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# Assessing optimum irrigation water use: additional agricultural and non-agricultural sectors

Science Report – SC040008/SR1

SCHO0107BLWP-E-P

ea/br/e/sci/v1

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This report is the result of research commissioned and funded by the Environment Agency's Science Programme.

**Published by:**
Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol, BS32 4UD
Tel: 01454 624400 Fax: 01454 624409
www.environment-agency.gov.uk

ISBN: 978-1-84432-623-5



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**Dissemination Status:**
Publicly available
Release to all regions

**Keywords:**
Abstraction, audit, golf course, racecourse, nursery, frost protection, irrigation, turf, reasonable need.

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**Science Project Number:**
SC040008/SR1

**Product Code:**
SCHO0107BLWP-E-P

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Steve Killeen

Steve Killeen

**Head of Science**

# Executive Summary

The Water Act (2003) and its preceding legislation requires the Environment Agency to assess and justify authorisations for irrigation abstraction, whether for agricultural, horticultural, amenity, sports turf or other use. A previous study, *Optimum use of water for industry and agriculture* (W6-056), has provided a framework for assessing the 'optimum' or 'reasonable' needs of a wide range of crops.

In this study, water use was analysed for a range of other agricultural and non-agricultural sectors dependent on irrigation, but not included in the W6-056 study. These include some sectors where new authorisations for trickle will be required, as well as for existing and new spray irrigation abstractions. The sectors considered include golf courses, racecourses, turf production, frost protection, horticultural nursery stock, pot plant and bedding plant production and glasshouse production.

The general approach used for each sector was to combine a review of published and 'grey' literature with information from site water audits, analyses of Environment Agency abstraction data (NALD), computer irrigation modelling and irrigation survey data.

The project provides best practice guidelines for each sector to help the Environment Agency establish 'reasonable' needs for abstraction licensing. The findings were verified by consulting with experts and stakeholders in the UK irrigation industry.

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# 1 Introduction

The Water Act (2003) and its preceding legislation requires the Environment Agency to manage authorisations for irrigation abstraction, whether for agricultural, horticultural, amenity, sports turf or other use. Previous research (Mathieson *et al*., 1999; Rees *et al*., 2003) under the *Optimum use of water for industry and agriculture* study (W6-056) provided the Environment Agency with a procedure to assess the 'optimum' or 'reasonable' irrigation needs of a wide range of outdoor crops. However, the procedure was limited in terms of its applicability to other agricultural sectors, including irrigated glasshouse production, ornamentals and nurseries, turf production and frost protection. The procedure was also not suitable for assessing the irrigation needs of non-agricultural abstractions, such as golf courses and racecourses.

To address these gaps, this study provides new information on irrigation water use in these sectors, together with guidelines to help the Environment Agency assess and set reasonable irrigation water requirements in the context of abstraction licensing. This report should be used in conjunction with the latest manual on water use, Optimum use of water for industry and agriculture (Rees *et al*., 2003). Environment Agency staff should also be aware of the study by Knox *et al.* (2004) with respect to assessing the reasonable needs of trickle irrigation abstractions.

This research began in July 2004 and was completed in June 2007. The report provides a summary of the research objectives, methods used and main outcomes of the study. The implications for allocating water resources for irrigation are highlighted, together with recommendations for further work.

## 1.1 Aim and approaches

The aim of this study was to assess the optimum or reasonable irrigation needs of a number of additional agricultural and non-agricultural sectors dependent on direct abstraction, and to provide guidelines to help the Environment Agency assess and set abstraction licences for irrigation. The study reviewed and combined information from desk-based research, industry surveys, water audits and computer modelling.

During 2005, a series of site-specific studies (audits) were undertaken to assess patterns of water use for a range of water-dependent activities excluded from the optimum water use manual (W6-056). These sectors included turf grass production, frost protection, nurseries, golf courses and racecourses. For each sector, a three-stage method was adopted:

1. **Literature review**. Data searches of published and grey literature were used to collate information on existing patterns of water use.

2. **Water use studies**. A number of representative sites (typically five) were identified for each sector. Each water audit required collation of existing water use data from the site and a detailed audit using pro-forma to collect information on patterns of water use. Sites were guaranteed confidentiality for their contribution to the project.

3. **Estimates of optimum water use**. By combining the water use data from Stage 2 with computer modelling of theoretical irrigation water requirements and discussion with industry informants, a set of guidelines to assess reasonable irrigation needs for each sector were produced. These draft guidelines were then distributed to industry informants to obtain feedback and assess the likely acceptance of these guidelines.

The study outputs are comprised of data and guidelines to assess the ‘reasonable’ irrigation needs within each sector. The study findings are intended to compliment the existing optimum water use technical report (W6-056/TR2).

## 1.2 Dry year definition

In previous optimum water use studies (Rees *et al*., 2002), a series of look-up tables were produced summarising the reasonable irrigation needs (mm) of a range of crops grown under different agroclimatic and soil conditions. These data were intended to reflect best practice and were defined according to a reference or ‘design’ dry year. This was statistically defined as the optimum irrigation needs in a year with an 80 per cent probability of non-exceedance (or a one in five return period), that is, meeting the irrigation need in 80 years in 100.

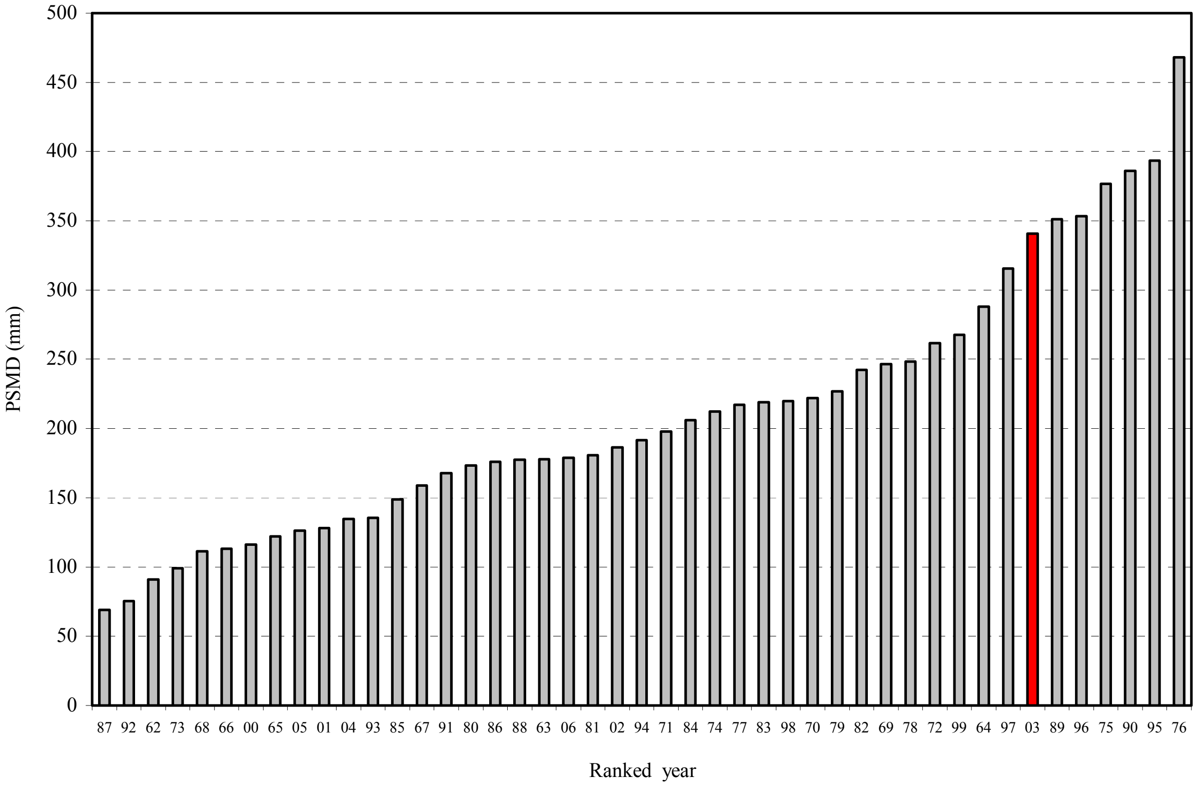
This study adopted a similar approach for consistency. However, for some sectors such as golf courses, the modelling approaches used previously were unsuitable, as the rationale for irrigating a golf course can be markedly different to that for a crop. This sector is rarely interested in maximising yield and quality, but instead aims for other criteria such as alleviating compaction, maximising bounce and playability and general aesthetics. Thus an alternative approach was required here, not only to take into account the impacts of seasonal climate variability on irrigation needs, but also to incorporate these non-agronomic factors.

For some sectors, we assessed actual (rather than theoretical) irrigation abstractions using benchmark sites. Using an agroclimatic indicator, annual abstractions were correlated against climate to assess a ‘design’ dry year irrigation need. The variable used was potential soil moisture deficit (PSMD), to take into account differences between rainfall and reference evapotranspiration (ET) during the irrigation season and to calculate an index of ‘aridity’ which has been shown to correlate with irrigation need (see Knox *et al*., 1997, 2000; Rodriguez Diaz *et al*., 2006). PSMD could then be used to define a year with an 80 per cent probability of non-exceedance in terms of agroclimate (and irrigation).

To illustrate this, the annual maximum PSMD ($PSMD_{max}$) for a site in Bedfordshire over a 44-year period (1962-2006) was calculated (Figure.1). In statistical terms, the ‘design’ dry year equates to a year with a $PSMD_{max}$ of 293 mm. This compares reasonably closely with the $PSMD_{max}$ in 2003, another dry year in irrigation terms.

Thus, in this study the year 2003 was chosen as a reference ‘design’ dry year for assessing ‘reasonable’ irrigation needs. This approach would be valid as long as the sites under investigation were unconstrained by equipment and/or water resources in that year.

**Figure 1.1 Ranked PSMD$_{max}$ (mm) for Silsoe (Bedfordshire) between 1962-2006, showing 2003 as the reference 'design' dry year.**



# 2 Sector water studies

This section summarises the findings of a series of water audits of agricultural and non-agricultural sectors dependent on irrigation, including golf courses, racecourses, turf production, frost protection and nurseries. Data collected were then combined with supplementary information to develop guidelines for the Environment Agency to assess and set optimum or reasonable irrigation needs for abstraction licensing.

## 2.1 Golf courses

This section integrates information from a literature review, industry survey, computer modelling of turf water requirements, detailed site studies and interviews with informants in the sports turf industry. Guidelines for determining optimum levels of water use or 'reasonable' irrigation needs for abstraction licences for golf course irrigation are provided. Further information on golf course irrigation (including public mains and direct abstraction) can be found in Knox *et al.* (2007).

The factors influencing irrigation water use in sports turf, including golf, vary markedly from other sectors. The main objective of sports turf irrigation is to produce and maintain safe, high quality playing surfaces. On all modern golf courses, irrigation is an essential tool in the management of turf surfaces. It serves to control the growth and quality of the turf, maximise playability, maintain the aesthetics required by players, and deal with the vagaries of UK summer weather. In providing an optimum playing surface, managers are also trying to alleviate compaction, maximise aeration and control drainage; irrigation helps to achieve these goals. Although irrigation is important for optimising turf growth (roots require both oxygen and water in the root zone to thrive), it is important in other ways, for example where soil water content affects bounce and playability. It is also important for other sports turf management practices (such as fertiliser applications and top dressing).

### 2.1.1 Current usage and underlying trends

Little information has been published on irrigation in the golf sector. A survey conducted by Herrington and Hoschatt (1993) provided a useful insight, but major changes in water regulation and rapid growth in the golf industry over the last decade mean the findings are now outdated.

This study used new data derived from a national survey of golf course irrigation conducted in 2003 (a very dry year in turf irrigation terms). This information was combined with Environment Agency abstraction data to provide a spatial and temporal assessment of water demand, underlying trends and water resource impacts. In 2000, there were a reported 2,049 golf courses in England and Wales (Ennemoser, 2005). In this study, approximately 2,140 golf courses were identified.

Using a geographical information system (GIS), the distribution of golf courses was mapped (Figure 2.1) and aggregated by Environment Agency region (Table 2.1), with a fifth of all golf courses located within the Thames region. High concentrations of golf courses can be found in parts of Midlands (Birmingham), North West (Merseyside and Lancashire) and North East Regions (Newcastle upon Tyne). Using a GIS, the location of golf courses in each Environment Agency CAMS area was also mapped (Figure 2.2) and identified (Table 2.2).

**Figure 2.1 Distribution of golf courses in England and Wales, by Environment Agency region, in 2003.**

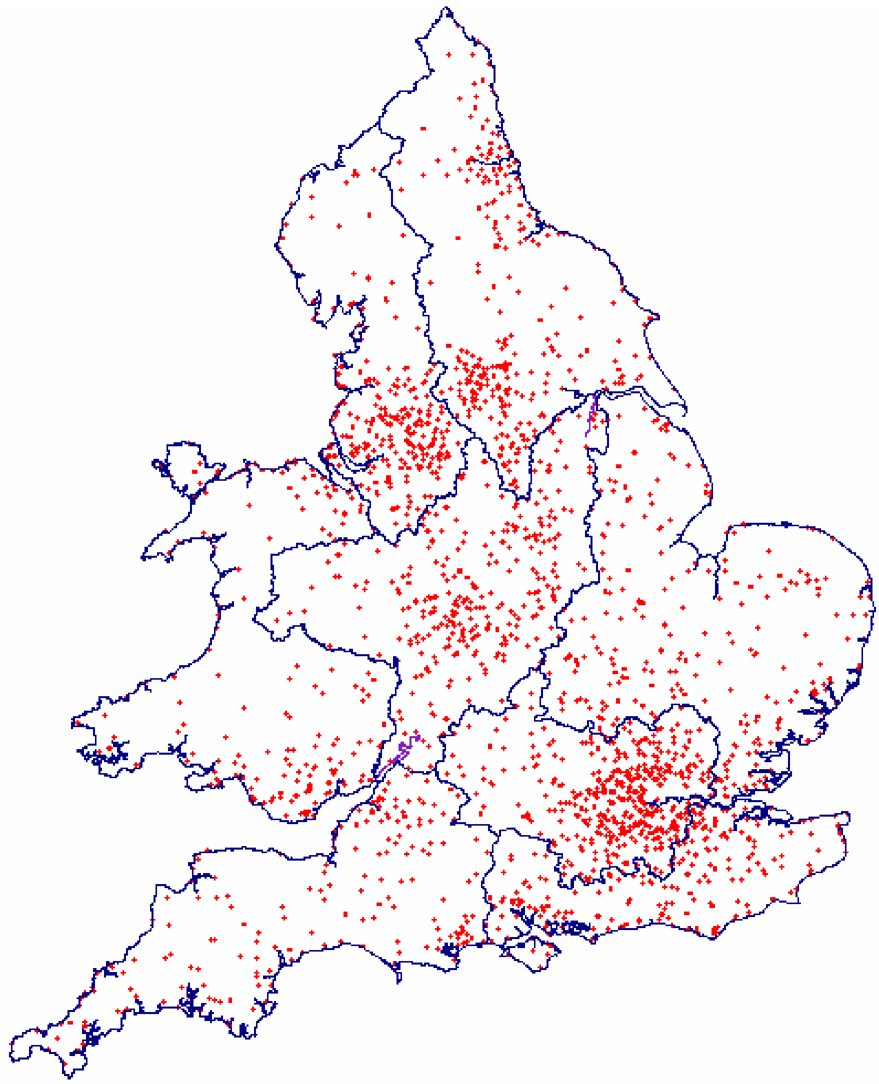
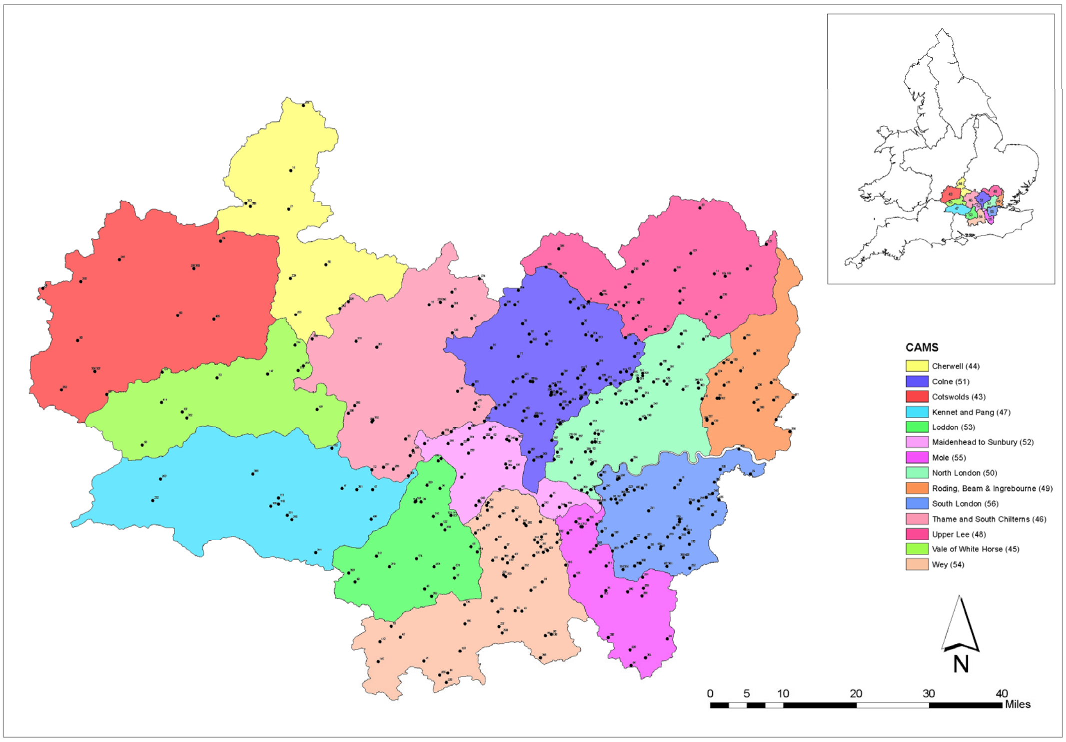


