Garden management in a changing climate

In this chapter, the components of a garden are taken individually and the potential impacts of climate change on each are considered in relation to the domestic and the heritage garden. Some of the costs associated with managing the impacts of climate change in gardens are identified in Box 6.1 at the end of this chapter.

6.1 Climate change impacts on soil

While much attention has been paid to changes in the aerial environment in response to climate change, our review suggests there has been much less work on soil. Soil changes brought about by climate change will have a very profound influence on plant growth, and garden management and use. These issues are considered briefly here.

The total carbon content of world soils is nearly three times that of above ground biomass, and twice that of the atmosphere (Piccolo and Teshale, 1998) (Figure 16).

Soils under arable cultivation have only 15-20% of the humus content of forest or grassland soils. On a world scale, the conversion of forests and grasslands to cultivated arable has had a major impact in reducing soil carbon content, contributing significantly to the increased carbon dioxide levels in the atmosphere, and hence to climate change. The importance of the soil as a sink for atmospheric carbon (Lal, 2000; Pearce, 1998), the effect of climate change on the soil itself (Norby and Jackson, 2000) and the vulnerability of organic soils (Bragg and Tallis, 2001) and wetlands (Winter, 2000), have all been considered to some extent at the agricultural level and in natural ecosystems, but these topics apply equally in gardens.

Changes in atmospheric levels of carbon dioxide will, in itself, not have a significant impact on soils, because carbon dioxide diffuses from the soil into the atmosphere, rather than from atmosphere to soil. The higher temperatures resulting from climate change will be more important. As soil temperature increases, so does the rate of biological activity in the soil. Higher temperatures typically result in increased breakdown of soil organic matter, releasing available nitrogen in the process and thus increasing plant growth (Medlyn *et al*., 2000).

However, higher air temperatures will substantially increase evapo-transpiration by plants, thereby reducing soil moisture content. In experiments at Cambridge, a 3°C increase in soil temperature caused a 30% increase in evapo-transpiration (Jeffery, 2001) and a 25% decrease in soil moisture (Harte *et al*., 1995). The UKCIP02 scenarios all point to higher soil moisture deficits over increasingly longer periods across the UK in the future. In conditions of extreme drought, this will result in cessation of organic matter breakdown. However, for most of the time, soils will retain some moisture, and the combination of increased aeration (air replacing water in the larger soil pores) and increased temperature will accelerate loss of soil carbon by oxidation to carbon dioxide.

Loss of soil carbon, as organic material is broken down, also results in release and mobilisation of soil nitrogen. Intermittent wetting and drying in early autumn causes accumulation of soil nitrate and, when the soil is once again at field capacity, leaching of this nitrate is increased. Jeffery (2001) measured a 47% reduction in the volume of drainage from soils heated to 3°C above ambient, but a doubling of nitrate loss in drainage water. Imposition of a two month drought during the experiments increased nitrogen loss from the soil, when the drought ended.

The principal effects of climate change on soils will be to accelerate loss of soil organic matter and to release nutrients in increasing amounts. These increases in oxidation of soil organic matter and mobilisation of soil nitrogen cannot continue indefinitely. If not replaced by natural processes or during cultivation, carbon content and nutrient status of the soil will be diminished, causing loss of fertility. Broadmeadow (2002a) suggests that microbial breakdown of leaf litter with increased carbon:nitrogen ratios, as plants fix atmospheric carbon dioxide in a scenario of reduced availability of soil nitrogen, will result in further reductions of available soil nitrogen to the point that plant growth will be adversely affected.

Loss of organic matter will also result in loss of soil structure. The soil therefore becomes more susceptible to wind erosion in the drier summers anticipated by the climate change scenarios, and less permeable to water, leading to increased water erosion and run-off in the heavier downpours of wetter winters (Piccolo, 1998).

When mobilisation of soil nitrogen coincides with a slowing of plant growth in the autumn, much of the nitrate will be lost from the soil in drainage water, possibly causing problems elsewhere in pollution of streams, ponds and lakes and adding to the problems being caused by increasing levels of nitrous oxide present in the atmosphere (see section 6.2.2).

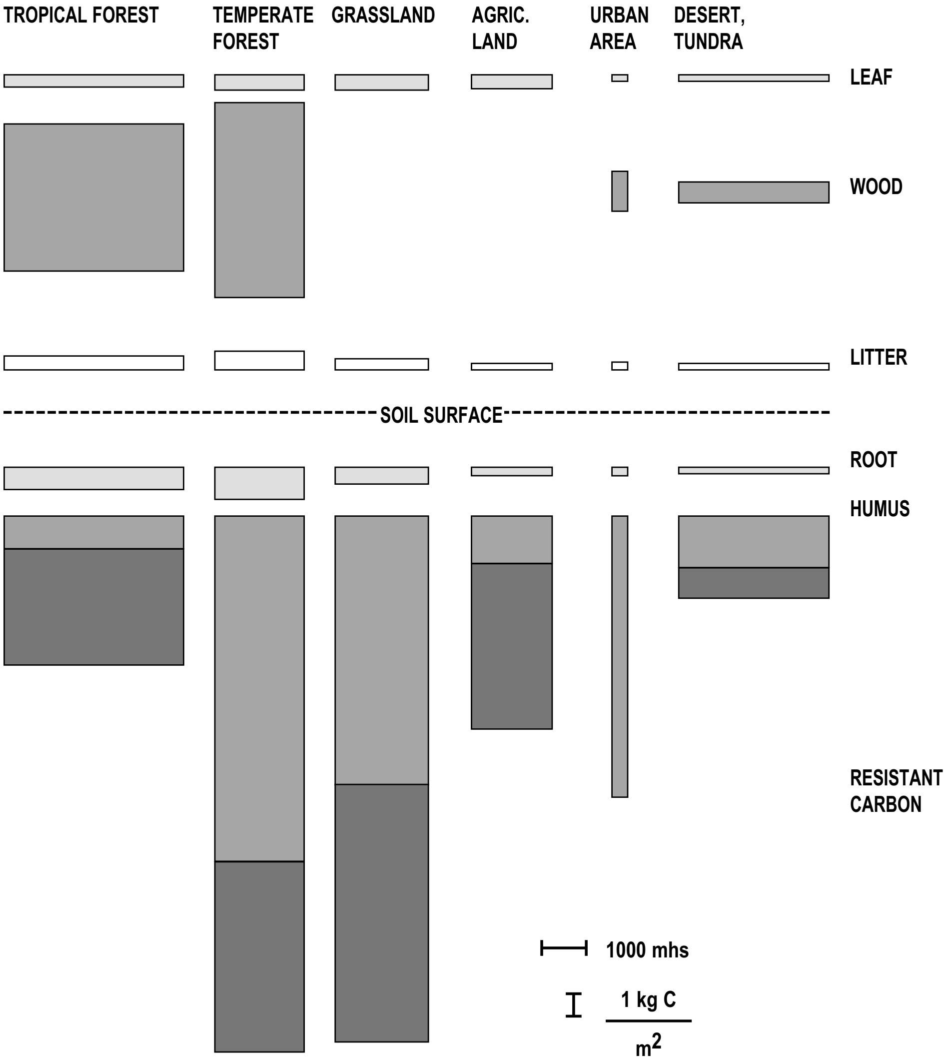

Figure 16: Carbon in the soil as compared to carbon stored in land cover. *Source: Piccolo, 1996.*

6.1.1 Climate change impacts on particular soils

The local effects of these changes on gardens will depend on soil type. In light, freely drained soils the increased biological activity in warmer and wetter winter months will lead to increasingly rapid loss of organic matter, and thus to increased susceptibility to erosion. Organic matter loss will also reduce waterholding capacity of the soil and further accelerate and exacerbate effects of summer drought as summer rainfall decreases.

Highly organic soils are at risk of rapid oxidation as the combined effects of increased evapo-transpiration and reduced summer rainfall lead to aeration of previously waterlogged profiles. The most dramatic example of this is in the East Anglian fens, where soil levels have dropped by tens of metres since the area was drained for cultivation in the 17th century. The loss, both by oxidation and wind erosion, is continuing to the extent that large areas will soon be unsuitable for commercial crop production.

A similar, though less visible, problem exists in upland areas where increasing oxidation of peat soils will not only affect the natural vegetation in SSSI and other designated areas, but may expose archaeological remains which are important cultural components of many parkland and garden landscapes (Farrar and Vaze, 2000).

Heavy soils may retain sufficient water and nutrients to sustain plant growth through the summer months, despite the drier regime, though on very retentive clay soils water available to plants will be much less than that held by the soil. However, these heavy soils may suffer from waterlogging in winter.

One obvious sensible response to climate change will be to work within constraints imposed by soil conditions. The need, also, to maintain or improve soil organic matter content, and hence its waterholding capacity, and to ensure adequate drainage, can not be over-emphasised.

i) Domestic gardens

The soil in the smaller, domestic garden is likely to have been much modified from the natural state during construction of the house and other built structures, such as drains, paths and driveways. There is potential for soil improvements to be made to minimise the effects of climate change. For example, the structure and nutritional status of soils can be improved by incorporating organic material and by mulching to reduce loss of organic matter as temperatures increase. Incorporation of grit or the construction of raised beds can counter the risk of waterlogging from heavy winter rains.

Such treatments will also ameliorate the impact of increased drought and increase the infiltration of heavy rainfall. The cost per square metre of these treatments, especially if materials are bought in small units at retail prices, will be very high, but the area to be treated will generally be small.

ii) Heritage gardens

There may be some scope for soil amendment and improvement in the intensively managed parts of heritage gardens, as in the domestic garden. The availability of leaf litter and other organic waste, and the availability of machinery for shredding, composting, transporting and incorporating organic matter will make handling relatively easier than in the domestic garden, though at considerable capital cost.

In less intensively managed areas, the prevention or reversal of soil deterioration will depend on maintenance of plant cover, retention of fallen leaves (perhaps using strategically placed plant groups to minimise wind-blow of leaves onto paths or lawns) and, where acceptable, return of lawn clippings to maintain organic matter levels and an open soil surface.

On slopes, it may be necessary to use interceptor gullies and soakaways to reduce soil erosion risks. Regular maintenance, perhaps upgrading and renewal of drainage systems will also be necessary.

Traditional gardening techniques have always been directed at maintaining fertile, water retentive, but well-aerated soil. The challenge in the 21st century will be to continue that tradition in the face of limited and often dwindling resources.

The reduction of soil carbon by clearing forests and ploughing grassland has been a major contributor to climate change. Soils are, in turn, significantly affected by climate change. Many factors interact in determining the soil's susceptibility to climate change.

Increase in temperature will increase the rate of loss of soil carbon by oxidation. This will lead to loss of soil structure and loss of permeability, so intense rainfalls may cause run-off (and therefore erosion and flooding) rather than the recharge of soil moisture reserves. Oxidation of soil organic matter also releases nitrates, which may increase plant growth, or leach out of the soil to pollute rivers and lakes.

Decreased rainfall will slow conversion of soil carbon to carbon dioxide, but the relationship is complicated and effect will differ from day to day. Usually, plants will cease to take up water (and therefore nitrates) from the soil before the soil has dried to the extent that organic matter breakdown stops. Nitrates will therefore accumulate in the soil and be leached out in heavy rains.

