtropical latitudes (5–35°N). Mallorca is situated at the transition between these two zones, at 39–40°N. Any future projections for precipitation changes accompanying global warming are likely to show similar regional disparities, and will be dependent upon accurate portrayal of any regional shifts in atmospheric circulation (Jones, Jonsson, & Wheeler, 1997).

It is hardly surprising, therefore, that GCMs have been unable to provide concordant scenarios for future precipitation in Mallorca, not least because these must be interpolated from regional-scale projections at a coarse resolution. For example, using the UK Meteorological Office five-layer GCM, Wilson and Mitchell (1987) suggested that a quadrupling of pre-industrial CO_2 levels would result in decreased precipitation over the Mediterranean Basin in both summer and winter. In contrast, the IPCC92 study suggested that a small precipitation increase in winter, the rainy season, and a more substantial decrease in summer precipitation would accompany a warming of 2–3 °C by 2030. Giorgi, Marinucci and Visconti (1992), using a GCM with improved spatial resolution to examine climate changes induced by a doubling of CO_2 levels, suggested an increase in precipitation of 11–12% over Europe generally, but with widespread reductions in October. In a much finer-resolution analysis for the Iberian Peninsula, von Storch, Zorita, and Cubasch (1993) reported decreasing precipitation of 7–9 mm a month accompanying a doubling of CO_2 after 100 years.

In a more recent study, Palutikof and Wigley (1996) used composite scenarios from four different GCMs to predict climate change with a doubling of CO_2 for the Mediterranean Basin. Interpolating values for Mallorca from their regional maps gives a mean precipitation increase of 1–2% per °C of global warming, but at 90% confidence intervals, the estimated range of precipitation change is −2% to +5%. Palutikof and Wigley (1996) also developed a down-scaling method to address the problems associated with coarse resolution in their composite GCM approach. Their resulting sub-grid-scale scenarios give interpolated values for Mallorca of 0 to −3% for annual precipitation and −4% for winter precipitation, in both cases accompanying 1 °C of global warming.

The latest GCM predictions from the Hadley Centre for Climate Change, using the HadCM3 model, vary according to different scenarios, but a marked drying in southern Europe and the Mediterranean region is among the most robust precipitation signals (Johns et al., 2001). Several model outputs show a daily reduction in precipitation of 0–1 mm for the western Mediterranean region during the period 2010–38 (Climate Research Unit, 2001). However, the spatial resolution of this model is far too coarse to support realistic predictions and informed response at the local level. For example, a precipitation reduction of 0–1 mm d^{-1} is equivalent to an annual reduction of c. 25% for the wetter parts of Mallorca but more than 100% for the drier parts. It seems highly unlikely that the steep, orographically determined precipitation gradient on Mallorca will meet with a uniform linear response to the changes in atmospheric circulation and storm tracks that is expected to accompany global warming. Whilst GCMs are undoubtedly useful at the global and regional scales, their

practical use at the scale of an island such as Mallorca requires further advances in down-scaling outputs or in the development of regional climatic models (Wilby & Wigley, 1997).

A simpler but arguably no less effective approach to predicting climate change in the near future is to examine the recent historical trends in Mallorca's climate in relation to their possible underlying mechanisms. As discussed above, the recent decline in precipitation may be linked to global warming, and is arguably as good a basis as any to expect further reductions in rainfall in the near future. In this context, Romero et al. (1998) have reported a 30-year (1964–93) daily rainfall database for Spanish Mediterranean regions, which includes 63 rain gauge stations on Mallorca itself. Although such data provide interesting trends, they are still of limited value for prediction. However, the establishment of such networks is important and will eventually provide medium- to long-term evidence of climate change effects. In addition, the historical data presented here show even more convincingly that both inter-annual and decadal-scale perturbations in Mallorcan rainfall are certain to continue; these short-term variations, in association with any global warming, are probably of much greater consequence for water supply on Mallorca than the more gradual but progressive long-term GCM projections.

Implications of climate change for water supply on Mallorca

As discussed above, climate change projections for precipitation are erratic, but it seems that any future increase in Mallorca's precipitation, if it does occur, will be minor at the most. Under most global warming scenarios, any such increases would not be sufficient to raise soil moisture levels during the critical summer months (Arnell, 1999). On the other hand, many GCM results, including HadCM3 (Johns et al., 2001), support the contention that a recent broad decline in precipitation and increase in temperature seem set to continue for the foreseeable future. If the recent trend towards warmer and drier weather continues, the consequences for Mallorca's water supply will be severe, particularly if it is linked to global warming.