**Table 2.1 Number of golf courses in England and Wales, by Environment Agency region, in 2003.**

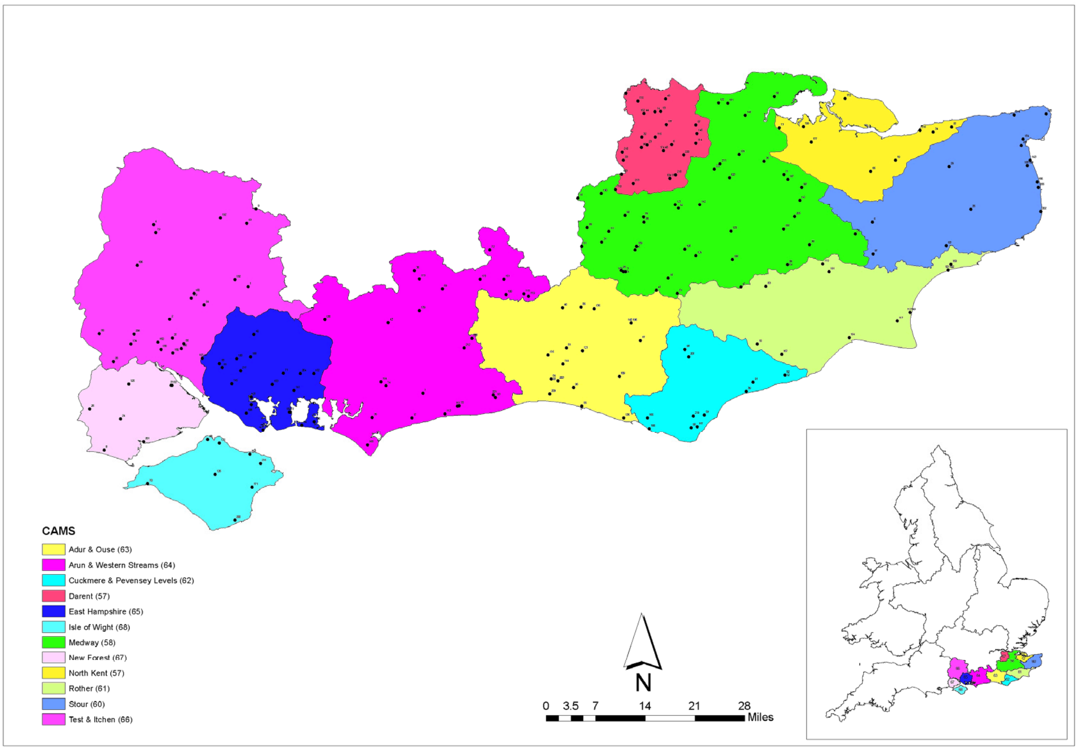
| Region | Number of golf courses | Percentage of total |
|---|---|---|
| Anglian | 256 | 12 |
| Thames | 421 | 20 |
| Southern | 222 | 10 |
| North East | 280 | 13 |
| North West | 273 | 13 |
| Midlands | 308 | 14 |
| South West | 189 | 9 |
| EA Wales | 191 | 9 |
| **Total** | **2,140** | **100** |

**Figure 2.2 Distribution of golf courses in (a) Thames region and (b) Southern region, by CAMS.**

(a) Thames region




(b) Southern region



The data shown in Table 2.2 accounts for 86 per cent of all golf courses in England and Wales. The Aire and Calder CAMS 11 in North East region contains the most golf courses. A high concentration of golf courses is also found around London in CAMS 51 (Colne), CAMS 56 (South London), CAMS 54 (Wey) and CAMS 50 (North London).

**Table 2.2 Estimated number of golf courses by CAMS, in 2003. Data are shown only for CAMS where 10 or more golf courses are located.**

| CAMS | Number | CAMS | Number |
|---|---|---|---|
| Aire and Calder | 74 | South Essex | 21 |
| Colne Thames North | 68 | Idle & Torne | 20 |
| South London | 55 | Roding, Beam & Ingrebourne | 20 |
| Wey | 54 | Staffordshire Trent Valley | 20 |
| North London | 49 | Swale, Ure, Nidd & Upper Ouse | 20 |
| Lower Mersey & Manch Ship | 44 | Dorset Stour South | 19 |
| Medway | 44 | Hull and East Riding | 19 |
| Upper Ouse & Bedford Ouse | 44 | Wharfe and Lower Ouse | 19 |
| Warwickshire Avon | 43 | Wye | 19 |
| Bristol Avon | 39 | Adur & Ouse | 18 |
| Lower Trent & Erewash | 39 | Derbyshire Derwent | 18 |
| Don and Rother | 38 | East Suffolk | 17 |
| Tame and Anker | 36 | Neath, Afan and Ogmore | 17 |
| Worcestershire Middle Severn | 34 | Roch, Irk and Medlock | 17 |
| Mersey and Bollin | 33 | Wear | 16 |
| Tyne | 32 | Bourne, Blythe and Cole | 15 |
| North Essex | 31 | Derwent | 15 |
| Ribble | 29 | Kennet and Pang | 15 |
| Thames and South Chilterns | 29 | Stour | 15 |
| Darent | 27 | Usk | 15 |
| Dee | 27 | Douglas | 14 |
| Nene | 27 | Sankey and Glaze | 14 |
| London Thames South | 26 | Cotswolds Thames West | 13 |
| Arun & Western | 25 | Grimsby and Ancholme | 13 |
| Maidenhead to Sunbury | 25 | Rother | 13 |
| Upper Lee | 25 | Tamar | 13 |
| Weaver and Dane | 25 | Tame, Goyt and Etherow | 13 |
| Cam and Ely | 24 | Clwyd | 12 |
| Northumberland Rivers | 24 | Cuckmere & Pevensey | 12 |
| Soar Midlands Lower | 24 | North Cornwall | 11 |
| Croal and Irwell | 22 | Vale of White | 11 |
| East Hampshire | 22 | Brue, Axe N Somerset Streams | 10 |
| Taff and Ely | 22 | Cleddau & Pemb Coastal Rivers | 10 |
| Tees | 22 | Llyn and Eryri | 10 |
| Test & Itchen | 22 | Severn Uplands | 10 |
| Witham | 22 | Severn Vale West | 10 |
| Broadland Rivers | 21 | Shropshire Middle Severn | 10 |
| Mole | 21 | Wyre | 10 |

### 2.1.2 Environment Agency (NALD) abstraction data

The Environment Agency has records of almost all abstractions for spray irrigation, including golf courses, since the Water Resources Act (1963) came into force. Data for 2003 from the national abstraction licensing database (NALD) was analysed here. A summary of the total number of abstraction licences, total licensed and total abstracted volumes for spray irrigation on golf courses in England and Wales, by Environment Agency region, is given in Table 2.3.

In 2003, there were a reported 833 abstraction licences for golf course spray irrigation. This represented two per cent of all abstraction licences in force in that year. Half of all golf course abstraction licences were located in three regions, namely Thames (18%), Anglian (16%) and Midlands (15%). The total licensed volume for golf course irrigation in 2003 was estimated to be 10,112 million litres. This represents three per cent of the total volume licensed for spray irrigation in England and Wales, with agricultural spray irrigation accounting for the vast majority of the remainder. The total volume abstracted for golf irrigation in 2003 was estimated to be 4,315 million litres, representing 43 per cent of the total volume licensed for golf irrigation. The average licensed and abstracted volume was 11,084 $m^3$ and 5,848 $m^3$, respectively, with significant regional variations.

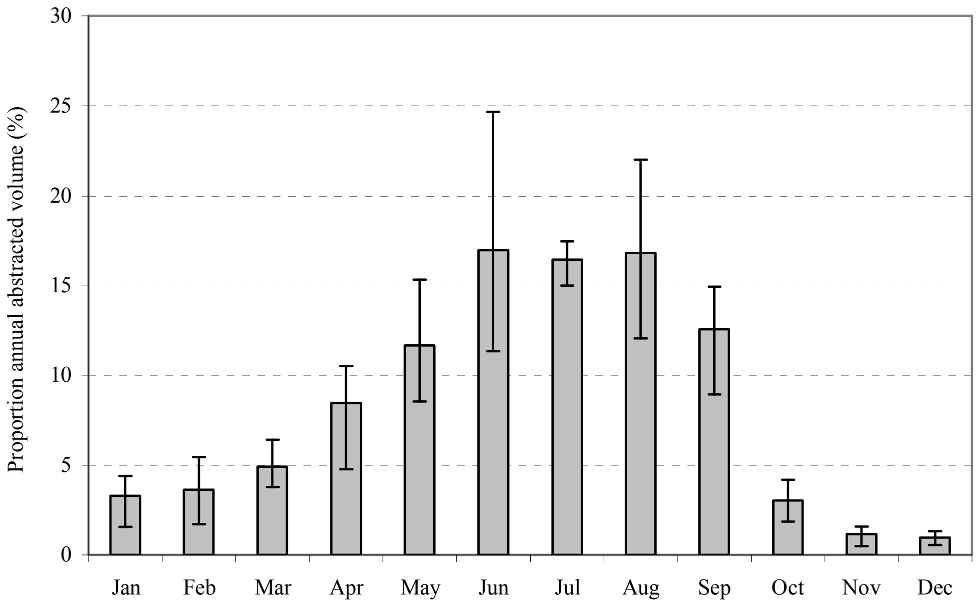
**Table 2.3 Total number of abstraction licences, total licensed ($m^3$) and abstracted volumes ($m^3$) for golf course spray irrigation, by Environment Agency region, in 2003.**

| Region | Total number of licences | Total licensed volume ($m^3$) | Average licensed volume ($m^3$) | Total abstracted volume ($m^3$) | Average abstracted volume ($m^3$) |
|---|---|---|---|---|---|
| Anglian | 131 | 1,376,100 | 10,505 | 570,793 | 4,357 |
| EA Wales | 51 | 457,072 | 8,962 | 191,839 | 7,378 |
| Midlands | 127 | 1,751,436 | 13,791 | 920,243 | 8,682 |
| North East | 77 | 559,060 | 7,261 | 216,147 | 3,325 |
| North West | 102 | 530,771 | 5,204 | 200,424 | 3,132 |
| South West | 108 | 788,208 | 7,298 | 162,382 | 3,690 |
| Southern | 84 | 980,634 | 11,674 | 423,087 | 5,567 |
| Thames | 153 | 3,668,714 | 23,979 | 1,629,755 | 10,652 |
| **Total** | **833** | **10,111,995** | **11,084** | **4,314,671** | **5,848** |

Nationally, golf irrigation is a relatively minor abstraction, but it is predominantly consumptive, peaking in the driest years and months when water resources are scarcest. It is the seasonal timing of golf irrigation demand, peaking during the summer months, that can cause water resource problems (Figure 2.3)

Environment Agency data suggest that three quarters of all water for golf course irrigation is abstracted and used directly. Although lakes are used as water hazards, their role as winter storage reservoirs is not widespread (yet), due to the aesthetic and environmental impacts of empty lakes during summer months. Environment Agency abstraction records for golf course spray irrigation do not include water taken via the public mains supply for irrigation.

**Figure 2.3: Mean monthly timing of golf irrigation abstraction, expressed as proportion of annual average abstraction (%), based on 2002-2004.** Bars show the variation over the three years.




### 2.1.3 Parts of the course irrigated

To complement the Environment Agency abstraction data, a national survey of golf course irrigation was undertaken. This collected information on the areas irrigated, volumes of water applied, water sources, operational (management) issues and attitudinal views on adaptation to climate change. The English Golf Union, British and International Golf Green-keepers Association, Institute of Groundsmanship, British Turf and Landscape Irrigation Association and National Turfgrass Foundation supported the survey. The survey was targeted at 2,140 golf courses; in all, 400 surveys were returned, representing a 19 per cent response rate. The findings are summarised below.

A typical course comprises 18 holes, with each hole having a tee, fairway, approach and green. Due to demands for high quality playing surfaces, most golf courses have an irrigation system, but only irrigate a small proportion of the course (Table 2.4).

**Table 2.4 Proportions of courses on which various parts of the course are irrigated**

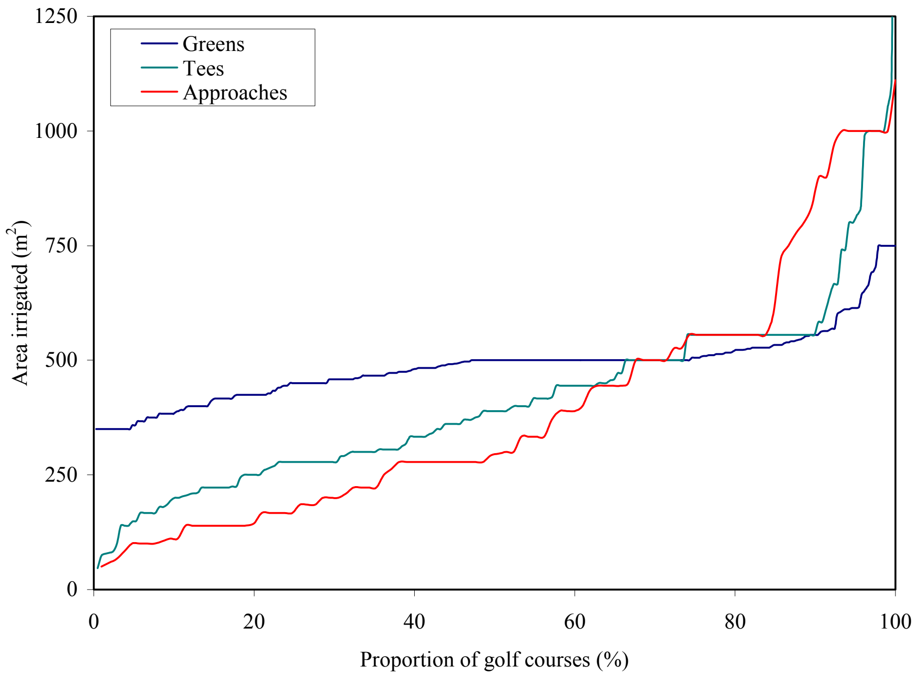
| Part of course | Proportion of course irrigated | | | |
|---|---|---|---|---|
| | All | Some | None | Total |
| Tees | 60 | 19 | 21 | 100 |
| Greens | 99 | 1 | 0 | 100 |
| Approaches | 26 | 29 | 45 | 100 |
| Fairway | 8 | 10 | 82 | 100 |

The data confirms that almost all golf courses water the greens and, to a lesser extent, the tees. Half of all courses also irrigate (either fully or partially) the approaches, but only a small minority (less than 10 per cent) irrigate the fairways. The greens and tees are the most important parts with respect to maintaining turf quality and playability. Full fairway irrigation systems are generally only installed on the most prestigious courses or those with exclusive membership. However, with increasing demands for high quality playing surfaces and the need to maintain aesthetics and playability, particularly during recent dry summers, many golf clubs are now considering extending their irrigation systems to cover the remaining parts of courses, including the fairways. At present, the typical areas irrigated on a golf course are relatively small, but increasing the irrigated (command) area to include the fairways would have major impacts on the volume of water required for irrigation, with consequent impacts on water resources and abstraction licensing.

### 2.1.4 Irrigated areas

From the survey, the range in typical areas irrigated ($m^2$) for greens, tees and approaches was derived (Figure 2.4). The equivalent range in reported areas irrigated for fairways is shown in Figure 2.5. The data shows a reasonably small variation in the reported areas irrigated for greens, ranging from 350 to 750 $m^2$.

**Figure 2.4 Reported areas irrigated ($m^2$) in 2003 for the greens, tees and approaches.**




However, the reported area irrigated for tees, approaches and fairways shows very wide variation. For the purposes of abstraction licensing and assessing ‘reasonable’ irrigation demands (a function of the area irrigated), a summary of the expected typical range in irrigated area for each part of a golf course are given in Table 2.5.