Highly organic soils, in fen and moorland areas, will be most susceptible to climate change and may lose their ability to support their characteristic vegetation.

Any action which increases soil organic matter will help to reduce all these problems and thereby will reduce the cause, as well as the impact, of climate change. Caring for and covering the soil will play a significant role in countering the adverse impacts of climate change.

6.2 Climate change impacts on water

Water exists in two forms in gardens: water supplies are used for irrigation; water features provide aesthetic, and often ecological and productive, benefits. In practice the two components are often linked. At the simplest level, a hosepipe (water supply) can be used to top up a garden pond, while the pond (a water body) can be used to fill a watering can. On a larger scale, a borehole might be used to fill a lake, while a lake or stream might provide a water supply for irrigation or domestic use.

The availability of water for use and its presence in water features is determined by the hydrological cycle. A very brief and much simplified description of the cycle is provided in Box 6.2, to set the important topic of climate change impacts on water into context.

6.2.1 WATER SUPPLIES

Water supply for human use may be obtained by taking water directly from rivers or by pumping it from underground aquifers. As river flows are uneven and demand is more or less even throughout the year, it becomes necessary to impound and store water in reservoirs, so that large flows in winter can be used to meet large demands through the summer. This is particularly the case in the more hilly and rocky parts of the country, where most water runs off the surface into streams rather than soaking into the soil, so stream flow is most variable.

Much of the water supply in the UK is provided from private water companies on a regional basis, but some users have their own private water supply, either directly from a river or, more commonly, by pumping from a borehole (Table 4). Such extractions require a licence.

Total water abstractions declined between 1971 and 1991 as a result of the closure of old, watercooled power stations and the decline of heavy industry (Table 4). Indeed the water table is rising under major cities in the UK as a result of this decline, threatening an increased risk of flooding and a danger of pollution of water supplies, as the water table rises through industrially polluted soils (Shackley and Wood, 1998). In the same period, public water supply increased from 14-18 billion litres per day, an increase from 34%-51% of total water abstractions, partly as a response to some increase in population, but mainly as a result of higher living standards.

The direct impact of climate change on overall demand for water is expected to be rather small. The main uses of water – for cooling of power stations in industry, and domestically for flushing toilets and washing clothes – will be little affected by climate change. The likelihood, though, of reduced supply as a result of climate change will present challenges in

Box 6.2 The Hydrological Cycle

The primary source of water supply is from precipitation. Water reaching the soil surface will either be absorbed into the surface or will run off. Water filtering down through the soil and underlying rocks will eventually reach an impermeable layer, above which it will accumulate to form an underground zone in which pores in the rock are more or less saturated with water. This natural reservoir is called an aquifer, and the level of water in the aquifer is the water table.

Because of inequalities in the soil and in the underlying rocks, this water table will sometimes reach the soil surface and the water will bubble out as a spring. For example, where a thick stratum of chalk (a very porous rock) overlies impervious clay, water will accumulate on top of the clay layer and emerge wherever the chalk/clay interface is exposed at the ground surface, to form a line of springs along a hillside. Water from the springs will flow down hill in streams. These streams meet each other and build into rivers, which make their way down to the sea.

It usually takes months or years for a drop of water arriving at the soil surface to filter down through the soil to the water table and then to emerge at the surface again, so short term fluctuations in precipitation are evened out and the output from springs is much less variable than is the input of rainfall. There will be a gradual increase of stream levels in winter, and a gradual decline in summer but day to day fluctuations are eliminated.

If water does not soak into the soil, but instead runs across the surface, it will flow down hill carrying with it soil particles. Trickles of water coalesce to form runnels, then streamlets and streams. Erosion of the land, as soil particles are carried down by the water, creates channels which determine the future course of the streams. As these channels become more clearly defined, the concentration of water increases and, with it, the ability to carry more sediment, including larger stones and rocks.

Surface run-off feeds into streams quickly, so the level and force of the stream will increase rapidly during periods of rainfall and decrease equally quickly when the rain stops. In heavy rains, the stream channel will be inadequate to carry the extra volume of water; the water will flood onto surrounding land, depositing most of the silt it carries and, in time, building up a flood plain. Some of the flood water will drain back into the stream as its level drops. Some will soak into the surface to replenish the water table. By eroding and depositing soil, the stream will gradually reshape the landscape.

In a natural ecosystem, rivers and streams will have a more or less steady base flow of water emerging from springs throughout the year, supplemented by short term increases of water from run-off after periods of rain or snow-melt. If the land surface is made less pervious, by compacting the surface or by covering it with concrete or tarmac, for example, infiltration and the steady base flow will be reduced, and the flash flows after rainfall will increase. The long term effects of this are to increase the risk of flooding, and to deplete groundwater reserves which feed the steady flow of streams and rivers.

Loss of groundwater is exacerbated by extraction for domestic, industrial and agricultural use. Decrease in surface permeability as a result of development also increases the sensitivity of the hydrological system to short term heavy downpours, and so greatly increases the risk of sudden floods in heavy rainstorms. Flooding is further exacerbated by channelling water into drains and river channels, which pass the problem more rapidly downstream. Every step in the process, from absorbent forest soil, to grassland, to bare arable soil, to tarmac accelerates and exacerbates the change from steady year-round flow of rivers and streams, to the sudden oscillations from spates after rainfall, to low base flows, and intensifies the problems of insufficient water supply to dilute pollutants. In the most extreme cases, streams will dry up completely in dry periods then turn into raging torrents for a few hours or days after heavy rainstorms.

Climate change is likely to intensify the hydrological cycle. Rates of evaporation will increase due to higher temperatures, variability of precipitation will increase (with increases in winter and decreases in spring, summer and autumn), as will variability of run-off owing to more intense rainfall. Water and soil management will be inextricably combined when protecting gardens and the wider landscape from the adverse effects of climate change. Increasing the humus content of the soil will help to reduce the vulnerability of soils to erosion, and to increase their capacity to absorb heavy rainfalls which might otherwise cause flooding.

Table 4: Licensed non-tidal water abstractions in England and Wales, 1971-1991. *Source: Herrington, 1996*

Year	Public Water Supply		Industry		Spray Irrigation		Agriculture		Electricity Generation		Fish farming and watercress production		Total
	Ml/d	% of total	Ml/d	% of total	Ml/d	% of total	Ml/d	% of total	Ml/d	% of total	Ml/d	% of total	Ml/d
1971	14345	33.60	9214	21.58	68	0.16	170	0.40	18896	44.26			42693
1972	14797	34.97	9162	21.65	63	0.15	170	0.40	18118	42.82			42310
1973	15252	36.41	8658	20.67	58	0.14	156	0.37	17767	42.41			41891
1974	15155	40.55	7080	18.94	78	0.21	76	0.20	14988	40.10			37377
1975	15360	42.86	6560	18.30	111	0.31	94	0.26	13714	38.27			35839
1976	15009	42.72	6655	18.94	161	0.46	96	0.27	13211	37.60			35152
1977	14747	41.72	6958	19.68	116	0.33	120	0.34	13406	37.93			35347
1978	15828	44.94	6626	18.81	81	0.23	150	0.43	12539	35.60			35224
1979	16267	45.20	6762	18.79	106	0.29	140	0.39	12710	35.32			35985
1980	16186	46.87	5034	14.58	92	0.27	133	0.39	13087	37.90			34532
1981	16105	48.05	4973	14.84	117	0.35	111	0.33	12208	36.43			33514
1982	16331	48.21	4729	13.96	139	0.41	117	0.35	11587	34.21	970	2.86	33873
1983	16224	48.06	4093	12.13	171	0.51	118	0.35	12179	36.08	971	2.88	33756
1984	16402	49.05	3892	11.64	199	0.60	122	0.36	11757	35.16	1066	3.19	33438
1985	16641	50.95	3939	12.06	137	0.42	130	0.40	10711	32.79	1105	3.38	32663
1986	16592	47.69	4114	11.83	167	0.48	125	0.36	12744	36.63	1048	3.01	34790
1987	17244	49.16	3712	10.58	102	0.29	122	0.35	12806	36.51	1089	3.10	35075
1988	17597	51.21	3901	11.35	144	0.42	120	0.35	11787	34.30	815	2.37	34364
1989	18205	51.64	3654	10.36	298	0.85	115	0.33	12189	34.57	794	2.25	35255
1990	18336	50.66	3795	10.49	378	1.04	129	0.36	12612	34.84	946	2.61	36196
1991	18181	50.78	3800	10.61	365	1.02	134	0.37	12430	34.72	895	2.50	35805

meeting even a modest anticipated increase in demand. The UKCIP02 scenarios all point to greater water deficits in summer and autumn months.

In terms of impact on overall demand for water, the horticultural industry, gardens and golf courses are, and will continue to be, of minor importance.

Water used by farmers and commercial growers for irrigation increased erratically from 68 million litres per day (Ml/d) in 1974 to between 100-200 Ml/d in the period 1974-1988 then rose rapidly to 365 Ml/d in 1991. This increase was a result of general intensification of farming, and the demand from the new supermarkets for regular and predictable supplies of high-quality vegetables, as well as the need for increased irrigation in hot, dry summers. It is not possible to separate out the effects of increased sophistication of production systems from increased need to match higher evaporation levels resulting from climate change, but the total increase represents a change from using 0.16% of the public water supply for irrigation in 1974 to using 1% in 1991. This is a very small proportion but a six-fold increase.

Domestic use in the south and east of England for lawn sprinkling increased from 0.1 litres per capita per day (l/c/d) in 1976 to 4.3 l/c/d in 2001 and, ignoring any effect of climate change, is estimated to rise to 8.7 l/c/d by 2021 (Table 5). The statistics for other garden uses are 1.1, 4.8 and 7.2 l/c/d respectively.

This rapid rise is associated with increased ownership and use of sprinklers, but the extent to which this reflects climate change impacts, as distinct from a general increase in the standard of living (ability to afford sprinklers and time to use them) and in appreciation of gardens, is again uncertain. While the change from 1.2 l/c/d in 1976 to 9.1 l/c/d in 2001 and 15.9 l/c/d in 2021 for lawn and garden watering represents a very large proportional increase it is, and will remain, less then use for personal washing (33.5, 46.5 and 61.6 l/c/d) and represents a change from 1% (1976) to 4.3% (1991) to 8.9% (2021) of total domestic demand in the south east, the driest part of the country.

In his analysis of domestic demand components of water supply for non-metropolitan south and east England 1991/2021, Herrington (1996) calculates that, with a 1.1° rise in temperature by 2021, water use for lawn sprinkling will increase by 35% and for other garden uses by nearly 20%.

Golf courses, with their need to create smooth greens and the current cultural insistence on a lush green setting, are conspicuous consumers of water but, in a national context, not highly significant. An

Table 5: Domestic demand components of water supply for non-metropolitan south and east England in 1981 and 2021 incorporating climate change. *Source: Herrington, 1996*

Component	**1991** Climate standardised	**2021** No climate change	**2021** +1.1°C warming
WC use	35.5	33.6	33.6
Showering	5.3	24.0	26.8
Other personal washing	41.2	37.6	37.6
Clothes washing	21.7	22.0	22.0
Dish washing	11.8	11.0	11.0
Waste disposal unit	0.4	1.5	1.5
Car washing	0.9	1.5	1.5
Lawn sprinkling	2.5	8.7	11.8
Other garden use	3.8	7.2	8.6
Miscellaneous use	23.9	31.3	31.3
Total domestic use	**147.0**	**178.4**	**185.6**

average golf course using the public water supply uses 2.7 million litres of water annually (Table 6). Assuming some increase in the number of golf courses, Herrington (1996) estimates that water demand in the south east for irrigation of golf courses might increase from 3.3 Ml/d (1992) to 4.8 Ml/d (2021) in the absence of climate change.

