Optimum Use of Water for Industry and Agriculture Dependent on Direct Abstraction

Best Practice Manual

WS Atkins Ltd & Cranfield University

R&D Technical Report W157

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Best Practice Manual

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This report summarises the findings of research carried out to assess the reasonable water needs of agriculture and industry. The information within this document is for use by EA staff, particularly those involved with licence applications.

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EXECUTIVE SUMMARY

Background

The Water Resources Act 1991 and its preceding legislation provides the Environment Agency with the means to manage water resources through the licensing of abstractions. Detailed demand forecasting techniques are available to EA staff when assessing the need for Public Water Supply applications, but there is currently little guidance concerning the water needs of industry and agriculture.

This report provides information on the optimum water requirements of different agricultural and industrial practices, and will allow EA staff to assess whether an existing or proposed abstraction is taking the appropriate quantities of water for an identified purpose.

The report is divided into three main sections, Agriculture, Industry and Potential Future Research.

Agriculture

Optimum water requirements for irrigation demand have been defined for varying agroclimatic conditions and soil types within England and Wales. Irrigation look up tables have been developed to enable EA staff to determine the dry year irrigation demand for principal irrigated crops including early potatoes, main crop potatoes, sugar beet, cereals, grass, vegetables, orchard fruit and small fruit.

The look up tables are based on seven agroclimatic zones of Potential Soil Moisture Deficit (PSMD), and three main classes of soil Available Water Capacity (AWC). To illustrate the use of the tables a worked example is included, showing the estimation of the annual irrigation requirements for 40 hectares (ha) of main crop potatoes, 40 ha of sugar beet and 100 ha of cereals.

Further background information is also provided on the efficiency of irrigation systems, the value of irrigation scheduling and the cost benefits of irrigation. The report also provides data on stock water requirements for dairy, beef, pigs, sheep, and poultry.

Industry

Water consumption data has been collected from a wide range of sources including published literature and industry contacts, to generate a series of look up tables for a wide range of industrial processes. The aim of the tables is to allow EA staff to calculate an initial estimate of the water needs for a particular site, in order to assess whether existing or proposed abstraction levels are reasonable. Two worked examples are provided, considering the manufacture of lead acid batteries and medium density fibreboard, to illustrate how the tables should be used in practice.

In addition to water consumption data, the tables provide information on the water using steps within each industrial process and the potential water saving initiatives which could be employed to reduce future consumption.

Conclusions and Recommendations

The data in this report provides an authoritative source of water use figures which will enable Environment Agency licensing staff to audit licence applications more confidently. Additionally the data will assist the Environment Agency in promoting best practice water use amongst its customers and throughout the water industry.

The report is seen as a working document and should be periodically updated with new and revised information. Recommendations on how the research could be further developed are set out in Section 3.0.

KEY WORDS

Water, Consumption, Demand, Industry, Agriculture, Irrigation, Efficiency, Licensing, Abstraction.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 OPTIMUM USE OF WATER FOR AGRICULTURAL PURPOSES

1.1 Background

The recent droughts and increased pressure on water resources in England and Wales have highlighted the limitations on water supply for agricultural and horticultural irrigation. Although irrigation remains a relatively small user of water at a national scale, it is a consumptive use concentrated in the driest areas in the driest months and in the driest years.

Most irrigation water is abstracted from rivers, streams and groundwater sources and is used directly, with relatively little on-farm storage (Fig 1.1). It has therefore become a very significant summer user in some catchments.

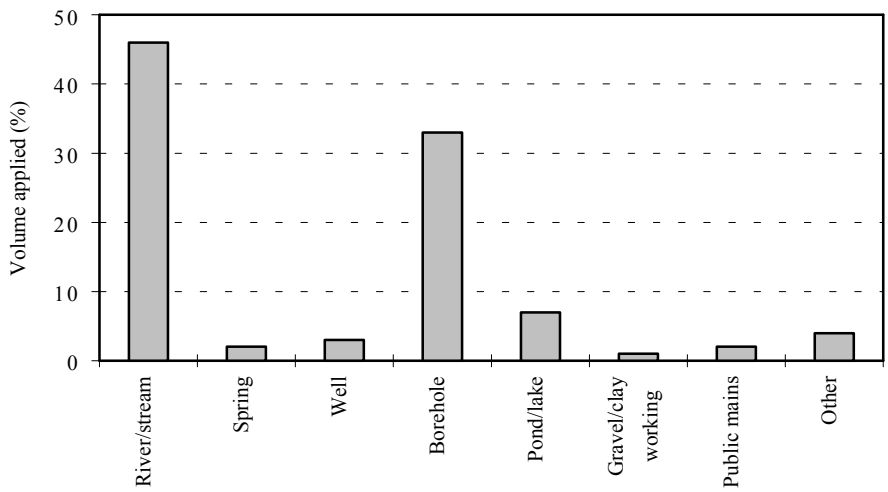

Fig 1.1 Source of irrigation water (%) in England in 1995 (MAFF, 1996).

Since 1955, the Ministry of Agriculture, Fisheries and Food (MAFF) has collected and published statistics on agricultural irrigation in England and Wales, through their 'Irrigation of Outdoor Crops' censuses. These have been carried out roughly triennially, most recently in 1982, 1984, 1987, 1990, 1992 and, for England only, in 1995. With only 1% of irrigation in Wales, these last six surveys essentially provide directly comparable results.

Table 1.1 and Table 1.2 list the areas irrigated and the volumes of water applied, by crop category, for the six most recent MAFF Irrigation Surveys. The areas irrigated and volumes of water applied each year vary greatly. However, any analysis using these data should be interpreted in relation to the weather in each particular year.

Table 1.1 MAFF reported areas irrigated (ha), by crop category, 1982-95.

Crop category	Year					
	1982	1984	1987	1990	1992	1995
Early potatoes	8050	7720	5360	8510	8180	8730
Maincrop potatoes	22810	34610	29520	43490	45290	53390
Sugar beet	15770	25500	10100	27710	10520	26820
Orchard fruit	3100	3250	1330	3320	2280	2910
Small fruit	3610	3560	2230	3470	2750	3250
Vegetables	14810	17460	11040	25250	20200	27300
Grass	16440	18940	6970	15970	7240	10690
Cereals	14800	24700	7510	28100	7160	13440
Other crops	4100	4890	2440	8650	4320	9120
Total	103490	140630	76500	164470	107940	155650

Table 1.2 MAFF reported volumes of water applied ('000m^3), by crop category, 1982-95.

Crop category	Year					
	1982	1984	1987	1990	1992	1995
Early potatoes	4680	4920	2350	6770	5590	9345
Maincrop potatoes	15280	32730	14700	51170	38520	74460
Sugar beet	8260	17370	3430	20320	4860	21295
Orchard fruit	2180	2430	550	2930	1220	2445
Small fruit	1890	2660	970	3180	2000	4320
Vegetables	6830	11390	4640	18450	12180	25500
Grass	10030	13550	3550	13100	4280	9920
Cereals	5040	8300	2160	11830	2260	5625
Other crops	1020	4030	1270	6040	4160	11160
Total	55210	97380	33620	133790	75070	164070

The distribution of irrigation between crop category, by area and volume of water applied, varies significantly (Table 1.3). In 1995, potatoes accounted for 40% of the total irrigated area, and 51% of the total volume of irrigation water applied.

Table 1.3 Irrigation demand for main crop types by area and volume of water applied.

Crop category	Irrigated area (%)	Volume applied (%)
Early potatoes	6	6
Maincrop potatoes	34	45
Sugar beet	17	13
Orchard fruit	2	1
Small fruit	2	3
Vegetables	18	16
Grass	7	6
Cereals	9	3
Other crops	6	7
Total	100	100

Table 1.4 shows the proportion of the whole cropped area that was irrigated in 1995, for each crop category. Almost half of all potatoes grown are now irrigated. Since 1990, there has been growth in the proportions of small fruit and vegetables irrigated, and a major drop for cereals.

Table 1.4. Proportion of each crop category irrigated in England in 1995.

Crop category	Proportion irrigated (%)
Potatoes (total)	48
Sugar beet	14
Orchard fruit	12
Small fruit	34
Vegetables	24
Grass	0.3
Cereals	0.5
Other crops	11

Overall the MAFF Irrigation Survey data confirms that irrigation is increasingly concentrated on the high value crops, and that these crops are being given more water.

1.2 Optimum Irrigation Needs

1.2.1 Background

A two stage methodology has been developed for assessing net irrigation demand for the principal irrigated crops as follows:

1. An agroclimatic zone map for each EA Region has been produced, using a geographic information system (GIS).
2. The net optimum or 'design' dry year irrigation needs for eight major crop categories grown on three contrasting soil Available Water Capacity (AWC) types, have been calculated for a range of agroclimatic zones, and summarised as a 'look up' table.

Using the agroclimatic zone map, in conjunction with the 'lookup' table, the 'optimum' irrigation needs for any given crop category/soil type/agroclimatic permutation, can be simply and quickly estimated. A brief description of each stage is given below:

1.2.2 GIS agroclimatic modelling and mapping

A map (Fig 1.2) showing the spatial change in agroclimate across England and Wales has been produced using a geographic information system (GIS). For this study, the potential soil moisture deficit for grass (PSMDg) was used as a climatic indicator. The map is derived from a 5 km resolution agroclimatic dataset extracted from LandIS, the Land Information System, held by the Soil Survey and Land Research Centre (SSLRC). The raw data (point) have been interpolated to produce a contour map showing the spatial change in PSMDg. In all, seven agroclimate zones have been defined. Apart from zone 1 (0-75 mm PSMDg) each zone is defined on a 25 mm interval, with agroclimatic zone 1 representing the wettest and zone 7 representing the driest (PSMDg >200 mm).

The PSMD zone map for England and Wales is shown in Fig 1.2. Individual A4 maps for each Environment Agency Region follow in Fig 1.2a to Fig 1.2h. Principal Ordnance Survey (OS) grid lines have been plotted on each map to aid site identification.

Each EA regional map has been enlarged to fit onto a single A4 portrait sheet. Scales between maps therefore vary. In Section 1.3 we discuss further options for improving presentation of the PSMDg data to aid location of individual sites on the maps.

1.2.3 Modelling irrigation needs

When determining irrigation demand it is standard practise to estimate this on the driest year in five (defined as the requirement with a 20 % probability of exceedence).

The 'design' dry year irrigation needs were calculated for eight major crop categories, grown on three contrasting soil AWC types, at 11 weather stations, using a water balance irrigation scheduling model (Irrigation Water Requirements (IWR)), developed at Cranfield University (Hess, 1994). The model is driven by daily weather data for each station using at least 20 years data.

The location of the 11 stations were chosen to represent the typical range of agroclimatic conditions across England and Wales, rather than to provide uniform geographical coverage.

The eight crops modelled are early potatoes, maincrop potatoes, sugar beet, vegetables, cereals, orchard fruit, small fruit, and grass. These categories match those used in the MAFF Irrigation Surveys. Carrots were chosen to represent vegetables, strawberries for small fruit, and mature apples for orchard fruit. The addition of further crops to this list is discussed in Section 1.3. The crop characteristics are defined in Table 1.5. Modelled irrigation applications were based on typical irrigation plans (or schedules) used in the UK. The irrigation plans for each crop category grown on the three soil types are given in Table 1.6 and a definition of the soil types are shown in Table 1.7. The PSMDg for each weather station was calculated using the IWR model (Irrigation Water Requirement Model) and actual daily weather data. For each crop category, a correlation between the 'design' dry year irrigation need and IWR PSMDg, for each soil type, was derived by linear regression analysis.

The PSMDg corresponding to each weather station location was extracted from LandIS. These data were compared to the IWR PSMDg's and a linear correlation between the two datasets derived (i.e. IWR PSMDg and LandIS PSMDg).
Using the regression equations, the 'optimum' irrigation needs for the 8 crop categories grown on the 3 soil types were calculated, for each agroclimatic zone (i.e. PSMDg <75 mm, 75-100 mm, 100-125 mm etc.).

The results have been summarised as a 'look up' table for each soil AWC type (Table 1.8). However, it should be stressed that a number of assumptions were made in the modelling for simplicity. The associated risks relating to the application of this 'look up' table are discussed later.