**Figure 2.5 Reported areas irrigated ($m^2$) in 2003 for golf courses with fairway irrigation.**

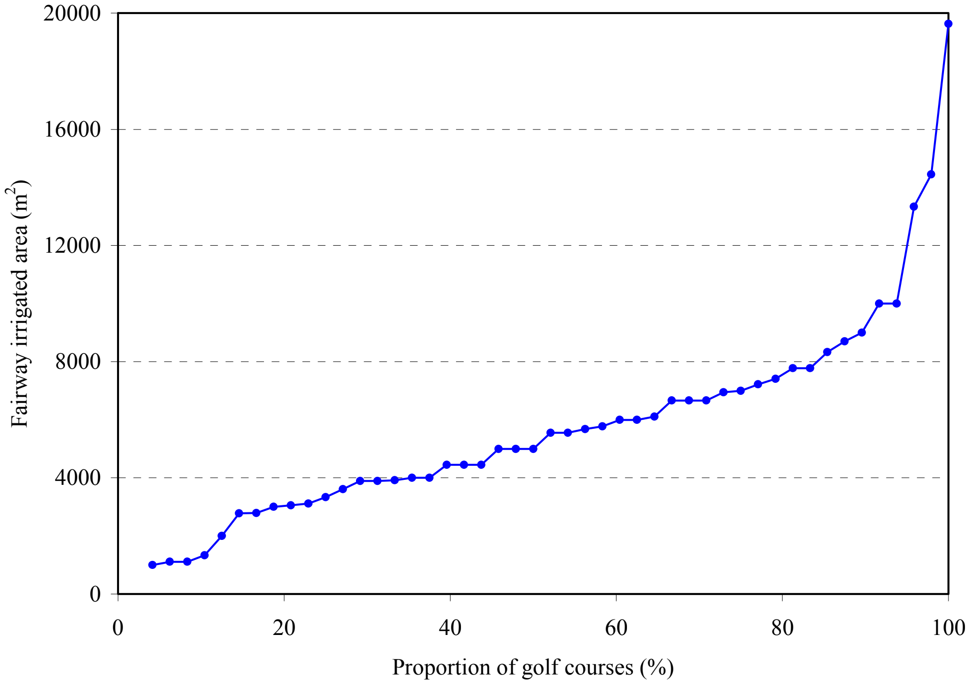



**Table 2.5 Estimated average, median and range in the area irrigated ($m^2$) for each part of a typical golf course.**

| Part of course | Irrigated area ($m^2$) per hole | | |
|---|---|---|---|
| | Average | Median | Range |
| Tee | 420 | 400 | 50 - 2,000 |
| Green | 490 | 500 | 350 - 750 |
| Approach | 395 | 300 | 50 - 1,000 |
| Fairway | 5,750 | 5,300 | 1,000 - 20,000 |

For an 18-hole golf course, estimated total irrigated areas ($m^2$) are shown in Table 2.6. The data suggest that for the majority of courses which irrigate only greens and tees, the typical irrigated area would be between 1.5 and 2.0 ha. For courses that irrigate approaches, the total area could be 2.5 to 3.0 ha, and for sites where full fairway systems are installed, the total area irrigated could be 11 to 13 ha. These relate to *average* areas for a typical 18-hole course; on some courses, the *actual* areas irrigated could be significantly higher (this is evident from the high range in values in Table 2.5 for approaches and fairways). However, the data in Table 2.6 provide a baseline for assessing whether an abstraction licence applicant's reported area irrigated is unusual and thus requires further investigation.

**Table 2.6 Estimated average and median areas irrigated (ha) for a typical 18-hole golf course.**

| Parts of the course irrigated | Total irrigated area (ha) for 18 holes | |
|---|---|---|
| | Average | Median |
| Greens only | 0.9 | 0.9 |
| Greens and tees | 1.6 | 1.6 |
| Greens, tees and approaches | 2.3 | 2.2 |
| Greens, tees, approaches and fairway | 12.7 | 11.7 |

## 2.1.5 Irrigation depths and volumes

Similarly, survey data were analysed to assess the typical depths (mm) of irrigation water applied during 2003; the data are again grouped according to the specific parts of a golf course that might be irrigated (Table 2.7).

**Table 2.7 Derived average and median depths of irrigation water (mm) applied to specific courses, based on survey data from 2003 (the standard deviation (SD) is also shown).**

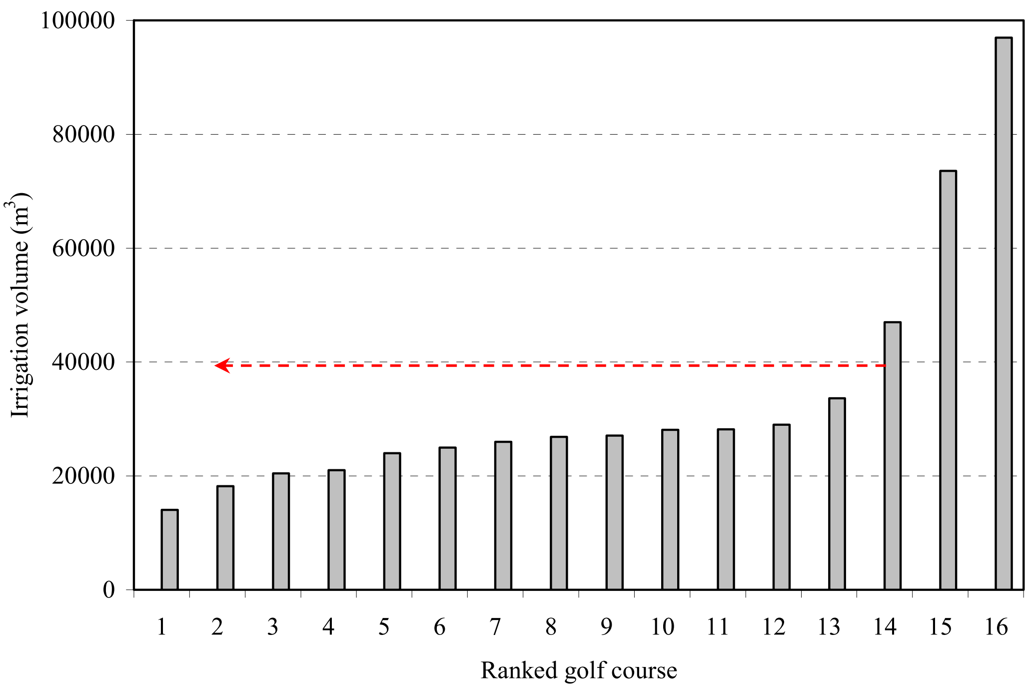
| Part of the course irrigated | Depth of irrigation water applied (mm) | | |
|---|---|---|---|
| | Average | Median | SD |
| Greens only | 220 | 219 | 150 |
| Greens and tees | 245 | 254 | 155 |
| Greens, tees and approaches | 276 | 252 | 116 |
| Greens, tees, approaches and fairway | 220 | 178 | 190 |

In 2003, the typical average depth of water applied varied between 220 and 275 mm (these are subject to significant variation, as evidenced by the standard deviations). For a typical 18-hole golf course irrigating tees and greens, this represents a dry year irrigation demand of approximately 4,500 $m^3$ (or 6,460 $m^3$ if the approaches are included). This compares with 5,848$m^3$, the average volume of irrigation applied in 2003 based on the Environment Agency abstraction data (Table 2.3). In a very dry summer, most golf courses irrigating greens and tees use approximately 600 $m^3$ per week at peak demand.

For comparison, an 18-hole golf course irrigating all parts of the course including the fairways would, on average, have applied 35,000 $m^3$ in a dry year such as 2003. This can be compared against actual irrigation volumes reported by 16 golf courses with full fairway irrigation that responded to the survey (Figure 2.6).

The ranked distribution shows that the total irrigation volume in 2003 on golf courses using full fairway irrigation ranged from 15,000 to 97,000 $m^3$, but with an average volume of 33,700 $m^3$. This value correlates closely with the derived average of 35,000 $m^3$, and provides a reasonable degree of confidence for the Environment Agency to use these data to assess ‘reasonable’ volumes of irrigation in the context of abstraction licensing.

**Figure 2.6: Reported irrigation volumes (ranked) for 16 golf courses using full fairway irrigation, based on 2003 survey (red line indicates the average irrigation volume).**




## 2.1.6 Optimal water use

This section describes a procedure to help the Environment Agency assess and set 'reasonable' needs for abstraction licences for golf course irrigation. The procedure relies on the provision of information from the licence applicant.

Each stage is described below.

*Stage 1: Background information on the type of golf course*

Request the applicant to supply information on the total number of holes and parts of the course to be equipped for irrigation (greens, tees, approaches, fairways, practice greens, driving range).

*Stage 2: Assess the total irrigated area on the golf course (ha)*

For each part of the course identified in Stage 1, request the applicant to supply information (preferably including an updated map) on the estimated total area irrigated (ha). For golf courses where no information is available, refer to

Table 2.5 for estimates of the average area irrigated for each part of a typical golf course.

Multiply the average area for each part of the course by the number of holes to determine the total irrigated area.

*Stage 3: Establish the optimum or 'reasonable' irrigation needs (mm)*

Request the applicant to estimate the total depth of irrigation water applied (mm) to each part of the course in a dry year. For golf courses where either no information is provided or indeed where data are provided, refer to Table 2.7 and compare the applicant's reported irrigation depths with guideline values for the median depths of water applied to each part of a course in a dry year. The standard deviations provide an expected range within which reported figures can be gauged to assess whether they are acceptable. Using this data, assess whether the applicant's reported depths of irrigation water to be applied in a dry year to each part of their course is considered reasonable.

*Stage 4: Calculate the seasonal volumetric irrigation water demand ($m^3$)*

Multiply the total irrigated area (ha) (Stage 2) with either the applicant's data on their required depths of water or the median value given in Table 2.7, to determine the total seasonal volumetric irrigation demand ($m^3$).

*Stage 5: Assess the peak abstraction rate/s*

Determine the minimum flow/water level conditions to which the licence will be subject, and assess whether the source is sensitive to any of monthly, daily, hourly and/or absolute peak flow rates under those conditions. Refer to the Environment Agency's best practice manual W6-056/TR or the appendix in this report.

The 'irrigation window' for golf courses is limited to a few hours per night, to avoid evening play and to allow time for the course to dry before morning play. Unless storage is available, this may require higher peak hourly rates (at night) than for other irrigation applications.

*Stage 6: Compare the irrigation volume requested by the applicant with the estimated volume calculated using this method*

The Environment Agency licensing officer should now be in a position to discuss with the applicant the Environment Agency's estimated irrigation demand, based on the information supplied by the applicant. Any significant difference between the volume requested and calculated using the above method should now be addressed.

### 2.1.7 Useful websites and references

Further information on turf irrigation on golf courses can be found at:

- British Turf and Landscape Irrigation Association (http://www.btlia.org.uk/)
- Sports Turf Research Institute (http://www.stri.co.uk/387.asp?SID=&CSID=42)
- UK Irrigation Association (http://www.ukia.org)
- Royal and Ancient (http://www.bestcourseforgolf.org)
- Knox *et al*. (2007). *Water resources for golf: current use and underlying trends*. Technical report for the English Golf Union.

## 2.2 Racecourses

This section reviews irrigation in the racecourse sector, and provides guidelines for assessing the 'reasonable' or 'optimum' needs for abstraction licences for racecourse irrigation. It is based on a combination of data from a national survey of racecourses, existing literature, Environment Agency abstraction data (NALD), water balance computer modelling and discussions with informants in the industry. The section concludes with a brief review of optimisation measures to improve the efficiency of racecourse irrigation.

Irrigation is an essential tool for maintaining a uniform turf surface for horseracing. It serves to promote grass (sward) growth and helps to soften hard or compacted racing surfaces, a common cause of track-related injury to horses and jockeys.

The rating of the turf condition on a racecourse is referred to as ‘going’, and relates primarily to surface hardness. Going is categorized as being either heavy, soft, good-to-soft, good, good-to-firm, firm or hard, where heavy is a slow wet surface, and hard is a fast dry surface. Most races occur on surfaces that are good-to-soft, good, or good-to-firm (Williams *et al*., 2001). The ideal going varies depending on the type of racing. Winter (1998) suggests that flat racing should have good-to-firm surfaces while jump racing (National Hunt) should have good or good-to-soft surfaces. The going can also vary around the racetrack, due to variations in soil type and moisture, compaction (particularly on the racing line), grass coverage, drainage and topography.

### 2.2.1 Current usage and underlying trends

In the UK, published literature on the irrigation of racecourses is limited. However, as part of a broader study funded by the Jockey Club to optimise the “going” using soil and water management, Mumford (2004) conducted a national survey to derive a baseline dataset on irrigation water use within the industry. The survey was targeted at 59 racecourses in England, Wales and Scotland, with an 83 per cent response rate (representing 48 racecourses). Some findings from this survey are described below.

There are three main categories of racecourse: flat, hurdle and steeplechase. Hurdle and steeplechase are collectively termed “jump”. The dimensions (length and width) of each vary significantly, with implications on the total area irrigated (ha) and total volume of irrigation water required ($m^3$). A summary of the observed range in dimensions for each type of racecourse is shown in Table 2.8. The data implies that a typical racecourse for flat racing might have a total mean irrigated area of 7.0 ha; a hurdle or steeplechase course would be marginally smaller with a total mean irrigated area of approximately 5.0 to 5.5 ha, but with substantial variation.

The survey data were also analysed for information on the sources of water (Table 2.9) and types of application equipment (Table 2.10) used for racecourse irrigation.

**Table 2.8 Estimated dimensions for flat and jump (hurdle and steeplechase) racecourses in the UK. Mean values given in brackets. Data derived from Mumford (2004).**

| Type of racecourse | Length (m) | Width (m) | Area (ha) |
|---|---|---|---|
| Flat | 1,650 - 4,180 (2,883) | 16 - 40 (24) | 2.6 - 16.7 (7.0) |
| Jump (hurdle) | 1.610 - 3,220 (2,460) | 10 - 40 (22) | 1.6 - 12.9 (5.5) |
| Jump (steeplechase) | 1.610 - 3,220 (2,475) | 11 - 40 (20) | 1.8 - 12.9 (5.0) |

**Table 2.9 Proportion of water sources (%) used for irrigation on racecourses in the UK.**

| Water source | Type of racecourse | |
|---|---|---|
| | Flat | Jump |
| Surface water (rivers, streams) | 34 | 53 |
| Groundwater (boreholes) | 44 | 34 |
| Public mains supply | 18 | 10 |
| Rain water harvesting | 4 | 3 |
| Water re-use | 0 | 0 |
| Other | 0 | 0 |
| **Total** | **100** | **100** |

The survey suggests that direct abstraction from surface and groundwater is the dominant source of water (70-80 per cent) used on racecourses. Public mains supply is only used on a small proportion of racecourses, typically 10 to 20 per cent. However, this split between direct abstraction and public mains supply conflicts slightly with Environment Agency abstraction data (discussed in the following section). There is no significant correlation between the types of course and water sources used for irrigation.

**Table 2.10: Application equipment (% split) used for racecourse irrigation in the UK.**

| Water source | Racecourse type | |
|---|---|---|
| | Flat | Jump |
| Static or hand-move sprinklers | 27 | 46 |
| Hose reel fitted with rain gun | 1 | 17 |
| Hose reel fitted with boom | 53 | 31 |
| Hose and hand-held spray gun | 0 | 0 |
| Pop-up sprinklers | 18 | 6 |
| Other | 0 | 0 |
| **Total** | **100** | **100** |

With respect to irrigation application equipment, there is a clear distinction between racecourse types. Almost half of all jump racecourses use static or hand-move sprinklers, for convenience and portability between fences. In contrast, only a quarter of flat racecourses use sprinklers, with the majority relying on hose reels fitted with booms. These are the logical choice and fit well into the race circuit dimensions. Automated pop-up sprinkler systems are only used on a few prestigious racecourses.

## 2.2.2 Environment Agency (NALD) abstraction data

The Environment Agency has detailed records of the licensed and abstracted volumes of water used for racecourse irrigation archived within their national abstraction licensing database (NALD). In this study, data from 2003 was provided, analysed and aggregated to Environment Agency regional level (Table 2.11).

**Table 2.11 Licensed and abstracted volumes ($m^3$) for racecourse irrigation in 2003 in England and Wales, by Environment Agency region.**

| Region | Number of licences | Total licensed volume ($m^3$) | Total abstracted volume ($m^3$) | Proportion abstracted (%) |
|---|---|---|---|---|
| Anglian | 6 | 65,511 | 39,970 | 61 |
| EA Wales | 2 | 30,549 | 28,555 | 93 |
| Midlands | 11 | 389,209 | 118,298 | 30 |
| North East | 4 | 126,420 | 54,225 | 43 |
| North West | 4 | 25,000 | 40,946 | 164 |
| Southern | 1 | * | 30,290 | n/a |
| South West | 2 | 110,455 | 46,456 | 42 |
| Thames | 4 | 107,050 | 162,548 | 152 |
| Total | 34 | 854,194 | 521,288 | 61 |

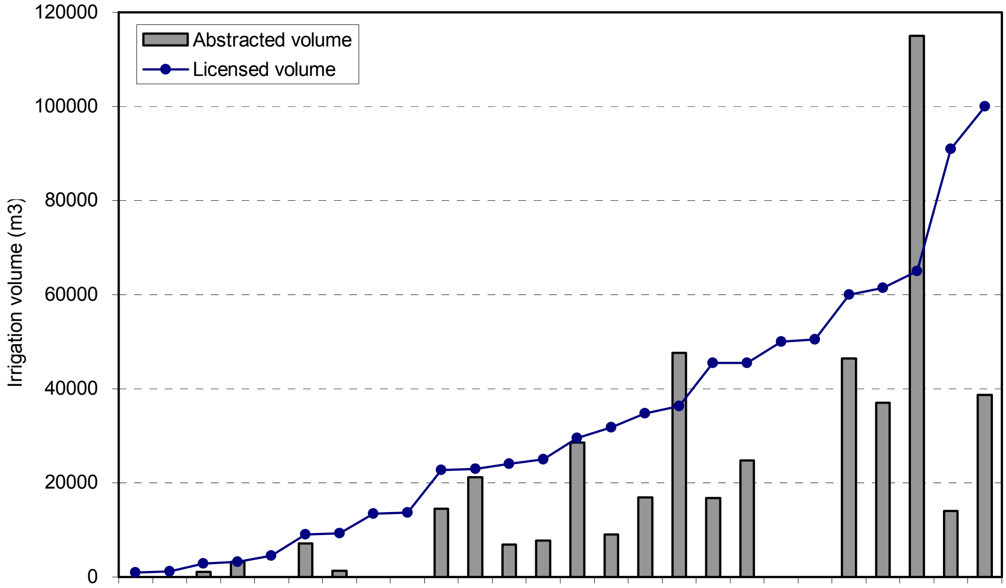
* Denotes missing and/or incomplete data

In 2003, there were a reported 34 racecourses with abstraction licences, with a third located within the Midlands region. Some racecourses have multiple abstraction points and hence more than one licence; the data for these abstractions were aggregated to reflect individual racecourses. There are 54 racecourses in England and Wales; this implies that approximately 63 per cent of racecourses in England and Wales have an abstraction licence for spray irrigation.