A 1.1°C increase in temperature by 2021, and a 2.1°C increase by 2051 (similar to temperature changes projected under the UKCIP02 medium high emissions scenario) is expected to add 4% (by 2021) or 8% (by 2051) to the requirements which would be expected in the absence of climate change. This 8% increase compares with estimates of 11.8% increase for agricultural irrigation, and 37.5% increase for air-conditioning. The total of 5 Ml/d estimated water use by golf courses in the south east in 2021 with moderate climate change, represents less than 0.1% of domestic water consumption and is therefore insignificant in terms of the total amount of water used.

These various horticultural uses of water are not large in relation to overall consumption then, but when seasonality of water supplies and peak demands in water use are taken into account, a very different picture emerges.

Not only are the levels of demand increasing rapidly, but the maximum demand for water for horticultural use occurs when water is least available. In a hot year, a golf course increases its water consumption by 40% over use in an average year (Herrington, 1996). Calculations of garden use of water in the Thames and Lee Valley catchments, suggest that public water supplies will need to increase by 1.2% to meet increases in demand related to climate change by 2050 on an annual basis, but this represents a 3-4% increase in demand for the six months April-September, or 7-8% for June-July. In East Anglia, 3% of annual water use in an average household was used in the garden in the wet year of 2001 (Chivers, *pers. comm.*). This figure was 6% in the dry year of 1996. Concentrated in the two driest months, the peak demand may rise to 25% above the average level of water use.

The situation is made worse by the fact that water applied to gardens, unlike water used in washing machines, baths and other household uses, is not returned quickly to replenish river flows. Although in the long term, water for horticultural (and agricultural) use is recycled *via* the hydrological cycle, replenishing the water table by infiltration or recharging clouds by evaporation from plants, substantial extraction of water for irrigation will lead in the short term to falling river levels.

The impacts *of* gardens *on* water demand as a result of climate change will, therefore, be a modest increase in total demand for water, but a very marked increase in peak demand in hot, dry summers. As climate change continues beyond 2050, and as expectations of gardens continue to rise, water use for gardens may cease to be a minor proportion of total domestic demand. Sales of garden watering equipment have risen from £21 million to

Table 6: South and east England golf course water use in 1992 and 2021, without and with climate change (numbers of courses and demand for water). PWS = Public Water Supply; DA = Direct Abstraction.
Source: Herrington, 1996

	1992 No climate change	2021 No climate change	2021 With climate change
PWS only	368 @ 2.70 Ml	546 + 55 @ 2.70 Ml	546 + 55 @ 2.81 Ml
DAs only	288 @ 3.64 Ml	427 + 43 @ 3.64 Ml	427 + 43 @ 3.79
Ml Mixed: PWS	144 @ 1.35 Ml	214 + 22 @ 1.35 Ml	214 + 22 @ 1.40 Ml
Mixed: DAs	144 @ 1.82 Ml	214 + 22 @ 1.82 Ml	214 + 22 @ 1.89 Ml
Total no. of courses	800	1187 + 120	1187 + 120
Water use: PWS	1188 Ml = 3.3 Ml/d	4.8 + 0.5 Ml/d	5.0 + 0.5 Ml/d
Water use: DAs	1310 Ml = 3.6 Ml/d	5.3 + 0.6 Mld	5.5 + Ml/d

£61 million in the past four years but ownership in the UK is still considerably below that of France and Germany, despite the higher proportion of people living in flats in those countries (Ofwat, 2002).

To adapt to these changes, either demand will need to be suppressed, by hosepipe bans or pricing structures, for example, or supplies will need to be increased, mainly by the construction of increasingly expensive reservoirs and in the face of increasing environmental opposition.

The impacts *on* gardens as a result of increasing deficits of natural water supply will come both directly, as a result of reduced rainfall and increased evaporation within the garden, and indirectly as a result of reduced availability or increased cost of water in the public supply system. Water shortage is likely to be the most serious single impact of climate change on gardens. In addition to damage to plants, especially to mature trees, summer drying or serious depletion of lakes in landscape parks is an increasingly frequent phenomenon, usually with serious ecological consequences as well as loss of visual amenity.

Deficits in natural supplies will occur in a context of decreasing availability to the water suppliers and increasing demand for water for other uses, primarily as a result of increased living standards. Gardeners could respond to these deficits in a number of ways. Planting schemes could be adapted to incorporate drought tolerant species (see sections 3.4, 4.2 and 6.3-6.8). Irrigation could be applied, although water for irrigation is likely to become more expensive and perhaps increasingly stringently controlled. Water could also be stored during wet periods to compensate for times of shortage

Water storage could take the form of improved water retention in soil, by mulching and increasing organic matter content, or by installing rain water butts, recycling of ‘grey’ water from baths and washing machines or, on a larger scale, by building reservoirs. Increasingly, users of large volumes of water (farmers, golf courses, nurseries) are building private reservoirs so that they can store (and in the case of nurseries recycle) water for use in times of shortage. Farm reservoir capacity nearly doubled between 1984 and 1995, from 33 million to 64 million cubic metres. This provides about 40% of the current water supply needed for irrigation. A further 30 million cubic metres of storage capacity would cost between £13 million and £73 million depending on individual site conditions (Orson, 1999).

Most such reservoirs are purely functional, regular in shape, steep sided and often fenced for safety. If the land and resources are available, there is no reason why they should not be designed as visually attractive ponds and lakes that could also look attractive (or at least acceptable) when the water level drops during peak extraction periods. The investment might well be worthwhile in large gardens threatened by water shortage. A 45,000m^3 reservoir has recently (September 2002) been completed in The Royal Horticultural Society’s garden at Hyde Hall (Essex) as the central feature of a new environmental area.

Although the use of water butts in domestic gardens might seem a trivial response to climate change, the widespread application of such conservation measures could have a significant impact in reducing peak demands for water. This dispersed storage could also be more economic than centralised provision of expensive and environmentally sensitive reservoirs (Entec, 2000).

Irrigation systems are already being installed in many public and private gardens and are considered to be an essential feature of any new golf course. Irrigation to reduce the impact of water deficits will be subject to availability of sufficient water resources. Continued climate change is likely to result in increasingly stringent control of extraction – perhaps even in the withdrawal of extraction licences – higher cost of water, and the possibility of restrictions on garden use in prolonged droughts, when water is most urgently needed. Trickle irrigation systems and leaky hose, or other surface and sub-surface systems, will economise on water loss by evaporation. But, reducing dependence on external water supplies and prioritising key areas of the garden which most need irrigation, will be increasingly important responses as climate changes intensify.

While reduced precipitation in the summer months will cause increasing shortages of water during the growing season, higher precipitation rates in winter may cause unwanted surpluses. A recent flash flood at Wallington (Northumberland) for example resulted in the collapse of a 17th century garden wall. The sudden release of floodwaters built up behind the wall, then caused severe erosion of paths and borders in the garden. On a wider scale, extensive floods in the winter of 2000/01, which filled news bulletins for many weeks, caused huge losses of property and widespread damage to gardens. The increased volume and intensity of winter precipitation anticipated by the UKCIP02 scenarios is likely to increase flood risk in future. The scale of damage caused by recent flooding events suggests that it would be wise to prepare for similar future events, while the experience gained is still fresh in the mind.

Adaptations might include physical protection of the garden, where possible, by earth mounding or, during Environment Agency flood alerts, preparing sand bags. Safety measures include ensuring that power points, water and gas taps, mower fuel and garden chemicals are installed/stored above anticipated flood levels. Any measures which will slow the flow of water through a garden (encouraging infiltration rather than run-off), or channel water to areas where it will cause least damage, will be worthwhile especially if the surplus can be stored for future use. Where parts of a garden flood regularly, terracing or decking above expected flood levels will allow access through the garden without treading on saturated lawns. Ensuring that drainage systems (open or piped) are in good condition and that the soil is in good physical condition to absorb water and resist erosion, are sensible aspects of garden management, even if floods are not anticipated. Reclamation of the garden in the aftermath of flooding is usefully described in the Environmental Agency booklet *Flooding in Gardens* (Environment Agency, 2002).

Modification of the long term composition of the garden in response to flood threats will usually not be advisable, except in those situations in which serious flooding has occurred in the recent past and there is some evidence that the frequency of flooding is increasing. Most plants which are tolerant of flooding are not tolerant of dry conditions, and drought as a result of climate change poses a much more serious threat to gardens than does flooding.

Water will be less available in summer, when it is most needed to sustain plant growth, and more abundant in winter. If water extraction increases (for domestic use and for irrigation) the water table will drop and steady river flows will be reduced. The likely impact of climate change will be lower summer flows in streams and rivers but sudden increases in water level after heavy rain. This trend will be exacerbated by urbanisation, and the damage resulting from it will be increased if houses and gardens are established on flood plains.

Although, as yet, a very minor component of total water demand, water demand for irrigation of gardens and golf courses will increase rapidly (it increased six-fold between 1974 and 1991), and concentration of demand into the hottest, driest months may increase peak demands by 25% in the south east. Where demand can not be met, the result will be reduced pressure, or restrictions in use and, in the longer term, higher costs to pay for new water supply infrastructure.

6.2.2 WATER FEATURES

Water in the garden, whether a bird bath in a tiny courtyard or a lake in a Capability Brown landscape, is a very attractive feature, both in itself and in the wildlife which is attracted even to the smallest water feature. Water features require a reliable supply of water, natural or piped.

The main impact of climate change on all water bodies will be increased evaporation from the surface. This will result in the need to top up water levels, by hosepipe or by borehole if permissible. A secondary effect of using tap water to refill a pond, is that the nitrate content of the water will encourage unwanted weed growth. Ponds and lakes relying on a natural water supply to keep them full will be at risk of drying out in hot, dry summers.

Higher summer temperatures present a further problem, because oxygen is less soluble in water as the temperature increases, but the demand for oxygen from aquatic organisms increases with temperature. Biological oxygen deficiency therefore increases sharply with temperature. In a balanced ecosystem this de-oxygenation would normally be compensated for by higher rates of photosynthesis in submerged plants, releasing oxygen into the water. However, when higher summer temperatures are combined with excessive nitrates (from accelerated breakdown of soil nitrogen, from increased leaching and erosion of agricultural soils and from increasing atmospheric pollution with nitrous oxides), the vigorous growth of a surface blanket of algae shades out submerged aquatics. As the algae exhaust the nutrient supply and die, breakdown of the dead mass rapidly depletes dissolved oxygen supplies and the water will become eutrophic – stagnant, unhealthy and foul-smelling. The 1990s droughts in Sheffield Park (Sussex), combined with an accumulation of silt, built up from leaf litter and part caused by soil washed off surrounding farmland in heavy storms, led to serious algal blooms. The cost of dredging to rectify the problem amounted to £40,000 (Calnan, *pers. comm.*; Owen, 2002).