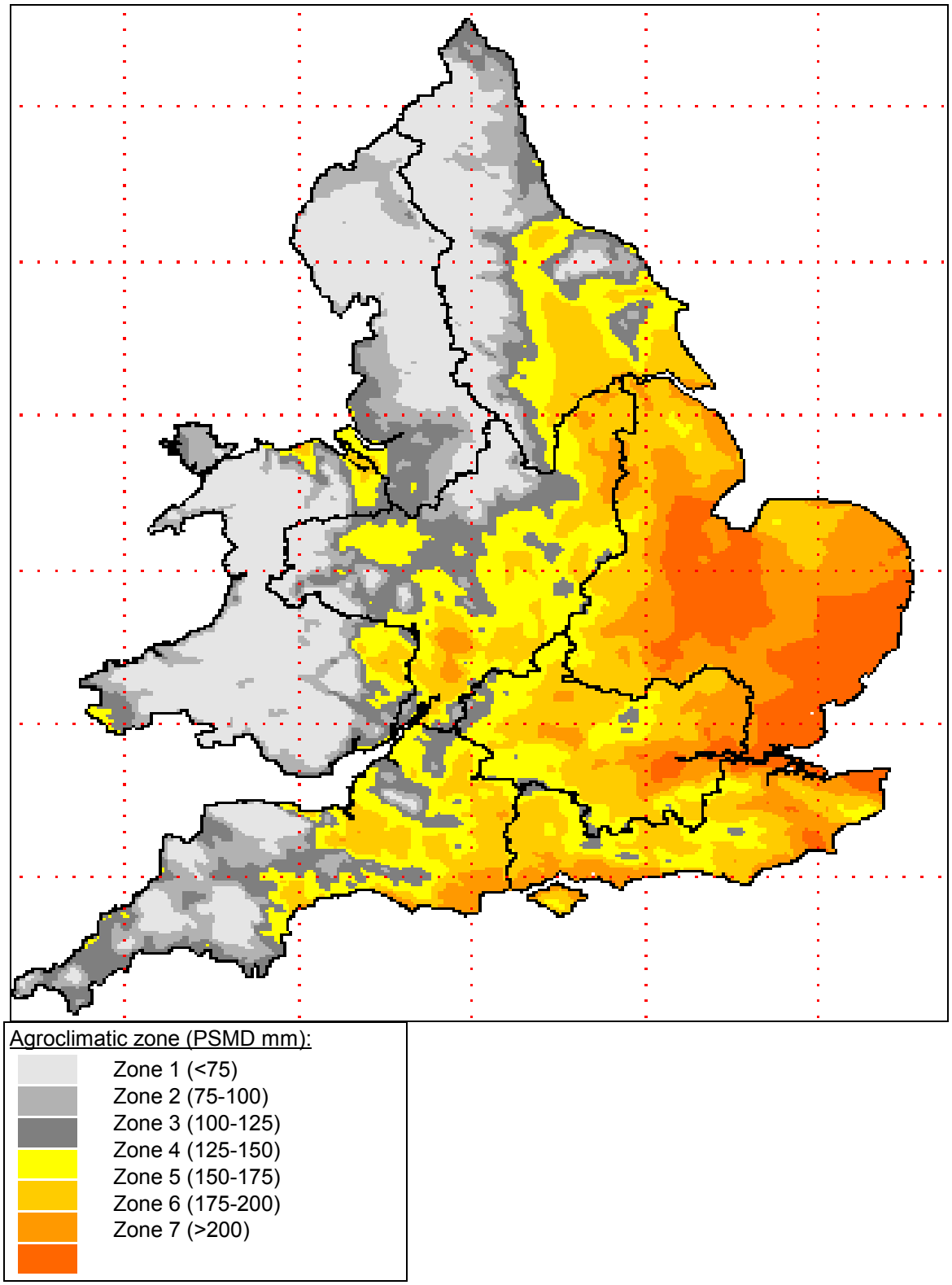

Fig 1.2 Agroclimatic zones for assessing irrigation need

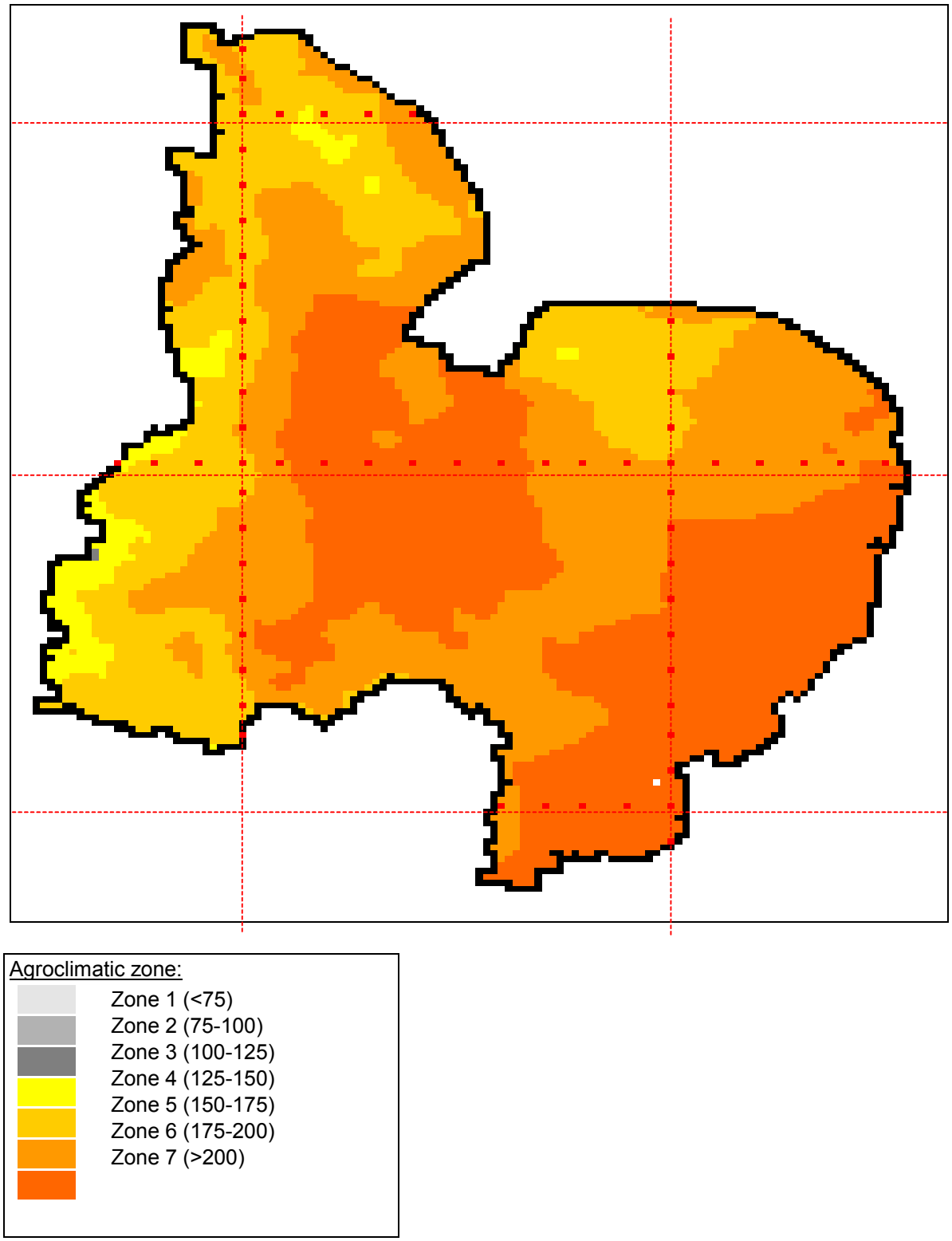

Fig 1.2a **Agroclimatic zones: Anglian Region**

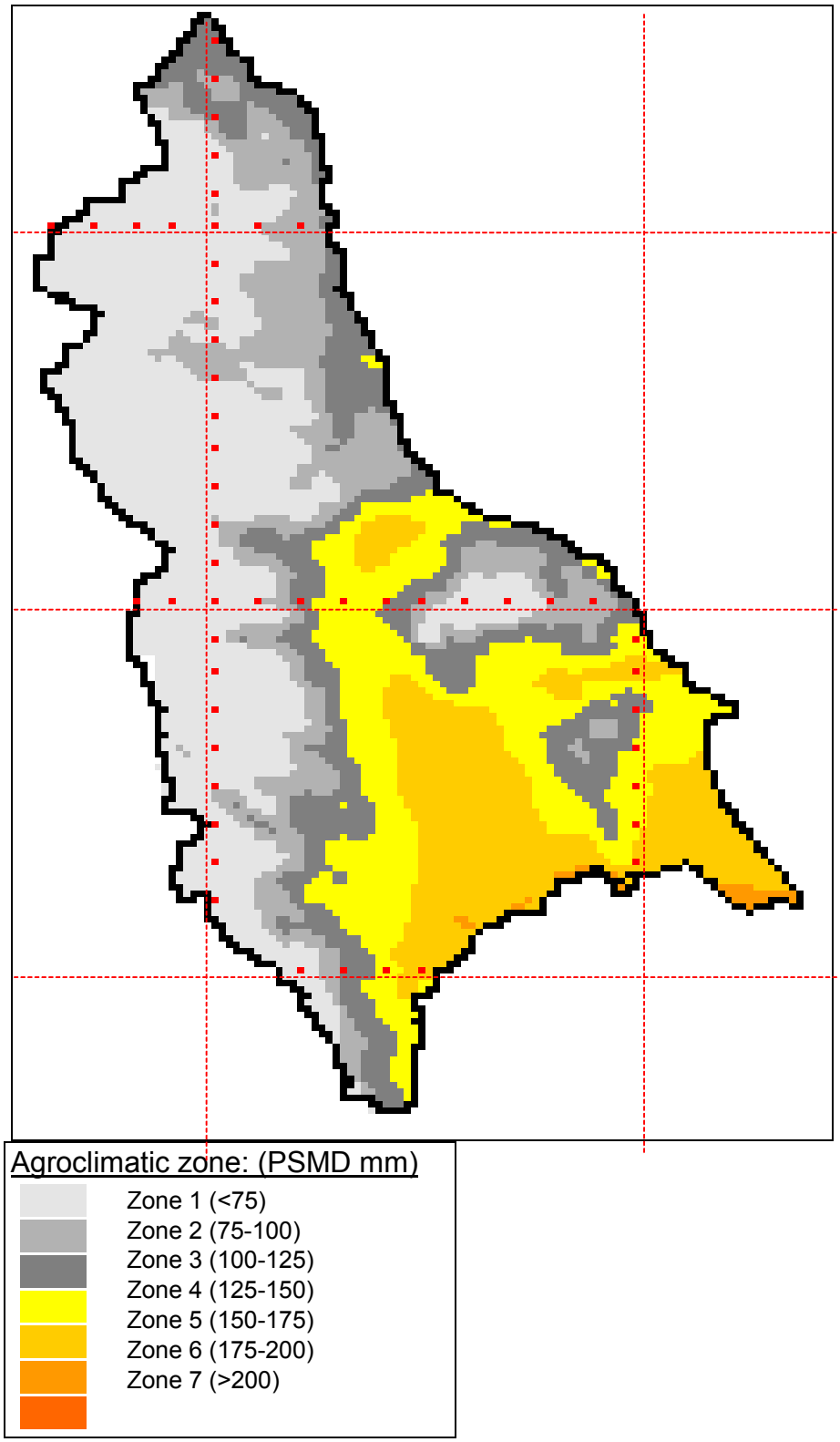

Fig 1.2b Agroclimatic zones: North East Region

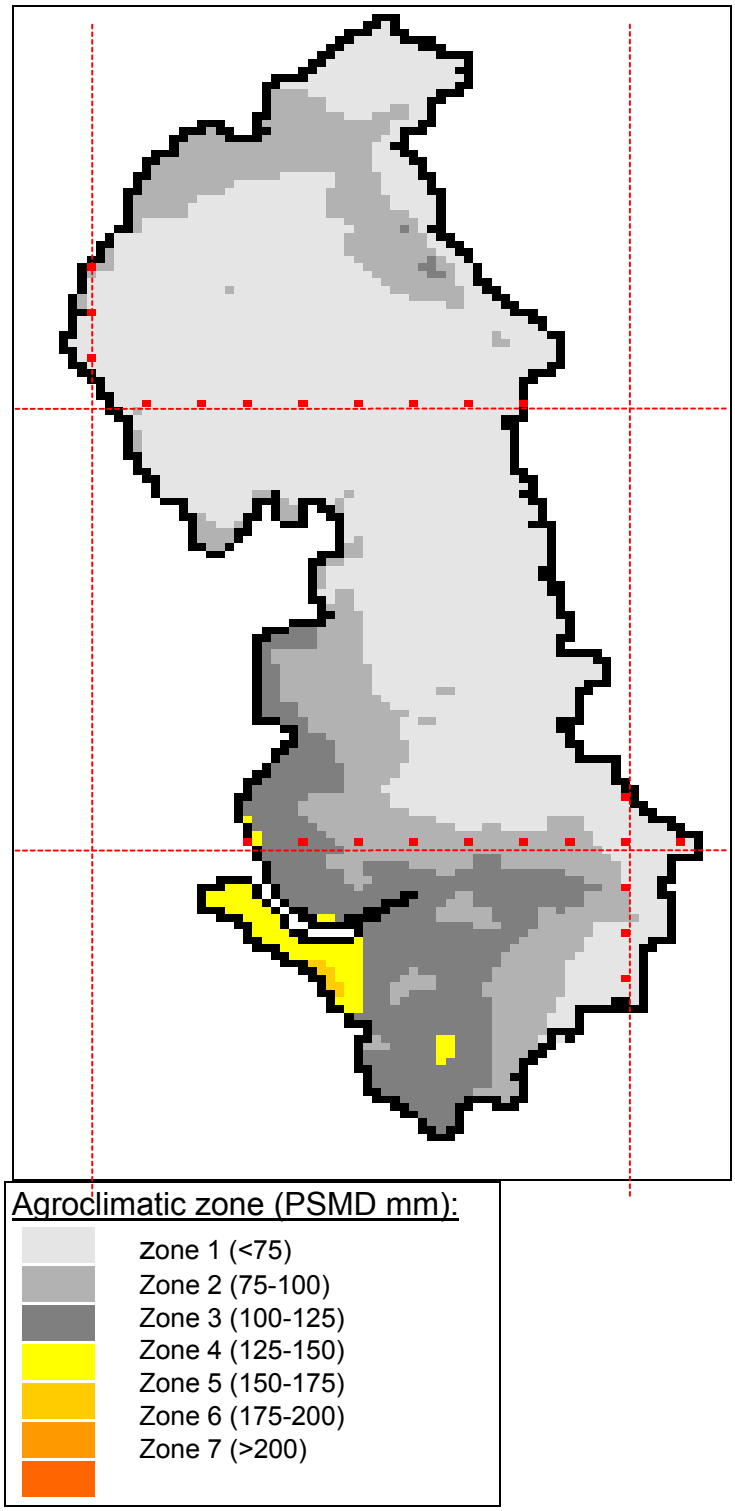

Fig 1.2c Agroclimatic zones: North West Region

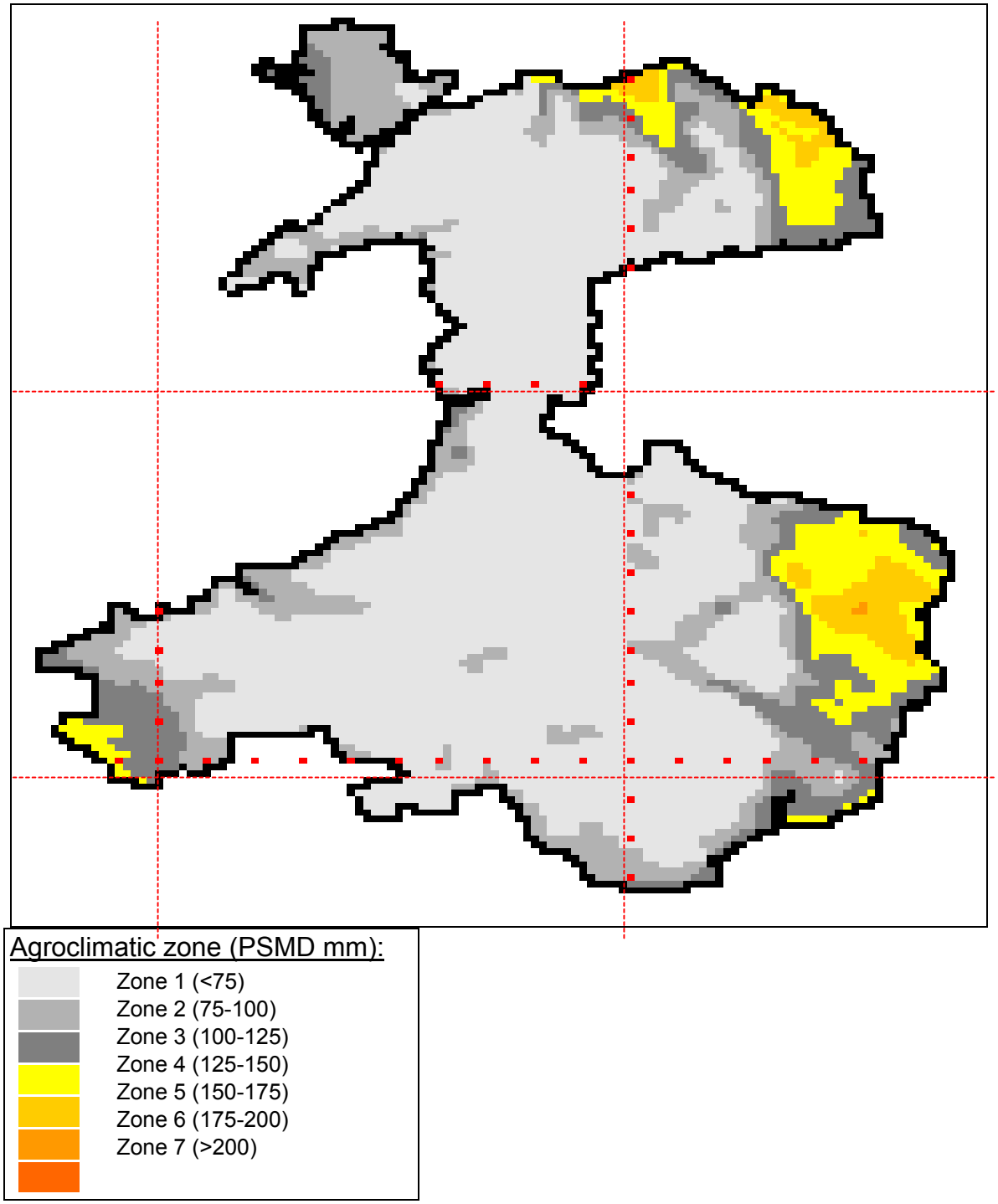

Fig 1.2d Agroclimatic zones : Welsh Region

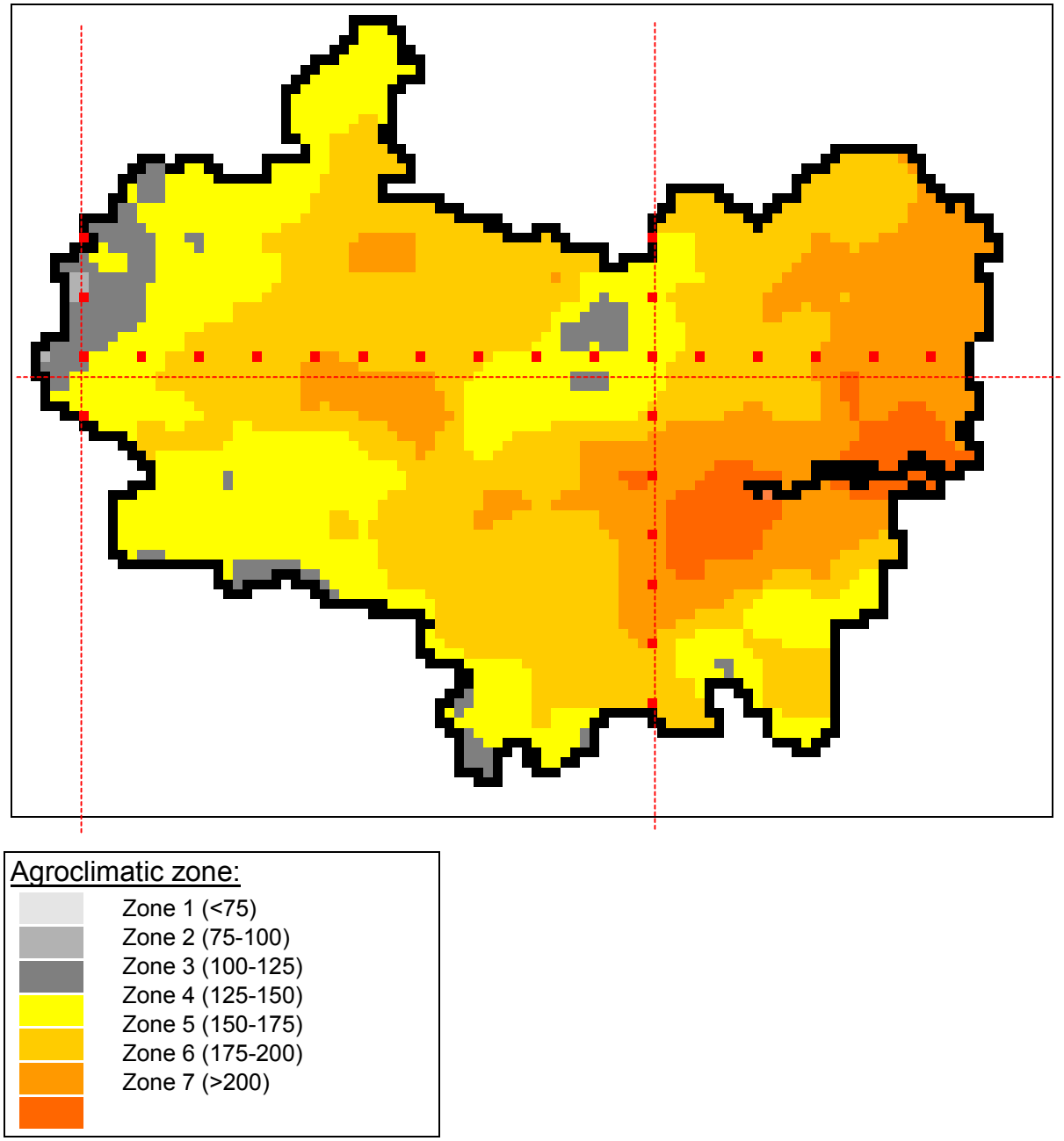

Fig 1.2e Agroclimatic zones: Thames Region

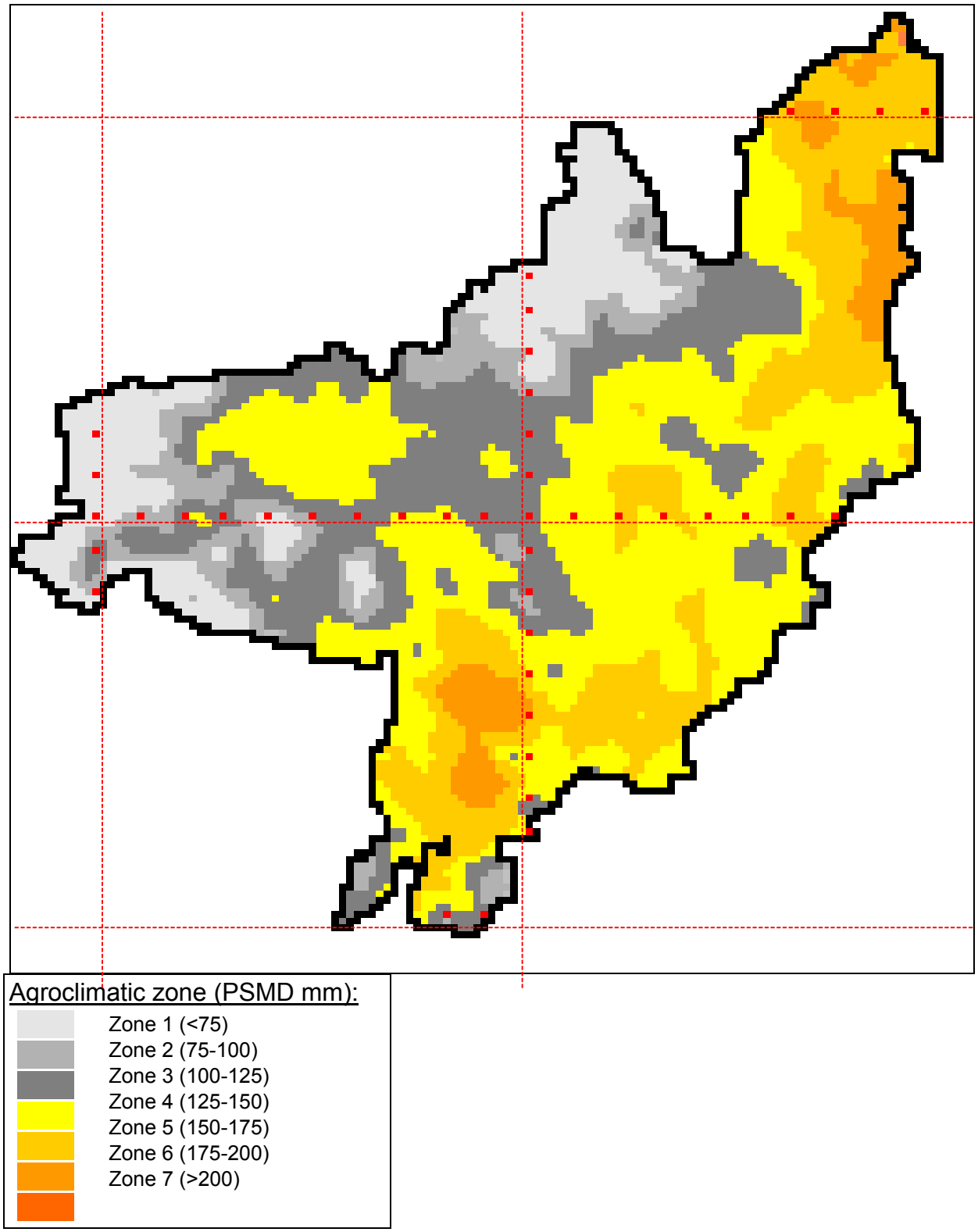

Fig 1.2f Agroclimatic zones: Midlands Region

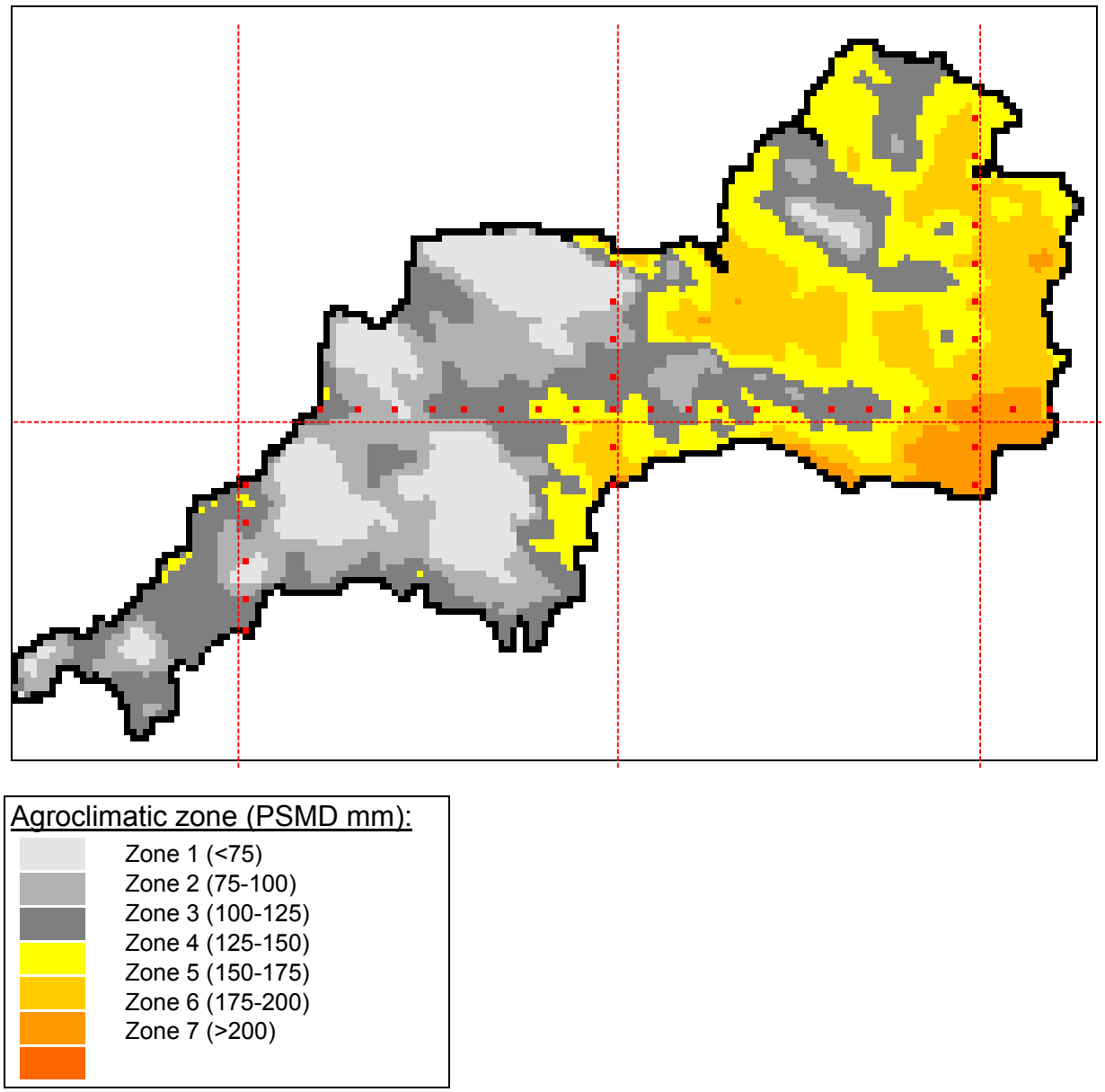

Fig 1.2g Agroclimatic zones: South West Region

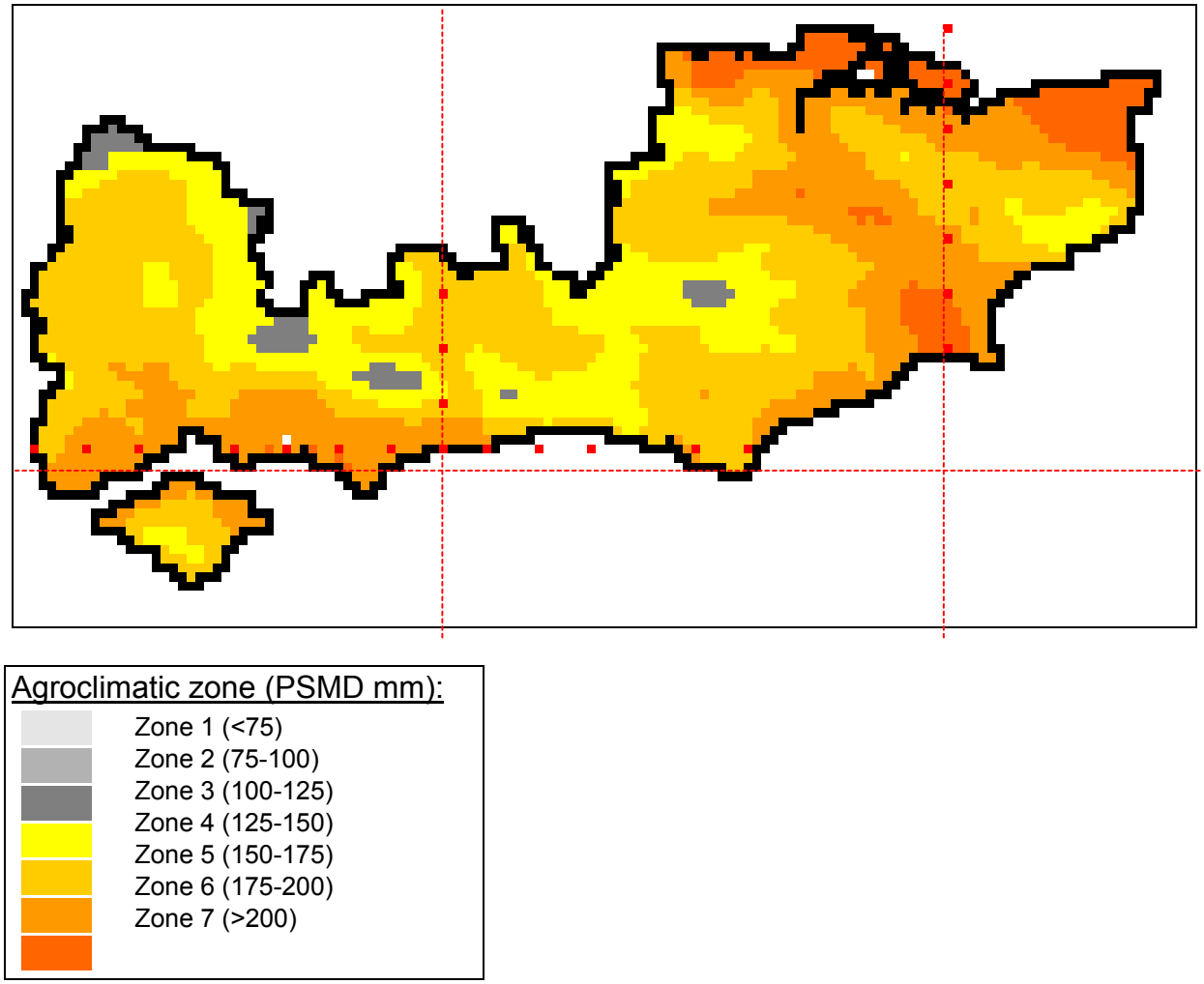

Fig 1.2h Agroclimatic zones: Southern Region

Table 1.5 Crop characteristics used for modelling irrigation needs in the Irrigation Water Requirements model (after Knox *et al.,* 1997).

Crop category	Early potatoes	Maincrop potatoes	Sugar beet	Cereals
Date of planting	1 March	1 April	1 April	1 April
Date of emergence	10 March	10 April	15 April	10 April
Date of 20% cover	1 April	10 May	15 May	25 May
Date of full cover	20 May	10 July	1 August	15 July
Date of maturity	20 May	10 August	1 August	15 July
Date of harvest	1 June	15 September	9 October	10 August
Date of max. rooting depth	20 May	10 July	1 August	15 July
Planting depth (m)	0.05	0.15	0.05	0.03
Max. rooting depth (m)	0.55	0.70	1.20	1.20
Max. crop cover (%)	100	100	100	100
Mulch cover at planting (%) [1]	0	0	0	0
Crop coefficient at full cover (*kc*) [2]	1.10	1.10	1.00	1.00

Crop category	Grass	Vegetables (carrots)	Small fruit (strawberries)	Orchard fruit (mature apples)
Date of planting	n/a	1 May	20 March	1 March
Date of emergence	n/a	9 May	20 March	10 March
Date of 20% cover	n/a	1 June	20 April	20 May
Date of full cover	n/a	15 August	10 May	20 June
Date of maturity	n/a	20 September	10 June	1 September
Date of harvest	n/a	20 September	5 July	15 September
Date of max. rooting depth	n/a	15 August	10 May	1 March
Planting depth (m)	n/a	0.01	0.05	1.00
Max. rooting depth (m)	1.00	0.80	1.00	1.00
Max. crop cover (%)	100	100	80	70
Mulch cover at planting (%)[1]	0	0	20	0
Crop coefficient at full cover (*kc*) [2]	1.00	1.00	1.00	1.00

Notes:

[1] Mulch cover at planting refers to the proportion of bare earth covered by a mulch (usually straw) but could be polythene in which case the value would be 100% and the water requirement slightly lower.

[2] Crop coefficient (*kc)* is the relationship of the evapotranspiration of the crop in question to that of a freely transpiring short grass crop.

Table 1.6 Irrigation plans for each crop category (mm irrigation applied @ mm soil water deficit).

Crop category	Period	Low AWC soil	Medium AWC soil	High AWC soil
Early potatoes	May-June	15@25	25@40	25@50
Maincrop	May	12@15	12@15	12@15
potatoes	June-August	25@30	30@55	30@70
Sugar beet	June	20@25	25@35	25@75
	July	25@35	25@50	25@150
	August	25@50	25@75	25@200
	September	25@65	25@125	25@250
Cereals	May-June	25@50	25@80	25@100
Grass	May-August	25@40	25@75	25@100
Vegetables	May-June	25@25	40@50	unirrigated
Small fruit	May-June	50@50	50@75	unirrigated
Orchard fruit	June-August	50@00	50@100	50@100
	September	40@40	40@70	40@100

Table 1.7 Soil texture and available water capacity class

A) Low AWC <12.5% by volume (<60mm/500mm soil depth)	Coarse sand Loamy coarse sand Coarse sandy loam
B) Medium AWC >12.5% by volume but < 20% by volume (60-100mm/500mm soil depth)	Sand Loamy sand Fine sand Loamy fine sand Clay Sandy clay Silty clay Clay loam Sandy loam Sandy clay loam Silty clay loam Fine sandy loam Loam
C) High AWC > 20% by volume (greater than 100 mm/500 mm soil depth)	Very fine sand Loamy very fine sand Very fine sandy loam Silt loam Silty loam Peaty soils

Note: Available water is less with increased stones, higher bulk densities (increased compaction) and reduced organic matter. Thus topsoils tend to have higher AWC's than subsoils of similar texture.

Table 1.8 Design dry year irrigation need (mm) by crop, soil type and PSMDg zone

Low AWC soil:

Agroclimatic zone	Early potatoes	Maincrop potatoes	Sugar beet	Cereals	Grass	Vegetables	Small fruit	Orchard fruit
1	45	165	110	0	120	135	60	165
2	50	185	130	5	140	150	70	190
3	55	200	145	15	160	165	80	215
4	60	220	165	25	180	180	85	240
5	65	240	180	35	200	195	95	265
6	70	260	200	40	220	215	105	290
7	75	280	220	50	245	230	115	315

Medium AWC soil:

Agroclimatic zone	Early potatoes	Maincrop potatoes	Sugar beet	Cereals	Grass	Vegetables	Small fruit	Orchard fruit
1	40	150	85	0	95	100	45	150
2	45	165	100	0	115	115	55	180
3	50	185	115	0	135	130	60	205
4	50	200	130	0	155	145	70	235
5	55	220	145	0	175	155	80	260
6	60	235	160	0	195	170	85	285
7	65	255	175	0	215	185	95	315

High AWC soil:

Agroclimatic zone	Early potatoes	Maincrop potatoes	Sugar beet	Cereals	Grass	Vegetables	Small fruit	Orchard fruit
1	30	135	0	0	45	0	0	125
2	30	150	0	0	70	0	0	155
3	35	165	0	0	90	0	0	180
4	40	180	20	0	115	0	0	205
5	45	200	40	0	135	0	0	235
6	50	215	55	0	160	0	0	260
7	55	230	75	0	185	0	0	285

1.3 Look-up Table Example

A farmer wishes to apply for an abstraction licence to irrigate 40 ha of main crop potatoes, 40 ha of sugar beet and 100 ha of cereals. The farm is located 5 miles north of Thetford in Norfolk.

Step 1 Establish soil AWC class (Available Water Capacity)
Refer to Table 1.7. Local knowledge may form the basis for deciding the AWC class. Alternatively reference should be made to the National Soils Map which shows the area to be Worlington Association. Reference to Hodge et al (1984) shows this association to be mainly sands and loamy sands and hence low AWC (the relevant extract is shown below). There may be patches of medium AWC land but the farmer has indicated he only wishes to irrigate cereals on his lightest land.

Sugar beet and potatoes will rotate around the farm and in some years be on light land and some years on medium land but for design purposes should be for the worst situation ie. light land.

Worlington series	**Euston series**	**Santon Series**