One consistent outcome to emerge from these various studies, therefore, is that soil moisture and groundwater levels in Mallorca will almost certainly decline during the 21st century. Similarly, the periods of soil moisture deficit (Fig. 3) can be expected to increase throughout the island. As the majority of Mallorca's water is currently supplied from groundwater reserves, these impacts have serious implications for water management. In addition, a recent declining trend in snowfall as a proportion of total precipitation is almost certain to continue with the rise in temperatures. Historically, spring melt of winter snowfall has been important in recharging reservoirs in the Sierra de Tramuntana, and these have provided an important supplement to the groundwater supply during summer months. It is hardly surprising that an overall decline and greatly increased variability in reservoir contribution during the 1990s (Fig. 4) has coincided with a reduction in snowfall. The likely continuation of these trends is a source of further concern for water supply management on Mallorca.

An additional threat to water supply and quality stems from sea level rise, which has been occurring gradually for the past century or so and may accelerate under future global warming scenarios (Milliman, Jeftiæ, & Sestine, 1992). The IPCC92 best estimate for global mean sea level rise, as a result of greenhouse-gas-induced global warming, was 65 ± 35 cm by the end of the 21st century (Houghton et al., 1996), whilst the latest estimates range from 9 to 88 cm (International Panel on Climate Change, 2001). Even if only the direct consequences of minor inundation were considered, the economic impacts would be significant for an island so reliant on tourism on the coastal strip. However, it could be argued that this sea level rise will be sufficiently gradual as to permit adjustments to be made to any shift in coastlines, albeit at considerable expense. Similar assessments have been made for the Mediterranean island of Malta by Attard et al. (1996).

A further, less obvious, consequence of sea level rise is the likely landward movement of the saltwater wedge, resulting in yet greater risk of contamination of freshwater sources (Fig. 7). Continued over-exploitation of wells may also cause the equilibrium saltwater line to move further inland. The process of saltwater intrusion due to this combination of exploitation of wells and sea level rise is illustrated conceptually in Fig. 7. Fig. 7a shows a sustainable situation where groundwater recharge is sufficient to maintain supply for all three wells shown. In Fig. 7b, over-exploitation has occurred, resulting in a lower water table, a smaller volume of freshwater reserve, and some saltwater intrusion. As a consequence, wells A and C are no longer reliable while the supply from well B may be subject to some saltwater contamination. This situation obtains at many coastal aquifers on Mallorca today. In Fig. 7c, continued exploitation has resulted in further reduction in the freshwater reserve, whilst sea level rise has led to further saltwater intrusion and more significant contamination of the supply from well B. It is important to realize that the diminution of groundwater reserves from these two processes, over-exploitation and sea level rise, will be independent of, but additional to, the reduction in groundwater supply likely to result from the climatic changes discussed earlier. The recent over-exploitation and saline intrusion reported for much of coastal Mallorca (Conselleria de Medi Ambient, 1998/9) is perhaps the clearest evidence yet that current levels of demand for fresh water are not sustainable.

Conclusion: water management in the future

The above discussion indicates that close attention must be paid to the conservation of water resources on Mallorca, as they are critical to environmental stability and the sustainability of tourism as its principal economic activity in the medium to long term. Water management is the key area of concern in the light of expanding populations, growth in tourism, and changing climate, particularly shifts in precipitation patterns. Coastal areas are always extremely sensitive to water pollution for the reasons discussed above. They are also the focal point of both permanent and