Management of water bodies is a complex matter. Shading of the surface by tree planting will help to reduce surface temperatures, which could become warm enough in future to kill fish populations. But autumn leaf fall from the trees could be detrimental, increasing the amount of organic material falling into the pond or lake. In natural, unlined, ponds, trees will also extract water and exacerbate the fall in water level.

Management of the edge to achieve a gentle gradient and a shelving beach, or transition from marginal vegetation (reeds for example) to deep water, will disguise changes in water level, and the latter especially will add to the biodiversity of the pond. Care will then be needed to ensure that the vegetation itself does not encroach too much on the water surface. Where blanket weed growth and eutrophication become important problems, surface skimming of the water to remove algae will result in immediate improvement, though at considerable effort on any substantial scale. Oxygenation of water using fountains or cascades, or air pumped through submerged porous pipes where decorative treatment of water is considered inappropriate, will improve water quality.

Running water bodies – streams and rivers – are also at risk of falling water levels in periods of reduced precipitation and high evaporation rates. The River Pang near Reading has dried out completely in recent, hot summers because of reduced rainfall and increased abstraction, spoiling the appearance of gardens through which it runs, but with much more serious loss to fish and other life.

On a garden scale, the problem of reduced water volumes is not easy to counter, except by pumping from elsewhere – usually at substantial cost and often at the risk of depriving other areas of much needed water. Reshaping of the stream bed, or construction of weirs so that the stream forms a chain of small ponds as water levels drop, will provide some refuge for water life until such time as rainfall restores the natural water flow.

Water bodies may also have to cope with periods of excess supply. Increases of water volume, through more intense and more prolonged rains, may cause scouring of the stream bed, overflow of banks or dams, loss of marginal plants and fish, and flooding of adjacent land. There is also a risk that flooding of garden ponds could release exotic water plants into adjacent streams, and thus into the wider landscape. Water flooding across farmland, the overflow of 19th century combined storm and sanitary sewers, and the flooding of septic tanks, can cause pollution of the water and contamination of water supplies.

The more natural the stream profile, with meanders, shallows and abundant marginal vegetation, the more able it will be to withstand fluctuations in water throughput. Engineering efforts to clean out the stream, to straighten and deepen the channel and to engineer the banks by removing vegetation, may solve a local problem but only by moving the problem even more rapidly downstream. Impeding water flow and diverting surplus water into areas which can safely be flooded temporarily (holding areas, silt traps and balancing ponds), will provide a far more effective and durable response. Such areas can usually be designed to increase biodiversity and visual interest.

The whole strategy of coping with the impacts of climate change, and especially in its effects on water supplies and water bodies, will need to rely on learning lessons from nature rather than trying to overrule it. Response to these alternating deficits and surfeits of water will require careful management of water flow and water quality. Techniques might include impounding run-off, recycling irrigation water and using grey water where possible, combined with land contouring, improving soil structure and better drain maintenance

6.2.3 WATER MANAGEMENT

i) Domestic gardens

The impacts of climate change on water supply to the domestic garden will be significant, but can be reduced by sound water management using methods described in section 6.2.2. Shortage of water in the summer can be made good by irrigation, preferably using stored water, and concentrating on the most important plants in the event of a prolonged hosepipe ban. Irrigation after dusk, using a timer or by staying up late, and irrigation using seep hose or trickle irrigation, will reduce evaporative losses.

In well managed gardens, surplus water in winter should infiltrate into good garden soil and run off drives, paths and patios onto lawns or borders, or into drains if levels are suitably designed. However, flood risk can be expected to increase in some areas in future (Hulme *et al*., 2002). Advice on how to cope with excess water in the garden is provided by the Environment Agency (2002).

In the long term, it will become advisable to adapt planting schemes to the new climatic regime of the particular area. It would certainly be wise, for example, to replace any plants which consistently suffer from summer drought, but fluctuations of weather will be more important than climate change in the domestic garden, so major changes in planting from year to year as a result of last year's weather damage, would be unwise.

Water bodies in domestic gardens will usually be small in scale, most typically a garden pond. Reduced rainfall and the increased evaporation resulting from higher temperatures will necessitate topping up of the pond. If this can be done using stored rainwater, it will avoid the secondary problem of nutrient enrichment which results if mains water is used. Some reduction of evaporation may be possible by ensuring that about 50% of the water area is shaded by surrounding vegetation.

ii) Heritage gardens

The principal dilemma in managing water supplies in heritage gardens is in deciding how closely it is necessary to adhere to the *status quo*. Key areas of the garden may justify irrigation, in which case a balance must be struck between the high capital cost of a sophisticated and automated system, and the high running costs of a hosepipe or watering can.

As in the domestic garden, maximum use of stored water – water butts, underground water tanks such as those in many old greenhouses or, where development is permissible, surface ponds or reservoirs – may be used.

Reference has already been made (in section 6.1.4) to the possible need for gullies and soakaways to direct excess surface water. Flooding, especially frequent flooding, is not often a problem in heritage gardens of the 18th century onwards as their creators usually built above flood level. Where flooding is occurring more frequently as a result of climate change or changes in land use, the only remedy is costly intervention to accommodate floodwater, by improving drainage ditches, or to divert it from the most vulnerable areas with earth bunds or other techniques, including perhaps pumping. Regular maintenance of drainage channels is an essential part of garden management. Upgrading of the drainage and flood defence systems may be called for in particular instances where increased flood risk is evident.

The problem of water bodies in heritage gardens as a result of climate change impacts is considerable because, as attractive features, they usually occupy key locations in the landscape. Falling water levels in summer may necessitate a pumped water supply. Barley straw is sometimes effective at reducing algal blooms. Oxygenation by pumping air through perforated hoses on the lake bed can improve water quality and save fish stocks. When appropriate, the creation of wetlands (such as reedbeds) or beaches, will buffer the visual impact of fluctuating water levels, increase the absorption of excess water into the water table and localise the deposition of silt in areas where it can be more easily and cheaply removed than from the lake itself.

Water surplus may result in overtopping of lakes. It is, therefore, very important to ensure regular inspection of dams, sluices and spillways to conform to the requirements of the Reservoirs Act (1974), so that the excess does not cause a threat to life or property.

Decreasing natural flows in summer will result in falling water levels in watercourses, ponds and lakes. This will affect the appearance of the landscape and have more serious consequences for the environment and for fisheries. Average water supplies may increase in winter, and major floods will remain a risk.

Increasing temperatures will also affect water bodies, decreasing dissolved oxygen levels and increasing the risk of algal blooms. Water bodies will, therefore, require more management in future.

6.3 Climate change impacts on trees

As the largest and longest-lived plants in a garden, trees are most vulnerable to the stresses induced by climate change. As complex and long-lived organisms they experience climatic impacts over a long time, sometimes centuries, and any impacts of the benefits or injuries imposed by long term climate change or short term fluctuations in the weather, will be reflected with compound interest as time passes (Ceulemans, 1998).

Root suffocation of cedars in the National Trust's garden at Osterley Park (Middlesex), drowning of beech trees in the lower part of the Royal Horticultural Society's garden at Hyde Hall (Essex) and the loss of fifteen million trees across the south of England in the storm of October 1987 are conspicuous reminders of the value of trees and of the threats facing them. The one night of 16th October 1987 saw a loss of trees equivalent to fifty years of natural tree decline (Rich, 1988).

Fire hazards, especially in coniferous windbreaks or woodland, will increase sharply as temperatures increase and summer droughts extend, although here many factors will interact. Evidence in recent years is that fire risk, not surprisingly, increases in hot, dry summers. The number of outbreaks also increases with increases in visitor pressure (also related to hot, dry summers), as most fires are started accidentally by cigarettes or picnic fires. However, although the number of fires in recent dry summers has increased, the damage caused has declined, because outbreaks are reported and dealt with more rapidly since the advent of the mobile phone.

The most serious threats facing trees are summer drought, possibly winter waterlogging and high winds. There is widespread concern, in particular, about the future prospects for beech (*Fagus sylvatica*). Beech is native to southern England and, under conditions of climate change the natural distribution would be expected to move north and east (Berry *et al.*, 2001; Broadmeadow, 2002a, b; Harrison *et al.*, 2001) (see Figure 14a in section 4.1). It was, however, extensively planted in the Chilterns and on the North and South Downs following the enclosure of downland in the early 19th century and the abandoning of arable cultivation after 1850 (Piggott, 1988).

Unfortunately, it is unable to tolerate the increasing water stress associated with climate change on these light soils and hilltop situations. There is a strong negative correlation between reduced rainfall in July, and crown density of beech in the following year (Cannell and Sparks, 1999), but the underlying causes of this correlation are complex. Low rainfall (and therefore high light intensity) in one summer, stimulate the beech to produce a heavy crop of seed (mast) in the following year. Whether this seed production is the plant physiological equivalent of a panic response to drought, or a result of high carbohydrate levels in the sunny year enabling the tree to invest in reproduction in the following year is uncertain, but the combined effects of drought stress in one year and the drain on resources of fruiting in the following year is manifest in a thin canopy of small leaves. The tree can take several years to recover and, if another dry summer occurs before this recovery is complete, the tree will go into long term decline.

The impacts of summer drought can be overcome to some extent by irrigation and soil improvement, and especially by replacing highly competitive grass with protective mulch beneath the canopy of the tree. The cost of this on a large scale, for scattered parkland trees or long avenues, for example, would be astronomical and the visual change from trees in grass to trees in large mulched circles will not always be acceptable.

Winter waterlogging can also be reduced by good soil care and drainage. In most instances, drainage of wet sites will improve the tree's root system, especially its depth of rooting, and make it more, not less, tolerant of drought. A particular problem will arise in gardens in which higher winter rainfall is likely to result in root death, making the tree less able to withstand reductions in summer rainfall. Careful attention to drainage will be needed in such situations.

To minimise the impacts of high winds gardeners will need to ensure good establishment of young trees and good shelter. In particular, planting open-ground stock rather than container grown trees, and planting trees as transplants, or even as seed, rather than as larger standards, will assist in the development of a wind-firm root system. Pit planting (in a prepared planting hole), rather than slit planting, has been shown in forestry planting to result in much higher stability of trees (Broadmeadow, 2002a). Improved drainage to reduce waterlogging will also reduce susceptibility to wind-throw as soil strength and root anchorage are greatly reduced at high soil moisture contents.

However, the main strategy for protecting trees from the adverse effects of climate change must lie in developing long term management and replacement programmes. Storm damage in 1987 was much higher in over-aged trees and in single-species plantations. Maintaining a good age structure and, where appropriate, using a mixture of species, will insure against massive storm damage. If historical precedent and historical significance do not constrain tree choice, there is much scope for regenerating tree plantings with more resilient species, as is already being carried out at Sheffield Park (see section 6.3.1 below, and especially Tables 3 and 4). Although old and decaying parkland and woodland trees are of great importance in conservation of biodiversity, it is important to remember that the population of 'veteran' trees depends, in the long term, on a flourishing population of young trees which will become veterans in centuries to come.