0-40 cm - Ap Dark brown, slightly mottled, very slightly stony and with bleached sand grains 40-100 cm - Eb Light yellowish brown, very slightly stony sand; single grain structure. 100-110 cm - Bt Strong brown, stoneless sandy loam; single grain structure. 110-120 cm - 2Cu Pale brown, moderately stony sandy loam; massive structure; calcareous.	0 - 30 cm - Ap Dark brown, very lightly stony loamy sand. 30-45 cm - Eb Yellowish brown, stoneless or slightly stony loamy sand or sand; weak medium angular blocky or massive structure. 45-65 cm - Bt Yellowish brown, very slightly stony sandy clay or clay; strong prismatic or massive structure; slightly calcareous. 65-100 cm - 2BCt Yellowish brown, stoneless or slightly stony sandy clay or clay; moderate fine angular blocky structure, calcareous	0-15 cm - Ap Dark greyish brown, slightly mottled, stoneless or very slightly stony sand. 15-30 cm - Ea Brown, slightly mottled, stoneless or very slightly stony sand; massive structure. 30-50 cm - Bh Dark brown, very slightly stony sand; massive structure. 50-100 cm - Eb Yellowish brown, very slightly stony sand; massive structure. 100-110cm - Bt Strong brown, stoneless sandy loam; massive structure. 110-120 cm - 2Cu Brownish yellow, slightly stony loam; massive structure; calcareous.

Hodge et al., (1984) - Soils and Their Use in Eastern England

Step 2 Establish agroclimatic zone
The farm lies in agroclimatic zone 6 (from Fig 1.2a) but close to the boundary with agroclimatic zone 7.

Step 3 Establish water demand
From Table 1.8 the following dry year in five demands apply for a low AWC soil.

Crop	Design depth (mm)	Area (ha)	Requirement (m^3)
Main crop potatoes	260 mm	40	100,400
Sugar beet	200 mm	40	80,000
Cereals	40 mm	100	40,000
Total Requirement			220,400

Because the site lies close to the boundary with agroclimatic zone 7 design depths for this zone are also acceptable.

1.4 Irrigation Efficiency

1.4.1 Definition of terms

Irrigation efficiency is the amount of irrigation usefully used by the crop divided by the total irrigation applied. Useful refers to crop water use. Unnecessary evaporation, drainage and deep seepage count as losses as does less effective use of rainfall. Application efficiency refers only to the performance of the application method and is the amount of extra water stored in the soil after irrigation divided by the amount of water applied.

Neither of the above definitions include yield. In most UK situations, it is useful to try to optimise water use efficiency (e.g. kg/m^3 or £/m^3), that is the extra yield produced (by volume or value) divided by the amount of water applied.

1.4.2 Overhead irrigation systems

Most UK irrigation is applied through hose-reel systems fitted with guns. All methods of overhead irrigation are prone to losses through evaporation in the air, from wetted foliage and from the soil surface. The poor application uniformity from many systems, particularly when windy, can result in some plants suffering water stress and/or others being over-irrigated, wasting water. Wind drift can also carry small droplets out of the irrigated area.

Despite the criticisms, there is surprisingly little hard data on application efficiency under UK conditions. Agronomists have reported that in hot dry weather sometimes only 70% of the water applied by hose-reel gun systems actually reaches the crop. However, these measurements have rarely been controlled and incorrect settings could have meant less water was applied than intended, or poor uniformity could have distorted results.

In recent water distribution measurements in France (CEMAGREF, 1997), at temperatures up to 31°C and at a range of wind speeds, 85% to 90% of the water discharged from guns was collected in catch-cans at canopy level. Evaporation from foliage could account for another one mm loss on potatoes, i.e. 4% of a typical 25 mm application. This suggests at least 80% should reach the soil in peak daytime summer conditions, and more at night and at normal UK temperatures. Seasonal application efficiency could average 90% or better.

Switching to other overhead methods may not therefore drastically improve application efficiency. Indeed, the very fine drops from some spray nozzles are more likely to evaporate and drift than the large drops from guns.

Possibly more important problems however, particularly with guns, are the poor uniformity of water application, inaccurate scheduling and inefficient use of rainfall. Poor uniformity and inaccurate scheduling will result in drainage losses on a fully

irrigated crop, particularly where a farmer tries to compensate by applying even more water. Applying large irrigations that bring soil to field capacity will waste any subsequent rainfall. The replacement of guns with booms should help significantly by applying water accurately, improving irrigation efficiency and helping provide a more uniform and higher quality crop.

1.4.3 Trickle irrigation

Trickle irrigation systems apply small amounts of water slowly and frequently, directly into the root zone, usually through emitters spaced along polyethylene tape or tubing. The laterals are either laid directly on the surface (e.g. in orchards), shallow buried (e.g. for potatoes) or sub-surface buried, depending on the crop and local soil conditions. Trickle is ideally suited to flat or gently sloping land, although more sophisticated pressure compensating emitters now allow it to be used on relatively steep or undulating terrain.

The MAFF Irrigation Survey for 1995 suggested trickle accounted for 2.5% of the total area irrigated in England (MAFF, 1997). Industry surveys show its use continues to grow strongly.

Trickle irrigation can potentially use less water than spray irrigation, and potential water use savings of up to 30% are often reported internationally, though mostly from hot arid climates. The crop water use (transpiration) from a fully irrigated crop is unchanged. However, spray evaporation, wind drift, and leaf interception are avoided, and soil evaporation is reduced. As a static (solid-set) system, it allows smaller and more timely applications, and is easier to automate than portable or moving overhead irrigation systems. This permits more accurate scheduling. Potentially, trickle can also give a high uniformity of application, reducing the need to over-irrigate to compensate for dry spots.