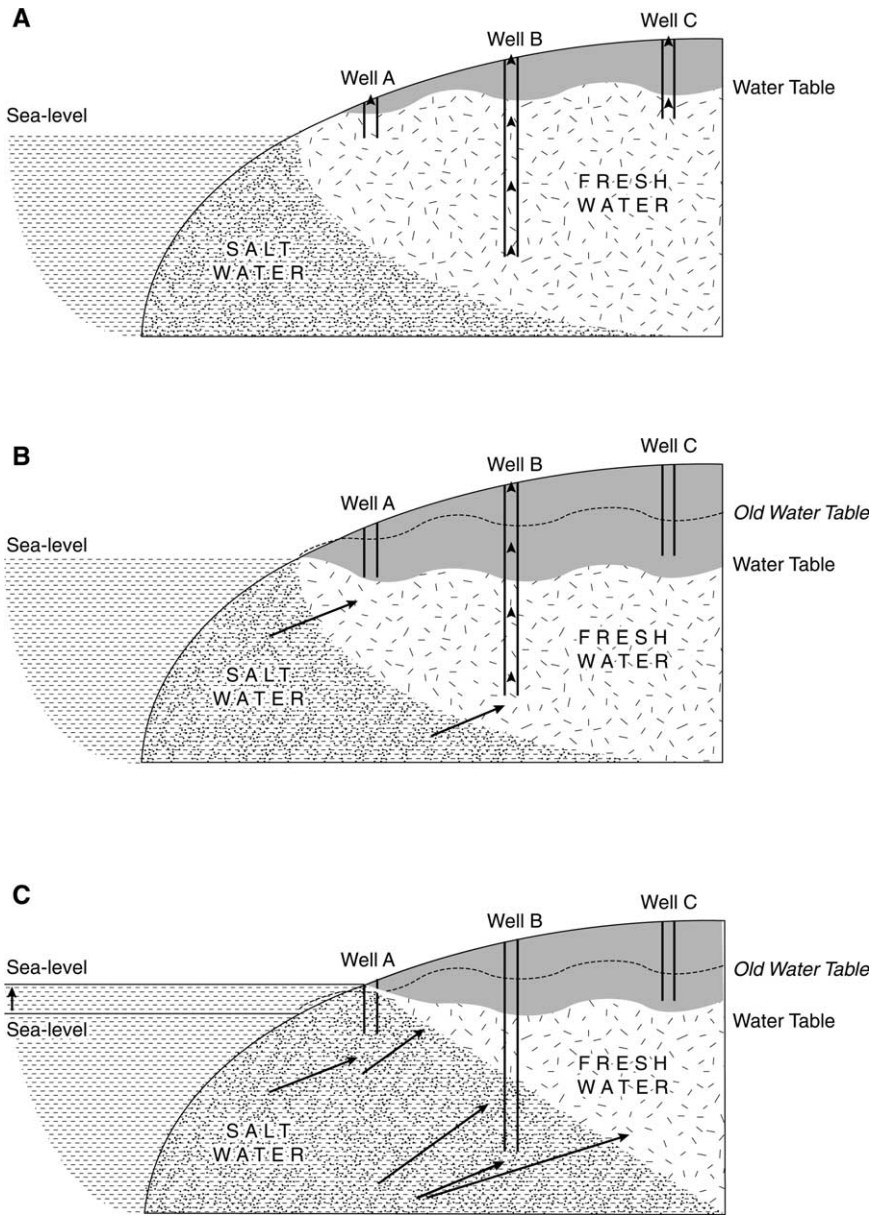

Fig. 7. Conceptual model of groundwater depletion and saltwater intrusion at the Mallorcan coast as a consequence of both over-exploitation and sea-level rise. The model assumes isotropic conditions and intergranular flow through a porous medium. (a) Original situation; (b) over-exploitation only, resulting in depletion of groundwater reserves and some saltwater intrusion; (c) both sea-level rise and over-exploitation resulting in further groundwater depletion and saltwater intrusion.

tourist populations, the latter creating an uneven water demand in space and time (Bull, 1997; Smith, 1997; Peplow, 1989; Gössling, 2001; Roberts, 2002). To be successful, water planning must seek to maintain a long-term balance between supply and demand in such a way that the needs and aspirations of the economy and society are met without serious damage to the environment or to sources of supply (Morris & Dickinson, 1987; Smith, 1997; Holden, 2000; Roberts, 2002).

However, the dynamics of both supply and demand are constantly changing in ways that are not easy to forecast. Even with careful management, it seems inevitable that the scarcity and hence the value of freshwater are set to increase, and that these factors will significantly influence patterns of economic and social change (Smith, 1997). In addition, mismanagement of water supply may trigger further damaging environmental impacts, including the lowering of water tables on the important wetland sites on the island, such as the Albufera.

An interesting further dimension to the problem has been provided by the proposal to introduce *la ecotasa* or 'ecotax', levied on all tourists and visitors to the island. The proposal was first made in 1999 by the ruling 'Progress Pact' of the regional government and received widespread public support. Although by no means representative, a web-based public poll of 1200 residents of the Balearic Islands in June 2000 indicated that 78% of voters were in favour of the tax, especially the younger generations (MallorcaWeb, 2000).