There will be many instances in which historical precedent and the visual delight of a lofty, single-age and single-species avenue, for example, prevail against a mixed-age, mixed species approach but in such cases it will be necessary to be aware of the

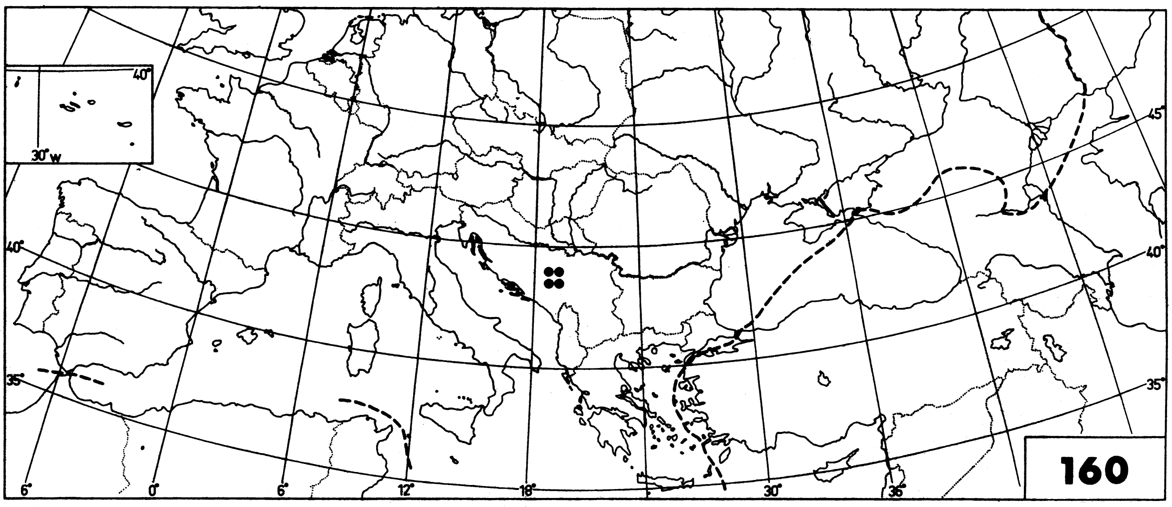

Figure 17a: Natural distribution of Serbian spruce (*Picea omorika*). *Source: Tutin et al., 1964.*

additional risks inherent in such situations, and to have in place a policy for replacement when the avenue declines, as it inevitably will.

6.3.1 TREE SELECTION

In Britain, in contrast to many other parts of the world, there are virtually no natural forests. Ancient woodland has been managed over centuries, sometimes millennia, to provide fuel, building materials and a habitat to attract deer and other animals to be hunted for food (Rackham, 1993). Much of our current tree stock has been planted, usually for a combination of economic and aesthetic reasons. Changes in social awareness and changes in agricultural land use have provided opportunities for tree planting in recent years. The shift away from planting monoculture of fast growing (many coniferous) species, to planting mixed woodland species (White, 1994), initially for ecological and amenity reasons, will be useful in insuring against total loss of a woodland if a particular species proves unable to survive climate change.

In deciding on suitable species for long term planting, natural distribution maps of plant species are of limited use as indicators of how plants might survive in gardens as the climate changes. Serbian spruce (*Picea omorika*), for example, has a very limited distribution in the wild (Figure 17a) but is described in *Hillier's Manual of Trees and Shrubs* (n.d.) and by Bean (1976) as one of the most adaptable spruces in cultivation.

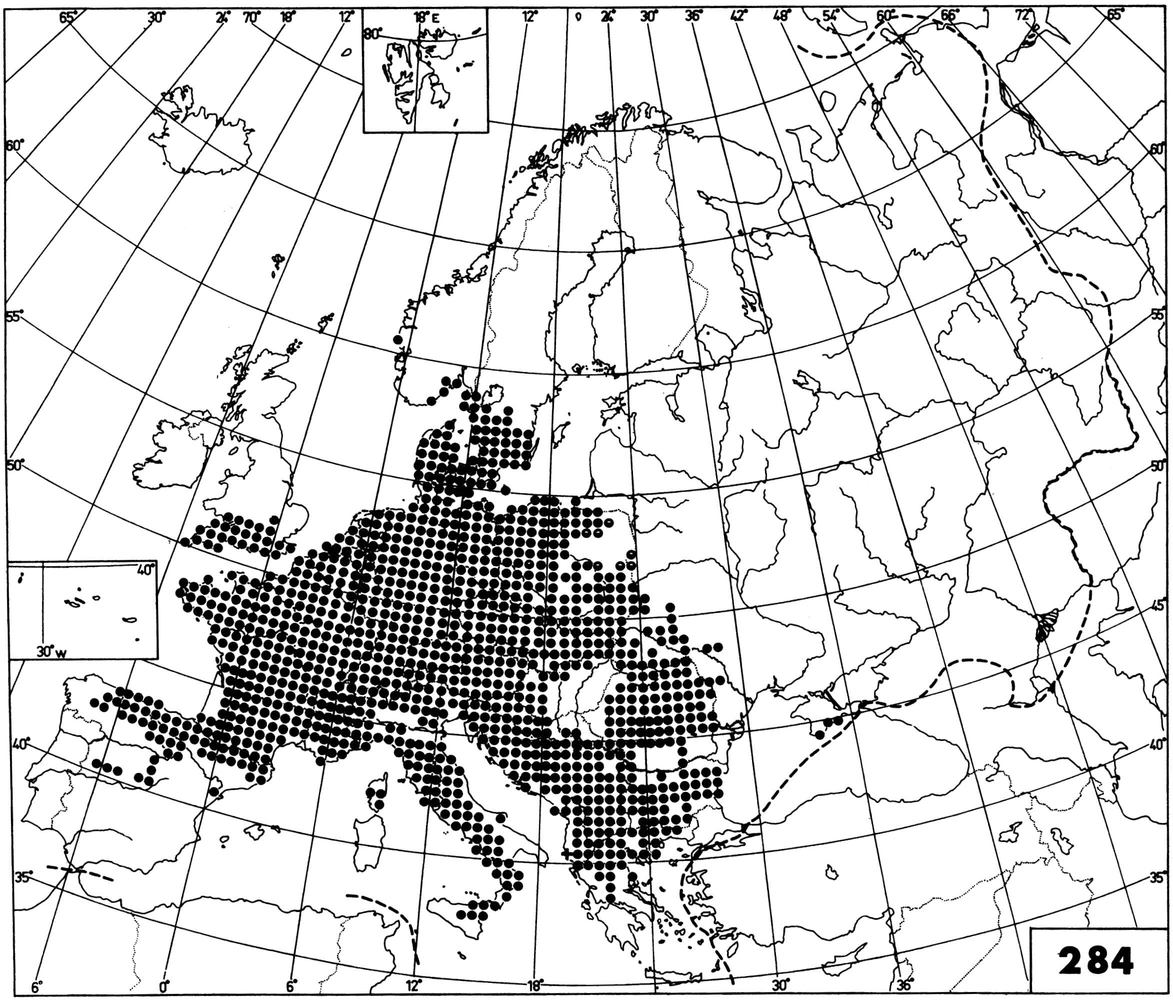

Figure 17b: Natural distribution of Beech (*Fagus sylvatica*). *Source: Tutin et al., 1964.*

Beech (*Fagus sylvatica*), on the other hand, has a very wide distribution from southern England to Sicily (Figure 17b), but is found only at increasingly high altitudes towards its southern limits, and then only on the well watered northern slopes of mountains. Survival of beech in Sicily, therefore, is clearly no guarantee that it will survive at low altitude on the hot, dry chalk soils of the Chilterns.

The distribution of pedunculate oak (*Quercus robur*) is even wider, from the north of Scotland to Sicily but this, too, is a result of differing altitudinal distribution, occupying higher altitudes in southern latitudes. There is also wide phenotypic variation within the oak population. Oak seeds collected from different zones and germinated or grown in one site show wide variations in dates of leaf emergence, leaf drop, rate of growth, degree of branching and other characteristics. Clearly it will be possible to find 'oaks' (in the broad specific sense) which, if planted today, will tolerate the climate of Britain in a hundred years time, but these may not have the form that is currently associated with the traditional English oak. Conversely, a particular phenotype of oak growing well in England now will probably not grow well after a century of accelerating climate change.

Similar problems arise with lime (*Tilia x europea*), a tree which exists in gardens as several distinct clones, each of which imparts its own particular character to avenues, parks and gardens. It may be necessary to consider whether limes failing as a result of climate change should be replaced by other clones of lime, which may have different forms, or to use another species of more similar silhouette.

Phenotypic variation will, however, be of some use in selecting tree provenances with greater tolerance of climatic changes. Such selection already forms part of the policy for redevelopment of the tree collections at Kew following the loss of many mature trees in the 1987 storm.

In a garden context, it is also necessary to distinguish between climatic tolerance and usefulness. Birch (*Betula pendula* and other species) is amongst the most tolerant of trees to a range of environmental stresses, but they respond to drought by losing their leaves. A near-leafless birch may survive increasing summer droughts, but will not make an effective aesthetic contribution to the landscape.

Table 7: Quality timber trees that should benefit from extra warmth in Britain. *Source: White (1994).*

Acer saccharinum	Silver maple
Carya cordiformis	Bitter nut
Cladrastis lutea	Yellow wood
Corylus colurna	Turkish hazel
Cupressus glabra	Smooth Arizona cypress
Cupressus sempervirens	Italian Cypress
Eucalyptus delegatensis	Woollybutt
Fagus grandifolia	American beech
Juglans nigra	Black walnut
Ligustrum lucidum	Tree privet
Liriodendron tulipifera	Tulip tree
Paulownia tomentosa	Foxglove tree
Platanus acerifolia	London Plane
Prunus serotina	Black cherry
Pyrus pyraster	Wild pear

Table 8: Trees that are resistant to storm damage. *Source: White (1994).*

Acer pseudoplatanus	Sycamore
x Cupressocyparis leylandii	Leyland cypress
Magnolia (tree species)	Magnolia
Ilex aquifolium	Holly
Metasequoia glyptostroboides	Dawn redwood
Robinia pseudoacacia	Black locust
Sequoiadendron giganteum	Wellingtonia
Taxus baccata	Yew

Table 7 lists trees which should benefit from higher temperatures in the UK, and Table 8 trees which are resistant to storm damage.

6.3.2 FRUIT TREES AND BUSHES

As discussed in chapter 4, many fruit trees and soft fruit bushes have a winter chilling requirement to break dormancy before flowering (then fruiting) can occur. Higher winter temperatures could pose a serious problem to fruit growers. Problems are already occurring with the blackcurrant crop after unusually mild winters (Carew, *pers. comm.*). The problem may be overcome in the short term by substitution of cultivars with smaller chilling requirement and, in the longer term, by breeding or by changing crops, from apples, pears and cherries to peaches. Clearly, this would represent a major investment requiring long term planning and having a significant impact on commercial fruit growers.

In heritage gardens, a particular problem may arise in growing historical cultivars of fruit trees. Many of these were selected and grown originally because of their close adaptation to local climatic conditions, so additional care in cultivation will be required when these conditions cease to exist.

6.3.3 TREE MANAGEMENT

i) Domestic gardens

Trees in or near smaller gardens will inevitably be near to property, so great care is needed in their management. It is very difficult to balance the visual and ecological value of a large oak on a housing estate, with the real or perceived danger of branch loss or toppling in strong winds. The presence of a house or houses will exacerbate the impact on large trees of high temperatures, summer drought and gusting winds, so it may be necessary to feed or water trees to maintain their health. All operations connected with tree care in confined spaces are expensive.