However, accurate scheduling and effective management and maintenance of the system are crucial to achieve any water savings at all. It is more difficult for the users to assess how much water is needed, and easy to switch trickle systems on too often or for too long. In practice, potential savings are not necessarily realised.

Actual water savings recorded on UK trials are varied. ADAS reported water use was not significantly different between trickle and sprinklers on the 1984 potato trials. Some recent farm trials suggested savings up to 40% between trickle and hose-reel gun systems. Accurate comparisons are difficult without replicated trials, and this research is still lacking.

Requiring potato growers to use trickle irrigation instead of hose-reel gun systems solely to save water would increase in-field costs substantially, and could be an expensive way to save water.

1.5 Irrigation Scheduling

1.5.1 Introduction

Irrigation scheduling provides the irrigator with information on his crop water needs so that he can ensure that irrigation applications are timely and of sufficient quantity.

Irrigation scheduling often leads to greater rather than less use of water. The reason for this is that the variability of summer weather means that irrigation requirements vary markedly week to week - without scheduling it is difficult to keep track of what is happening. Irrigation requires considerable effort so there is a tendency to put it off in the absence of advice to the contrary. Additionally many systems in the UK are underdesigned. Scheduling shows this deficiency and encourages farmers to invest in more equipment so as to be able to keep up with their advised schedules.

Despite the availability of commercial scheduling systems for at least 15 years the take up has not been as widespread as might have been expected. Table 1.9 and 1.10 show that about 800 to 1,000 farms subscribe to a commercial scheduling system. In addition, a number of marketing groups have developed their own scheduling systems, while other individuals use tensiometers to monitor their soil water status.

There were nearly 12,000 irrigation licenses current in England and Wales in 1996 (of which about 60 percent were either in Anglian or Midland regions). Some holdings have more than one license and the total number of irrigating holdings in England and Wales was believed to be about 7,800 in 1995 (Stansfield 1997). The number of holdings receiving scheduling is unlikely to be more than about 15 percent. However the majority of large irrigators subscribe to a scheduling service so that the proportion of the total irrigated area (estimated at 155,650 ha in 1995) receiving scheduling is much higher than the proportion of holdings receiving scheduling.

1.5.2 Approaches to scheduling

Commercial irrigation scheduling is provided by a number of organisations in the UK. The two main approaches, direct field measurements of soil water and modelling of soil water, and the main organisations providing each service are shown in Table 1.9 and 1.10.

Each method of scheduling has advantages and disadvantages. The greater the effort the greater the accuracy. All systems suffer from the problem of poor uniformity of application. The main method of irrigation application is the hose-reel irrigator which throws water high into the air. Not only can losses be created by wind drift but not all parts of the field receive the same amount of water. None of the scheduling systems make it clear whether they are scheduling for the driest, average or wettest part of the field because this information is not usually available. The assumption is that conditions are uniform across the field.

The other difficulty is that all systems are retrospective and forecasting irrigation requirements is difficult. The use of more sophisticated weather forecasting techniques is of some help but usually too general to provide more than a rough guide. In practice the irrigator has to make his own decisions between the arrival of his weekly soil water update although some services will provide *ad hoc* advice over the telephone if extreme climatic events occur unexpectedly.

The tables show that of those receiving scheduling about 60 percent use some form of direct measurement and about 40 percent rely on model only based systems.

1.5.3 Model based systems

The model based system has its roots in the simple water balance sheet which the UK agricultural advisory service promoted in the 1960s. The farmer kept a daily record of rainfall and irrigation applications and some fairly crude measures of crop water use were incorporated to provide a daily track of soil water status or deficit - the depth of water required to return the soil to field capacity which is defined as the theoretical maximum water held in a soil before drainage losses occur.

This approach has been greatly assisted by the advent of the personal computer (pc) and a number of sophisticated models are available which use local meteorological data to forecast water use through a calculation of evapotranspiration. The weakness of the modelling approach is that it is only as good as the input data. Irrigation applications can vary across the field and what a farmer thinks he has applied is often not what reaches the ground, rainfall can vary across the field, crop cover varies and so on. With care and effort (use of in-field rain gauges, grids to asses crop cover etc) these variables can be monitored and the system made to function accurately but where this care is absent the model can quickly show major departures from reality.

Model based systems are cheap to operate and are optimally run by the farmer on his own PC linked to his own automatic weather station. However this level of sophistication requires a large farm with several fields under irrigation and considerable commitment on the part of the grower. The commercial services provide this commitment and provide the service for the smaller grower with only one or two fields under irrigation.

1.5.4 Soil water measurement systems

Direct measurement of soil moisture has the advantage of avoiding measurement of many of the difficult inputs to a water balance model. The most commonly used instrument, the neutron probe, gives a measurement of soil moisture status throughout the root zone and as such can be extremely accurate. The difficulties with the system are that the probe is an expensive and difficult instrument to use and not really suitable for individual growers to operate. Its use for scheduling therefore requires weekly visits and hence the cost of scheduling is relatively high. The system also has the limitation of only examining a relatively small part of the field in which conditions may vary from elsewhere. As with the modelling approach, if well managed, the system provides an accurate means of scheduling.

Recently, capacitance probes have been used for scheduling. These measure soil electrical frequency which is a function of the soil water content. The system avoids the nagging safety worries of neutron probes and lends itself to sophisticated farmer managed scheduling in which sensors in a number of fields can be linked to a central processing system allowing the farmer to evaluate the soil moisture status at any time. However the system has a relatively high capital investment cost (compared to neutron probes) and is really only likely to provide major benefits to the larger and more sophisticated irrigator.

1.5.5 Benefits of scheduling

The relatively poor uptake of irrigation scheduling is a reflection of the difficulty of being able to accurately quantify the benefits that scheduling provides. The theoretical benefits are:

- Reduction in water and energy use.
- Reduction in potential loss of fertiliser through leaching.
- Better control of diseases particularly common scab.
- Increased yields

Most growers know that they will get more benefit from over-irrigating rather than under irrigating. The cost of applying water is relatively low at £0.16 £/m^3 (Weatherhead *et al,* 1997) when compared to the extra net margin on say maincrop potatoes at £0.65/m^3 (Table 1.12). On the other hand many systems are underdesigned and the grower does not need to receive scheduling information telling him to apply more water when he does not have the capacity to apply it. It is simply easier to keep irrigating at or near the capacity of the system unless extreme rainfall events occur. This probably explains the relatively poor take-up of scheduling especially where water resources are not limited.

Table 1.9 Field soil water measurement systems

Service Name	Contact	Address	Area covered	Service	Costs	Approx. No of farms served
Alliance of Irrigation Management Services comprising:						
Agri-tech Services	Simon Turner	8 Caldecote Road, Ickwell, Biggleswade, Beds SG18 9EH. T/F: 01767-627334	NE and central Midlands	Weekly site visit to measure soil moisture with neutron probe (3 tubes per site). Forecast water use based on experience and long term records.	£200-£400 / site	80
A & P Hill Fruit	Graham Hill	Oakleigh, Thorn Rd, Marden, Tonbridge, Kent TN12 9EJ T: 01622-831350 F: 832492	South and SE	As above	As above	80
Fullpoint Probe Services	Dick Dickens	168, Butley Rd, Eyke, Woodbridge, Suffolk IP12 2RY T: 01394-460682 F: 460366	E. Anglia	As above	As above	130
IMS	Lucinda Joule	Sutton Cottage, Sutton, Market Drayton, Shropshire. T/F: 01630-653290	N. Midlands and NW	As above	As above	<50
Peter White Water Management	Peter White	White's Fruit Farm, Ashbocking, Ipswich IP6 9JS. T/F: 01728-453579	E Anglia and SE	Weekly measurement of soil moisture using Enviroscan capacitance probe (1 probe per site). Data can be downloaded remotely and system run by farmer. Forecast water use based on experience.	£250/site + £3-4K initial equipment purchase.	50

Table 1.10 Model based systems

Service Name	Contact	Address	Area covered	Service	Costs	Approx. No of farms served
Irriguide	Nigel Simpson	ADAS, Chequers Court, Huntingdon, Cambs PE18 6LT T: 01480-52161 F: 412049	Nationwide	Weekly prediction of SWD using met station and farmer supplied data. Forecasts based on Met Office predictions. Strong research support.	£130/ site	200-300
Levington Agriculture Irrigation Service	Martin Ashburn	Levington Agriculture, Levington Park, Ipswich IP10 OLU. T: 01473-717951 F 659025	Nationwide	Weekly prediction of SWD using met station and farmer supplied data.	£93/site	100-150
Cambridge University Farm Irrigation Scheduling Service	Mark Stalham	Cambridge University Farm, Huntingdon Rd, Girton Rd, Cambridge CB3 OLH. T: 01223-277347. F 277030	Nationwide	Weekly prediction of SWD using met station and farmer supplied data.	£150/site	75
MORECS (The Met Office)	Pamela Jebson	Environmental Consultancy Services, Johnson House, London Rd, Bracknell, Berks RG12 2SY	Nationwide	General prediction based upon 40 km grid square. Could be used for manual or computerised water balance but not targeted at irrigation scheduling.	Specific to requirement	Not known but low.
IMS Model	Tim Hess	Cranfield University at Silsoe, Water Management Group, Silsoe, Beds MK45 4DT, T 01525-863000. F 863001	Nationwide	Water balance software (to be run by purchaser) developed during field service offered in 1980s.	£150	Not known as mainly used by agronomic advisers to support their service.

1.6. Costs and Benefits of Irrigation

1.6.1 Irrigation costs

The costs of irrigation vary considerably according to local circumstances, therefore generalisations of costs can be misleading (Morris, 1994). Costs vary according to:

- the crop requirements for irrigation;
- the characteristics and location of the water source;
- the need for water storage;
- the size, configuration and topography of the irrigated area; and
- the type of application system.

Most agricultural irrigation in England is applied through hose-reel gun systems. The costs of irrigating from various water sources using a hose-reel gun on a 'typical' farm are compared in Table 1.11. This shows first the initial (capital) costs; then the resulting annual fixed costs (amortisation of capital costs plus insurance) and the annual variable costs (repairs, fuel, labour and water charges), added to give the total annual costs. Costs are also shown as average costs per unit of water applied (net of losses), again subdivided into fixed, variable and total costs.

Table 1.11 Summary of typical average costs of irrigation.

Water source:	Surface		Borehole		Surface	
Direct abstraction or reservoir:	Direct		Direct		Reservoir (unlined)	
Application method:	Hose-reel gun		Hose-reel gun		Hose-reel gun	
	£	%	£	%	£	%
Initial (Capital) Costs (£/ha)						
	2799		3214		5304	
Annual Costs (£/ha/yr)						
Fixed costs *	314	63	358	64	579	74
Variable Costs:						
repairs	75	15	82	15	112	14
fuel	40	8	49	9	42	5
labour	17	3	17	3	22	3
water	53	11	53	9	7	1
reservoir engineer fees	0	0	0	0	24	3
Total variable costs	185	37	201	36	207	26
Total Annual Costs	500	100	559	100	786	100
Unit Costs (£/m³ applied net)						
fixed	0.25		0.29		0.46	
variable	0.15		0.16		0.17	
Total Unit Costs	0.40		0.45		0.63	

Notes: 1996/7 prices.
Assumes 24 ha irrigated with average annual application of 125mm net of losses, 155 mm gross abstraction.
Unit costs are per m^3 usefully applied, i.e. net of losses, but costed at an assumed 80% efficiency.
* Including amortisation of initial capital cost over 20 years at 6%.

For a typical hose-reel system without winter storage, capital costs are £2800-£3200 per hectare irrigated, while the total annual cost is approximately £500-£600 per hectare irrigated, or £0.40-£0.45 per m^3 applied net of losses. Adding winter storage typically increases the annual costs by 50% and 130% for unlined and artificially lined reservoirs respectively, although there may be economies of scale for larger reservoirs.

Trickle irrigation costs vary greatly, depending particularly on the spacing between the lateral lines, the design life of the equipment, and whether the lines have to be removed each year. Trickle systems on potatoes and vegetables can have total annual costs of £700-£1000 per hectare even without reservoir storage, though costs on orchards would be substantially lower.

The structure of these costs can be important. Fixed costs account for over 60% of total costs even for direct abstraction to hosereel-gun systems, and over 70% with storage. The more efficient systems, including boom systems, centre pivots, and trickle systems, have an even higher proportion of fixed costs to variable costs.

1.6.2 Irrigation benefits

Existing crops

For farmers wishing to irrigate an existing crop, irrigation serves mainly to increase crop *yield* and crop *quality* over and above that obtained through rain-fed production. Irrigation improves yield (t/ha) and quality (£/t), with consequences for revenue (£/ha). The two effects are multiplicative, rather than additive. In very dry years, sale prices may also be higher due to lower production elsewhere. The size of the benefits depends on crop type and variety, the stages in the crop cycle when water is applied, the standard of crop husbandry, and environmental factors; especially soil and climate.

Table 1.12 shows estimated average *yield benefits* per unit of water applied to the main irrigated crops, using average prices for quality (irrigated) produce. The extra costs include additional harvesting, handling, drying, and where relevant, direct packaging and marketing costs. The yield responses are averages based on available experimental data and field experience for well managed crops in areas of established irrigation need (ADAS 1977; MAFF 1984; Bailey, 1990). They represent the average returns to water application *over the relevant range* of water applied, with the latter varying according to soil and climatic conditions. Yield response to water and hence irrigation is reasonably documented for potatoes, sugar beet, grass and some fruit and vegetables under specific circumstances, but for many other crops reliable data is limited.

For most irrigated crops, the *quality benefits* of irrigation are substantial. They relate to the whole crop, not just to the extra yield due to irrigation. Quality criteria are increasingly specified by buyers; failure to meet contract quality can lead to large price reductions, and possibly to rejection and loss of contract. The link between irrigation and crop quality is complex, and much of the evidence is anecdotal. A review of research literature, information derived from interviews with farmers and marketing agents, and analysis of published price data were used by Morris *et al* (1997) to derive

estimates of possible price reductions due to poor irrigation in the Fens. These results are site specific, because of variation in soils and climate.

For a given site, the average combined benefit can be calculated by adding the yield and quality benefits and dividing by the depth of water applied. For simplicity (and for lack of better data in most cases), a linear relationship between benefits and irrigation depth over the normal range of irrigation has been assumed here. Table 1.13 summarises the *average combined yield and quality benefits* (£/m^3 of water applied), for selected crops grown near Mepal, Cambridgeshire. In a dry year, the benefits of irrigation *per hectare* are of course much higher than the averages shown. For most crops, the benefits *per m^3 of water applied* do not change so much, because more water has to be applied. Exceptions can occur where dry years lead to increased prices.

Changing crops

Farmers without adequate water resources may have to restrict the area of crops that need irrigation. The potential benefit of irrigation would then depend on the difference in net margin between the irrigated and the rain-fed crops. For example, farmers in the Fens without irrigation might revert to a mainly cereals and oilseed rotation, moving out of root crops (Morris *et al.*, 1997). In this case, the benefits would only have been worth around £0.80/m^3 net of losses, rather than the £1.56/m^3 shown in Table 1.13.

Other benefits

In addition, irrigation may also:

- enable a wider range of crops to be grown;
- enable multiple cropping;
- improve seed bed preparation;
- provide protection against frost damage;
- enable effective use of herbicides and fertilisers;
- soften tillage pans and clods.

These additional benefits are not considered here.

Economic Benefits

A financial analysis, as used above, shows the benefit of irrigation *to farmers*. From the national viewpoint, an economic perspective is required. In the flood defence sector, for example, MAFF advise the use of adjustment factors to net out the costs of support and subvention for commodities which are heavily supported and or regulated. For irrigation, however, the results of the financial analysis can be used as a reasonable indicator of the short term economic impact, without the need for further adjustment, because most irrigated crops are sold in a relatively free market without government support.

1.6.3 Summary

The above analysis shows that the marginal benefit of irrigation varies enormously between enterprises. For farmers with inadequate supplies, additional water to avoid water stress on existing maincrop potatoes could give average benefits of £1.50/m^3 net of losses, and by much more on some other specialist crops, against average application costs of £0.25 to £0.70/ m^3 net of losses. However, it may not be feasible to grow some

of these crops without irrigation, and the true value of the irrigation needs a comparison against alternative land uses.

Table 1.12 Average yield benefits (£/m^3) in Eastern England.

Crop	Potential yields (t/ha)	Crop price (£/t)	Extra crop costs (£/t)	Extra net margin £/t)	Crop response (t/ha.mm)	Extra net margin (£/m^3)
Maincrop potatoes	50	95	14.25	80.75	0.08	0.65
Early potatoes	25	150	22.50	127.50	0.08	1.02
Sugar beet	42	40	4.00	36.00	0.13	0.47
Cereals	7	100	3.00	97.00	0.02	0.19
Peas - dried	4	115	3.45	111.55	0.04	0.39
Peas - vining	5	315	78.75	236.25	0.04	0.95
Carrots	45	90	13.50	76.50	0.13	1.00
Parsnips	40	200	30.00	170.00	0.13	2.21
Beetroot	40	60	9.00	51.00	0.13	0.63
Turnips (culinary)	35	100	15.00	85.00	0.13	1.10
Swede (culinary)	32	100	15.00	85.00	0.14	1.19
Celery	25	400	60.00	340.00	0.08	2.72
Leeks	25	500	75.00	425.00	0.08	3.40
Cabbage (spring)	35	130	19.50	110.50	0.14	1.55
Calabrese	8	675	101.25	573.75	0.05	2.87
French beans	7	280	42.00	238.00	0.06	1.43
Runner beans	21	450	112.50	337.50	0.05	1.69
Brussel sprouts	13	300	45.00	255.00	0.04	1.02
Cauliflower	15	240	36.00	204.00	0.07	1.43
Lettuce (outdoor)	30	450	112.50	337.50	0.05	1.69
Bulb onions	40	100	15.00	85.00	0.08	0.68
Salad onions	18	800	200.00	600.00	0.08	4.80
Radish	5	450	112.50	337.50	0.03	1.01
Asparagus	3	450	112.50	337.50	0.02	0.67
Grass-graze	6	95	0.00	95.00	0.03	0.28
Grass-silage	6	95	20.90	74.10	0.03	0.22
Strawberries	8	1700	425.00	1275.00	0.03	3.83
Raspberries	6	2000	500.00	1500.00	0.03	4.50
Blackcurrants	6	650	162.50	487.50	0.03	1.46
Rhubarb	35	550	137.50	412.50	0.05	2.06
Dessert apples	15	400	100.00	300.00	0.02	0.60
Pears	10	450	112.50	337.50	0.03	1.01
Plums	8	1350	337.50	1012.50	0.02	2.02
Cherries	8	1000	250.00	750.00	0.02	1.50

Additional costs:	% of gross output
Combinable crops	3
Sugar beet	10
Potatoes and field scale vegetables	15
Fruit and Horticulture	25
Grass (grazed)	0
Grass (silage)	22

Average response based on ADAS (1977), MAFF (1984) and Bailey (1990).

Extra costs include additional harvesting, handling, drying, & where relevant, direct packaging & marketing costs. Estimates based on Nix (1995), ABC (1996), Outsider's Guide (1995), Renwick (1997).

Table 1.13 Average combined (quality plus yield) benefits attributable to irrigation on a medium AWC soil at Mepal, Cambridgeshire.