The volumes of water abstracted for irrigation vary annually depending on summer rainfall. In 2003, a very dry year in irrigation terms, on average 61 per cent of the total licensed volume was abstracted. Again, there is significant variation between regions, with over-abstraction reported in the North West and Thames. The median licensed volume is approximately 21,000 $m^3$ per racecourse, although there is significant variation between regions (10,000 to 50,000 $m^3$). Similarly, the median abstracted volume is 14,000 $m^3$ per racecourse, with a variation of 7,000 to 41,000 $m^3$. On a typical racecourse with an irrigated area of seven hectare, an abstraction volume of 14,000 $m^3$ would equate to a total seasonal application of 200 mm.

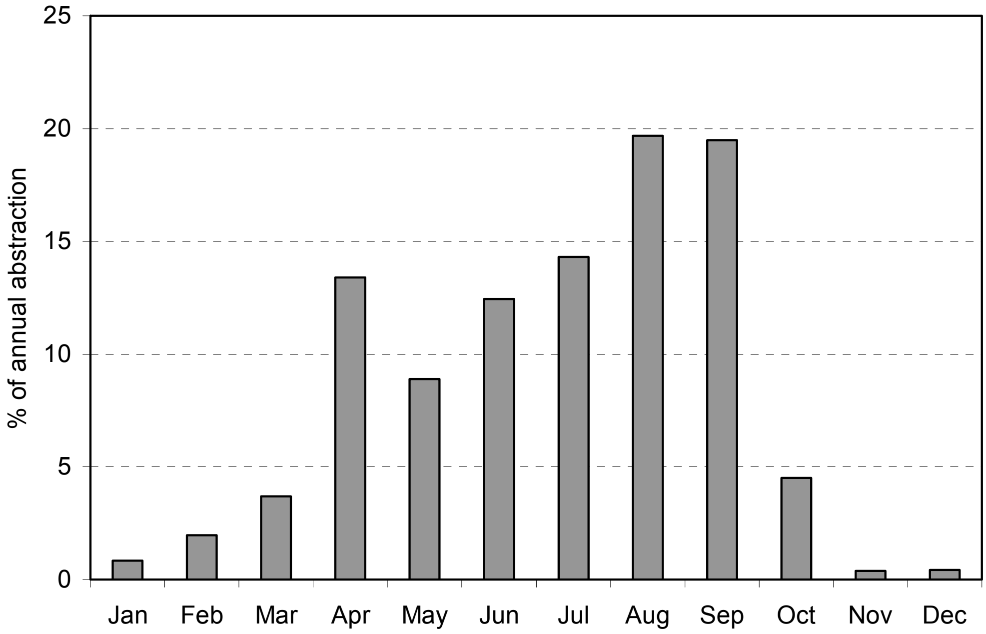
The aggregated data mask significant variations at individual racecourse level. The total volume licensed for irrigation for each licence is ranked and compared against actual abstraction in 2003 in Figure 2.7.

**Figure 2.7 Licensed volumes (ranked) for racecourse irrigation and actual abstractions (bars) in England and Wales in 2003.**




The data confirms that a large number of licences are unused, underused or set to reflect licensed irrigation needs in excess of that required in a dry year such as 2003. The data was also analysed to assess the seasonal timing of demand (Figure 2.8)

**Figure 2.8 Seasonal timing of irrigation water demand in 2003 (expressed as percentage of total abstraction) for racecourses with abstraction licences.**




Almost 90 per cent of water is abstracted between April and September, confirming that most water is abstracted and used directly, with little on-site seasonal storage.

### 2.2.3 Optimal water use for racecourses

This section describes the development of a procedure to help the Environment Agency assess and set abstraction licences for racecourse irrigation. The method enables the 'reasonable' or 'optimum' volumetric irrigation demand ($m^3$) in a 'design' dry year for a racecourse to be estimated, taking into account the total area irrigated, and local variations in climate and soil type. The approach has been subject to industry consultation (via the Jockey Club) to ensure that the proposed optimum water use figures are reasonable and reflect best practice within the industry. The procedure has also been tested with the help of experts from the racecourse industry.

The agronomic needs for irrigated sports turf are primarily a function of the local climate and soil type. The demand for irrigation is usually determined by the daily balance between rainfall and evapotranspiration (ET) in the summer months and the consequent impacts on soil moisture. However, to optimise turf conditions for racecourses, irrigation may also be applied for other reasons, for example to alleviate compaction, modify "going" or minimise risks associated with horse welfare (injury).

The optimum water use method (agriculture) developed for the Environment Agency (W6-056) provides a useful framework for assessing the optimum or reasonable irrigation needs of a range of agricultural land uses, taking into account crop types, local soil and climate conditions and typical irrigation management practices. For racecourses, a similar approach has been adopted, and is briefly described below.

A computer irrigation scheduling water balance model developed by Hess (1994) was used to simulate the annual irrigation needs for racecourse turf-grass grown under a range of soil and agroclimatic conditions. Three soil classes and seven agroclimatic zones were defined. Soil classes (low, medium and high) were defined according to soil available water-holding capacity (AWC) and grouped according to soil texture (Table 2.12).

Agroclimatic zones were based on potential soil moisture deficit (PSMD), a derived variable that reflects the long-term (typically 30-year) monthly balance between rainfall and ET. Apart from Zone 1 (0-75 mm PSMD), each zone was defined on a 25 mm interval; Zone 1 corresponded to the wettest and Zone 7 the driest (PSMD above 200 mm). The agroclimatic zone map for England and Wales is shown in Figure 2.9.

Modelled annual irrigation needs were then correlated against the three soils and seven agroclimate zones using linear regression analyses. The results are presented in the form of an 'irrigation need look-up table' (Table 2.13).

**Table 2.12 Soil moisture properties (available water-holding capacity or AWC) of typical soils (adapted from MAFF, 1984).**

| Soil AWC | Definition | Typical soils |
|---|---|---|
| Low AWC | AWC < 12.5% by volume (not more than 125 mm per one m depth) | Coarse sand<br>Loamy coarse sand<br>Coarse sandy loam |
| Medium AWC | AWC > 12.5% by volume but < 20% by volume (more than 125 mm but less than 200mm per one m depth) | Sand/loamy sand<br>Fine sand/loamy fine sand<br>Clay/sandy clay/silty clay<br>Clay loam/sandy loam<br>Sandy clay loam/silty clay loam<br>Fine sandy loam/loam |

| | | |
|---|---|---|
| High AWC | AWC > 20% by volume (greater than 200 mm per one m soil depth) | Very fine sand/loamy very fine sand<br>Very fine sandy loam<br>Silt loam/silty loam<br>Peaty soils |

**Table 2.13 Optimum irrigation needs for sports turf on racecourses, classified by agroclimatic zone and soil AWC type.**

| Agroclimatic zone | Soil available water-holding capacity (AWC) | | |
|---|---|---|---|
| | Low AWC | Medium AWC | High AWC |
| 1 | 175 | 165 | 155 |
| 2 | 190 | 180 | 170 |
| 3 | 205 | 195 | 185 |
| 4 | 220 | 210 | 200 |
| 5 | 235 | 225 | 215 |
| 6 | 250 | 240 | 230 |
| 7 | 265 | 255 | 250 |

Table 2.13 summarises ‘reasonable’ or optimum’ irrigation needs (depth of water applied, in mm) for racecourse turf-grass in a ‘design’ dry year, for each soil type and agroclimatic zone. A ‘design’ dry year is statistically defined as the 80 per cent probability of non-exceedance (meeting the irrigation need for 80 years in 100). However, before these data can be applied to an individual racecourse, information on local soil type and agroclimate for each racecourse must be collated.

The survey conducted by Mumford (2004) collated information on the geographic location of 48 racecourses, together with site-specific data on course type (jump, flat or both) and dominant local soil type (texture). By combining these data with spatial climatic information within a GIS, the characteristics of each course, in terms of soil available water-holding capacity (AWC) and climate (agroclimate zone) was derived. For consistency, the same soil AWC classes and agroclimatic zones defined in the optimum water use method (W6-056) were used here. The Environment Agency CAMS catchment in which each racecourse was located was also identified. The data were grouped by course type, and summarised in Table 2.14 to 2.16.

**Figure 2.9: Agroclimatic zone map for England and Wales.**

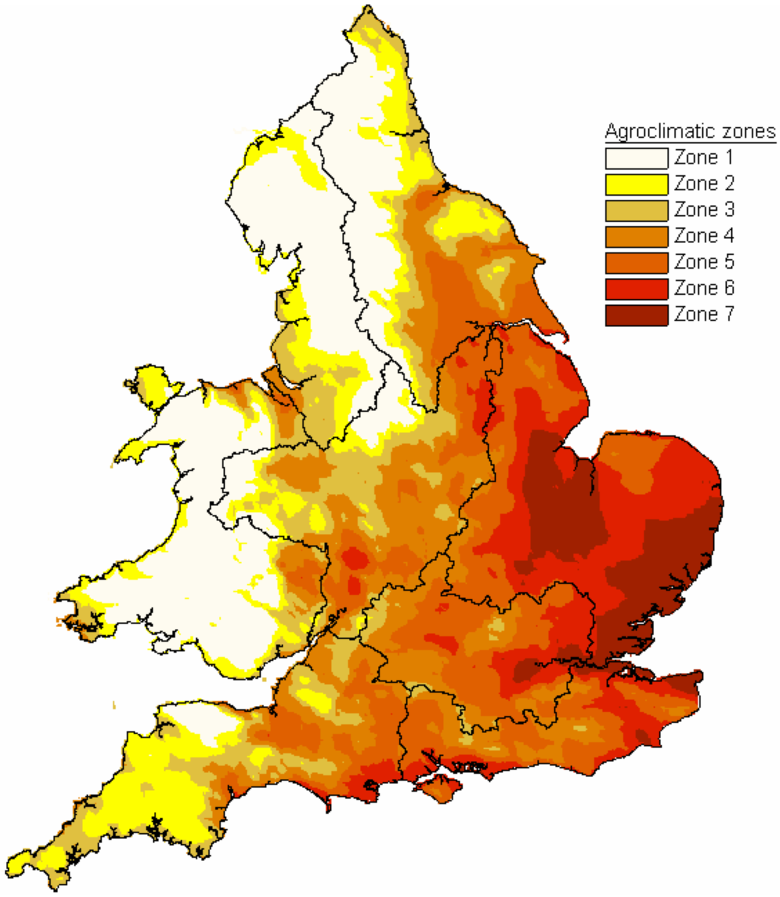



**Table 2.14 Summary of flat racecourses classified by dominant local soil type, soil AWC, agroclimatic zone and Environment Agency CAMS (name/number).**

| Racecourse | Dominant local soil type | Soil AWC | Agcl zone | CAMS Name | CAMS No |
|---|---|---|---|---|---|
| Bath | n/a | n/a | 4 | Bristol Avon | 88 |
| Beverley | Clay loam | Medium | 4 | Hull and East Riding | 10 |
| Brighton | Silt loam | High | 5 | Adur and Ouse | 63 |
| Chester | Silt loam | High | 5 | Dee | 107 |
| Epsom Downs | Sandy loam | Low | 5 | South London | 56 |
| Goodwood | Sandy loam | Low | 4 | Arun and Western Streams | 64 |
| Market Rasen | n/a | n/a | 5 | Grimsby and Ancholme | 13 |
| Newmarket | n/a | n/a | 6 | Cam and Ely Ouse | 24 |
| Nottingham | Sandy loam | Low | 4 | Lower Trent and Erewash | 28 |
| Pontefract | Clay loam | Medium | 4 | Aire and Calder | 11 |
| Redcar | Sandy silt loam | Medium | 4 | Tees | 5 |
| Ripon | Clay loam | Medium | 4 | Swale, Ure, Nidd & Up Ouse | 7 |
| Salisbury | Sandy clay loam | Medium | 5 | Hampshire Avon | 69 |
| Thirsk | Sandy loam | Low | 4 | Swale, Ure, Nidd & Up Ouse | 7 |
| Wetherby | Clay loam | Medium | 4 | Swale, Ure, Nidd & Up Ouse | 7 |
| Windsor | Sandy silt loam | Medium | 6 | Maidenhead to Sunbury | 52 |
| Wolverhampton | n/a | n/a | 3 | Worcestershire Middle Severn | 37 |
| Yarmouth | Sand | Low | 6 | Broadland Rivers | 20 |
| York | Clay loam | Medium | 5 | Swale, Ure, Nidd & Up Ouse | 7 |

**Table 2.15 Summary of jump racecourses classified by dominant local soil type, soil AWC, agroclimatic zone and Environment Agency CAMS (name/number).**

| Racecourse | Dominant local soil type | Soil AWC | Agcl zone | CAMS Name | CAMS No |
|---|---|---|---|---|---|
| Aintree | Sandy loam | Low | 3 | Alt | 115 |
| Bangor-on-Dee | Clay loam | Medium | 4 | Dee | 107 |
| Cartmel | Clay loam | Medium | 2 | Leven and Crake | 122 |
| Cheltenham | Clay loam | Medium | 5 | Warwickshire Avon | 40 |
| Exeter | Silt loam | High | 5 | Exe | 74 |
| Fakenham | Sandy loam | Low | 5 | Broadland Rivers | 20 |
| Fontwell Park | Clay loam | Medium | 5 | Arun and Western Streams | 64 |
| Hereford | Silty clay | Medium | 5 | Wye | 90 |
| Hexham | Clay loam | Medium | 2 | Tyne | 2 |
| Huntingdon | Clay loam | Medium | 7 | Upper Ouse and Bedford Ouse | 26 |
| Kempton Park | Sand | Low | 7 | Maidenhead to Sunbury | 52 |
| Ludlow | Sandy loam | Low | 3 | Teme | 36 |
| Newton Abbot | Clay | Medium | 5 | Teign and Torbay | 75 |
| Plumpton | Clay | Medium | 4 | Adur and Ouse | 63 |
| Stratford (Avon) | Clay | Medium | 5 | Warwickshire Avon | 40 |
| Taunton | n/a | n/a | 5 | Tone | 85 |
| Towcester | Clay | Medium | 5 | Upper Ouse and Bedford Ouse | 26 |
| Uttoxeter | n/a | n/a | 3 | Dove | 31 |
| Worcester | Sandy silt loam | Medium | 6 | Worcestershire Middle Severn | 37 |

**Table 2.16 Summary of racecourses with both flat and jump facilities, classified by dominant local soil type, soil AWC, agroclimatic zone and Environment Agency CAMS (name and number).**

| Racecourse | Dominant local soil type | Soil AWC | Agcl zone | CAMS Name | CAMS No |
|---|---|---|---|---|---|
| Ascot | Sandy loam | Low | 5 | Wey | 54 |
| Carlisle | Sandy clay loam | Medium | 2 | Eden and Esk | 126 |
| Catterick | Sandy loam | Low | 3 | Swale, Ure, Nidd and Upper Ouse | 7 |
| Chepstow | n/a | n/a | 3 | Severn Vale West | 41 |
| Doncaster | Sandy silt loam | Medium | 5 | Idle and Torne | 29 |
| Folkestone | Silty clay | Medium | 5 | Stour | 60 |
| Haydock Park | Sandy clay loam | Medium | 2 | Sankey and Glaze | 114 |
| Leicester | Clay loam | Medium | 5 | Soar | 27 |
| Lingfield Park | Clay loam | Medium | 5 | Medway | 58 |
| Newbury | Sandy clay loam | Medium | 4 | Kennet and Pang | 47 |
| Newcastle | Sandy clay loam | Medium | 2 | Tyne | 2 |
| Sandown Park | Sandy loam | Low | 6 | Mole | 55 |
| Sedgefield | n/a | n/a | 3 | Tees | 5 |
| Southwell | n/a | n/a | 5 | Lower Trent and Erewash | 28 |
| Warwick | Sandy clay loam | Medium | 4 | Warwickshire Avon | 40 |
| Wincanton | n/a | n/a | 4 | Dorset Stour | 70 |

For example, with reference to Table 2.13, a flat racecourse located in Norfolk (say, in agroclimatic Zone 6) with turf grass grown on a predominantly sandy loam soil (low AWC), would require a total seasonal application of 250 mm in a 'design' dry year (equivalent to 2,500 $m^3$ $ha^{-1}$). Assuming the irrigated area of a racecourse was 7.0 ha, the seasonal volumetric irrigation water demand for a dry year would equate to 17,500 $m^3$. The data presented in Table 2.13 to 2.16 can thus be used by the Environment Agency to assess an abstraction licence for racecourse irrigation. A brief description of the procedure is given below.

### 2.2.4 Application of the proposed methodology

In order to assess the 'optimum' or 'reasonable' irrigation need of a racecourse, a seven-staged method is proposed. The procedure relies on the provision of basic information from licence applicants themselves. Each stage is described below.

*Stage 1: Identify the dominant local soil type and establish soil AWC class*

For most racecourses in England and Wales, the dominant local soil type and soil AWC class have already been identified (refer to Table 2.14 to Table 2.16). For racecourses where data are missing, refer to the National Soils Map (Boorman *et al*., 1995) or request the abstractor to supply information on the dominant local soil type (many racecourses have detailed soil maps derived from electromagnetic scanning in support of their course management and 'going' assessment).

*Stage 2: Establish the local agroclimatic zone*

The agroclimatic zone in which every racecourse in England and Wales is located has been identified (refer to Table 2.14 to Table 2.16).

*Stage 3: Assess the total irrigated area on the racecourse (ha)*

Request abstractor to supply information on the total irrigated area (ha). Many racecourses have a detailed map of the racecourse. Refer to Table 2.8 to check whether reported area is reasonable.

*Stage 4: Establish the optimum irrigation water needs (mm)*

For the relevant soil AWC class and agroclimatic zone, identify the optimum irrigation need for the racecourse turf-grass in a dry year (refer to Table 2.13).

*Stage 5: Calculate the seasonal volumetric irrigation water demand ($m^3$)*

Multiply the irrigated area (ha) by the optimum irrigation need (mm) to calculate the total seasonal volumetric irrigation demand ($m^3$) in a dry year.