With newly planted trees, management is less complicated. The most important management consideration is to match the choice of species to site conditions. Most owners will plant small, ornamental trees with limited lifespans, so long term considerations of adaptation to climate change will not be an important factor in the choice of species. Large species are nevertheless important features of our urban landscapes and future planting policies need to perpetuate and enhance tree cover and ensure good management.

ii) Heritage gardens

A very different situation applies to the management of trees in large gardens, and especially in those heritage gardens which include parkland and ornamental woodlands.

The average unit cost of dealing with trees damaged by weather extremes or weakened by climate change, using skilled forestry or garden staff from the estate, will be much less than the cost of dealing with a tree in the urban setting of a domestic garden using external contractors, although of course the total cost of dealing with large numbers of trees (or with a large cedar in a courtyard) will be very much higher.

Because of the generally high levels of knowledge and skill in heritage gardens, the need to attend to trees will be recognised and measures such as soil aeration, irrigation, feeding and mulching are more likely to be undertaken to arrest decline.

On average, again, a higher level of stress imposed damage and decline may be tolerated in heritage gardens if the tree is seen at a distance, is unlikely to create a serious hazard, or is one of many trees. Veteran trees are of historic and wildlife importance, and they are often an intriguing feature.

Given the long term nature of heritage gardens, more attention will be given to the systematic replacement of the tree population than to fire-fighting treatments on individual trees. The main response to climate change impacts on trees in heritage gardens will need to be directed at ensuring a balanced age range and, where possible, diversity of species, including species chosen to tolerate the anticipated climate changes for the next century. The long term advantages of using small planting stock will usually prevail over the need to create an instant impact with large trees which, when moved from the nursery, will have difficulty in establishing and in surviving hot, dry summer conditions.

Trees constitute the most vulnerable and most visible component of the garden to face the impacts of climate change. They are long -lived, so face the longest period of exposure to climate change and the highest risk of damage by infrequent events.
They also have the largest sail area exposed to the elements. Beech will be especially vulnerable on light soils and in dry areas of the south east, areas where it has been extensively planted, is least suited to, and which will suffer the largest degree of climate change.

It will not be difficult to find trees suited to the climates anticipated by the scenarios for the 2050s or even the 2080s. Planting young trees from open ground stock rather than container grown material, and planting in autumn rather than spring, on well prepared sites, will maximise the trees' chances of surviving climatic stresses. However, planting in anticipation of continuing healthy growth for centuries will not be possible, unless the rate of climate change is abated.

6.4 Shrubs and sub-shrubs and climate change

6.4.1 SHRUBS

Like trees, shrubs are vulnerable to summer drought, waterlogging and wind damage, although they are less susceptible to toppling by winds. The enormous range of shrubs, such as roses, means that it would not usually be difficult to substitute one species for another where such substitution is acceptable. The life span of a shrub is such that climate change during its lifetime is unlikely to shorten its useful lifespan. A particular problem can arise, as at the National Trust's Sheffield Park (Sussex), when the canopy of mature trees is lost or thinned by storms, leaving shade demanding shrubs exposed to full sun and to the competition of vigorous weed growth in the wake of disturbance.

6.4.2 SUB-SHRUBS

Sub shrubs such as *Fuchsia*, *Indigofera*, *Penstemon* and some *Ceanothus* may become increasingly useful with climate change. Many are marginally hardy because they originate in regions where the climate does not require adaptation to a cold season, and so allows more or less perpetual flowering. Given increasing temperatures in the UK, and especially the anticipated reduction in frost, sub-shrubs may make a major contribution to the garden of the future. They are, though, often rather brittle and will, of course, suffer badly in exceptionally severe winters. Most are not tolerant of waterlogging.

6.4.3 SHRUB AND SUB-SHRUB MANAGEMENT

i) Domestic gardens

The domestic gardener is likely to view shrubs as part of a changing garden population. If a shrub is killed by severe drought or by flooding, it will be replaced, perhaps with something more tolerant but more probably with something more interesting or novel. The main factor determining the fate of shrubs in domestic gardens is their size. As they encroach too far beyond bounds they may be pruned, or removed and replaced. Shrubs are unlikely to be in place long enough to experience any adverse impact of climate change.

High standards of husbandry – feeding, watering, pruning – will reduce impacts of adverse weather within the smaller domestic garden, but the more permanent the plant, the less likely it is to be recognised as needing or benefiting from such treatment.

Sub-shrubs have a promising role to play in domestic gardens as mean temperatures increase. Long flowering seasons and, in many species, some tolerance of drought, make them useful substitutes for the more demanding annuals. Many are also more decorative than the majority of shrubs.

ii) Heritage gardens

As with other aspects of heritage gardens, the impacts of climate change will depend on the degree to which the status quo is considered important. In most heritage gardens carefully thought through management plans have had the effect of making systematic pruning and/or replacement of shrubs the norm, rather than allowing the structure of the garden to be swamped by excessive growth, then trying to rectify the damage by wholesale clearance, perhaps prompted by widespread losses following drought, flood or storm damage. Where some freedom of interpretation is acceptable, shrub replacement may reflect conditions resulting from climate change. Otherwise, high standards of husbandry will be needed to retain authentic planting until it becomes impossible.

If there is scope for innovation, then the potential for use of sub-shrubs will be as for domestic gardens.

Shrubs will be affected by climatic change in the same way as trees but to a lesser extent because of their smaller size and generally shorter lifespan.

Sub-shrubs may play an increasingly important role in gardens. Their long flowering season is an advantage and their marginal hardiness will become less of a hindrance to use as temperatures increase.

6.5 Herbaceous perennials

The range of herbaceous perennials is such that it is difficult to generalise on their responses to climate change. The Beth Chatto garden in Essex, where conditions range within a few metres from dry gravel to heavy clay, and where the plant range varies accordingly, is one of the best examples of this diversity (Chatto, 1994).

Many of the denizens of the traditional herbaceous border will not adapt well to climate change, and especially to water stress in summer. This is especially so for the most highly developed herbaceous perennials such as aster (eg, *Aster novi-belgii*), delphinium (*Delphinium x cultorum*), lupin (Lupinus x regalis) and phlox (*Phlox paniculata*) which have been selected and bred for garden use, on the assumption that soils will be deeply cultivated and well supplied with nutrients and water (Martineau, 1913; Roper, 1960). There is also a problem in selecting plants tolerant both of summer drought and winter wet. Old cultivars of iris, for example, are tolerant of dry summer conditions but will be killed by waterlogged conditions in winter.

As with most other plant forms, good soil cultivation will help to ameliorate the adverse components of climate change. Improvement of soil drainage and raising the soil level even by 10-15cm will improve the chances of survival of plants intolerant of wet conditions. Recent trends in the adoption of Dutch and German ideas in naturalistic planting of herbaceous perennials (von Schoenaich, 1994) and gravel gardening or dry gardening are already becoming popular in the UK. They may be tailored to suit a particular suite of climatic conditions by appropriate plant choice, with modifications to the landform where necessary to improve drainage.

One characteristic of herbaceous perennials is that most establish very quickly, usually within a season and certainly by the second year. If planting schemes in general are increasingly threatened by regular swings from summer drought to winter floods, a scenario which greatly exaggerates the changes anticipated by UKCIP02 scenarios, increasing reliance on herbaceous perennials, provides one attractive strategy for rapid reparation of the damage – as always, within the bounds of what is acceptable in any particular garden.

It is possible that the need to stake plants will decline if summer rainfall intensity declines and average wind speeds drop, as plants may also be more robust as a result of higher carbon dioxide levels. However, the uncertainties associated with storm predictions and the potential impacts of these events are such that inherently unstable plants should continue to be supported.

6.5.1 HERBACEOUS PERENNIAL MANAGEMENT

i) Domestic gardens

The domestic gardener will have the freedom to choose from a very wide range of perennials having the ability to cope with conditions created by climate change in a particular place. The usual balance will have to be struck between increasing maintenance inputs to grow particular plants, or choosing plants suited to a particular situation.

ii) Heritage gardens

The need to retain the essence, and perhaps the detailed composition, of a traditional herbaceous border will impose some management difficulties in heritage gardens. However, given the high inputs needed in the past in soil cultivation, regular lifting and replanting, staking and other operations, the additional effort of adapting to climate change will not be as great as with more permanent forms of planting.

Herbaceous perennials are a very diverse group so it will not be difficult to find some which will grow in altered conditions. They are more or less short-lived so will not need to adapt to any significant degree of climate change in the course of their life. Because they mature quickly, they could play a useful temporary role where shrubs and trees have had to be replaced either in phased renewal or as a result of storm or flood damage.

6.6 Bulbs

Spring bulbs are strongly influenced in their development by temperature (Rees, 1972). The general pattern is that they require low temperature (i.e. winter) to stimulate root development, rising temperature (spring) to stimulate leaf expansion and flowering and, in some cases, such as tulip, high temperature (summer) to stimulate flower formation in the newly developing bulb for the following year. Actual temperatures controlling this development vary from one genus to another, usually reflecting closely the natural climatic conditions within which the particular genus evolved.

Many spring bulbs are already flowering much earlier as a result of warmer winters and springs than they were 20-30 years ago and may continue to do so. However, if winters become too warm, root initiation may fail and the plant may be severely weakened or killed. It will then be necessary to lift and store bulbs in refrigerated stores (as is already done to force early flowering in tulip and narcissus), rather than using them as permanent garden plants. Increasing soil and air temperatures may also upset the synchronised development of the bulb, for example by causing leaves of hyacinths to expand more quickly than the flower spike, thus reducing the visual impact of the flower. Spring displays of carpets of naturalised bulbs, like daffodils and crocus may disappear as a garden feature.

Some spring bulbs (tulip, some crocus) are intolerant of flooding while others (many *Narcissus*) are more tolerant, and others (*Camassia*) will grow in very wet soils. The natural distribution of the bulb gives a very good indication of its tolerance or intolerance of flooding.

Most summer and autumn flowering bulbs will flourish in higher temperatures. Temperature increases anticipated in the UKCIP02 scenarios may permit an increasing range of these late flowering bulbs (including bulbs, corms, tubers and other plants with fleshy rootstocks) to be grown as permanent inhabitants of the garden. They may also be grown more widely across the UK, but only if spared wet winter conditions, to which most summer bulbs are exceptionally sensitive.

Bulbs are strongly influenced by temperature so climate change will affect their timing and sometimes their healthy development. Most summer and autumn flowering bulbs flourish at high temperatures and will respond positively to dry summer conditions. They will become increasingly useful, and increasingly hardy as winter temperatures increase, but are very intolerant of wet winter conditions.

6.7 Annuals and tender perennials

Many annuals, especially hardy annuals, will exhibit accelerated development and/or suffer from water stress, given the higher temperatures and reduced summer precipitation expected with climate change. They will flower, seed and die earlier, thus reducing their garden-worthiness. On the other hand, higher spring temperatures will permit earlier planting of half-hardy annuals and higher winter temperatures will permit an increasing number of annuals to be grown as hardy, rather than half-hardy annuals, and will permit an increasing number of hardy annuals to be sown in autumn for an earlier summer display. Many tender perennials, especially the *Pelargonium*, are well adapted to hot dry summers and will flower more freely in such conditions. All are removed at the end of the summer season, so tolerance of winter conditions is not an issue.