Crop	Net depth	Unirrigated yield	Quality premia	Quality benefits		Yield Benefits			Total Benefits
	mm	t/ha	% price	£/ha	£/m³	t/ha	£/ha	£/m³	£/m³
Maincrop potatoes	125	40.0	30%	1140	0.91	10.0	808	0.65	1.56
Early potatoes	44	21.5	23%	741	1.68	3.5	450	1.02	2.70
Sugar beet	77	32.0	3%	38	0.05	10.0	361	0.47	0.52
Cereals	37	6.3	0%	0	0.00	0.7	71	0.19	0.19
Peas - dried	66	1.7	18%	35	0.05	2.3	258	0.39	0.44
Peas - vining	44	3.2	16%	163	0.37	1.8	417	0.95	1.31
Carrots	77	35.0	15%	472	0.61	10.0	768	0.99	1.61
Parsnips	66	31.4	6%	377	0.57	8.6	1463	2.21	2.78
Beetroot	103	26.6	13%	208	0.20	13.4	683	0.66	0.86
Turnips (culinary)	74	25.4	8%	204	0.28	9.6	813	1.11	1.38
Swede (culinary)	74	21.7	8%	174	0.24	10.3	875	1.19	1.43
Celery	74	19.1	40%	3089	4.20	5.9	2000	2.72	6.92
Leeks	92	17.6	13%	1147	1.25	7.4	3125	3.40	4.65
Cabbage (spring)	74	24.7	7%	225	0.31	10.3	1138	1.55	1.85
Calabrese	81	4.0	12%	320	0.40	4.0	2320	2.87	3.26
French beans	74	2.6	17%	123	0.17	4.4	1050	1.43	1.60
Runner beans	88	16.6	16%	1194	1.35	4.4	1489	1.69	3.04
Brussel sprouts	74	10.1	14%	422	0.57	2.9	750	1.02	1.59
Cauliflower	74	9.9	14%	331	0.45	5.1	1050	1.43	1.88
Lettuce (outdoor)	147	22.6	40%	4076	2.77	7.4	2482	1.69	4.46
Bulb onions	99	32.1	24%	769	0.78	7.9	675	0.68	1.46
Salad onions	92	10.6	20%	1704	1.85	7.4	4412	4.80	6.65
Radish	74	2.8	8%	101	0.14	2.2	744	1.01	1.15
Asparagus	59	1.3	16%	95	0.16	1.2	397	0.68	0.84
Grass-graze	51	4.5	3%	13	0.02	1.5	147	0.29	0.31
Grass-silage	51	4.5	3%	13	0.02	1.5	114	0.22	0.25
Strawberries	40	6.8	11%	1269	3.14	1.2	1547	3.83	6.96
Raspberries	37	4.9	11%	1077	2.93	1.1	1654	4.50	7.43
Blackcurrants	37	4.9	11%	350	0.95	1.1	538	1.46	2.41
Rhubarb (in the open)	74	31.3	8%	1378	1.87	3.7	1517	2.06	3.94
Dessert apples	74	13.5	20%	1082	1.47	1.5	441	0.60	2.07
Pears	74	7.8	14%	491	0.67	2.2	744	1.01	1.68
Plums	74	6.5	14%	1234	1.68	1.5	1489	2.03	3.70
Cherries	74	6.5	14%	914	1.24	1.5	1103	1.50	2.74

Note: This table assumes mathematically that first the quality benefit is applied to the unirrigated yield and then the yield benefit is valued at the full quality price; the reverse approach would show higher quality benefits and lower

yield benefits but the same total benefit. Example calculation: Quality benefits on potatoes: (40t/ha x £95/t x 30%) / (125 ha mm x $10m^3$/ha mm) = £0.91/m^3. Yield benefits on potatoes: (10t/ha x £80.8/t net) / (125 ha mm x $10m^3$/ ha mm) = £0.65/m^3

1.7 Stock Water Requirements

Although spray irrigation is a major water use in agriculture, stock water use can create significant local demands. Stock water requirements can vary with type of livestock and the methods by which they are managed on a day to day basis.

Table 1.14 shows average water use for the main livestock groups. Figures on water use for slaughter houses and food production are provided in the industrial section of the report.

Table 1.14 Stock Water Requirements

Animal	System	Litres/day/animal.
Dairy Cows	Cleaning non-power hose	14-22
	Cleaning power hose	27-45
	Drinking [1]	45-70
Calves	Drinking	15-25
Beef Cows	Drinking	25-45
Pigs [2]	Cleaning after each batch (10 pigs/pen)	16-24
	Lactating sows	15-30
	Pregnant sows & Boars	9-14
	Weaners	5
Sheep	Drinking	2.5-5
	Dipping (per dip)	2.5
Poultry	Layers /100 birds	20-30
	Fattening/100 birds	13
Turkeys	Fattening/100 birds	55-75

[1] Higher values for lowland production in Southern England.
[2] For outdoor pigs the maximum litres/day/animal should be increased by 50% to allow for wastage and wallows.

1.8 Current Limitations

1.8.1 Mapping of PSMDg

The spatial integrity of the computerised dataset used in this GIS analysis (PSMDg) is a potential source of error. This is a common problem for any GIS based modelling. However, for this study, potential errors have been minimised by defining broad agroclimatic zones.

1.8.2 Irrigation benefits and efficiency

The use of various data on irrigation benefits (yield and quality) which were derived for the Fens region, but commonly applied across England and Wales, are likely to be a source of error if applied to specific farms.

Morris *et al.* (1997) assumed a linear relationship between benefits and irrigation depth over the normal range of irrigation. In practice this is unlikely, but a better estimate is unavailable for most crops modelled. Indeed, availability of water alone may not guarantee that the potential benefits estimated will be achieved.

It should be noted that there remains little scientific documented data on irrigation application efficiencies under UK conditions. Much of the evidence reported is either anecdotal or derived from conditions experienced outside UK. The application of such data must therefore be interpreted with caution for UK conditions.

1.8.3 Mapping of irrigation demand and additional crop types

Proposals for improving the mapping of irrigation demand and the coverage of crop types are set out in Section 3.0 of this report.

TABLE OF CONTENTS
PART 2 :

Page No.

2.0 OPTIMUM USE OF WATER FOR INDUSTRIAL PURPOSES

2.1 Introduction

Most industrial sites consume water for use in their manufacturing processes in addition to the consumption for sanitation. The purpose of the tables in Section 2.3 is to enable an initial estimate to be made of the actual, annual demand for water from a particular industrial site. The tables are only sufficiently accurate to act as a general guide to the demand for water and to provide a simple overview of the important aspects of each manufacturing process.

The actual consumption of water depends upon a number of factors:

- Type of industry
- Production capacity
- Exact method of manufacture

Different industries have different levels of usage of water. For example a paper mill uses considerable quantities of water as a fundamental part of the process to manufacture paper whereas a metal fabrication company will use relatively small quantities of water.

However, there is a clear distinction between water usage and water consumption. A paper mill can recycle significant quantities thus reducing consumption.

The resource for this research project was directed at those industries that are significant users of water and an estimation of the level of significance is included in Section 2.3.

Most industrial sites that consume significant quantities of water have a demand that varies in an approximately linear manner with the production demand. That is, if production levels increase, the water usage increases by a similar amount. Therefore, the maximum production capacity of the manufacturing site and the planned production capacity are important factors to be established when determining water demand.

This data will be accurately available for all industries and is most often in terms of tonnes per annum of the site's products. Therefore, the tables in Section 2.3 are usually expressed in terms of the specific water consumption (m^3 per tonne of product). Some industries measure their production in units other than tonnes e.g. milk is measured in m^3, cars are measured in number of cars.

Examples of how to use the data are given in Section 2.2 to aid clarity.

The exact method of manufacture influences the demand for water to a greater or lesser extent depending on the industry type. Some industries are relatively consistent using the same process, the same up to date equipment and producing similar products (e.g. tissue manufacture) whereas other industries use different processes, different equipment and produce very different products (e.g. the chemical industry). Therefore,

the usefulness and relevance of the approach taken in Section 2.3 varies with the actual industry under consideration.

In general terms, those industries that are covered by Integrated Pollution Control (IPC) are not included. This is partly because the relevant data is available in their IPC application and partly because they are mainly chemical industry companies for which the approach taken is not really applicable and each process and site has to be assessed on its own merits and not on a 'typical consumption basis'.

The quality of the data in Section 2.3 varies from well researched, published, industry benchmarks to limited data supplied directly from one company. In all cases the source of the data is given as a reference. Data from outside the UK is included where this was judged as useful. Some industries do not have any data that is suitable for use so in this case the absence of data is shown in Section 2.3.

In general terms, the industry sectors that were approached directly for data were extremely co-operative and provided the data if it was available. Further data could be collected if companies had more time to determine their usages.

2.2 Examples of how to use the data

To illustrate the intended use of the tables in Section 2.3, hypothetical examples are given below.

2.2.1 Lead acid battery manufacturer

A proposed site intends to produce lead acid batteries and requires water for the factory at 165,000 m^3 per annum.

Information Required:

Question	Answer
Which type of batteries are to be produced?	Batteries for fork lift trucks
What is the manufacturing capacity of the site, in terms of annual lead processed?	10,000 tonnes per annum of lead

Calculations:

From Section 2.3 the 'best available' figure for water consumption is 15 m^3 per tonne of lead. Therefore, 15 multiplied by 10,000 gives a 'best available' value for the proposed site of 150,000 m^3 per annum.

Conclusions:

Hence the site's request for 165,000 m^3 per annum of water seems reasonable compared to 150,000 m^3 per annum calculated from the 'best available' table.

2.2.2 MDF manufacturer

A manufacturer has proposed constructing a facility based on Ref. 39 to manufacture 100,000 tonnes of MDF (medium density fibreboard) and request 90.3 m^3 per hour of water.

Information Required:

Question	Answer
What is the product?	MDF
What is the production capacity?	100,000 tonnes per annum
How much water is required?	90.3 m^3 per hour
How many hours operation in a year?	8000 hours

Calculations:

From Section 2.3 the 'best available' for water consumption is 0.31 m^3 per tonne of board.

Assume 100,000 tonnes of board is the production capacity (assume density is 1000 kg per m^3), therefore 'best available is 0.31 times 100,000 equals 31,000 m^3 per annum.

The request is for 90.3 m^3 per hour for 8000 hours per annum, equals 722,400 m^3 per year.

Conclusions:

Hence the site's request for 722,400 m^3 per annum of water seems unreasonable compared to 31,000 m^3 per annum calculated from the 'best available' table. Significant potential for recycling water and so reducing the consumption would appear to exist.

2.3. Industry Tables

2.3.1 Classification of industry

Table 2.1 lists the different types of industrial premises and ranks them against expected water usage.

'H' are expected to use High quantities of water
'M' are expected to use Modest amounts
'L' are expected to use relatively Low amounts

The search for data was concentrated on the high usage industries although data for some of the other industries is included. The table indicates those industries for which water consumption data has been found.

MAIN SECTOR	SUB SECTOR	WATER USAGE	DATA AVAILABLE
AIRPORTS			⑩
ASBESTOS PRODUCTS		M	
BASIC METALS	Refining	H	⑩
(iron,steel,copper,lead,zinc)	Finishing	M	
BEVERAGES	Soft Drinks	H	⑩
	Brewing	H	⑩
	Distillery	H	⑩
	Tea.coffee etc.	M	
CARPET MANUFACTURE		L	
CERAMICS & GLASS	Glassfibre Production	M	
	Ceramic Tiles	M	⑩
	Ceramic Goods	M	⑩
	Bricks	M	⑩
CHEMICALS		H	⑩
COAL		M	
COSMETICS & TOILETRIES		H	⑩
DOCKS & SHIPPING		?	
ELECTRICAL GOODS	Cables	M	
	Goods	L	⑩
	Lamps & Lighting	L	
	Domestic	L	
ELECTRONICS		L	⑩
FIBREGLASS		H	⑩

MAIN SECTOR	SUB SECTOR	WATER USAGE	DATA AVAILABLE
FOOD	Slaughterhouses & Meat Preparation	M	⑩
	Bakeries	L	⑩
	Fish & Fish Processing	M	⑩
	Oils, Fats and animal by-products	M	⑩
	Frozen Food	L	⑩
	Tinned Food	M	⑩
	Fresh Fruit and Vegetables	L	⑩
	Animal Foodstuffs	M	⑩
	Food Miscellaneous	M	⑩
GARDEN CENTRES		L	
HAIRDRESSERS		L	
HOTELS & RESTAURANTS		M	⑩
HYDRAULIC		L	
LAUNDRIES	Retail	H	⑩
	Industrial	H	⑩
LEATHER	Tanning	M	⑩
	Leather goods manufacture	L	
	Shoemaking	L	
METALS WORKING	Strip Products	M	⑩
	Casting	L	
	Forming & Machining	L	
	Plating/Anodising/coatings	M	
	Lead Acid Batteries	M	⑩
OIL EXTRACTION		H	
ORES & MINERALS	Concrete Manufacture	M	⑩
	Quarries	H	
	Ore Processing	H	
	Minerals Processing	H	
PACKAGING		L	⑩
PAPER & BOARDS	Pulp Production	M	⑩
	Paper Manufacture	H	⑩
	Tissue Manufacture	H	⑩
PETROCHEMICALS		H	
PLASTIC PRODUCTS		H	⑩
POWER GENERATION		H	⑩
PRECISION EQUIPMENT		L	
PRINTING & PUBLISHING		L	
REFINING		H	
RUBBER GOODS	Tyres	H	
	Car Components	H	
	Other Goods	M	
STATIONARY MANUFACTURE		L	⑩
SWIMMING POOLS, ZOOS, THEME PARKS & AQUARIA		M	
TEXTILES	Yarn	M	⑩

MAIN SECTOR	SUB SECTOR	WATER USAGE	DATA AVAILABLE
	Weaving	L	✓
	Bleaching, Dyeing and printing	H	✓
	Finishing	M	✓
TOBACCO		L?	
TOYS		L	
TRANSPORT		L	
VEHICLES	Washing	M	
	Car Assembly	L	✓
	Vehicle Assembly	L	✓
WOOD GOODS	Chipboard & MDF	H	✓
	Timber Finished Goods	L	✓

Table 2.1 - Industrial classification and expected relative water consumption

2.3.2 Contents of water consumption tables

The contents table below lists those industries for which water look-up tables have been generated. The industries are cross referenced to the NALD Abstraction Purpose Code Matrix (see Appendix B).

1. BREWING (Ref. 95)

Processing Steps

The basic raw materials (hops, malt, sugars) are boiled in a wort kettle to extract the sugars and flavours before the addition of yeast for the primary fermentation. The beer then undergoes a secondary fermentation and filtration before kegging or bottling or canning.

Water-Use Steps

- cleandown
- raw material
- steam heating

Water Consumption m^3 per m^3 of beer

Average Range	5 - 15
Typical	10
Potential Minimum	5

Water Reduction/Reuse Steps

The actual usage depends upon the efficiency of the brewery. The more modern larger breweries tend to have more efficient systems and equipment for the reuse of water.

2. PLASTICS MANUFACTURE (Ref. 73)

Processing Steps

The basic industrial processes employed in the manufacture of plastics are as follows:

Preparation of reactants	purification of monomer feedstock and catalysts
Polymerisation	addition polymerisation - monomer is polymerised using a catalyst to activate the monomer molecules and trigger polymerisation reactions. polycondensation - two monomers are linked together in condensation reactions where water molecules are split off of the reacting monomers Processes are either continuous, typically used for large-volume commodity polymerisations or batch/ semibatch for low volume, speciality polymerisations.
Polymer recovery	To recover the polymer, the reaction mixture goes through a series of three separation and purification steps: 1. unreacted monomer is separated from the polymer by volatilisation 2. liquids and solids are separated 3. polymer is dried to remove residual water or solvents
Polymer extrusion	Molten polymer is extruded to form plastic pellets
Supporting operations	Equipment Cleaning, reactant and product storage

Water-Use Steps

Process	***Process Water***
Preparing Reactants	little or no water used
Polymerisation	little or no water used
Polymer recovery	little or no water used
Polymer Extrusion	extruder quench water
Equipment Cleaning	reactor and floor wash water
Unloading and storage of Reactants	cleaning of transport vehicles
Pollution control systems	water for absorption columns and strippers

Water Consumption (m^3/tonne)

Polyethylene	2.50 - 9.99
Polypropylene	1.67 - 2.75
Elastomer	9.16 - 37.47
PVC	9.16
Monomers	66.62
Resin	5.83

Water Use Reductions

Water use reduction steps are similar to those outlined for speciality chemicals.

3. SPECIALITY CHEMICALS (Ref. 74)

Processing Steps

The speciality chemicals sector is too varied to enter into a discussion of processing steps within this document.

Water-Use Steps

- Cooling
- Steam Production
- Raw material
- Product Washing
- Effluent Dilution
- Air pollution control
- Plant and vessel washing
- Product washing/ Housekeeping/ Domestic uses

Water Consumption

Product Type	Water Consumption (m^3/tonne)
Resins, adhesives, detergents, disinfectants, photographic solutions.	<1.0
Sulphonic Acids, detergents, rubbers, resins, pigments, salts.	1 - 2
Silicones, Polyacrylics, water treatment chemicals, chelating agents, surfactants, amine products, synthetic organic polymers, sulphonic acids, esters, imides, anhydrides, quaternaries, alkyl ethers, salts, soaps	2 - 5
brightening agents, dyes, biocides, herbicides, insecticides, phosphates, pharmaceutical, intermediates, polyacrylics, amine products, esters, soaps	5 - 10
Esters biocides, fungicide intermediates, mercaptan gas, odorants, carbonates, thioglycollates, thioureas	10 - 50
Pharmaceutical intermediates, acrylates, amine products	50 - 100
Liquid Crystals, buffer solutions, pigments, chlorine and bromine products	100+

Water Use Reductions

Measures for water use reductions may be split into three distinct areas, water management techniques, good housekeeping measures and plant/ process modifications. The table below lists those measures that have been successfully implemented and the corresponding reductions in water use.

Measures Introduced	Reduction in water use (%)
Water management techniques	
Metering individual product areas and setting reduction targets	30
A package including production scheduling, improvements in plant wash-downs and use of triggered hoses	50
Good housekeeping measures	
Improved pipework to reduce leaks	10
Good housekeeping, taps on hoses, etc.	8
Better housekeeping to avoid cleaning	3
Storm water prevented from entering effluent system	7
Leak detection and reduction	30
Flow restrictors on vessel cooling lines	5
Plant and process modifications	
Cooling water re-use	21
Installation of cooling tower	50
Improved cooling tower	50
Re-use of wash water for batch dilution	25
Installation of pressure washers for cleaning blending tanks	5
Recirculation of water in liquid ring vacuum pumps	50
Replacement of water seal vacuum pumps with dry versions	24
Installation of air chillers	5
Reduction in process water wastage	5
Water minimisation project	20
Modernisation of manufacturing facilities	38
Improvements in process efficiency	5

4. THE PRODUCTION OF CHIPBOARD AND MEDIUM DENSITY FIBREBOARD (MDF) (Ref. 31 34 & 39)

Processing Steps

Logs and waste wood are shredded and mixed with resin (urea, formaldehyde) and 'pressed' into board. The precise size of the wood particles and the amount of resin used determine the type of board.

MDF can be coated with melamine to give a finished board for the manufacture of furniture, kitchen units etc.

The significant process stages are formaldehyde production (IPC regulated), chip drying, board pressing, board sawing and melamine coating.