*Stage 6: Assess the peak abstraction rate/s*

Refer to Table A1 and supporting information given in the appendix of this report (and also provided in the Environment Agency's best practice manual W6-056/TR).

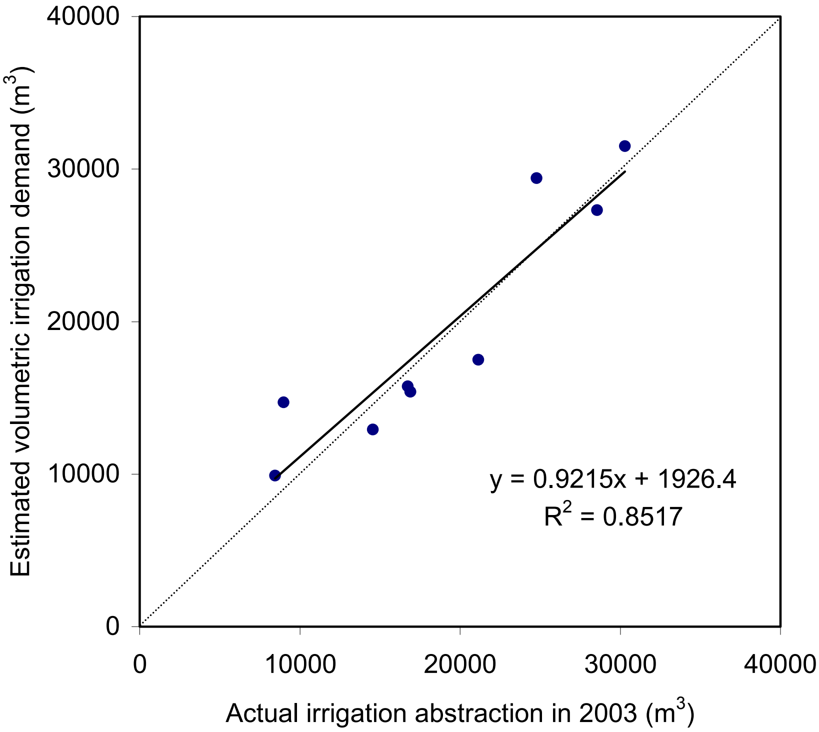
*Stage 7: Compare the irrigation volume requested by the applicant with the estimated volume calculated using this method*

The Environment Agency licensing officer should now be in a position to discuss with the applicant the Environment Agency's estimated irrigation demand, based on the information supplied by the applicant. Any significant differences between the volume requested and calculated using the above method can now be addressed.

### 2.2.5 Theoretical and actual water use

The procedure described above provides a framework for assessing the 'optimum' or 'reasonable' volumetric irrigation demand for a racecourse in a 'design' dry year. This represents a theoretical optimum and assumes that the racecourse has adopted best irrigation management practices, and that equipment and water resources are unconstrained. When auditing water use within specific sectors, an important objective is to verify that the proposed theoretical approaches and assumptions are scientifically robust. A limited number of racecourses were identified and used to validate the methodology. Nine racecourses with contrasting soils and agroclimatic conditions were identified. The proposed methodology was then applied to each racecourse to calculate the optimum volumetric irrigation water demand. These values were compared against their actual abstraction in 2003, equivalent to a 'design' dry year (Figure .10).

**Figure 2.10 Comparison of predicted 'optimum' irrigation water demand in a 'design' dry year with reported actual irrigation abstraction in 2003 for nine racecourses.**




The correlation between reported abstractions in 2003 and estimated irrigation demand from these racecourses shows a strong linear relationship ($R^2$ = 85 per cent). Assuming these racecourses were unconstrained by water resources and equipment, this implies that a reasonably high degree of confidence can be attached to the methodology for use in estimating the optimum or reasonable volumetric irrigation water demand for racecourses.

## 2.3 Turf grass production

This section reviews the use of irrigation water in the turf grass production sector, and provides guidelines for assessing the 'reasonable' or 'optimum' irrigation needs for abstraction licences for turf production. It is based on a combination of data from an industry survey of irrigation practices, water balance computer modelling and consultation with key informants in the turf grass industry.

### 2.3.1 Current usage and industry survey

In the UK there are approximately 200 suppliers of turf grass, covering an estimated 30,000 ha production. The turf is used to supply a range of sectors including landscapes (such as commercial developments, parks and households), sports surfaces (football, cricket, rugby, tennis, horseracing) and amenities (such as golf, bowling). Turf grass is grown commercially in many parts of the country, although there are regional pockets of concentration in Lincolnshire, Herefordshire, and Shropshire and around York. Turf grass production is considered an agricultural rather than an amenity land-based activity. Indeed, many turf grass farms in the UK are also involved in traditional agricultural cropping.

The Turfgrass Growers Association (TGA) represents the interests of the industry. This organisation comprises 39 members and is collectively responsible for producing approximately 10,000 ha, representing a third of the cultivated turf grown in the British Isles. The TGA has developed a standard for the production and supply of commercial turf. This defines the turf dimension (including height of sward, soil depth and thickness of thatch), soil classification, grass cultivars, cutting height, thickness of the soil, sod netting, turf strength and weight.

The turf sward is produced using a mixture of grass cultivars including ryegrasses, fescues, meadow grasses and bents. The species mixture and resulting quality of the turf depend on its intended application (whether for sports turf, landscape or amenity). The species mixture can be varied to provide specific turf characteristics such as improved resistance to wear and durability. For example, for sports turf, characteristics such as firmness, bounce and speed are critical. For other uses such as landscape, colour, durability and aesthetics are considered important.

Growing turf requires a high degree of land and water management. Turf grass should have good root development to aid early sod cutting. With experience and good management, the growing cycle length necessary to achieve this should be approximately 12 months. Turf with less than adequate root development will result in higher harvest losses. Good weed control is also important. A management programme consisting of timely fertilization, irrigation and mowing will result in optimum turf grass development and the ability to harvest a crop early. Turf is typically grown for between 12 and 15 months in order to create a strong, healthy sward. It is then harvested and supplied in two sizes: standard (one $m^2$) and large rolls (ranging from 12 to 20 $m^2$).

In the UK, there is limited published literature on the turf grass production sector. In order to improve our understanding of water use within this sector, an industry postal survey was targeted at selected members of the Turgrass Growers Association (TGA). The survey requested information relating to the turf area irrigated, sources of water used, types of equipment, water management (scheduling), and abstraction licensing. In all, 14 completed forms were received. A summary of the findings is presented below.

The survey data suggest that the average turf area irrigated is 160 ha. This is consistent with the national figure of 150 ha, assuming that 200 suppliers grow an estimated 30,000 ha. However, the survey data confirms that there are large variations between individual enterprises; the majority of enterprises typically grow more than 100 ha, but a number of turf producers grow between 250 and 500 ha.

The industry data suggest that the majority (42 per cent) of turf producers use direct abstraction from surface sources (rivers and streams). Groundwater accounts for approximately 20 per cent of water abstracted. However, many rely on storage reservoirs (37 per cent), although the primary source (surface or groundwater) is unknown. Public mains water is not used for turf grass production.

All turf grass irrigation relies on hose-reels fitted with either rain guns (71 per cent) or booms (29 per cent).

The dominant form of in-field irrigation management (scheduling) is through visual inspection (71 per cent). Many also use an auger to assess soil moisture in the topsoil layer. A quarter of respondents (24 per cent) use in situ soil moisture monitoring (such as a tensiometer, neutron probe); and only a small minority (six per cent) use water balance computer models and weather stations to schedule the timing of irrigation. This split between non-scientific (visual) and scientific (computer and in situ measurement) scheduling is consistent with current practices within the agricultural sector. However, using a combination of visual inspection and some form of scientific approach to provide a more quantitative assessment of soil moisture is recommended. For example, one tool considered appropriate for estimating turf water use is the ETgage, which has been shown to accurately measure reference (grass) evapotranspiration in the UK (Hess, 1996). Readings from this device are made directly, so there is no need for a computer model or any electronic equipment.

The survey also collected information relating to the typical depths of water applied to turf grass in a very dry year. The majority of the reported values ranged from 120 to 250 mm (equivalent to 1,200 to 2,500 $m^3$ $ha^{-1}$) although some growers located in wetter climates reported much smaller applications of between 25 to 35 mm (equivalent to 250 to 350 $m^3$ $ha^{-1}$). A comparison of these figures with modelled (theoretical) values for turf grass irrigation under contrasting soil and agroclimate conditions are provided below.

### 2.3.2 Optimal water use for turf production

This section describes the development of a procedure to help the Environment Agency assess and set abstraction licences for turf grass production. The method enables the seasonal volumetric irrigation demand ($m^3$) in a 'design' dry year to be estimated, taking into account the total area irrigated and local variations in climate and soil type.

The approach has been subject to industry consultation (Turfgrass Growers Association) to ensure that the proposed optimum water use figures are reasonable and reflect best practice within the industry. The procedure has also been tested with a number of informants involved in the commercial production of turf grass. As with other turf uses (such as racecourses), the agronomic needs for turf grass production are primarily a function of local climate and soil type. Agronomic demand for irrigation is usually a function of the running balance between rainfall and evapotranspiratiion (ET) in the summer months and the consequent impacts on soil moisture.

The optimum water use method (agriculture) developed for the Environment Agency provides a framework for assessing the optimum or reasonable irrigation needs for a range of agricultural land uses taking into account crop types, local soil and climate conditions and typical irrigation management practices. For turf production, a similar approach has been adopted, and is briefly described below.

A computer irrigation scheduling water balance model developed by Hess (1994) was used to simulate the annual irrigation needs of turf grass grown under a range of soil and agroclimatic conditions. As before, three soils (Table 2.12) and seven agroclimatic zones were defined (Figure 2.9). Simulated annual irrigation needs (from the water balance model) were then correlated against the three soil types and seven agroclimate zones using linear regression analyses. The results are presented in the form of an irrigation need look-up table

(Table 2.17). This table summarises the reasonable or optimum irrigation need (depth of water applied, mm) for turf grass in a design dry year, for each soil type and agroclimatic zone.

**Table 2.17: Reasonable or optimum irrigation needs (mm) for turf grass production, classified by soil AWC type and agroclimatic zone.**

| Agroclimatic zone | Soil available water holding capacity (AWC) | | |
|---|---|---|---|
| | Low AWC | Medium AWC | High AWC |
| 1 | 100 | 90 | 85 |
| 2 | 110 | 100 | 95 |
| 3 | 125 | 115 | 105 |
| 4 | 135 | 125 | 115 |
| 5 | 145 | 135 | 130 |
| 6 | 155 | 145 | 140 |
| 7 | 165 | 155 | 150 |

For example, a grower located in Lincolnshire (say, Zone 7) producing turf grass on a coarse sandy loam soil (low AWC), would require a total seasonal application of 165 mm in a design dry year (equivalent to 1,650 $m^3 ha^{-1}$).

Table 2.17 can be used by the Environment Agency, in conjunction with computer (GIS) maps on soils and agroclimate, to assess an abstraction licence for turf grass irrigation. A brief description of the procedure is given below.

### 2.3.3 Application of the proposed methodology

In order to assess the reasonable irrigation need for turf (commercial turf production), a seven-stage method is proposed. The procedure relies on the provision of information from licence applicants themselves. Each stage is described below.

*Stage 1: Identify the dominant local soil type and establish soil AWC class*

Refer to the National Soils Map (Boorman *et al*., 1995) or request the licence applicant to supply information on the dominant local soil type (or range of soil types on which the turf is cultivated). The Environment Agency uses a computerised soils map to locate the dominant soil type using postcode geo-referencing.

*Stage 2: Establish the local agroclimatic zone*

Refer to Figure 2.9 to identify the agroclimatic zone in which the site is located (the Environment Agency use a computerised version of this map to locate the site using postcode geo-referencing).

*Stage 3: Assess the total irrigated turf area (ha)*

Request the abstractor to supply information on the total irrigated area (ha).

*Stage 4: Establish the optimum irrigation water need (mm)*

With reference to Table 2.17, for the relevant soil AWC class and agroclimatic zone identify the optimum irrigation needs (depth of water applied) for the turf grass.

*Stage 5:* *Calculate the volumetric irrigation water demand ($m^3$)*

Multiply the irrigated area (ha) by the optimum irrigation need (mm) to calculate the volumetric irrigation demand ($m^3$) for the site.

*Stage 6:* *Assess the peak abstraction rate/s*

Refer to Table A1 and supporting information given in the appendix (and also provided in the Environment Agency's best practice manual W6-056/TR).

*Stage 7:* *Compare the irrigation volume requested by the applicant with the estimated irrigation volume calculated using this method*

The Environment Agency licensing officer should now be in a position to discuss with the applicant the Environment Agency's estimated irrigation demand, based on the information supplied by the applicant. Any significant differences between the volume requested and calculated using the above method can now be addressed.

## 2.4 Frost protection

In the UK, overhead-misting irrigation is used in orchard fruit production (and to a lesser extent in soft fruit) to limit the perennial problem of frost damage. Frost can damage fruit blossom, with a consequent reduction in fruit pollination. Frost can severely affect crop reliability and lead to unpredictable volumes of fruit for the fresh and processed markets.

There are two types of frost. Wind frosts usually occur when high pressure brings cold air from the northern parts of Central Europe and Asia or from the Arctic (Hamer, 1975; Tinsey, 1999). They are infrequent during the spring in most UK fruit-growing areas. In contrast, radiation frosts occur as a result of differences between incoming and outgoing radiation, and are more usually the cause of frost damage in orchards and soft fruit. Despite the risk, only a small percentage of the orchard area is protected from frost in England (Tinsley, 1999). In 1995, the total area equipped for frost protection by irrigation equipment in England and Wales was reported to be 2,470 ha (Defra, 1996) compared to a total orchard irrigated area of 10,000 ha. This is in contrast to other European countries, such as Italy and the Netherlands, where 100 and 60 per cent, respectively, of the orchard crops are protected. In South East England, frosts of sufficient severity in April, May and June cause significant losses every one in five years, but minor frosts cause blemishes more often (Hamer, 1980). It has been estimated that on average, six per cent of the nation's Bramley apple crop is lost and a further 16 per cent is blemished. Severe frosts in 1997 (Kent, East Anglia) and 1998 (Northern Ireland) caused major losses (Tinsley, 1999).

Frost damage occurs when ice crystals form on or within the plant tissue. As freezing water expands, it ruptures the cell membranes and kills plant tissue (Moxey, 1991). If the reproductive plant tissues (styles and ovaries) are frozen, fruits will not develop. However, if only superficial tissues of buds or flowers are frozen, then the fruits will be blemished or misshapen (Modlibowska, 1975). Both cases result in financial losses to the grower in terms of reduced crop quality. The frost damage to a plant depends on its development stage. Buds are most frost-resistant in winter when they are fully dormant. The sensitivity of buds and flowers increases as their water content increases (Modlibowska, 1975). The range of damaging temperatures for different stages of apple bud development is shown in Table 2.18.

**Table 2.18: Damaging temperatures for different stages of apple bud development.**

| Development stage | Damaging temperature (°C) |
|---|---|
| Bud burst | - 7.0 |
| Mouse ear | - 4.5 |
| Early green cluster | - 3.0 |
| Late green cluster | - 2.0 |
| Pink bud | - 1.5 |
| First open flower | - 1.0 |
| Full bloom | - 0.5 |
| Ten per cent petal fall | 0.0 |
| Early fruitlet | 0.0 |

Source: Tinsley (1999).

Different measures are therefore needed at different times to protect the crops against frost damage.

### 2.4.1 Environment Agency abstraction data

There are currently a reported 125 abstraction licences for frost protection in England and Wales (Table 2.19). Almost three-quarters of all licences are located within the Anglian region, with a further 11 per cent in the Southern region. Licences for frost protection constitute a minor form of abstraction in other regions.