Spring flowering biennials such as wallflower (*Cheiranthus cheiri*) and forget-me-not (*Myosotis sylvatica*) will benefit from higher winter temperatures. In northern areas, where spring planting has been the norm for wallflower, it will be increasingly possible under conditions of climate change to move to autumn planting, and the quality of overwintered plants should improve in most areas. Wallflower, in particular, is not tolerant of wet soils. In areas in which increased winter rainfall is anticipated and the result is likely to be poor winter drainage, it will be necessary to avoid its use or to improve soil conditions by cultivation or, more usefully, by raising soil level.

Strategies of response to climate change might include improved cultivation (especially irrigation where possible), a change in the garden flora (replacing short-lived hardy annuals by the more durable half-hardy annuals – which will become less half-hardy as temperatures increase) and perhaps moving in the mildest areas from twice-yearly replacement of spring then summer bedding, towards a permanent planting of plants previously considered to be tender perennials (Owen, 2002).

In warmer parts of the world, such as the southern United States and Japan, it is common to use three bedding schemes per year – in spring, summer and autumn -, instead of two, where summer bedding is expected to flower until late autumn. As summer temperatures in the UK rise and summer drought causes premature senescence of summer annuals, this practice could be employed in southern areas (Shaddick, 2000). This obviously has major cost implications if carried out on any substantial scale, but for most domestic gardens the extra cost is likely to be lower because of the smaller areas involved. Autumn bedding presents significant opportunities for nurseries and garden centres to stimulate sales at what is currently a very quiet time of year (see Chapter 8).

Overall, the advantages of climate change in relation to cultivation of annuals might outweigh the disadvantages: the opportunities to experiment with new half-hardy plants which may eventually become hardy as temperatures increase, are legion (Shaddick, 2000). The great risk with annuals is that, if weather conditions in a particular season are unfavourable to the plants being used in that year, the effect may be disastrous. On the other hand, if the planting does fail to produce the planned-for result, there is no permanent loss to the garden. Good ground preparation and, where possible, the availability of irrigation as a precaution against excessively dry summers, will maximise the likelihood of favourable results.

Annuals and other short-lived and temporary plants will obviously not need to adapt to climate change in their own lifetimes. Many hardy annuals will flower earlier but seed and die more quickly in hot, dry summers. Half-hardy annuals and tender perennials will be favoured by higher temperatures but most will need adequate water supplies to sustain lush growth and free flowering. On balance, climate changes will favour the exciting uses of annuals and other ephemerals.

6.8 Lawns and other grass areas

Grasslands are very characteristic of large areas of the UK's landscape and a very important component of many gardens. A long history of grazing animal husbandry and what has been a very equable climate, has led to much of the countryside being clothed in grasslands. These habitats often exhibit great species diversity. Visual delight in this greenness encouraged the cultivation of lawns which could be maintained with relatively little effort compared with most other parts of the world, and are much admired by overseas visitors.

The image of the UK as a 'green and pleasant land' is an important factor in encouraging tourists to visit, and it may be an increasingly important factor in encouraging UK citizens to holiday at home instead of travelling to increasingly hot, dry destinations abroad. It is our view that the image could be damaged if, as seems inevitable in some parts of the UK, climate change leads to summer browning of the grass. There is a more direct economic impact for large gardens and parks in which the grass is used by grazing animals. Lower stocking rates and greater conservation of grass as hay or silage may be necessary. On a regional scale, changes in farming practice in response to climate change, such as the conversion of grassland to arable cultivation or the replacement of wheat by sunflowers (Wade *et al*., 1999), will also have impacts on the setting of the rural garden.

6.8.1 THE DIVERSITY OF GRASS AREAS

The lawn, meadow or parkland represents a particular type of plant community created by regular defoliation of the vegetation, by grazing animals or by cutting. Over many years (centuries in some instances), the species composition adapts to local soil and climatic conditions. Many grasslands contain a rich diversity of species. Some surviving fragments of species-rich grasslands have been designated as Sites of Special Scientific Interest (SSSIs) supporting a wide range of insects and other invertebrates, as well as many species of plants. Old garden lawns, such as those at Chatsworth (Derbyshire) or Charles Darwin's garden at Down House (Kent) which have been regularly mown, can also be of considerable ecological significance.

On the other hand, it is possible to manage the lawn to favour only a small range of the finest-leaved grasses and to eliminate especially the broadleaved plants, in order to achieve a fine, rich green lawn of bowling green quality. It is also possible to modify the lawn, by heavy feeding and careful attention to drainage, to make it tolerant of heavy wear, whether from sports activities or from casual use by garden visitors.

As a general principle, the shorter the grass, the greater the desire for uniformity (especially the absence of weeds), and the smaller the area of the lawn, the more effort will need to be invested in it. A first class bowling green may require mowing every day, brushing, spiking, feeding at frequent intervals and irrigation, if dry weather persists for more than a few days. At the other extreme, a large expanse of grassland serving mainly as a green setting might, if not grazed, be cut once a year (even less, on a poor soil) and receive no other treatment, but still continue to serve its purpose well.

As lawns are almost invariably maintained using mowers powered directly or indirectly by fossil fuels, they constitute a visible contributor to climate change. Calnan (*pers. comm.*) has calculated that the National Trust uses 82,000 litres of fuel each year to mow 30 square miles (77 sq km) of lawn at a cost of £136,000. In the context of the 70,000 litres of fuel required to power a Boeing 747 on a single journey across the Atlantic, this annual consumption is insignificant, but if the principle of reducing fossil fuel use by changes in management (see section 6.8.3) can be demonstrated in National Trust and other heritage gardens, the message may be picked up more widely.

6.8.2 CLIMATE CHANGE IMPACTS ON THE GROWTH OF GRASS

The traditional smooth, closely-shaved lawn of UK gardens will be disadvantaged by higher summer temperatures, drier summers and wetter winters.

Increasing temperatures, in particular, will lead to temporary and long term changes in the composition of the grassland community. Jeffery (2001) found that annual meadow grass (*Poa annua*) decreased when turf temperature (and indirectly air temperature) was increased by 3°C, while clover (*Trifolium repens*), yarrow (*Achillea millefolium*) and browntop bent (*Agrostis tenuis*) increased. In Australian research, extreme but short term temperature increases decreased the proportion of cool season grasses, such as fescues and increased the presence of warm season grasses, such as Bermuda grass, but the effect was temporary (White *et al*., 2000).

Water deficits result in reduced growth. The productivity of grassland is inversely proportional to July and August temperatures and directly proportional to summer rainfall (Sparks and Potts, 1999). This is not usually a disadvantage in itself in gardens, but it can cause severe problems in parkland, where the grass is a food supply for grazing animals as well as a visual amenity. Deficits also eventually result in discoloration of the grass. This in itself causes long term damage only in very extreme circumstances. After the summer-long drought of 1976, for example, it took just ten days for lawns in the University of Reading's teaching garden to return to a satisfactory state of greenness. However, the immediate damage in visual terms is very serious for ornamental lawns. Water stress will be especially serious on close-mown areas, as continuous close mowing restricts root development (Bisgrove, 1980).

Summer saturation of lawns after very heavy downpours poses a potentially bigger problem, in that the grass will be very susceptible to compaction and this will cause long term damage to the lawn, unless extra effort is expended on aeration and other intensive maintenance practices. At Hidcote Manor (Gloucestershire), the cost of lawn repairs and reinforcement is currently £3000 per annum and it is still necessary to close important grass paths at times, to prevent more serious deterioration from visitor pressure after heavy summer rains. Compaction problems may also arise in warm, dry summers as visitor pressure can be damaging when the soil is dry.

Increasing mean temperatures, a longer growing season and increased rainfall during increasingly frost-free winters will result in greater productivity and more mowing, probably throughout the winter in the mildest areas. This has resource implications, but also poses management problems, in that mowing into the winter, combined with expectations of higher winter rainfall, means that the risk of soil compaction by mowing equipment will be increased, and permanent damage to the grass root system is likely.

Increase of soil and air temperatures will almost inevitably also lead to higher incidence of pest and disease outbreaks in lawns, because of the general increase in biological activity. Moss is only a major problem on most lawns in early spring when the mosses, with their lower temperature thresholds for growth, are able to flourish in the absence of actively growing grasses. In many regions, moss will probably become more prevalent but paradoxically, also less of a problem. Higher temperatures will allow the moss to grow over a longer period in winter, but earlier growth of grass in the spring will conceal and suppress the mosses.

6.8.3 GRASS MANAGEMENT

In order to explore potential responses to the impacts of climate change on lawns and other grass areas, it is necessary to understand firstly that grassland results from regular defoliation and secondly, that management inputs increase as the need for a short and uniformly green surface increases.

One possible response to adverse climate impacts would be to accept different standards and thus to permit altered maintenance methods. A very likely impact of climate change will be increasing drought stress and temporary discoloration of the lawn. Coping with the browning of lawns in dry periods will require decisions as to whether to tolerate the discoloration (to the visual detriment of the garden and perhaps the displeasure of paying visitors) or to irrigate using increasingly scarce water resources. Raising the height of cut, and returning clippings to the lawn, could increase the resilience of lawns to drought, reduce the period and degree of discoloration in summer and often reduce the incidence of moss in spring (Bisgrove, 1980), but may lead to an increase in thatch problems. In parts of the United States, lawns are sprayed with green dye to disguise the browning which occurs as a result of low temperatures in winter or drought in summer.

In large gardens, the owner or manager could contemplate greater development of more naturalistic 'meadow' areas (Owen, 2002) with less frequent cutting, bearing in mind that long grass may pose increased fire risk in dry summers and may eventually harbour ticks and other undesirable wildlife, if temperatures continue to increase (see section 7.1).

There is a further complication in decision-making in relation to frequency of grass cutting, in that a rotary mower uses much more fuel to cut a given area of lawn than does a cylinder mower. Any change in mowing regime which results in the need to change from cylinder to rotary mower (in order to tackle longer grass), will not give the savings in fuel consumption or time that one might initially expect, although it may produce a more resilient turf.

In small gardens, gardeners might respond to more frequent browning of lawns by applying more irrigation and fertiliser), or by replacing grass with paving, gravel or ground cover.

Increasing variability of weather conditions will also complicate management. Routine mowing of lawns during a summer of alternating drought, when growth ceases, and heavy rain, when growth is rapid but soil conditions unsuitable for mowing, could become questionable. The need to mow grass in increasingly warm but wetter winters becomes increasingly probable. In long, wet periods it will be necessary to decide whether to mow the grass and risk soil compaction or to accept greater variability in height and tackle longer grass intermittently in the drier periods. Mowers could be developed to help gardeners manage lawns through predicted milder winters.

If mowing is done in-house (and especially in domestic gardens where the owners are ‘the staff’), a more flexible regime may be possible, switching between mowing and other operations on a more *ad hoc* basis, but the management of lawn areas by contractors will be more difficult to specify and therefore more costly. In any case, management will be more complex.

Some respite from increasing temperatures may be achieved by using newer cultivars of turf grasses developed in the United States, though these usually have the disadvantage of being bred for golf courses and other highly managed landscapes, so require high nutrient and irrigation inputs.