The suggestion was that a charge be made for each night spent on the island, varying according to the standard of accommodation, ranging from 0.5 euros for campsites to 2 euros for a five-star hotel (c. £0.32–1.28). Such charges represent an increase of £40–75 for a family of four with two children over the age of 12 on a fortnight's holiday. The expected annual revenue from the tax is estimated to be in the region of 60×10^6 euros, representing approximately 6% of the budget for the Balearics in 2002 (MallorcaWeb, 2002a).

Since 2000, there has been extensive debate on the ecotax in both the island parliament and in the media. Two problems have emerged. First, who should collect the tax and how should it be collected? Hoteliers are reluctant to carry out the administration for no reward and tour companies could be unwilling to be involved; thus hotels might have to bear the entire cost if the tax were not included within the package holiday price. Second, the Green Party, in particular, has argued that the revenues gained should be hypothecated to pay for environmental conservation and management, presumably including environmental aspects of water supply, while others have demanded that the income be spent more widely within the economy (*Daily Telegraph*, 2001; *Observer*, 2001, 2002; *Daily Express*, 2002).

Although the new tax was approved by the Balearic parliament in April 2001, the Spanish central state government considered its introduction to be unconstitutional, arguing that it would reduce VAT and fiscal business tax income by discouraging visitor numbers. A constitutional review was instituted in September 2001, with the tribunal rejecting the central government's claim in January 2002. The purpose of the tax was to promote environmental and cultural protection and was thus in the public interest. The decision allowed the Balearic parliament to declare that the tax would be implemented from May 2002. The revenue generated will provide

resources for a Tourist Areas Restoration Fund to be used to redesign and restore tourist areas, the natural environment and heritage features. However, continued opposition of local hoteliers may still delay the introduction of the tax. The Federación Hotelera de Mallorca is in the process of appealing to the Superior Tribunal of Justice of the Balearics. International pressure against the tax has also been forthcoming from various tour operator associations, such as the International Federation of Tour Operators, the Association of British Travel Agents and the Association of German Travel Agents (MallorcaWeb, 2002a). The island's main environmental group, Grup Balear d'Ornitologia I Defensa de la Naturalesa (GOB), have even attempted to pacify adverse public opinion in Germany by staging a press conference in the press agency of the German government in Berlin to explain and justify the purpose of the tax (MallorcaWeb, 2002b). Obviously, there is considerable commercial opposition to the attempt to introduce environmental responsibility into the industry by providing the economic resources to manage the island's environmental problems, which have been induced largely by tourism.

A further postscript is provided by the fact that in January 2001, the Spanish Cabinet voted to accept the Hydrological Plan for the whole of Spain. The Balearic government, however, voted against accepting the National Plan, partly because large-scale redistribution of water from the Ebro basin in the north of Spain to other mainland locations is envisaged as a key element of the project.

An already potentially serious situation therefore seems set to worsen. The Hydrological Plan for the Balearic Islands has gone some way towards addressing these problems, but evidence suggests that possible implications of climate change have not been seriously addressed. Part of the difficulty, however, concerns the accuracy of predictions for such future change. There are three particularly important issues that require further research:

- how will any regional-scale changes in precipitation, evapotranspiration and the resulting soil moisture regime be manifested across the heterogeneous Mallorcan landscape?
- how will the marked inter-annual and decadal-scale variations in precipitation of recent times be moderated or exacerbated by future climate change?
- how will any sea level rise impact upon freshwater extracted from coastal aquifers?

Similarly, the predictions for the increase in future tourist numbers seem conservative. In terms of action to be taken to alleviate this crisis, it is still likely that the capacity to apply conventional engineering solutions to improve the efficiency of the existing water supply infrastructure has not yet been reached. However, as Smith (1997) points out, as the crisis inevitably worsens, the limits of the existing infrastructure will be reached, at which point more drastic measures will be required. Desalination, water importation and conservation measures have been tried with only limited success so far. Other alternatives, such as rationing, much higher charges

and the 'ecotax' may provide other solutions, but cannot be implemented without direct negative impacts on the key industries of tourism. Perhaps the sustainability of water supply will prove to be a major factor determining the long-term viability of tourism on the island.

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