Water-Use Steps

- formaldehyde plant
- steam system
- cooling
- cleandown
- resin manufacture
- abatement equipment

Water Consumption (m^3 per tonne of board produced)

	Chipboard	MDF
Range	0.23-7.2	0.31-7.2
Best Available	0.23	0.31

Higher figure of 7.2m^3/tonne is for manufacturing plant with once-through use or minimal reuse of water. Lower value of 0.23 m^3/tonne is for a plant intentionally striving to minimise water usage, and at present represents UK 'best available' value for water consumption.

Water Reduction/Reuse Steps

Significant reuse of water is inherent in the process and the potential for further reductions depends upon process development of the existing systems. The best

practical environmental option for reduction of water usage can be a balance between less water but greater energy consumption.

5. THE PRODUCTION OF BRICKS (Ref. 33)

Processing Steps

Bricks are manufactured by grinding natural clays and mixing into a marl by the addition of water. The exact composition of the marl determines the type of brick.

The water content of the marl is accurately controlled and consists of added water and water from the clay.

The water content of the marl is removed during the firing process and represents the main process demand for water.

A typical range is 15% to 30% w/w for the water content of the marl.

Water Consumption

	Bricks (m^3 per tonne of bricks produced)
Average Range	15 - 30

Water Reduction/Reuse steps

Monitoring of actual usage versus production to maintain usage as close to the theoretical minimum (marl water content specification) as possible.

6. THE PRODUCTION OF FIBREGLASS (Ref. 28, 31)

Processing Steps

Glass is produced in a furnace and extruded into fibres before coating with a range of binding agents. The glass fibre is usually wound before forming into the final product that can be insulation or chopped strand mats. These products are manufactured to a wide range of specifications. Water consumption depends upon the actual binding agents used and the final form of the product.

Water-Use Steps

- Production of binding agents
- Plant cleandown
- Cooling

Water Consumption

	Fibreglass (m^3 per tonne processed)
Average Range	10 - 20

Water Reduction/Reuse Steps

- Efficient vessel clean down systems, e.g. use of spray balls
- Longer campaigns for less frequent cleandowns
- Closed loop cooling circuits
- Water consumption monitoring and management system

7. CEMENT AND CONCRETE PRODUCTS (Ref. 86, 78)

Processing Steps

Cement is manufactured using both wet and dry manufacturing processes.

In the wet process, raw materials including limestone, iron oxide, sandstone and ash are mixed with water and then fed to ball mills to form a slurry. The slurry is fed to a kiln where it is dried, calcined and then further heated to form clinker. The kilns are fired with pulverised coal or coke and/or oil.

In the dry process, the primary materials are blended and fed directly to the roller mill. As with the wet process the blended materials are sent to a direct fired kiln to be transformed into clinker.

The resulting clinker from both processes is mixed with small quantities of gypsum and then ground in ball mills to form cement.

Concrete is manufactured by blending suitable proportions of cement, sand, aggregate and water.

Water Use Steps

Product Water
Cooling Water

Water Consumption

Cement Manufacture	Cooling Water Product Water	0.41 kg/kg clinker 0.325 kg/kg raw materials
Concrete Products	Total	1 m^3/tonne product
Concrete Blocks	Total	1 m^3 per 200 blocks.
Reinforced Concrete	Total	0.63 m^3/m^3

8. POWER GENERATION (Ref. 81, 82)

Water-Use Steps

The generation of electricity, through the combustion of fossil fuels, requires water for the following uses:

- Boiler Feedwater
- Auxiliary plant cooling
- Control of flue gas concentrations
- Ash handling
- Sanitary, laboratory
- Condenser cooling water system

The major use of water in most thermal power stations is the cooling water system, which is used to condense the steam being exhausted from the low pressure end of the steam turbine. There are three main options commonly used for cooling power stations, as outlined below;

Direct wet cooling	Water from the sea or very large river is passed once through the steam turbine condenser and is then returned directly to the source.
Indirect wet cooling	Cooling water is circulated many times around a separate closed loop cooling water circuit that incorporates cooling towers. A make-up flow is required to compensate for evaporative losses and the continuous purge flow that is required to prevent build-up of scaling deposits and loss of station efficiency. *Hybrid cooling* is also employed in which the water vapour plume from the plant is made less visible by introducing a flow of warm air.
Direct air cooling	Steam passes through finned tubes and is cooled by means of an induced air flow. This arrangement is often used in Combined Cycle Gas Turbines (CCGT).

Specific Water Consumption (m^3/GWh)

	Direct Cooled	Indirect Cooled
Coal	220 - 330	1280 - 2550
Oil	320 - 4600	no data

Specific Water Abstraction (m^3/GWh)

	Source	Direct Cooled	Source	Indirect Cooled
Coal	sea	12800 - 162000	river abstraction	2500 - 6500
Oil	sea/ estuary	26000 - 3600000	-	-

The figures for Specific Water Abstraction include water required for cooling, which is returned to the water source.

9. QUARRIES (Ref. 31 & 35)

Processing Steps

Quarries are classified as 'hard rock' (limestone, basalt, graphite) or 'sand and gravel'.

Depending upon the geographical location, the depth of quarry and other features, it may be necessary to abstract water to prevent flooding. In addition, water may be produced from dewatering operations. Hence a quarry may be a net 'producer' of water for discharge to a suitable location. If this discharge is back to the aquifer from which the water was originally abstracted then there is, in effect, no net usage of water by the quarry.

Therefore, the type of quarry, the quality of the deposits, the product quality required and the local hydrogeology all have a significant effect on the water requirements as well as the production levels.

Water-Use Steps

During processing in sand and gravel quarries, water is used for:

- washing out of clays and silts
- washing out of lignite
- classification (separation) of the different types of sand
- dust suppression
- wheel washing of the vehicles

During processing in hard rock quarries, water is used for:

- wheel washing
- washing for ballast

Water Consumption

Due to the factors outlined above it is not possible to determine an average value for water consumption. Each water abstraction will need to be treated individually and assessed on its own merits.

Water Reduction/Reuse Steps

The main factors determining water usage are detailed above and are very specific to the particular type of quarry, its location and products.

Process efficiency of the usage of water depends upon the efficiency of collection, treatment (usually settling in lagoons) and reuse of the water.

10. FISH PROCESSING(Ref. 14, 15)

Processing Steps

The main processes involved in fish processing are as follows:

Tuna receiving ➔ thawing ➔ butchering ➔ pre-cook ➔ cleaning ➔ canning ➔ retorting ➔ labelling ➔ casing.

Shrimp Receiving ➔ Rock separation ➔ peeling ➔ cleaning ➔ inspection ➔ deveiner ➔ grader ➔ packaging

Other sea fish Live fish are received and dumped into holding tanks
Fish are stunned with low voltage electric shock and then conveyed to either ***dressing*** or ***filleting*** line.
Dressing consists of removing dorsal fin, deheading, evisceration, skinning, chilling, sorting, freezing.
Filleting consists of deheading, slitting, skinning, trimming, refrigeration and or breading/coating.

Water Use Steps

- Holding/Thawing tanks up to 30-40%
- Butchering
- Water Chilling
- Water glazing
- Cleaning
- Cooking
- Spray Cooling

Individual steps depend on final product e.g. fresh or frozen

Water Consumption (all values in m^3/tonne)

	Tuna	Other fish	Filleting	Herring	Shrimp	Fish meal
Average	10 - 20	17	9 - 25	4 - 8	30 - 60	1-3
Best Available	<10	3.72	9	4	30	1

Water Reuse/Reduction Potential

- Elimination of the use of all flumes for in-plant transport of product
- Air cooling to replace water cooling
- Reduction of water use in the butchering area and in frequency of cleaning by using more efficient systems such as high pressure spring loaded hose nozzles, automatic cleaning brushes and biodegradable detergents.
- Pressure controls in water distribution lines to reduce use especially during clean-up operations

11. FOOD PROCESSING - FRUITS (Ref. 17)

Processing Steps

Frozen apple slices	Frozen apple slices are prepared from sound, fresh apples of proper maturity and proper ripeness. Apples are checked, washed, sliced, after which the slices are conveyed to tanks containing a sodium dioxide solution, which retards enzymatic oxidation. The slices are then filled into a vacuum tank where they are brined and blanched.
Fruit Preserves and jams	Cold pack or canned fruit is mixed with water, sugar and pectin and heated to 60°C. Water is evaporated at atmospheric pressure or under vacuum. After cooling is complete the finished product is deaerated and then pasteurised, before further cooling and filling.
Fruit Puree	There are 3 phases in an aseptic fruit purée plant. • The first is the fruit preparation. This involves fruit washing, sorting and pulp extraction. The pulper converts the fruit into a purée and separates seeds and pits from the purée. • The second phase is aseptic processing. Puree is heated to the required sterilising temperature, held at this temperature for a prescribed length of time and then cooled to near ambient temperature. • The third phase is the filling operation, which is undertaken in an aseptic environment.

Water Use Steps

Frozen apple slices	washing
Fruit Preserves and jams	heating, cooling, product mixing
Fruit Puree	preparation, processing, filling

Water Consumption - (all values in m^3/tonne)

	Frozen Apple	Fruit Puree	Fruit Jam/ Preserve
Average water (m^3/tonne)	2.00	0.40	8.03
Average steam (tonne/tonne)	----	0.18	0.281

Water Reduction/Reuse Actions

Recycle wash water
Air cooling
Steam recycle

12. FOOD PROCESSING - VEGETABLES (Ref. 17)

Processing Steps

Frozen Vegetables	Vegetables are received, trimmed and washed. The product is blanched in order to inactivate enzymes and to preserve the colour of the product. Product is cooled, frozen and packaged.
Tomato Paste	Field tomatoes are washed, inspected to remove foreign materials and trimmed. The tomatoes are chopped, sterilised at 112°C. The pulp is cooled to 100°C sent to a the rough finisher-pulper for removal of the peel, sticks and pods, and then to the fine finisher for removal of seeds and fibres. The finished juice is evaporated in a the double effect evaporator where it is concentrated from 5.5% to 32% solids. The paste is pasteurised, then cooled and packaged.
Mushroom Farm	Compost is prepared from suitable material, wetted, filled into wooden frames and steamed to kill any bacteria. The compost is cooled to 35°C and then spawned. The bed is maintained at 35°C, without light and watering for five days in which time mushrooms appear. Light and ventilation are introduced. The mushrooms are harvested.
Refined Vegetable Oil	Crude oil is mixed with caustic soda under controlled conditions to neutralise fatty acids that are then separated in a continuous centrifuge. Phosphoric acid can be used to remove any gums. The oil is then washed to remove remaining soap, followed by vacuum drying. Bleaching earth is added to the oil under vacuum. The light-coloured oil is filtered and then deodorised using live steam.

Water -Use Steps

Frozen Vegetables	washing, blanching
Tomato paste	washing, cooling
Mushroom Farm	Compost watering, steam
Vegetable Oil	washing

Water Consumption - (all values in m^3/tonne)

	Frozen Vegetables	Tomato Paste	Mushroom	Vegetable Oil
Water	25.24	0.33	25.00 (incl. steam)	1.67

13. FOOD PROCESSING - DAIRY PRODUCE (Ref. 9, 10, 17)

Processing Steps

Dairy Plant	Milk is transferred from road tankers through the milk meter, deaerator and plate cooler to the raw milk silos. The milk is cooled to 4°C. Milk is pasteurised at 75°C for 20 seconds, cooled to 3°C and then bottled.
Blue Cheese	The milk and cream are blended and continuously injected with a mixture of selected bacteria to increase the acidity of the milk as it is pumped into pre-ripening tanks. Blue mould culture and rennet, which is needed to coagulate the milk into junket, are added, and the whole is agitated. The resulting curd is cut, fed into plastic blockforms and the whey is drained off. The cheese is cooled, immersed in brine, then lifted and sprayed with a mould. Ripening takes 12 to 14 days. The cheese is pierced with holes regularly to allow the mould to grow. Whey, from the cheesemaking process, goes through a separator to extract fat (whey cream). The whey cream is old to other food companies for us in their products.
Ice cream	Raw materials for ice cream manufacture are milk powder, liquid milk, fats, sugars, flavourings and colour agents. Powdered raw materials are taken to a weighing bowl by means of a screw conveyor. The ingredients are mixed and then pasteurised. The mix is ripened overnight Flavours, colours and chocolate powder are added. Mix is drawn from the ageing tanks or the flavouring tanks to ice cream freezers where it is partially frozen and mixed with air, before packaging.
Yoghurt	Skim-milk powder, water and sugar are blended into pasteurised skim-milk and stored in mixing tanks. Cream is added and agitated at high speed. The yoghurt milk is pasteurised and homogenised simultaneously. The product is inoculated and then packaged
Powdered Milk	The unit operations used in milk powder production are evaporation and spray drying. The milk is pasteurised, evaporated, spray dried and the resulting particles are collected in a bag filter.

Water-Use Steps

- cleaning
- steam heating
- cooling

Water/ Steam Consumption (all values in m^3/tonne)

	Dairy Plant	Blue Cheese	Ice Cream	Yoghurt	Powdered milk
Water	5.76	11.29	0.88 m^3/m^3	4.24	0.03
Steam	0.192	0.353		0.135	0.091

14. FOOD PROCESSING - FLOUR PRODUCTS (Ref. 17, 19)

Processing Steps

Bread	All small ingredients (yeast, salt and dough improvers) are premixed, with an average ingredient/water ratio of 1:4, using a high speed agitator. Flour is added to form a dough. A divider cuts the dough into chunks of pre-set volume, the dough pieces are then rounded. After rounding, the pieces of dough are proofed, or fermented, before moulding where the finished texture and cell formation of the loaf are created. The loaves are deposited in baking pans, proofed and then baked. After baking, the bread is cooled, depanned, sliced and wrapped.
Bakers Yeast	A sugar-containing substrate such as molasses is pre-treated, inoculated with a small amount of yeast and aerated. The yeast cells reproduce, so generating large quantities of yeast that is then separated and packed
Corn Starch	The main processes in corn starch manufacture are: Corn steeping - to soften the corn ready for degermination Degermination Washing of husks and screening of starch milk Purification of starch milk Starch dewatering and drying Dewatering and drying of germs Evaporation of steep water Concentration, dewatering and drying of gluten
Corn Snacks	The raw material for corn snacks is corn meal. The meal is moisturised to prevent the product from burning and to aid expansion during extrusion. Heat and pressure convert the meal into a semi-liquid state before extruding it through the face plate. The extruded product is cut into the desired length by rotating knife, coated and then dried. Flavours are applied by spraying a metered amount of a slurry mixture onto the product.
Pasta	Flour is mixed with water and extruded through a die-head. Additives such as egg and spinach may be proportioned in to the extruder. Extruded product is dried and the cut for long-cut pasta or cutting, heated in a multi-stage unit for short-cut pasta

Water-Use Steps

Bread	ingredient feed, mixing, proofing, cooling conveyor
Bakers Yeast	Pre-treatment
Corn Starch	
Corn Snacks	moisturising
Pasta	

Water Consumption

	Water (m^3/tonne)	Steam(tonne/tonne)
Bread	2 - 6 *	0.06
Bakers Yeast	25.00	0.40
Corn Starch	6.28	---
Corn Snacks	0.03	---
Pasta	0.30	---

*Lower value based on audit of multi-product bakery in North Carolina (Ref.17)

Water consumption data is based on actual requirement with no recycle. Treat as worst case values.

15. FOOD PROCESSING - MISCELLANEOUS (Ref. 17, 24)

Processing Steps

Cane Sugar Refining	The main processing steps in cane sugar refining are: Affination - to remove adhering molasses Sugar dissolution Clarification - addition of diatomaceous earth followed by filtration Percolation - to remove impurities. Grading
Refined Beet Sugar	The main processing steps in beet sugar refining are: Prewashing, weighing and slicing into long narrow strips Sugar extraction countercurrently with warm water Rough screening to remove foreign material Precipitation of impurities Bleaching Concentrating Decolourising, centrifuging, washing Drying and granulating
Baby Food	Soft fruit (e.g. berries) is pre-crushed, heated up to 100 - 110°C and deposited into the mixing vessel. Vegetables are sorted and then pre-crushed, heated, from where they are transported into the mixing vessel. Meat is cut, cooked, and then precrushed. In the mixing vessel the final formula is thoroughly mixed. Seasonings are now added; for fruit and vegetable baby foods: sugar, corn syrup, starch powder, yeast extracts, vegetable protein, etc.; for meat baby foods: salt, spices, milk protein, etc. The finished formula is now pumped into a colloid mill for grinding, emulsifying and homogenising. The product is de-aerated, which removes all air from the product and, therefore, prevents any changes in flavour, aroma or colour due to oxidation. The product is heated and then filled.

Water-Use Steps

Refined Cane Sugar	Washing, Dissolution, cleaning
Refined Beet Sugar	Washing, dissolution, cleaning
Baby Food	Washing, sterilising

Water Consumption (all values in m^3/tonne)

	Refined Cane Sugar	Refined Beet Sugar	Baby Food
Water	41.00	9.00	0.2

16. FOOD PROCESSING - MULTI PRODUCT CONFECTIONARY PLANT (Ref. 18)

Processing Steps

Based on a water audit of a Cadbury Schweppes plant in Australia producing chocolate confectionery products. The base chocolate is produced from milk, cocoa liquor, cocoa butter, sugar and emulsifiers. It is then further processed to make other products.

Water Consumption

	Water Consumption m^3/tonne
Before Audit	6
After Audit	1.5

Main reasons for reduction in water consumption are specially designed wash bays, automatic hoses on nozzles, automatic taps and utensil washers.

Water Reuse/Reduction in the Food Industry (Ref. 92)

Product Washing - Wherever possible, countercurrent washing should be employed so that the cleanest water washes the nearly clean product and the reused water washes the dirty incoming product. This technique saves not only water, but also effluent volume.

Install automatic cut-off valves on water line if product flow-line is subject to stoppages.

Transporting product Particularly relevant to food industries. Recycle of water should be considered as should other modes of transport.

Clean in-place It is standard practice in automated cleaning-in-place(CIP) systems to reuse final rinse water as a pre-rinse.

In food factories the final rinse water should be oh high microbiological standard with a free chlorine residual present.

Improved clean-up
- Trigger action hose guns in washdown
- Dry clean-up techniques - brush clean

	• Industrial floor cleaners/ vacuum cleaners. • Use of reuseable wastewater streams
Others	• Water monitoring and management system • Maximise condensate return to boiler house • Automatic taps

17. BEVERAGES (Ref. 17, 6)

Processing Steps

Carbonated Soft Drinks	Manufacture of carbonated soft drinks involves formulation of syrups together with blending of syrups with water, carbonation and filling of bottles or cans
Orange Juice Concentrate	Fresh oranges are brushed to remove dirt, washed and brushed. The outer layer is removed in a scarifier. The juice is extracted. Pulp and peel are pressed and disposed of. Oils are recovered in an essential oils line. The juice is heated, depulped by centrifuge and then concentrated in an evaporator.
Fruit Juice	Fruit juice is manufactured by blending of juice concentrates as described above with water.