**Table 2.19 Total number of spray irrigation abstraction licences for frost protection, by Environment Agency region, in 2003.**

| Region | Number of licences | Percentage of total |
|---|---|---|
| Anglian | 93 | 74.4 |
| Midlands | 7 | 5.6 |
| South West | 5 | 4 |
| Southern | 14 | 11.2 |
| Thames | 3 | 2.4 |
| Wales | 3 | 2.4 |
| North West | 0 | 0 |
| North East | 0 | 0 |
| **Total** | 125 | 100 |

Total volumes licensed and abstracted between 2000 and 2003 for frost protection, by Environment Agency region, are summarised in Table 2.20. The Anglian region accounts for almost 80 per cent of the total licensed volume. Nationally, the volume licensed for frost protection represents only two per cent of that licensed for spray irrigation. The volumes abstracted for frost protection vary each year, depending on weather conditions each spring (Table 2.21)

**Table 2.20 Total licensed and abstracted volumes of irrigation for frost protection from 2000 to 2003, aggregated by Environment Agency region.**

| Region | Volume licensed ($m^3$) | Volume abstracted ($m^3$) | | | |
|---|---|---|---|---|---|
| | | 2000 | 2001 | 2002 | 2003 |
| Anglian | 1,839,917 | 165,021 | 135,135 | 119,522 | 126,912 |
| Midlands | 130,565 | 0 | 0 | 0 | 0 |
| South West | 41,453 | 32,622 | 15,384 | 18,077 | 24,958 |
| Southern | 238,210 | 13,095 | 15,006 | 14,215 | 41,758 |
| Thames | 79,092 | 0 | 0 | 0 | 0 |
| Wales | 6,613 | 1,560 | 0 | 0 | 4,455 |
| North West | 0 | 0 | 0 | 0 | 0 |
| North East | 0 | 0 | 0 | 0 | 0 |
| **Total** | 2,335,849 | 212,298 | 165,525 | 151,814 | 198,083 |

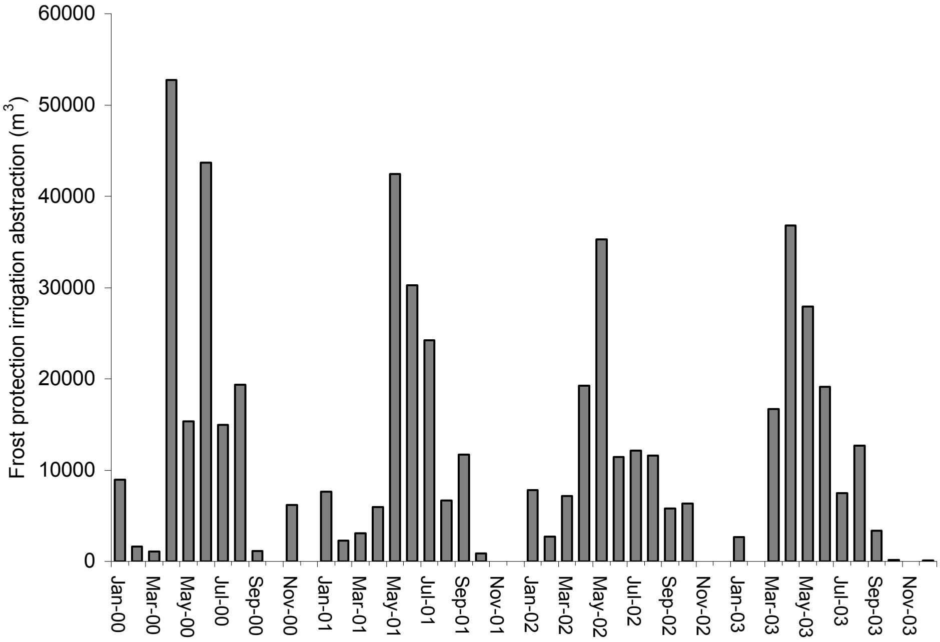
**Table 2.21 Proportion (%) of total licensed volume abstracted for frost protection, by Environment Agency region (2000 to 2003).**

| Region | Proportion of licensed volume abstracted (%) | | | |
|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2003 |
| Anglian | 9 | 7 | 6 | 7 |
| Midlands | 0 | 0 | 0 | 0 |
| South West | 79 | 37 | 44 | 60 |
| Southern | 5 | 6 | 6 | 18 |
| Thames | 0 | 0 | 0 | 0 |
| Wales | 24 | 0 | 0 | 67 |
| North West | - | - | - | - |
| North East | - | - | - | - |

Between 2000 and 2003, on average only eight per cent of the total licensed volume was abstracted, but this low figure masks significant regional variation and high peaks in the seasonal timing of demand. For example, in the South West and Wales, on average 55 and 23 per cent of total licensed volume in that region was abstracted, respectively. Overall, the figures reflect the impact of a series of relatively mild winters and warm springs experienced in the UK in recent years.

Finally, NALD data was analysed for the seasonal timing of irrigation demand for frost protection (Figure 2.11). Peak abstraction occurs in April and May when crops are most vulnerable to night frost. The data also shows considerable abstractions during July and August, when night frosts are uncommon. This is because some licences are not exclusively for frost protection, but can also be used for spray irrigation.

**Figure 2.11 Monthly timing of irrigation abstraction for frost protection in Environment Agency Anglian region between 2000 and 2003**.




## 2.4.2 Optimal water use

Frost protection is usually practiced on orchard fruit (predominantly apples) and selected soft fruit (blackcurrants and strawberries). The following application rates have been reported for these specific crop types.

**Apples:** The following application rates on apples have been reported: 2.5 mm per hour (Modlibowka, 1975) and 3 mm per hour (De Rocker *et al*., 2001).

**Blackcurrants:** Historically, most farmers grew a variety termed Baldwin. This flowered early and was susceptible to frost damage when temperatures dropped below freezing (0°C). However, many have now have converted to Scottish varieties that flower later and are hardier; damage on this variety will not generally occur until temperatures drop below -2°C (*personal communication,* A. Marshall).

The following application rates on blackcurrants have been reported: 3.0 to 3.6 mm per hour (Mathieson, 1978) and 2.5 mm per hour (*pers. com*. A. Marshall).

**Strawberries:** The following application rates on strawberries have been reported: 6.4 mm per hour (Hochmuth *et al*., 1993).

To verify whether these reported figures were still applicable for determining the reasonable irrigation needs for frost protection licences, a limited number (four) of structured interviews with key informants was undertaken. Interviews were used to collect information on the rationale of frost protection and the volumes of water generally applied. The feedback from the interviews is summarised below.

Four farmers were interviewed using a semi-structured questionnaire. Two used frost protection for top fruit (apples, pears, plums) and were located in the South East. The other two used frost protection on soft fruit (blackcurrants) and were located in Eastern England.

All used systems with overhead sprinklers to spray the crop. Underground pipes and mains supplied three of the systems; one used underground mains with above-ground pipes. The systems had been in place for a considerable amount of time, ranging from 15 to 50 years. All interviewees had a winter storage reservoir. The size of the reservoir varied in having enough water for four to 12 nights of frost protection. All farmers used a thermometer coupled with an alarm in the orchard to trigger irrigation when the temperature fell below a preset threshold.

Whether frost protection is really needed depends on a number of factors. If, for instance, frost doesn't occur until early in the morning, it may not be worth switching on the spray, as very little damage will be done in the time until the sun comes up and heats the fields. Similarly fog, clouds and rain may influence the choice to spray or not to spray.

Top fruit farms were located in areas prone to night frosts. In the 1980s, a number of severe frosts caused a lot of damage. One farmer lost an entire crop because no frost protection was in place. This was subsequently put in. The damage caused by frost is usually less devastating. With apples, damage ranges from 'frost eye' (a wide ring of different coloured skin around the bottom of the apple), small blemishes and misshapen fruits to 'June-drop', where poor pollination causes apparently healthy fruits to break off and fall. All these will lead to a reduction in yield and/or economic loss, as blemished fruits are only suitable for processing. In the past couple of years, during the months of April and May, top fruit farmers experienced on average between five and 10 nights that required frost protection. The application rate on those nights varied between 2.5 and 4 mm per hour. The actual temperature at which the frost protection system is switched on depends on the development stage of the fruit, the crop type and the farmer. One of the farmers has an alarm threshold ranging from -0.5°C to -2°C, another ranges from -0.2°C to -0.7°C.

The blackcurrant farms were located in an area with fewer problems with night frosts than there used to be. This area was close to the sea and although winter frosts could be severe and prolonged, spring frosts tended to occur less often as the warm sea air helped keep temperatures up. In the 1970s and 1980s frosts occurred night after night, with a record of 21 consecutive nights. However, one of the farmers had not used frost protection for four years, and the other had seen a considerable drop to only a handful of nights each year. Both farmers believed this change to be due to climate change.

The decreased requirement for frost protection was also due to a change in variety. Ten to 20 years ago, most blackcurrant growers used a variety called Baldwin, which was susceptible to frost damage. Most Baldwin bushes have now been replaced by so-called Scottish varieties such as Ben Lomond, Ben Alder and Ben Gairn (blackcurrant bushes last between 12-15 years). Some of these varieties are much more frost hardy and can survive temperatures up to -2°C or -4°C without sustaining damage, while others flower later in the season and are therefore less likely to be damaged by night frost. Even though there is currently less need for frost protection, this will not always be the case. One manufacturer of blackcurrant juice drink uses around 95 per cent of all blackcurrants. This manufacturer determines which varieties it will accept. If in future this manufacturer decides more frost prone varieties are better, that is what farmers will have to respond to. For instance, Ben Alder, which is very hardy, is currently being phased out due to its lack of taste. The application rate for one of the farmers averaged about 2.6 mm per hour; it was not possible to ascertain the application rate on the other farm.

Some alternative ways of frost protection are available. Wax candles were used in the 1960s by one of the top fruit farmers, but they gave off a very thick black smoke. Both top fruit farms are located in very densely populated areas (one farm has 200+ neighbours) and the smoke given off by wax candles would not be popular in these areas. Similarly, wind machines would be unacceptable as they make a lot of noise. Noise is also the reason that the Frost

Buster (a tractor-mounted fan heater) is not used. A recent development is poly-tunnels, which are large enough (6 m high x 8 m wide) to be put in orchards that have dwarf varieties. These tunnels allow for better retention of heat, but as one farmer said, are “very, very expensive”.

### 2.4.3 Possible optimisation measures

Several methods are available to protect plants from frost damage. Small areas are easily covered with protective materials such as straw, boxes, sacking, plastic or mulch that will act as a blanket to prevent the ground from absorbing heat during the day and radiating it at night (Law, 1968; Tinsey, 1999; Witte, 1958). Although this method is effective, for large areas this can be impractical or costly (Moxey, 1991).

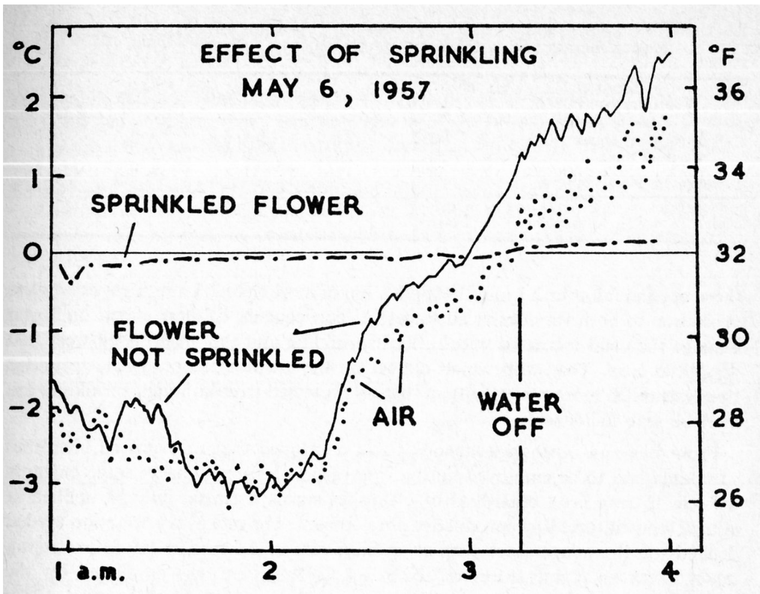
Fires and heaters can be used to increase the air temperature near plants. Convection currents from the fires help to mix cold and warm air layers, thus warming the air. This method was used in the 1960s in Europe and is still being used in the USA (Law, 1968; Tinsey, 1999). It can be labour-intensive, however, as fires need tending and up to 125 small fires or 400 heaters per hectare may be needed to keep temperatures high enough (Law, 1968; Tinsey, 1999). Another problem with fires and heaters are the higher energy requirements and poor air quality (from paraffin/diesel fires/heaters) (Barfield *et al.*, 1981). The amount of heat needed in the UK can be in the region of 700 kW per ha per hour, making it too expensive for most.

In some parts of the world (New Zealand, USA), helicopters are used for frost damage prevention (Tinsey, 1999). Flying low over the crop will cause air currents which mix warm and cold air layers, thus increasing the temperature near the crop.

Currently, the most used method to prevent frost damage is sprinkler irrigation. As temperatures drop below zero, sprinklers are turned on and spraying continues until the temperature reaches 0°C again. As water falls on a plant and freezes, 80 kCal/l (or 335 kJ/l) of latent heat is released. This heat is enough to ensure that a crop stays at 0°C until either all the water freezes or all the ice is defrosted (De Rocker *et al.*, 2001). It is therefore important to ensure that the plant remains wet and does not freeze. It may be better to not protect a crop at all rather than try and fail. Mathieson (1978) reported that unprotected plants suffered 40 per cent reduced yield compared to protected ones, but partially protected plants were completely wiped out.

Figure 2.12 shows the effect of sprinkling flowers in order to prevent frost damage. Unprotected flowers follow the air temperature very closely and reach a minimum temperature of -3°C. At this temperature, major damage to flowers can arise. In contrast, irrigated flowers stay close to 0°C and are less likely to be damaged.

**Figure 2.12 Temperatures of sprinkled and unsprinkled flowers, and of air, on 6 May 1957 (from Modlibowska, 1975).**




In Northern Ireland (Kilmore), an alternative to misting irrigation has been developed. A fan-assisted frost protection system has been installed to eliminate frost damage to the developing fruit buds in the orchard canopy. The system comprises a diesel-powered five metre rotating propeller fan, mounted on an 11 m tower. Typical fan rotation speed is 2,450 rpm. This technology is used in many US citrus groves and fruit orchards. The principle behind fan-assisted frost protection is to exploit the natural phenomenon of 'temperature inversion'. During some nights in the critical spring season, radiation of daytime heat from the ground can cause the soil surface to cool more rapidly than air layers above, which are then warmed by the radiation at some height above the ground, especially in a period of sunny weather and high atmospheric pressures. The orchard may fall to sub-zero temperatures while the settled air overhead remains above freezing.

The same phenomenon can occur when cold night air drains downhill to settle in valleys and low ground, displacing the surrounding warm air, which is less dense. Huge volumes of this warmer air can be drawn back down into the orchard by the action of a tower-mounted fan, which runs only during these frost-prone periods. As well as giving a measurable lift in temperature, the fan continuously rotates air around the trees and so minimises cold penetration into the flower cluster. The fan rotates 360 degrees every four and a half minutes.

## 2.4.4 Environment Agency guidelines for licence determination

Due to the very small number of cases, it is recommended that abstraction licences for frost protection are considered on a case-by-case basis, taking into account the local circumstances of the abstractor, the reported application rates given in Section 2.4.2 and the experiences of other users as documented.

# 2.5 Nursery stock, pot plant and bedding plant production

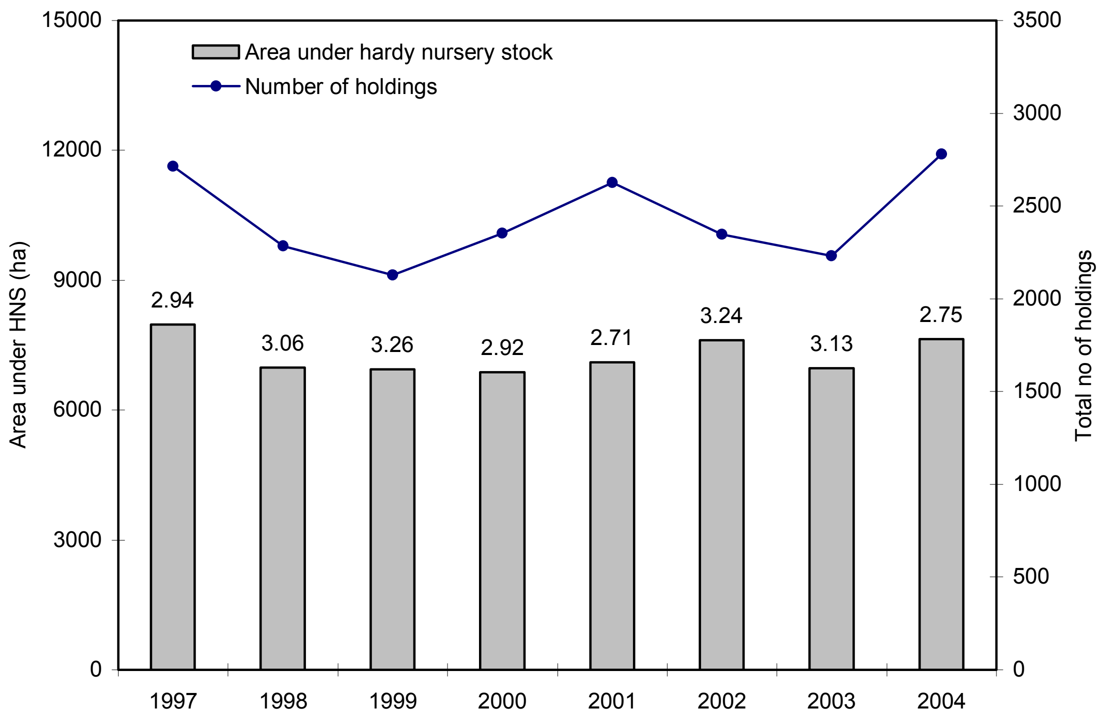
This section assesses irrigation water use in the horticultural nursery stock, pot plant and bedding plant sectors. It combines data from a literature review, government surveys and existing research with an analysis of Environment Agency abstraction data, and information from structured interviews and site visits with key informants within the industry. Guidelines for assessing the quantities of water required for optimum production within each sector, together with supporting information on achieving best practice, are provided.

## 2.5.1 Government cropping census data

Each year the government conducts a crop survey, termed the Agricultural June Census. This collects information on land use, crops, livestock, labour, horticultural and glasshouse production. Legislation requires each farmer to state the agricultural activity happening to the land as of June each year. The data are reported via postal questionnaire, then aggregated and published as annual reports (see Defra, 2004).

The June Census contains information on hardy nursery stock (HNS), including the total number of holdings and areas cropped at regional level. The data from 1997 to 2004 have been analysed and are summarised in Figure 2.13.

**Figure 2.13: Reported total number of holdings and area (ha) under hardy nursery stock in England, between 1997 and 2004.** The values shown represent the average area (ha) of each holding in that year.




The data suggests that the total area under HNS has remained relatively stable over the last decade, typically ranging between 7,000 and 8,000 ha per annum. The total number of holdings, however, has shown large fluctuations, dropping 27 per cent from a peak in 1997, but then climbing steadily back since 1999 to almost 3,000. The average area of each holding during the period was three hectare.

### 2.5.2 Environment Agency (NALD) abstraction data

The Environment Agency holds records of licensed and abstracted volumes of water used for horticulture and nursery irrigation within their national abstraction licensing database (NALD). The data cannot be split into different types of nursery production (such as nursery stock, pot or bedding plants). In this study, data from 2003 have been analysed and aggregated to Environment Agency regional level (Table 2.22).

**Table 2.22 Licensed and abstracted volumes ($m^3$) for horticulture and nursery irrigation in England and Wales in 2003, by Environment Agency region.**

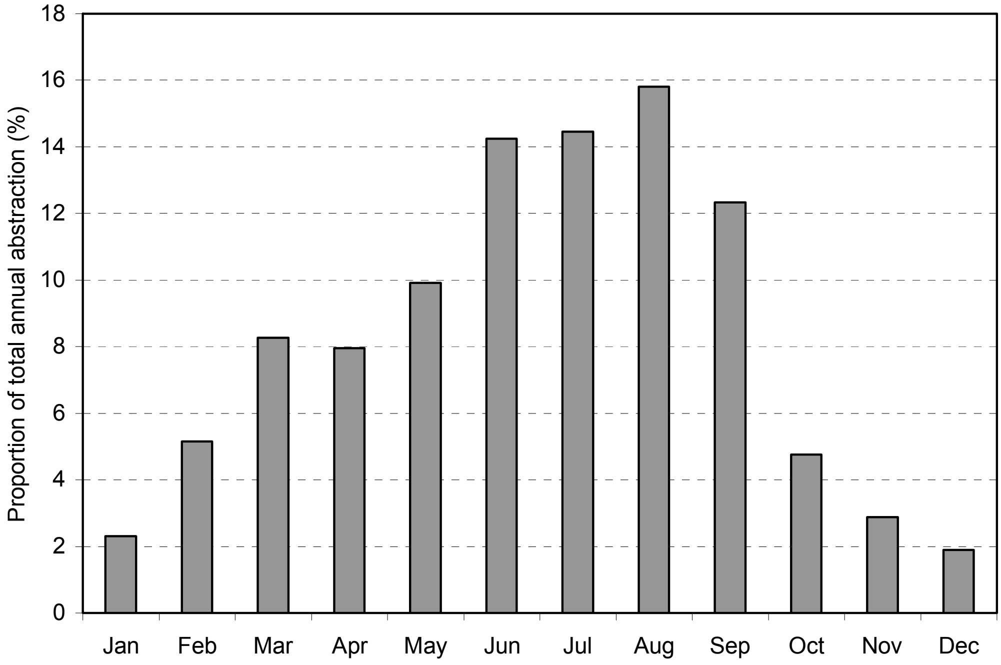
| Region | Number of licences | Total licensed volume ($m^3$) | Total abstracted volume ($m^3$) | Proportion abstracted (%) |
|---|---|---|---|---|
| Anglian | 19 | 301,409 | 78,656 | 26 |
| EA Wales | 10 | 163,571 | 80,194 | 49 |
| Midlands | 31 | 401,492 | 107,173 | 27 |
| North East | 57 | 1,256,934 | 459,876 | 37 |
| North West | 13 | 120,479 | 65,801 | 55 |
| South West | 84 | 204,708 | 15,019 | 7 |
| Southern | 44 | 1,043,618 | 501,225 | 48 |
| Thames | 78 | 704,808 | 247,149 | 35 |
| Total | 336 | 4,197,018 | 1,555,093 | 37 |

In 2003, there were an estimated 336 irrigation abstraction licences for horticultural nursery production. Almost half the licences are located within the South West and Thames regions. However, the average licensed volume within each region varies significantly; for example, South West has the highest number of individual licences, but with an average licensed volume of just 2,500 $m^3$; in contrast, in the Southern region which has only half this number of licences, the average licensed volume is nearly 24,000 $m^3$. Clearly, there are major regional variations in the size of individual horticultural nurseries.

In 2003, the total abstracted volume in England and Wales was estimated to be 1,555 million litres, representing 37 per cent of the total licensed volume in that year. However, the South West region, where only seven per cent of the total licensed volume in that region was abstracted, heavily skews this national average. In other regions, the figure was nearly 50 per cent, which is considerably higher than the equivalent for agriculture.

Finally, the NALD data was analysed to assess the seasonal timing of irrigation demand for horticultural and nursery production in 2003 (Figure 2.1). Almost 90 per cent of all water abstracted occurred between April and September, confirming that most is abstracted and used directly, with very little on-site storage.

**Figure 2.14 Monthly timing of abstraction for horticultural and nursery irrigation in 2003.**




## 2.5.3 Definitions and methods of water application

A brief definition of each horticultural sector, together with a description of the typical methods of irrigation used, is given below.

### *Nursery stock*

The term 'nursery stock' includes shrubs and trees grown in plastic containers, and larger trees grown directly in the soil. Seedlings or cuttings start indoors under cover on mist benches or beds. Typically, they are moved onto floor-level beds in polythene tunnels, and later still outdoors on to standing beds of sand or gravel. Containerised nursery stock can be planted out at any time of the year. Lined-out trees grown directly in the soil are limited to planting out after leaf fall in the winter, and so are less popular. Because the waterproof plastic container wall confines the plant roots, there is no depth of compost to retain water, and watering must be done once or even two times per day in dry weather (HDC, 1995; 2001a; 2001b).

The propagation stage uses overhead mist lines with short bursts of mist controlled by a sensor. The amount of water used is very small, but it needs to be clean and low in hardness to avoid mist nozzle blockage.

Floor-level beds in polythene tunnels are typically of sand or gravel, and are watered with overhead sprinkler lines of uPVC or aluminium attached to the roof.

Gravel standing beds are free draining and watered with overhead full circle or part circle sprinklers mounted on risers.

Sand beds typically water the plant containers from beneath (sub-irrigation) by capillary attraction through holes in the base of the container. The plant compost includes a wetting agent to encourage capillary rise. The sand is held in a shallow tray with low timber sides around 10 centimetres deep lined with strong polythene sheeting, and dead level. The popular Efford sand bed uses agricultural drain piping laid in the sand to bring water to the sand, which may also be used to drain the beds during the winter.

A relatively new approach is the ebb-and-flow bed, which comprises watertight shallow above-ground trays with timber sides lined with strong polythene or butyl rubber. This is flooded with water once or twice a day to a depth of five to 10 centimetres and then drained dry, each container taking up the amount of water it requires. Drainage water returns to a storage tank, usually below ground, and is then recycled, the water taken up by the plants being topped up from the mains supply. Some systems include biological sand filters or ultraviolet irradiators in the recycling loop, to reduce the likelihood of infection from pathogens circulating with the water.

Containers for large trees cannot be watered by sub-irrigation, because the capillary rise is too great. In this case, drip lines with nozzles are suspended over the containers, with one or more nozzles per container, depending on the size. The water supply is turned on for a cycle of, say, one hour at a time, the water dripping down into the container compost from above, typically at a rate of two litres per hour per nozzle. Drip (trickle) irrigation needs clean, filtered water free from lime or iron to reduce the risk of blockage.

Lined-out trees grown in the soil are only watered in dry weather, usually by portable sprinklers.

### *Pot plants*

Typically, pot plants are germinated from seed in ‘plugs’ (small wedges of compost) in specialist indoor propagation units with controlled temperature and humidity. Once the leaves have formed, they are moved into plastic pots for growing under glass. The pots stand on the floor or on mobile metal benches. In both cases, they stand on strips of capillary matting (mats of synthetic fibres with high wicking properties). Water is brought to the matting with runs of trickle tape, with outlets at intervals of around 15 centimetres. Overhead sprinklers are used occasionally in hot weather. Hot air blowers or hot water pipes provide artificial heating in winter.

### *Bedding plants*

Like pot plants, bedding plants start off in small 'plugs’ of compost in a plastic tray, each with a single seed. These are germinated in specialised propagation units. When the leaves appear, the plants are moved into larger cells of compost in trays holding six, 12 or 24 plants. These are grown under glass or polythene in early spring, and then moved outdoors with covers at night to 'harden' them before sale. Artificial heating, usually by blown air, is needed during frosty weather.

Propagation houses are temperature and humidity controlled and plants generally consume little water. For the growing-on stages, watering is by overhead sprinklers in the roof of the glasshouse or polythene tunnel, or by hand-watering when moved outdoors for hardening.

## 2.5.4 Quantities of water required

### *Nursery stock*

Containerising nursery stock permits a high density of plant stocking, and the increased area of leaf surface per square metre gives a much higher water requirement than for crops grown directly in the soil. Traditional overhead sprinkler watering is inefficient, because the overhead leaf canopy makes it difficult to ensure water reaches the roots, especially for conifers which shield the compost surface. Also, because overhead sprinklers rely on an overlap between circles, over-watering is necessary to ensure plants furthest from the nozzles still receive sufficient water. For this reason, a maximum daily water application of six mm (60 $m^3$ $ha^{-1}$) can generally be allowed for outdoor nursery stock beds with sprinklers in hot weather. Sand beds need approximately four mm $day^{-1}$ (40 $m^3$ $ha^{-1}$) maximum.

Indoors in polythene tunnels, a four mm $day^{-1}$ (40 $m^3$ $ha^{-1}$) maximum would apply. Year round, an average of 1.5 to two mm $day^{-1}$ (15 to 20 $m^3$ $ha^{-1}$) per day can be allowed for a mixture of tunnels and outdoor beds excluding roadways. In practice, most watering takes place between May and September. Economies can be made by improving the efficiency of watering, especially by introducing sub-irrigation, ebb-and-flow or drip lines, and by storing winter rainwater in lagoons.

### *Pot plants*

Typically a heated plot plant house would need between 1.5 and 2.5 mm $day^{-1}$ year round, equivalent to 25 $m^3$ $ha^{-1}$.

### *Bedding plants*

Typical indoor water consumption would be around one to 1.5 mm $day^{-1}$, year round (equivalent to 15 $m^3$ $ha^{-1}$ $day^{-1}$), although the main season runs from November to June, with peak water consumption during May and June.

## 2.5.5 Achieving best practice

### *Nursery stock*

Overhead sprinklers. For outdoor nursery stock beds, overhead sprinkler systems, while cheap to install, are wasteful of water. It is impossible to water a rectangular area evenly using overlapping circles. Typically, some plants will receive water from two or three nozzles, and others from only one. To ensure those plants receiving the least water still have a sufficient amount, other areas have to be over-watered. Recent research by the Horticultural Development Council (HDC) has shown that ideally each plant should receive water from four sprinklers (Burgess, 2006), but being overthrown beyond the edge of the bed wastes water. Wind drift will also reduce the amount of water deposited along the up-wind side, requiring a longer watering time to ensure these plants receive sufficient water, and adding to the wastage. Weighing pots before and after watering gives a guide to take-up (Briercliffe, 2005) and it may be better to water in short pulses with time for the compost to absorb it, rather than one long session. Directing the drainage water into an underground tank can reduce water losses, or a sump from which it can be pumped into an above-ground metal tank. It can then be recycled, possibly with biological sand filtration to reduce the risk of contamination with pathogens (Briercliffe, 2005).

Sand beds (sub-irrigation). The Efford constant-level sand bed is highly water efficient, with excellent evenness of distribution and a good saving of summer rainwater. However, some species such as conifers will not thrive with a constant high humidity near the roots, and proliferation of liverwort can be troublesome.

Ebb-and-flow beds. This approach, which simulates a natural daily rainfall wetting and drying cycle, suits a variety of species and has a minimal wastage of water. Problems with recycling of pathogens such as *phytopthera* have proved less serious than was feared. It is now thought that a low level of infection with a range of pathogens encourages plants to develop resistance to disease. However, the capital cost of installing the complex control equipment and pumps is considerable.

Drip lines (trickle irrigation). Trickle irrigation is a highly efficient method of watering, since there is minimal wastage from evaporation, with all the water going into the root system. The capital cost limits this approach to larger or specimen trees. Traditional greenhouse systems are sometimes used, with a polythene line running down the centre of a double row, and flexible leads left and right feeding nozzles and stakes anchored into the compost. However, this equipment is vulnerable to damage, and a better approach is site drip lines with in-line nozzles above the compost, dripping downwards. Suspended from a straining wire on the inside of the trunks, these can be left in position when the containers are moved away. For standard-sized trees, a 'pigtail' with several nozzles may be laid around the trunk on top of the compost to ensure rapid and even watering. Self-cleaning, automatic pressure-compensating nozzles are recommended. If the water supply has more than 200 ppm calcium, a special nitric acid injection may be necessary to lower the pH. Iron salts found in aquifers in the east of England cause serious blockage and are difficult to remove.

## *Pot plants*

To reduce evaporation and control growth of algae, the matting needs to be sandwiched between two layers of polythene, the base watertight, and the top layer black in colour and perforated with small holes. To avoid excess drainage, runs of matting must be dead level in both directions and free from hollows. Alternatively, the matting can be laid with a small fall across the width of the bed or bench, and the trickle tape positioned at the upper edge, so that water drains downwards. In this case, a short pulse of water should be sufficient to wet the matting without run-off. Repeated pulses are added during the day, controlled by a timer and solenoid valves.

Collection of rainwater from the glasshouse roof can make a huge contribution to water saving. Drainage from the eaves into an above-ground metal tank, or a below-ground reservoir lined with butyl rubber or black polythene, of sufficient size to hold winter rainfall can, even in the eastern counties, provide most of the water needed for irrigation. Also, rainwater can have a lower pH than mains water, which is better for many pot plants. Serious problems from infection with spore-borne organisms can be overcome by biological sand filtration or ultraviolet treatment. To reduce the risk of collecting algae or disease organisms, the water intake should be positioned 0.5 m below the surface and at least the same distance above the bottom. Algal growth in the water can be controlled with a lightproof cover over a storage tank, though this may not be practical with a reservoir. Standard sand filters will remove algae. When water levels drop to a minimum in summer, both tanks and reservoirs should be pumped free from sludge and disinfected.

## *Bedding plants*

With bedding plant production, evenness of distribution is vital to ensure uniformity of the product. Where overhead sprinklers are used in glasshouses or polythene tunnels, the HDC irrigation calculator (Briercliffe, 2005) can be used to check the efficiency of watering. This calculates three popular standards for application rate (rate of watering), scheduling (programming the watering time) and uniformity (lack of wet or dry areas due to overlap). These are the mean application rate (MAR), Christiansen's Coefficient of Uniformity (CU) and the scheduling coefficient (SC).

Recommendations are: MAR less than 15 mm hour$^{-1}$, a CU above 85 per cent and SC below 1.5.

Because of the prime importance of a uniform appearance in the product, most growers use hand-watering to supplement areas that look dry.

As with pot plant production, collection of rainwater from the roofs of glasshouses or buildings (it is difficult to catch drainage water from polythene tunnels) can provide big savings in water costs.

### 2.5.6 Water audit case studies

In order to verify best practice figures, a number of site visits were made to discuss water auditing and to assess patterns of seasonal and peak water use. Three contrasting enterprises specialising in nursery stock, pot plants and bedding plant production were visited during 2005. The findings from these structured interviews, presented in the form of three case studies, are summarised below.

*Case Study 1: Nursery stock production, Northamptonshire*

This enterprise has been growing nursery stock on a seven hectare site for over 25 years. All water comes from the public mains supply that fills a 160 $m^3$ storage tank. Two pumps feed the nursery, which can be switched over for maintenance or repair. Liquid feed can be injected as required. A separate ring main connected to the public mains supply provides emergency watering in the polythene tunnels.

All stock comes in as rooted cuttings, with polythene tunnels for the nursery stages, and then standing out beds, mostly on sand but with some gravel. The layout is highly water efficient. Sand beds in the tunnels are precisely levelled and watered via an Irridrain system, which has a small storage tank set into the ground at one end of the tunnel and 50 mm lengths of agricultural drainage pipe laid in the sand. Water is kept at a constant level, which can be precisely adjusted with a Torbeck valve. In winter the water level is set to drain the sand. Outdoor standing beds are watered with a similar system, but overhead sprinklers provide supplementary watering in hot weather. There are a few gravel beds with overhead sprinklers; these are more wasteful of water, because rainwater quickly drains through the gravel, whereas rainwater falling onto the sand beds percolates more slowly.

Large containerised trees are set out in lines and watered with a trickle irrigation drip line with one or two emitters per container, depending on tree diameter. Initially, an attempt was made to create a reservoir for winter drainage water, but this caused blockages in the trickle irrigation lines, so now only mains water is used.

The main problem from sand bed watering arises through liverwort, which needs to be controlled by chemicals and scraping. When the sprinklers are used, they are switched on for 45 minutes in the early morning. The large tree drip lines are kept on for between one and 2.5 hours per day on each of the two sections.

The sand beds receive water continuously by gravity supply from the storage tank. Over a three-year period, the water consumption averaged 4,171 $m^3$ per ha. This is equivalent to 1.1 mm $day^{-1}$ year round, but the gross area of seven ha includes roads and buildings, so the figure per area ($m^2$) of actual bed would be slightly higher. Rainfall during the spring and autumn is trapped by the sand beds and makes a useful contribution. The cost of water at bulk mains supply rates of £0.60 per $m^3$ to £0.72 per $m^3$ equates to a total annual cost of around £7,500. Fixed service water charges are approximately seven per cent.

*Case Study 2: Glasshouse pot plant production, Lincolnshire*

This large pot plant nursery has five three-quarter acre blocks of pot plants on mobile benches and capillary matting, with a total of 6.5 hectares. Plants are grown for supermarkets to order and include chrysanthemums, begonias and poinsettias. All the rainwater from the glasshouses and nearby buildings is collected and diverted by gravity into open reservoirs. Natural rainfall in this part of the country is approximately 780 mm per year. Assuming that all the rainfall is captured without loss by overflow and ignoring losses by evaporation from the reservoirs, collection from the 6.5 hectares would be equivalent to 2.3 mm $day^{-1}$ over the glass area. This reduces the need for mains water to a minimum. The soft rainwater is better for plant growth, especially for *saintpaulias*, as well as reducing water costs. Initially, a UV filter was installed to sterilise the water before application in the glasshouses. However, it was found better to expose the plants to some infection at a lower level, rather than trying to make the water sterile.