Water-Use Steps

Carbonated soft drinks	product, sterilising, cleaning	
Orange Juice Concentrate	pasteurizer	10%
	evaporator	85%
	other	5%
Fruit Juice	cooling tower	83%
	product	17%

Water Consumption (all values in m^3/m^3)

	Carbonated soft drinks	Orange Juice Concentrate	Fruit Juices
Average	4.0	0.55 m^3/t oranges	14.50
Best Available	3.0		3.0*

* Assumes recirculation of cooling water

18. GOLF COURSES (Ref. 91)

Water Use Steps

The major use of water on golf courses is for irrigation of greens and tees. Some golf courses practise watering of approaches and fairways.

Types of irrigation systems in use are automatic systems with pop-ups, manual installations with sprinklers working from hose points and travelling sprinklers.

Water may be supplied from a variety of sources, normally defined as the following types:

PWS (Public Water Supply, direct or water into storage first)
DAS (direct from abstraction or into storage first)

Water Consumption (megalitres per year)

PWS - only course	2.7 - 4.0
DAS -only courses	2.9 - 5.4
All courses	3.2 - 6.4

The above data ranges cover UK 9 and 18 hole golf courses.

This data is taken from a study carried out by the British Turf and Landscape Irrigation Association based on the responses from 89 golf course greenkeepers in southern and eastern England.

Little data was provided on the breakdown of water use but the following information was available:-

56% irrigated both greens and tees.
27% irrigated greens only
7% irrigated greens, tees and approaches
10% irrigated greens, tees, approaches and fairways.

19. LAUNDRY (Ref. 69, 76, 77)

Processing Steps

Commercial laundries fall into two main categories: smaller laundries equipped with traditional washer extractors processing up to 50,000 pieces/week, and larger laundries equipped with a combination of tunnel washers and washer extractors processing up to 200,000 pieces/week. Laundry is washed in a series of either hot or cold washes followed by a series of hot and cold rinses. After the washing process, the effluent is discharged to drain at temperatures ranging from 20 - 80°C

Water Consumption (all values in m^3/tonne)

	Hospital Laundry (UK)	Hospital Laundry (US)	Domestic Washing Machine
Average	27	38	20 - 15
Best Available	21	10	15

Water Conservation Measures

- Reuse of clean final rinse water through filtering and storage of effluent.
- Flash steam recovery
- Replacement of leaking valves

20. THE PRODUCTION OF LEAD ACID BATTERIES

(Ref. 94, 32)

Processing Steps

The main raw materials are lead, lead oxides and sulphuric acid. The basic stages consist of casting the lead internal components, producing the lead oxides to fill the appropriate electrodes, assembly, acid filling and charging (for industrial use e.g. Fork Lift Trucks). Automotive and standby batteries tend not to be charged hence the water cooling requirement is eliminated.

The quality of the water in contact with the battery internals is important to ensure an acceptable battery life.

Water-Use Steps

- Lead oxides slurry preparation
- Cell filling
- Plate washing
- Cooling
- Acid dilution

Water Consumption (All values in m^3/tonne lead processed)

	Industrial	Automotive & Standby
Average	16 - 20	5 - 10
Best Available	15	5
Potential Minimum	10	2 - 5

Water Reduction/Reuse Actions

- Water monitoring and management systems
- Filter and reuse water from slurry preparation
- Reuse cooling water (charging operation)
- Reuse plate washing water
- Use of dry fume abatement systems

21. METAL FINISHING (Ref. 42-47)

Process Steps

Metal finishing involves preparation of machined metal products into finished goods by various surface preparation techniques including washing, polishing, acid/alkali cleaning, electroplating and galvanising.

Processes may be batch or continuous as outlined below. Continuous operations are most frequently used in finishing of metal wires in which the product is continuously drawn through the plating and cleaning baths.

Water Use Steps

Electroplating Baths
Rinse Baths

Water consumption can be considerable in continuous operations due to drag-out of the bath liquors.

Water Consumption

	Metal Finishing m^3/m^2	Metal Finishing m^3/tonne	US Electroplaters m^3/m^2	Galvanisers m^3/tonne
Average	0.18 - 0.50	2.5 - 11.68	0.04482	0.025
Best Available	0.07	0.5	0.00077	

N.B. Water use will be product, material and finish specific. Water consumption is normalised against tonne of product or treated surface area depending on the form of product, e.g. plate material or door furniture.

Water Reuse/Reduction Potential

- Reuse of rinse water (reduce water consumption by up to two thirds)
- Countercurrent rinsing (two counter-current tanks can reduce water use by up to 90-97%. The addition of a third tank will reduce water use by 95 to 99%)
- Correct rinse tank design (ensure rinse water is completely mixed)
- Zero discharge, complete recycle of water. Metals ions may be removed by membrane or ion-exchange techniques. Captured metal should be recovered otherwise waste must be landfilled.
- Vacuum devices to remove drag-out liquid.

22. METAL PROCESSING (Ref. 48, 95)

Processing Steps

After mining most metal ores are subjected to an initial concentrating process, at the mine itself, based on physical and chemical methods. The next concentrating stage is usually smelting, where the metal is melted and oxidised to allow separation from the ore. The smelted metal is then refined into the commercially useful grades by a variety of pyrometallurgical or electrochemical processes.

Water-Use Steps

- cooling circuits
- cleandown
- steam raising

Water Consumption (all values in m^3/tonne)

Nickel

	Smelting	Refining	Iron Castings
Average	0.57	5.01	0.4

Lead

	Refining
Average	0.4

Water Reduction/Reuse Actions

Efficient cleaning methods and coating make-up procedures.
Recycling of cooling water.
Efficient steam system, including condensate return and minimum leaks.

23. STEEL MANUFACTURE (Ref. 43)

Processing Steps

The main steps in steel manufacture are as follows:

Coke manufacturing	prepared from high quality coal, heated up for 18 hours
Ore preparation and sintering	ore is passed beneath a sintering hood that produces an iron-rich material called sinter.
Desulphurisation	by injection of magnesium
Basic Oxygen Steelmaking	oxygen is blown across the surface of the molten iron to oxidise unwanted elements, thus enabling them to be removed as gas or slag. Ferro-alloy additions are made as necessary to make the required steel composition.
Slag Removal	
Final specification	Molten steel is stirred with argon and trimmed as necessary for final specification. Vacuum degassing removes dissolved gases that are unwanted in the final steel product.
Casting	Steel is cast into billets, blooms or slabs, or teemed into ingots
Milling	Steel billets are sold direct to customers. Slabs, blooms and ingots are rolled into finished products.

Water-Use Steps

- Coke Ovens
- Sinter and Ore Preparation
- Blast Furnaces
- Basic Oxygen Steelmaking
- Continuous casting
- Milling
- Steam Generation
- Domestic

Water Consumption

	Steelmaking (m^3/tonne)
Average	2.8 - 62.0
Best Available	2.6

Best available is based on results of pinch analysis at British Steel Scunthorpe Works

Water Reuse Options

- Cooling water recycle
- Cascade use of water

24. SEMICONDUCTOR WAFER FABRICATION (Ref. 11, 12)

Processing Steps

Typical facilities use 1 to 3 million gallons per day of ultra pure water(UPW) for rinsing of wafers.

Water Use Steps

- Major water use step is ultra pure water rinsing of wafers.
- The amount of UPW used per wafer varies from site to site, from company to company, and with wafer size.
- Actual demand on municipal water supply is approximately 25% greater than the quantity of UPW, due to losses in the water purification step.

Ultra Pure Water(UPW) Consumption, m^3/m^2

	Semiconductor Wafer
Range	56 - 345

Water Minimisation Options

Rinse Water Reduction

- Spray rinsing vs. Overflow
- Rinse tank geometry improvements
- Hot UPW instead of cold UPW
- Megasonic rinsing
- Idle Flow rate reduction

Water reclamation/reuse

- Reuse of water in cooling towers and air scrubbers
- Recycle of spent rinse water back into UPW treatment system
- Analytical instrument discharge for various uses.

Risks Associated with Water Recycling

- The introduction of impurity spikes into the system
- The build-up of recalcitrant compounds
- Inadequacy of present purification methods in removing process generated compounds
- Risk of new chemical interactions caused by recycle
- Contamination due to biofouling

25. ELECTRONIC ASSEMBLIES (Ref. 75, 79)

Processing Steps

This represents a wide range of products including computers, peripherals, photocopiers communications equipment, information storage, measurement/ instruments, and laser devices. Individual unit processes are product specific.

Water Consumption (m^3/Std hr/m^2)

Water consumption is normalised against standard hours worked (Std hr) and/or production floorspace (m^2). Data is product specific.

low consumption	medium consumption	high consumption
0.02	---	30.00
photocopiers domestic appliances computers data storage devices	digital test equipment instruments	clean room operations for example manufacturing of laser devices

26. CERAMICS MANUFACTURE (Ref. 7, 85)

Processing Steps (Porcelain)

Raw materials are mixed with water and then passed over a magnetic separator, screened and stored.

Most of the water is removed in the filter press. All the air is removed in the pug mill, assisted by vacuum and slicing knives.

The prepared clay is formed into blanks in a hydraulic press or by hot-pressing in a suitable mould.

The blanks are preliminarily dried, trimmed, finally completely dried and then coated with the required glazing material.

The vitrification of the body and glaze is carried out in tunnel kilns.

Water-Use Steps

- Equipment cooling, e.g. kilns, vacuum pumps and compressors
- Product Finishing
- Glaze Preparation
- Equipment washing

Water Consumption (all values in m^3/tonne)

	Ceramic whiteware	Sanitary ware	Stone Ware	Glazed Tile m^3/m^2	Fine porcelain
Range	15 -20	6 - 15	2 -10	0.5 - 8	5.5 - 14.0
Typical[1]	1.6	2.36	2	0.04	

[1]Typical values take into account the closed cooling water cycle and the fact that demand for water used for auxiliary needs is met by the water reclaimed from the purified industrial wastes.

Water Reduction/Reuse Actions

- Recirculating cooling water
- Reuse of reclaimed water from industrial wastes
- Reuse of filter press effluent
- Fully closed water cycle

27. SERVICES (Ref. 1, 2, 71, 80)

Water-Use Steps

Hotel	Food Preparation, Sanitary, Cleaning, Gardening
Airport	Food Preparation, Washrooms, Cleaning, Landscaping
School	Food Preparation, Sanitary, Cleaning

Water Consumption

	Hotel (litre/guest/day)	**Airport (litre/passenger)**	**School (litre/pupil/day)**
Poor performance	500 - 600		
Fair Performance	440 - 500	40 - 160	58
Good Performance	<440		

Note: No significant differences in the specific water consumption due to production level.

Water Reduction/Reuse Actions

- Installation of water efficient sanitary ware, e.g. low-flush water closets.
- Automatic taps
- Collection of rainwater
- Grey water recycle
- Educational initiatives

28. COSMETICS MANUFACTURE (Ref. 8)

Processing Steps

Standard steps in the manufacture of cosmetics and toiletries are mixing of ingredients, either in cold or hot form, filling, and packaging manufacture. Some sites may import packaging and containers from other sources.

Water-Use Steps

	% total water use
Bulk Manufacturing and plastics	61.28
Production (filling)	14.3
Warehouse	11.2
Offices	13.1

Water Consumption (m^3/tonne)

	m^3/tonne
Typical consumption	4.18

Water Reuse Actions

- Efficient use of water for cleaning
- Steam recycle

29. LIGHT INDUSTRIAL ESTATE WATER CONSUMPTION (Ref. 78)

Usage	Consumption
Basic factory requirements for cleaning and sanitation	0.05 m^3/d per worker
Average consumptions in light industrial estates with no large water-consuming factories	0.25 - 0.50 m^3/d per worker
Average consumption in light industrial estates that include a proportion of factories engaged in food-processing, ice-making and soft drinks manufacture	0.9 - 1.1 m^3/d per worker
Typical factory consumptions SE England • clothing and textiles • leather, fur, furniture, timber products, printing, metalworking and precision engineering. • plastics, rubber, chemical products, mechanical engineering and non-metallic products	 90% under 6 m^3/d per factory 80% under 25 m^3/d per factory 85% under 125 m^3/d per factory

30. THE PRODUCTION OF TISSUE (Ref. 30, 31)

Processing Steps

The raw material is either virgin fibre (logs) or recycled fibre (recycled paper). The recycled fibre is de-inked before pulping (producing the fibre/water slurry) and fed to a tissue machine that produces reels of tissue. These reels are finished by converting into the recognisable products of toilet rolls, hand towels, wipes, handkerchiefs and 'adult care products'

Water-Use Steps

- Tissue machine (to keep felt clean and clear)
- Pulp preparation
- De-inking
- Steam system blowdown

Water Consumption (m^3 per tonne product)

Average	8 - 50
Best Available	10 - 15
Potential Minimum	8

In general terms the heavier the product (thicker) the more water is needed for satisfactory operation of the tissue machine that consumes most (70%) of the water. Hence toilet rolls' water consumption is less than hand wipes.

LOWER VALUES	Toilet rolls/handkerchiefs/kitchen towels/wipes/hand towels	HIGHER VALUES

Water Reduction/Reuse Steps

Considerable reuse of water is practised, hence further improvements are usually relate to efficient treatment and reuse of water. Complete reuse of water is limited by the need to remove small fibres and prevent build up of dissolved solids. Paper mills are usually covered by IPC.

31. PULP AND PAPERMAKING (Ref. 49-58)

Processing Steps

Pulping

Process is either achieved chemically (e.g. Kraft pulping) or mechanically. Choice of process is dependent on primary wood type. All processes have the same goal-to release the fibrous cellulose from its surrounding lignin. Fibres are bleached prior to papermaking

Papermaking

Beating - improves fibre qualities
Pulp blending - to achieve desired properties
Refining - addition of fillers, sizes and dyes.
Dewatering
Drying
Smoothing

Water Consumption Steps

Pulping

- Debarking
- Mechanical Pulping
- Chemical Pulping
- Bleaching

Papermaking

- De-inking (Wastepaper only)
- Steam raising
- Cooling
- Process

Water Consumption (all values in m^3/tonne)

UK Average PIRA	Average over whole of industry	35
UK, well designed (PIRA)	Production of paper from wastepaper	3.72
Netherlands Average (PIRA)	Average of 18 mills	8.5
Fine Paper (AIChE)	Modern system with closed white-water system	13.64
Newsprint (AIChE)		2.27

Reference (ETBPP, Based on a UK Survey)

	Minimum	Maximum	Mean
Packaging Board	1	50	14
Corrugated Case	2	46	23
Newsprint	---	---	29
Printings/Writings	2	68	32
Tissue	44	75	60
Speciality	18	180	38

Note: Water consumption is directly linked to paper quality (e.g. fine paper or newsprint) and starting material (e.g. wood pulp or wastepaper)

Water Reuse/Reduction Issues

- Closed circuit is feasible and has been demonstrated in Canada (dependant on paper quality)
- Mechanical seals rather than liquid seals on pumps
- Close-up bleaching operation by use of chlorine-free bleaching
- Reduced water use can result in increased discharge levels and non-compliance with discharge standards

- Improve white water systems
    - correct design and sizing
    - separate white water systems for each paper machine
    - storing pulp at a higher consistency
    - effective maintenance and operation of fibre recovery systems

- White water recycling
    - dilution of fibre raw materials
    - dilution of fillers

- Shower water systems
    - use of white water rather than fresh water. Not suitable for all locations.

32. THE PRODUCTION OF FRESH RED MEAT (Ref. 41)

Processing Steps

Mechanical Processing and Handling -	Animals are brought from lairage and are stunned, bled and then passed to the dressing lines Dressing involves hide or pelt removal and the evisceration of the carcass. The resulting by-products are separately processed for edible and inedible use. Processing of pig meat differs in that the skin is not removed. The usual method is for the pig carcass to pass through a scald tank or a set of steam sprays to loosen hair, followed by scraping to remove the hair. The carcass is finished by singeing.
Chilling -	Carcasses are chilled in batch chillers to less than 7°C prior to dispatch to cutting plants, wholesalers or on to further processing.
Cutting -	Takes place in a temperature controlled environment. The carcasses are prepared into specific meat cuts, vacuum or gas film packaged, boxed then palletised. Products are stored in dispatch chillrooms or cold stores for long term storage and dispatch.
Further Processed meats -	Pigmeat for curing is injected with curing solution and immersed in a brine tank, followed by curing. Meats for smoking are transferred to smoke houses or smoking units where they are cooled by showering with water/brine.

Water-Use Steps

- Cleaning
- Sterilising
- Injection and Curing
- Scalding

Water Consumption (all values in m^3/tonne)

	Lamb only	Beef & Lamb only	Multi-Species	Beef Only	Pig Meat Only
Average	2.2	3.3	4.7	5.8	8.9
Best Available	1.6	2.36	0.2	4.27	3.34

Note: No significant differences in the specific water consumption due to production level.

Water Reduction/Reuse Actions

- Water monitoring and management system
- Maximise condensate return to boiler house
- Trigger action hose guns in washdown
- Plastic cylindrical basins to minimise evaporative losses from sterilisers
- Metering valves to reduce water wastage from steriliser basins

- Cover water surface in scald tanks with plastic balls
- Direct hot water spray scalding and carcass brushing to replace singeing plant

33. POULTRY PROCESSING (Ref. 59)

Processing Steps

Reception area	Live birds are normally delivered to an abattoir in crates. The reception area is kept clean for hygienic reasons by frequent wash-down. Crate washing is also practised.
Slaughter area	Birds are stunned by immersing the head and neck in an electrified water bath. Throats are slit.
Scalding and Defeathering	Birds are bled and then immersed in a scalding tank operating at 50-55°C in order to loosen the feathers. Following scalding, birds are defeathered. Feathers are collected in a flume and pumped over screens before further processing
Evisceration	Head and Feet are removed and carcasses are sprayed with chlorinated water. Carcasses are cut open, viscera pulled out for inspection and then sorted into edible and inedible offal. Offal is transported in water flumes
Chilling	Birds are chilled to below 10°C using chilled water.
General Washing	Process areas are regularly cleaned as are vehicles
By-product Processing	Rendering of blood, feathers, inedible offal and condemned carcasses produces a saleable product. Water is used to wash rendering cookers. Water cooled condensers are used to condense malodorous vapours leaving the cookers.

Water -Use Steps

Cleaning
Chilling
Offal and feather transport
Condensers and Absorption columns

Water Consumption (all values in litres/bird)

	>10000 birds/day	< 10000 birds/day
Average	17	20
Range	15 - 20	15 - 30
Best Available	15	20

Water Reduction/Reuse Actions

Dry clean-up - e.g. removing all dry waste from floor before cleaning with water
Water monitoring and management system
Maximise condensate return to boiler house
Trigger action hose guns in washdown
Metering valves to reduce water wastage from steriliser basins
Direct hot water spray scalding and carcass brushing to replace singeing plant

34. VEHICLE MANUFACTURE (Ref.13, 72,78, 88)

Water Use Steps

- Engine test bed cooling

Production

Water Consumption

	Passenger Vehicle (car)	Commercial Vehicle	Engine Manufacture
Average	2.6 - 8.0 m^3	12 - 16.0 m^3	0.04m^3

Water Reuse Options

- Cooling water recycle
- Cascade rinsing in metal finishing operations.

35. LEATHER TANNING (Ref. 24, 40)

Processing Steps

Soaking - To remove blood, manure and dirt

Lime painting - Lime paste is applied to flesh side of hides to loosen wool
Mechanical de-wooling machine removes wool from hides
Dewooled hides are dipped in a lime vat to remove epidermis and any remaining hair.