Water wastage is minimised by watering the capillary matting in short bursts of a few minutes on each section, using a Prima controller. This allows time for the water to be taken up into the pots without run-off. The plant compost contains a wetting agent to enhance capillary lift, and the matting is covered with black perforated polythene to reduce evaporative losses and discourage algal growth. The mobile benches slope slightly from one side to the other, and the water is brought to the upper edge by trickle tape. The floor beds are level and watered using lengths of trickle tape. On a hot day, more short cycles are administered to match evaporation rates.

*Case Study 3: Glasshouse bedding plant production, Cambridgeshire*

This site comprises 0.7 hectare of glasshouse and poly-tunnel for growing bedding plants all year round. There is a standing out area of 0.9 hectares used in the spring. All watering is carried out by hand, since the best overhead sprinkler systems still give variations in quality in the plant trays. Originally, all irrigation water was taken from the mains, but with a calcium level above 300 ppm, the alkalinity of the water affected plant growth, and water splashes left white marks on the leaves. Approximately five years ago, the grower purchased a secondhand water storage tank with a capacity of 4,540 $m^3$. Rainwater from the largest glasshouse is now piped via a PVC pipe into this storage tank. Pressurised water to the hand hoses is then provided via a pump. Since converting to rainwater harvesting, mains water consumption has been reduced to 160 $m^3$ $year^{-1}$. Assuming a typical winter rainfall is captured, mains water is only needed after a long hot summer. From the glasshouse roof area (2.8 ha), assuming no losses from overflow or evaporation from the tank, this is equivalent to 3,000 $m^3$ $yr^{-1}$. Average water consumption through the year is approximately 1.2 mm $day^{-1}$. Unlike glasshouses used for pot plant production, only minimal heating is required during the winter months. There is still spare capacity in the storage tank; plans for further expansion of the business can therefore rely on further rainwater harvesting.

### 2.5.7 Environment Agency guidelines for licence determination

Due to the specific conditions under which irrigation is used in horticultural sectors, it is recommended that abstraction licences are considered on a case-by-case basis, taking into account the local circumstances of the abstractor and the optimal water use guidelines given in Section 2.5.4.
A worked example is given in Table 2.23 to illustrate how the data presented in this chapter can be used to estimate the reasonable irrigation needs for a horticultural enterprise involved in the production of nursery stock and bedding plants.

**Table 2.23 Worked example of how to estimate the 'reasonable' irrigation needs for a horticultural business growing a mixture of nursery stock, pot plants and bedding plants.**

A nursery plans to extend their existing production of nursery stock and bedding plants. The new development will comprise of 3.4 ha outdoor nursery stock plant production; these include shrubs and trees grown in plastic containers outside and irrigated using a mixture of overhead sprinkler lines (two ha) and the remainder using sand beds. A further 0.75 ha will be for bedding plant production. These will initially be grown indoors and then moved outdoors and irrigated using overhead mini sprinklers, supplemented by hand-watering.

| Production type | Location (indoor/outdoor) | Irrigated area (ha) | Irrigation system | Peak water use (mm/day) | Peak water use ($m^3$/day) | Average water use (mm/day) | Number of days | Annual water use ($m^3$/year) |
|---|---|---|---|---|---|---|---|---|
| Nursery stock | Outside | 2.0 | Overhead sprinklers | 6 | 120 | 3 | 365 | 21,900 |
| Nursery stock | Outside | 1.4 | Sand beds | 4 | 56 | 2 | 365 | 10,220 |
| Bedding plants | Indoors and outdoors | 0.75 | Overhead mini-sprinklers | 1.5 | 11.3 | 1.5 | 183 | 2,053 |
| **Total** | | | | | **187** | | | **34,173** |

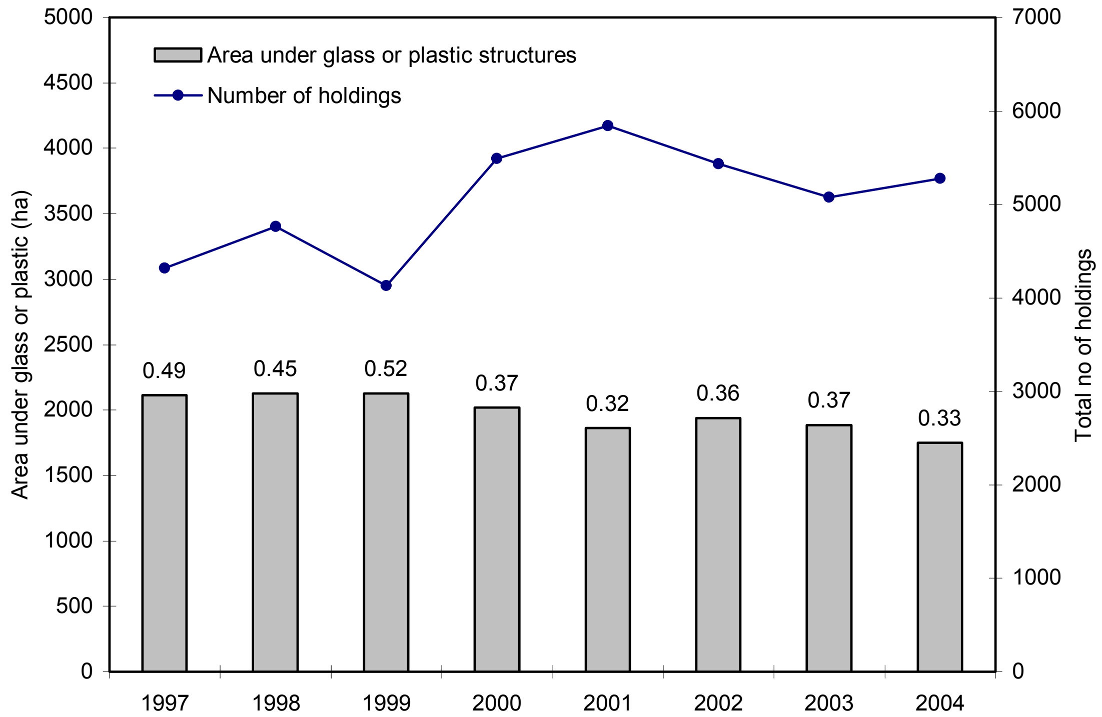
## 2.6 Glasshouse salad production

This section assesses irrigation water use within two horticultural (salad) glasshouse production sectors, namely (i) tomatoes, cucumbers and peppers and (ii) lettuces. It combines data from a literature review, existing research, government surveys and information derived from structured interviews and site visits with key informants within the industry. Guidelines for assessing the quantities of water required for the optimum production of these glasshouse salad crops, together with supporting information on achieving best practice, are provided. This section complements the information provided in Section B2 (pp 132-133) of the best practice manual (W6-056/TR2).

### 2.6.1 Government glasshouse cropping census data

Each June, the government collects census data relating to agricultural and horticultural production (termed the June Census). The reported total number of holdings and the area (ha) under glass or plastic in England between 1997 and 2004 are shown in Figure 5. The data shows that the total number of holdings has fluctuated quite dramatically since 1997, but now appears to have stabilised at around 5,200 holdings. The total reported area under glass has declined from 2,100 ha in 1997 to approximately 1,800 ha in 2004. The average area of each holding over the same period has also reduced from 0.5 ha to 0.3 ha.

**Figure 2.15 Reported total numbers of holdings and area (ha) under glass or plastic structures in England, between 1997 and 2004.** The values shown represent the average area (ha) of each holding in that year.



### 2.6.2 Tomatoes, cucumbers and peppers

These crops are grown under glass or in polythene tunnels, with heating. A typical tomato crop may be grown for 11 months. Direct soil cultivation of these crops is rare due to the high cost of labour and soil sterilisation. Instead, two mains types of cultivation are used:

(i) **Rockwool cultivation** is a semi-hydroponic approach, where the plants are initially grown in small peat blocks, then laid out on rock wool slabs in double rows on polythene sheeting. Rockwool is made from minerals such as basalt, and spun into porous, disposable pressed slabs (like that used in flower arranging). Water is applied to the top of the slabs through drip nozzles fed from polythene pipe running down the double row. Each plant is fed with a single nozzle and the water application rate is typically two litres per hour.

(ii) **Nutrient film technique (NFT)** is a fully hydroponic system for growing salad crops. The ground is covered with polythene and set out with low plastic channels, with a slight fall to one end. A strip of thin matting is used to anchor the roots of the plants, which are spaced approximately 0.30 m apart. Water enters the top end and drains past the roots to the lower end, where it collects in a sump. It is then returned for re-circulation; sensors controlling the injectors adjust the pH and nutrient levels automatically.

*Quantities of water needed for tomatoes, cucumbers and peppers*

Rockwool cultivation requires approximately four mm day$^{-1}$ year round, equivalent to 40 m$^3$ ha$^{-1}$ day$^{-1}$. NFT production is more efficient, needing around 2.6 mm day$^{-1}$ or 26 m$^3$ ha$^{-1}$ day$^{-1}$ (Rees *et al.*, 2003).

### 2.6.3 Lettuces

Traditionally, lettuces are grown in soil under glass with blown air heating in winter. Seedlings are germinated in small compost blocks and then transplanted in rows. Watering is by overhead sprinklers suspended from the roof. Problems with disease build-up require periodic sterilisation of the soil, which is expensive. An alternative is hydroponic production (NFT), similar to tomato systems, where the lettuce blocks are set into channels of plastic or concrete with a small slope from one end. Water is pumped in at the upper end, and drains past the blocks to a sump at the lower end, from where it is recycled. Before the return, the pH is adjusted with nitric acid, and the nutrient level checked and topped up with artificial fertiliser.

*Quantities of water needed for lettuce production*

The water requirement for year round lettuce production in the soil would be approximately 1.5 mm day$^{-1}$. This is equivalent to 15 m$^3$ ha$^{-1}$ day$^{-1}$. Hydroponic production recycles all drainage water, and uses less water.

*Best practice in glasshouse lettuce watering*

It would be hard to improve the efficiency of NFT, since this approach has no drainage losses and evaporation is reduced to a minimum.
Overhead sprinkler systems for in-soil lettuce production should be tested for efficiency of water distribution using the HDC Irrigation Calculator (Briefcliffe, 2005). There are also opportunities to save water by collecting rainwater from the glasshouse roof in a reservoir or above-ground tank. Supermarkets require high quality water to be sprinkled onto lettuce,

because of the danger of microbiological contamination (Tyrrel et al., 2006) and ultraviolet treatment may be essential.

*Water audit case studies*

In order to verify the best practice figures provided above, a site visit was conducted to discuss water auditing and to assess the patterns of seasonal and peak water use within a glasshouse lettuce production site. Findings from the interview conducted during 2005 are presented as a case study below.

*Case Study: Glasshouse lettuce production, York*

This site belongs to a large salads group that supplies the major supermarkets. They grow celery outdoors and lettuce in a 2.25 ha glasshouse.

All irrigation water is taken from the public mains supply. Overhead sprinklers are used in the glasshouse, fed from a storage tank, pumped and controlled by a timer. The watering cycle lasts seven minutes per day, then two days later five minutes per day. The soil is sandy and sterilised with Basimid every two years. Two acres of celery grown outdoors are irrigated after planting in May with overhead sprinklers. Over a two-year period, the water consumption averaged 4,100 $m^3$ $ha^{-1}$ $year^{-1}$. This is equivalent to 1.2 mm $day^{-1}$, increasing to 2.2 mm $day^{-1}$ during the summer months. The water costs £0.86 per $m^3$, plus fixed charges. The approximate cost of water for the nursery is £15,000 per year. The option of using borehole water was considered, but dismissed because the groundwater was too saline.

All rainwater drains directly into a dyke behind the nursery, and rainwater storage seems an obvious method of reducing the cost of irrigation. It was suggested that this water would need to be sterilised with an ultraviolet irradiator, since supermarkets are concerned about the quality of water applied to salad crops for human consumption. Construction of a below-ground reservoir would be impractical, since it would occupy valuable land which could be used more profitably for growing crops, but it should be possible to construct a sump to catch rainwater drainage from the glasshouse roof, and pump this up into an above-ground galvanised storage tank. With rainfall of approximately 820 mm $year^{-1}$ and assuming no losses from overflow or evaporation from the tank, it would be possible to meet most of the daily demand of 1.2 mm. With an annual water cost of £15,000 per year, it would not take long to recoup the costs of the tank and pump.

### 2.6.4 Environment Agency guidelines for licence determination

Due to the very specific conditions under which irrigation is used in glasshouse production, it is recommended that abstraction licences are considered on a case-by-case basis, taking into account the local circumstances of the abstractor and the optimal water use guidelines given in Section 0 (tomatoes, cucumbers and peppers) and Section 0 (lettuce production).

# 3 Conclusions

The optimum or reasonable irrigation needs for a number of additional agricultural and non-agricultural sectors dependent on direct abstraction have been assessed.

The sectors investigated included golf courses, racecourses, turf grass production, frost protection, nursery stock, pot plant and bedding production, and glasshouse salad production.

Guidelines to support the Environment Agency’s role in assessing and setting abstraction licences for irrigation for these individual sectors have been provided. The data presented in this report complement the optimum water use guidelines provided in the Environment Agency’s optimum water use best practice manual (W6-056).

# Acknowledgements

The authors are grateful for the support of the following individuals and organisations:

- Paul Crane, Naomi Savory and water resources and abstraction licensing staff at the Environment Agency;
- Anthony Hopkins (Wroot Water Systems) for providing key contacts and sites for investigating in-field irrigation performance;
- Pat Goode (Redsell) for providing sites and support for conducting irrigation fieldwork;
- Melvyn Kay (UK Irrigation Association);
- Juan Pablo Marmol for his assistance with fieldwork, data collection and analysis;
- David Pearce (independent consultant) for his assistance with the horticultural nursery and glasshouse salad production sectors;
- Dr Tonny Tessa de Vries (Cranfield University) for her assistance with the frost protection sector;
- Steven Bryne (Wisley Golf Club), Derek Mason (Highgate Golf Club), Colin Robinson (John O Gaunts Golf Club), Paul Smith (Royal Lytham and St. Annes Golf Club);
- Royal Horticultural Society (RHS Wisley), including Jim Gardiner and Claire Griffiths for provision of metdata;
- Giles Wardle and Marcus White (Irriplan);
- Turfgrass Growers Association (TGA), including Tim Fell (Tillers Turf), Tim Canon (Cannons Turf) and Simon Hutton;
- The Jockey Club, including Fraser Garrity.

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# Appendix

Determine the minimum flow/water level conditions to which the licence will be subject, and assess whether the source is sensitive to any of monthly, daily, hourly and/or absolute peak flow rates under those conditions. For the most sensitive duration, determine whether the suggested peak rates provided in Table A1 and described in the Environment Agency's best practice manual (W6-056/TR) are reasonable.

**Table A1 Suggested peak irrigation water requirements as a fraction of licensed annual abstraction ($m^3$).**

*Summer abstraction direct to irrigation*

| Period | Units | Fraction of licensed annual abstraction ($m^3$) |
|---|---|---|
| Monthly | $m^3$/month | ½ |
| Daily | $m^3$/day | 1/40 |
| Hourly | $m^3$/hour | 1/600 |
| Absolute | $m^3$/hour | As hourly |

*Winter abstraction from surface water to reservoir storage**

| Period | Units | Fraction of licensed annual abstraction ($m^3$) |
|---|---|---|
| Monthly | $m^3$/month | 1 to 1/3 (depending on source reliability) |
| Daily | $m^3$/day | 1/30 to 1/90 (depending on source reliability) |
| Hourly | $m^3$/hour | 1/720 |
| Absolute | $m^3$/hour | As hourly |

*Winter abstraction from groundwater to reservoir storage*

| Period | Units | Fraction of licensed annual abstraction ($m^3$) |
|---|---|---|
| Monthly | $m^3$/month | 1/3 |
| Daily | $m^3$/day | 1/90 |
| Hourly | $m^3$/hour | 1/2160 |
| Absolute | $m^3$/hour | As hourly |

* These values should not be used where high hands-off flows have been set and the abstractor has agreed to take water at high flows or flood conditions only.

Note also that the ratios only set limits on how fast the water can be abstracted. Slower abstraction and longer working hours are not precluded.

Select a suitable rate to protect the source. For other durations, where necessary, aim to set less onerous (higher) rates. Do not set rates where they are unnecessary, or covered by other restrictions.

The suggested figures for abstraction direct to irrigation allow for 20 days (for example, four weeks at five days/week) irrigation with an average 15-hour day during the peak month, using up half the annual water requirement. Alternatively, they would allow irrigation for 10 hours per night every night during the peak month, using up half the annual water requirement, or eight hours per night every night during the peak month using 40 per cent of the annual water requirement.

The suggested figures for winter abstraction from surface water to reservoir storage allow for 720 hours of pumping. Using off-peak electricity, this could be 120 days at six hours a day or 90 days at eight hours a day. However, if the source is at all unreliable, the option of pumping continuously for 30 days should be retained if possible.

The suggested figures for winter abstraction from groundwater to reservoir storage allow for 90 days of continuous pumping.

### Tanks and balancing reservoirs

The use of a tank or balancing reservoir allows an abstractor to smooth out peaks in irrigation need, and allows significantly lower peak ratios. Relatively small tanks can spread hourly peaks over a day's abstraction; many days storage would be needed to spread daily peaks; a half season's reservoir storage may be needed to spread monthly peaks.

The use of storage should be discussed with the applicant where problems with short-term peaks may make issuing of a licence problematical. However, the additional capital cost and energy use through double pumping should be taken into account. Where the applicant also has a winter abstraction licence, the winter storage reservoir may usefully provide a balancing function for the summer abstraction by pumping via the reservoir.

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