Fleshing operation - Hides are pressed by a roller and shaved
Rolling drum removes liming solution from hide
Addition of salts, kerosene and degreasing agents to degrease hides
pH adjustment with acid solution

Chromium tanning - Chromium sulphate solution stabilises the collagen in the hide
Wet hides are aged for 24 hours on pallets

After tanning and ageing, the hides are wrung and shaved. The hides are neutralised with sodium carbonate. After rinsing, the hides are retanned by adding fat liquoring compounds that give the letter its feel and suppleness. The hides are then rinsed, air dried, trimmed, stretched, and pinned to a metal net for dying.

Water-Use Steps

- Soaking
- Liming
- Tanning
- Washing

Water Consumption

	m^3/tonne
Average , Chrome tanning	40 - 67
Average, Vegetable tanning	16 - 27

Water Reduction/Reuse Actions

Effluent recycle from secondary treatment to pre-tanning step.
Reuse effluent from liming wash.

36. TEXTILE MANUFACTURE (Ref. 60-69)

Processing Steps - Natural Fibres

In its broadest sense, the textile industry includes the production of yarn, fabric and finished goods. This discussion briefly outlines the four main production stages; yarn formation, fabric formation, wet processing, fabrication.

Yarn Formation

Textile fibres are converted into yarn by grouping and twisting operations used to bind them together. Natural fibres are processed as follows:

Opening/Blending - Bales of fibres are separated.
Carding - Fibres are mechanically aligned into parallel sheets
Combing - Similar operation to carding
Drawing - fibres are combined and stretched into a rope-like strand. Blending of fibres may occur.
Drafting - Yarn is stretched further on a frame
Spinning - Fibres are spun together into yarn

Fabric Formation

The major methods of fabric formation are weaving and knitting. Yarn is normally coated with a size solution before processing to prevent snagging and abrasion.

Wet processing

Woven and knit fabrics cannot be processed into apparel and other finished goods until the fabrics have passed through several water intensive wet processing stages. Wet processing involves the following stages:

Singeing - Protruding fibres are burnt to give the fabric a smooth finish
Desizing - Size solution is removed by enzymatic action
Scouring - Fabric is cleaned using alkali solution
Bleaching - Decolourises fabric prior to printing
Mercerising - Improves dyeability of cotton goods

Dyeing - Addition of colour to the textile. Many different methods are available
Printing - Variety of techniques including rotary screen, direct, discharge, resist, ink-jet and heat transfer
Finishing - Chemical and mechanical treatments performed on the yarn or fabric to improve appearance, texture or performance

Processing Steps - Man-made Fibres

Viscose fibres

Viscose fibres are regenerated cellulose fibres derived from wood pulp. Typical processing is as follows:

- Pulping of Wood
- Purification of Pulp - bleaching and pressing operations
- Alkalisation - Loosen cellulose fibres by immersion in alkali
- Shredding
- Ageing/Preripening
- Xanthanation - formation of cellulose xanthanate by reaction with carbon disulphide that is then dissolved in a weak solution of caustic soda.
- Spinning - viscose solution is extruded into an acid bath.
- After treatment - Filaments are stretched, washed, twisted and wound on to bobbins.

Acrylic

Acrylic or polyacrylic is a fibre produced from acrylonitrile by forcing the acrylonitrile to undergo a polymerisation reaction with various combinations of styrene, vinyl acetate, vinyl bromide, and vinyl chloride in the presence of an activator, and a catalyst. The resulting polymer is shaped into fibre by dry or wet spinning. Aftertreatments include washing, drawing, finishing and crimping

Water Consumption

Fibre	Process	Water Usage (m^3/tonne)
Cotton	Desizing	3 - 9
	Scouring or Kiering	26 - 43
	Bleaching	3 - 124
	Mercerising	232 - 308
	Dyeing	8 - 300
Wool	Scouring	46 - 100
	Dyeing	16 - 22
	Washing	334 - 835
	Neutralisation	104 - 131
	Bleaching	3 - 22
Nylon	Scouring	50 - 67
	Dyeing	17 - 33
Acrylic	Scouring	50 - 67
	Dying	17 - 33
	Final scour	67 - 83

Polyester	Scouring Dyeing Final scour	25 - 42 17 - 33 17 - 33
Viscose	Scouring and dyeing Salt bath	17 - 33 4 - 13
Acetate	Scouring and dyeing	33 - 50

37. WALLCOVERINGS (Ref. 90)

Processing Steps

The basic process consists of coating and printing paper to produce the product which is then cut and assembled as a roll. The exact nature of the coating and printing depends upon the specification of the product designs that are constantly changing to meet the fashion demands of the market.

Water-Use Steps

- preparation of coating agents
- cleandown
- process cooling
- steam heating

Water Consumption (litres per roll of product)

Average Range	1 - 5

Water Reduction/Reuse Steps

Efficient cleaning methods and coating make-up procedures.
Recycling of cooling water.
Efficient steam system, including condensate return and minimum leaks.

2.3.3 Water consumption by purpose for various industrial sectors.

The graph on the following page, depicts water consumption by purpose for various industrial sectors. Data has been taken from the Census of Manufacturers - Water Use in Manufacturing published by the US Department of Commerce (Ref. 96).

The following end purposes are distinguished between:

- Boiler Feed
- Cooling
- Production
- Sanitary
- Other

As would be expected, the major use in all sub-sectors is production and cooling.

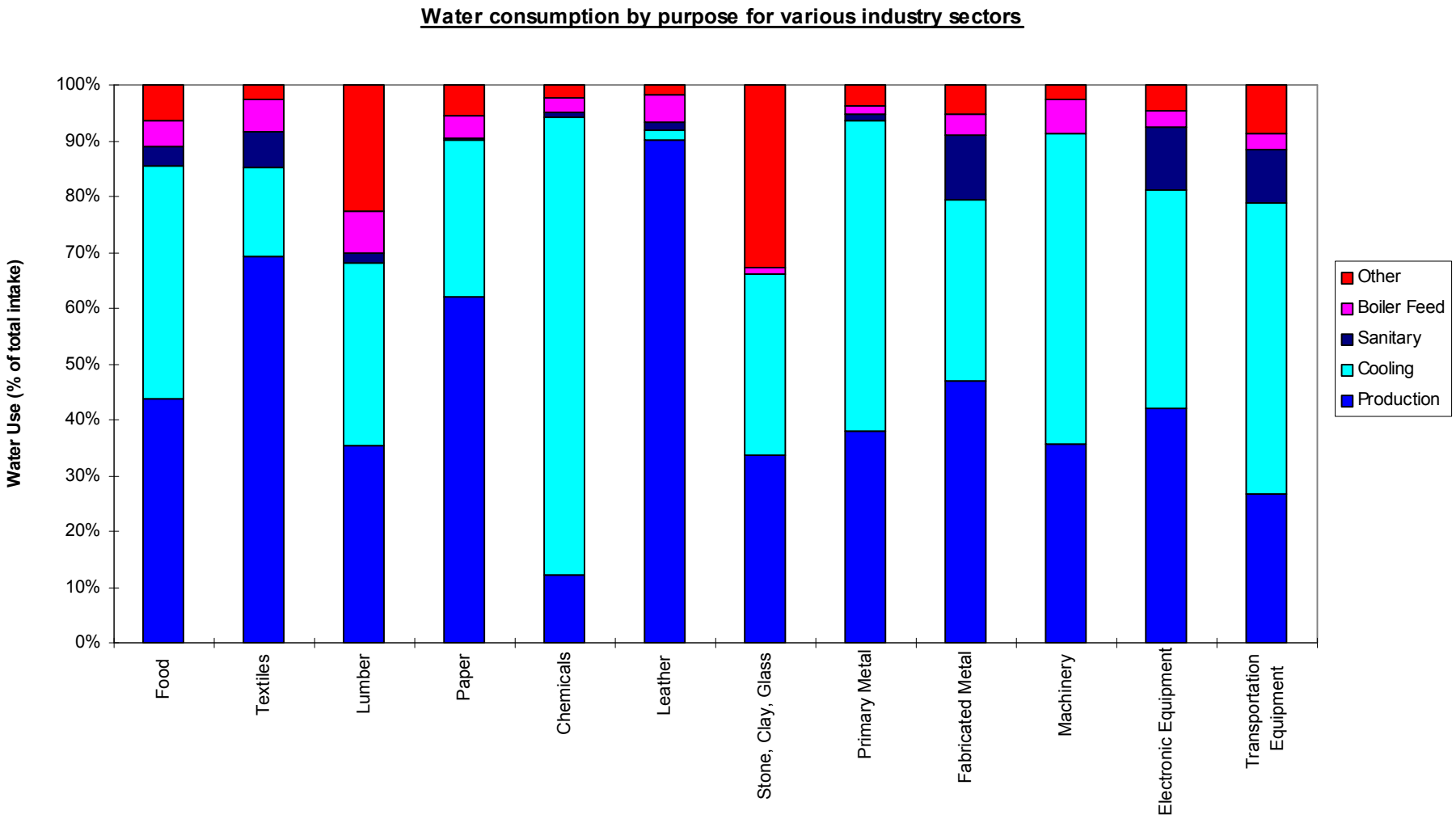

Fig 2.1: Water consumption by purpose for various industry sectors

2.4. Potential for Minimisation of Water Consumption

The typical usage of water by an industrial site is greater than the absolute, theoretical minimum necessary. The degree by which a particular site exceeds this minimum is usually determined by historical development of the process which in its turn was usually influenced by the cost of implementing water reduction measures compared to the cost savings.

However, in relatively recent times many companies (Ref. 31, 32, 37) have created significant reductions in their consumption of water by applying a systematic waste minimisation approach. The basic methodology is described in reference 38 and reductions of 50% are not uncommon.

These companies have achieved reductions in consumption in cost effective ways that have sometimes reset the benchmarks for their industry. Therefore, it is impossible to accurately predict the minimum water usage that may be achieved from a concerted effort to minimise its usage.

Best practice is considered to be a continual improvement management system that monitors the water consumption and compares the results to the industry benchmark and to its own targets for improvement. In addition, the company should continually strive to seek out new ideas to reduce consumption of water and should have a programme for this linked to quantitative improvement targets.

The 'best available' data in Section 2.3 attempts to define consumption after a company has undergone a waste reduction programme.

A company that has vigorously pursued a water reduction programme may typically only have potential to reduce water by a further 5-10% over a 1 to 5 year period. Otherwise, a company may have the potential to improve by 50% over a similar period.

Many of the publications referred to in this document offer excellent information on water reuse and reduction strategies for industry. The following publications, are recommended for further reading.

- Cutting Water and Effluent Costs, IChemE, 1995
- Water Use and Reuse, IChemE, 1994
- Environmental Technology Best Practice Programme (ETBPP) publications. A full list of publications is available from the ETBPP helpline, Tel No. 0800 585794

2.5. Conclusions

- Industry consists of many diverse sectors and water consumption is not a significant cost to many sectors.

- Those industries that consume significant quantities of water are usually aware of the quantity consumed per unit of production but may not necessarily publish the data.

- Reasonable data exists for sufficient industries to produce the data in this report.

- More data could be collected but this would require significant resource to contact a representative sample of the industry sector.

- The data in this report can be used to benchmark a particular company in order to gain a preliminary view of their efficiency of use of water.

- In most industry sectors, the best available value for water consumption could be reduced but this may require significant investment and may not be the best environmental option.

3.0 POTENTIAL FUTURE RESEARCH

3.1 Water Consumption in Agriculture

3.1.1 Mapping of Irrigation Demand

The irrigation demand computations described in Section 1.2 were based upon long term daily weather data from 11 different weather stations. These stations with their corresponding $PSMD_g$ are as follows:

Station	$PSMD_g$	Agroclimatic Zone
Cardington, Bedford	231 mm	7
Gatwick, W.Sussex	162 mm	5
Keele, Staff	82 mm	2
Mepal, Camb	219 mm	7
Morley, Norfolk	157 mm	5
Rosewarme, Cornwall	102 mm	3
Shawbury, Shropshire	130 mm	4
Silsoe, Bedford	198 mm	6
Wattisham, Suffolk	218 mm	7
Wellesbourne, Warks	171 mm	5
Wisley, Surrey	193 mm	6

Although these stations provide a reasonable degree of confidence for defining irrigation demand it was suggested at the EA Abstraction Licensing Group meeting on 22.1.98 that local users of the manual would have their confidence in the accuracy of the approach enhanced if they could see that a relatively local weather station had been used in the analysis (particularly in the areas of main irrigation demand). In addition, station cover for the lower PSMD zones is relatively poor although irrigation demand in these areas is generally low.

In order to overcome these problems it was suggested that approximately 10 further stations could be included as an extension to the existing study. Should this further work proceed, these stations should be broadly located within the following areas:

SE Essex, Kent, Central Fens, Nottinghamshire, Vale of York, Vale of Evesham and the Hants/Wilts area. Two stations should represent agroclimatic zones 1-4, and there should be at least two stations in each of zones 5, 6 and 7.

The proposed approach for selecting the additional stations and the associated costs, is set out in a separate letter to the Environment Agency's Project Manager.

3.1.2 Additional crops

The main irrigated field crops have been included in the analysis but only representative crops have been included for vegetables (carrots), small fruit (strawberries) and orchard fruit (apples). At the ALG meeting on 22.1.98 the group suggested that the list should be expanded to include all significant irrigated crops. These would comprise vining peas, cabbage, runner beans, brussels sprouts, cauliflowers, lettuce, onions, parsnips, raspberries, blackberries and nursery stock. Golf courses would also be included bringing the total number of crops covered to 20. Additionally glasshouse demand would also be considered.

The time and cost for undertaking this work is also set out in the letter to the Project Manager already referred to above.

3.1.3 Irrigation regimes

At the ALG meeting of 20.5.98 concern was expressed that much of the advice on irrigation offered nationally was in fact based on the East Anglia experience. In discussing irrigation regimes it was pointed out that quite different regimes for irrigating potatoes can be used in different parts of the country. In particular it was pointed out that the data in Table 1.5 could be more regionalised for certain crops.

A possible means of doing this would be to undertake consultation on irrigation regimes using specific regional centres (eg research stations and commercial irrigation advisory services) to provide comment on the regimes proposed and to suggest modifications to suit their local conditions.

A balance would need to be found between providing adequate regional cover and developing a too complex system. The review of actual irrigation demand, discussed in 3.1.5 below, would show the relative significance of irrigation in particular areas and would provide an indicator of the level of detail that may be appropriate for that area.

3.1.4 Presentation of PSMDg data

The Abstraction Licensing Group have expressed a number of views as to how best to finally present the PSMDg maps. There is some measure of agreement that 1:250,000 regional maps, including background details would be satisfactory. These could then be used as wall maps for locating individual sites.

The production of a table of values for each 5 km square was favoured by one of the group members but not by the majority.

Alternative means of presentation could be explored and mock-ups presented to show the effects of scale etc.

3.1.5 Examination of actual irrigation use

The study has so far produced guidelines based on design dry year irrigation need. There has been a suggestion (from the National Water Demand Management Centre) in commenting on the draft of this report, that there is a need to examine average and actual water use.

Data on actual irrigation use is retained by the EA and a comparison of actual water use and licensed abstraction in any one year against the predicted use would be instructive. However data on individual crop areas receiving irrigation would not be available. Broad estimates of crop distribution could be made but more accurate data would be obtained by taking a number of individual farm case studies in different parts of the country and looking at irrigation use on the farm in some detail over a number of years. This would yield useful data on why actual abstraction is often only half the licensed quantity even in dry years.

3.2 Water Consumption in Industry

3.2.1 Updating the information

The 'benchmark' data provided by this Manual will need to be kept up to date for it to be useful. The methods of achieving this could be explored and an effective system recommended.

3.2.2 IPC applications

The IPC chemical companies were not covered because they tend to need water on a process by process basis and there are many thousands of such processes each unrelated in water demand even if the product is similar. However, the IPC application could be modified so that key parameters such as water consumption per tonne of product were defined. This would allow the regulator to monitor progress but this is also a key step in encouraging the manufacturer to explore ways of reducing demand. There are now plenty of examples to demonstrate the economic benefits of this to the manufacturer as well as the environment.

For example, tissue manufacture around 1985 consumed 290 m^3 per tonne of tissue produced and recognised 60 m^3 per tonne as the then 'best available'. Now the target is 10 to 15 m^3 per tonne.

3.2.3 Cost/benefit analysis

Reuse and recycling of water within Industry is readily achievable but water saving strategies have an associated cost. A cost/benefit analysis could be undertaken for all industry sectors. Such analysis would reveal the costs and benefits associated with water reduction strategies. Additionally, the data set could be used in defining the increase in unit cost of water supplied to Industry to achieve a given reduction in water consumption.

3.2.4 Unit volume data from EA Licence applications

As new licence applications are processed by the Agency it is recommended that the unit volume data for different industrial processes is collated to form a new dataset. This could then be compared against the consumption data included in this Manual.

3.3 Dissemination and Training

At the ALG meeting of 20.5.98 group members were asked to undertake a trial exercise to test the procedures proposed in this report for agriculture and industry. As a result it was agreed that licensing officers in each region would need possibly a one day seminar/training session to introduce them to the background concepts and to have the opportunity to work through examples under supervision.

Data collected in this and subsequent studies could be made readily available to interested parties, including members of the public by creating an Internet site or adapting the existing Environment Agency Web site. The following information could be included:

- Information on water related research projects (past, present and future)
- On-line and down loadable copies of research reports and Best Practice Manuals.
- General information on water reduction/ recycle strategies
- Recommended publications list
- On-line water consumption and reuse questionnaire.

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NALD ABSTRACTION PURPOSE CODE MATRIX

Code	Primary Category	Code	Secondary Category
W	Water Supply	PRV	Private water Supply
		PWU	Private Water Undertaking
		PWS	Public Water Supply
		WAT	Water Supply Related
A	Agriculture	AQF	Aquaculture Fish
		AQP	Aquaculture Plant
		FOR	Forestry
		AGR	General Agriculture
		HOR	Horticulture and Nurseries
		ORC	Orchards
		ZOO	Zoos/Kennels/Stables
I	Industrial, Commercial, Public Services	BRW	Breweries/ Wine
		BUS	Business Parks
		CHE	Chemicals
		CON	Construction
		CRN	Crown and Government
		DAR	Dairies
		EXT	Extractive
		FAD	Food and Drink
		GOF	Golf Courses
		HOL	Holiday Sites, camp Sites and Tourist Attractions
		HOS	Hospitals
		HTL	Hotels, Public Houses, and Conference Centres
		LAU	Laundry
		MCH	Machinery and Electronics
		MTL	Metal
		MIN	Mineral Products
		MUN	Municipal Grounds
		NAV	Navigation
		OTI	Other Industrial/ Commercial/ Public Services
		PAP	Paper and printing
		PET	Petrochemicals
		PAD	Public administration
		RAC	Race courses
		REF	Refuse and Recycling
		RES	Research non University/ College
		RET	Retail
		RUB	Rubber
		SCH	Schools and colleges
		SLA	Slaughtering
		SPO	Sports Ground/ Facilities
		TXT	Textiles and Leather
		TRA	transport
P	Production of Energy	ELC	Electricity
		MEC	Mechanical Non Electrical
E	Environmental	NRE	Non - Remedial River/ Wetland Support
		OTE	Other Environmental Improvement
		PUM	Pump and Treat
		REM	Remedial River/ Wetland Support
M	Amenity	IND	Industrial/commercial/Energy/Public services
		PRI	Private non industrial