Very substantial increases in temperature may eventually necessitate the replacement or reinforcement of the current range of cool temperate (C3) grasses with warm-temperate and subtropical (C4) grasses, as in much of the southern United States and southern Europe, but this is very unlikely to be necessary by the 2080s even under the high emissions scenario. Cool temperate grasses have an optimum air temperature for growth of 15-24°C and an optimum soil temperature of 10-18°C, compared with 27-35°C and 24-29°C respectively for warm season grasses (Ward, 1969), and warm season grasses discolour badly at sub-optimum temperatures. Such substitution would represent a very major change in the quality of lawns in the UK as warm season grasses are generally coarser and less tolerant of close mowing. Very considerable inputs in terms of irrigation, fertiliser application and disease control would then be required to maintain the fine textured, short and soft turf which has been the hallmark of the UK lawn.

i) Domestic gardens

In a small domestic garden, intensive management of lawns is possible because of the small scale, even to the extent of using bath water for lawn irrigation in times of hosepipe bans. More commonly, most domestic gardeners are accepting and moving to lower standards of maintenance, slightly longer grass cut by rotary rather than cylinder mower, and with some acceptance of weeds and summer discoloration. Because of the regular time commitment imposed by lawns, perhaps combined with problems resulting from increasingly frequent summer droughts, small lawns in particular are being replaced by gravel, paving or decking.

ii) Heritage gardens

The specific character of different parts of a heritage garden will call for particular standards of maintenance which may vary from bowling green to rough meadow. The skills are available for sensitive, appropriate and varied maintenance. An extensive armoury of equipment for mowing, aeration, irrigation and other operations is available, though at a cost, and the scale of the garden may merit investment in a range of such equipment.

Particular problems of compaction caused by mowing in wet weather or by increasing visitor numbers after wet weather may require sports turf type management, but the cost may be justified by increased visitor capacity.

There may be some scope for conversion of fine grass surfaces to lower maintenance meadows, especially in those gardens where excessively high maintenance is a recent departure from earlier conditions. In grazed areas, the problem of balancing stocking rates with varying productivity of parkland grass will need to be addressed.

The lawn is a very characteristic feature of UK gardens and is very likely to be adversely affected by climate change. The more the lawn departs from a natural meadow community towards a highly managed, very short and weed-free green carpet, the more vulnerable it will be to climate change impacts.

High summer temperatures and reduced precipitation will reduce grass growth, sometimes completely, and cause the lawn to go brown.
In winter, increasing temperatures and rainfall will stimulate grass growth throughout the winter, particularly in the southern UK. The mowing season may shift with year-round mowing possible in the mildest areas. The need to mow when the soil is wet and therefore susceptible to compaction will be difficult to manage.

Adaptation to climate change will require cultural modifications (increased height of cut, timely application of fertilisers, or acceptance of brown summer lawns), or technical responses (irrigation and perhaps new mowing equipment) or a combination of these. Sensitive and responsive management will be increasingly important.

6.9 Paths, walls and garden structures

6.9.1 PATHS AND WALLS

Paths will need to be designed, constructed and maintained to prevent washing out in storms and to avoid large volumes of water being discharged from paved surfaces onto erosive soil during heavy rainstorms. It may also be necessary to choose path and paving surfaces to avoid (or facilitate the treatment of) algal growth, especially if gardens are opened to the public early in the year as the flowering and garden visiting season advances.

6.9.2 GARDEN BUILDINGS AND STRUCTURES

Wind and sun damage to fabric, and increased wetness from driving rain are likely to be the main problems associated with garden buildings (Jarman, 2001). Deterioration of fences, pergolas and other wooden structures will probably accelerate if high summer temperatures dry the timber excessively, leaving gaps for penetration by winter wet and fungal decay organisms. Higher standards of construction (including larger gutters and downpipes) and maintenance, and more use of durable timbers from sustainable sources where appropriate, will assist in overcoming these problems. There will be cost implications though, and limitations to such adaptations in listed and other important buildings. Antique statuary may require special protective covers in winter to prevent damage from extreme weather events.

Above and below ground, archaeology may also be vulnerable to climate change impacts, such as ruins in gardens exposed to flash floods. In recent years, flash flooding episodes have become more frequent at Studley Royal (Yorkshire), causing particular concern for the surviving structure and foundations of one of the garden’s picturesque ‘eye-catchers’ – Fountains Abbey.

Good ventilation of greenhouses and adequate shading will be necessary to avoid excessive build-up of heat in summer, for the benefit of the plants and of the gardeners looking after them.

On the positive side, glasshouse heating costs in the winter should be substantially lower in warmer winters, and frost damage to stone and brickwork, sculpture and other features of ‘hard’ landscapes will be reduced.

High summer temperatures, heavy downpours and driving rain, sun and wind damage, and increased pest activity may accelerate deterioration of garden structures. Higher standards of construction and upkeep, and improved techniques of decay prevention will be required to maintain garden structures. On the other hand, frost damage and glasshouse heating costs could decrease as a result of climate change.

6.10 Garden staff

Those faced with the maintenance and management of gardens in the 21st century will face a more challenging task in dealing with climate change. Physical working conditions should improve throughout much of the year as temperatures increase in winter and rainfall decreases in summer, but very hot or very wet conditions will make work more difficult at times. Care will be needed to prevent dehydration in high temperatures and more consideration will be needed in choosing protective clothing suitable for use at high temperatures. Care will be needed, too, to guard against the effects of higher UV light levels in summer.

Coping with climate change may involve more work and more stress, especially for those who have invested years of their lives in establishing and caring for their gardens. Maintenance (especially mowing) will be less predictable. Dealing with storm, flood or disease damage to the garden is likely to be mentally stressful as well as physically demanding. The additional ameliorative or remedial work required to respond to the impacts of climate change, such as soil cultivation, irrigation, mulching, more complicated mowing and more active intervention to ensure a healthy age range of trees, are all likely to add to the cost of managing gardens.

6.10.1 PERCEPTIONS OF CLIMATE CHANGE BY GARDEN MANAGERS

When garden managers were asked about their perceptions of the potential impacts of climate change, most respondents saw a mean temperature rise of 2-5°C as an advantage as the range of plants which could be grown could be extended, and heating costs in glasshouses could be reduced. More extreme changes – a threefold increase in the number of days above 27°C – could enable arid zone plants to be grown in the garden and might increase visitor spend in shops, if they seek relief there from the outdoor heat. These comments indicate the diversity of factors which garden managers need to consider.

Generally agreed negative aspects included the need for increased watering, the possibility of new or increased pests and diseases, the need for increased mowing and the possible loss of visitors to the coast in sunny weather. The prospect of 5-10 days each year with temperatures in excess of 40°C was seen by all respondents as a negative impact, as it could lead to plant damage, severe problems under glass, the need for irrigation and a probable reduction in visitor numbers.

In other respects there was an obvious regional influence in the perceived impacts of climate change. A longer growing season and a substantial reduction in the number of frost days were considered to be beneficial, especially in northern gardens, but pest, disease and mowing problems were raised.

Responses to the prospect of a 20% increase in winter rainfall were more varied. One respondent in the east of England saw a potential benefit in improved tree health, but others saw only disadvantages resulting from waterlogging, saturated lawns, more damage, a reduction in available working time and decreased visitor numbers.

The prospect of a decrease in summer rainfall received equally varied responses. Several respondents identified the need for increased irrigation as the main potential disadvantage, with possible damage to lawns and some plant loss as secondary concerns. Interestingly, the respondent from the driest garden saw no problem as the challenge was already present, but saw the possibility of growing more plants from semi-arid regions as an advantage. The respondent from one of the wettest gardens also saw possible advantages of reduced summer rainfall in improved summer weather for visitors, and in creating better meadows.

Not surprisingly, the likelihood of more variable rainfall with more frequent droughts and heavy rainstorms was viewed as an entirely undesirable aspect of climate change, making planning of events and operations more difficult. However, three of the ten respondents suggested that uncertainty was already a normal feature of their operations and that any further change would make little difference. The possible increased incidence of strong winds was also seen as wholly undesirable with the potential for damage to plants and buildings, tree loss and increasing the need for safety audits.

The prospect of a 50cm rise in sea level was considered irrelevant to most respondents except the one manager gardening on the coast, whose garden had been under water for several months in the previous winter. He noted from first hand experience that sea level rise would be devastating in its effects on plants and visitor numbers.

The threat of new pests, salt damage, ultra-violet light damage and managing the uncertainty of change were also identified as potential difficulties or challenges. The potential inability to grow the existing plant range was also raised as a problem by one gardener, as additional management input would be required to design new planting schemes. The fact that this point was raised just once suggests that managers are either confident of their ability to grow plants under future climates, or that other problems associated with climate change, were considered more pressing.

When asked if actions were being taken to adapt to or mitigate climate change, six interviewees replied that they were engaged in or planning measures to reduce the environmental impact of their operations, including recycling, minimising carbon dioxide emissions and reducing greenhouse heat losses. A seventh had installed a new irrigation system to counter drought. No actions were planned by the other three respondents – in one case because none was affordable.

A majority of the responses to the individual questions suggested that climate change would be disadvantageous. Of the hundred individual responses (ten respondents with ten questions), 51 indicated disadvantages, 27 advantages, 12 a balance and 10 no impact. Paradoxically, though, when asked what the overall effect of these possible changes would be, four replied “advantage”, three “balance” and three “disadvantage”

6.10.2 RESPONSES OF GARDEN STAFF

i) Domestic gardens

In domestic gardens, the impacts of climate change and responses to it will depend on the nature of the owner/gardener. The owner may choose to garden at different times of day (in the cool of the late evening), or to postpone maintenance in wet weather. They may also choose to exploit climate change with more adventurous planting, to battle against it using more intensive management, or to avoid its impacts by adopting low maintenance features.

ii) Heritage gardens

In heritage gardens, the impact of climate change will depend on the nature of the garden. There may be some sense in changing working practices, for example an earlier start or later finish and longer midday break in very hot weather, but the manager will need to operate within the constraints of employment law and contractual obligations. The most difficult situation will apply when maintenance operations are contracted out, a situation which often applies in relation to grass maintenance. A horticulturally sensible approach of cutting grass when it needs cutting and when soil conditions are suitable for mowing is more difficult to write into a standard contract than is the specification of a routine mowing regime. If such a specification is produced, the contractor will almost inevitably increase their quote to protect themselves against the uncertainties within the task.

One of the important and costly impacts of climate change on heritage gardens is that staff will need to be increasingly highly trained to be able to contend with impacts of change on the garden itself. Many of the operations described above, although an integral part of good garden management, will need to be carried out more often and with greater thoroughness, so increasing staff levels will be required if standards are to be maintained.

Climate change will have some benefits for garden staff in terms of their working environment in generally warmer and drier springs, summers and autumns. Very high temperatures in summer and wetter winter conditions will need to be contended with.

Coping with the uncertainties and adverse impacts of climate change and with damage caused by extreme weather events may increase job stress for gardeners. Most respondents to the questionnaire felt that climate change presented a mix of advantages and disadvantages with their responses being influenced by the geographical situation of their garden. When asked about the overall impact of climate change on their garden, responses ranged very evenly across the spectrum of “advantage” to “no overall impact” to “disadvantage”.

Box 6.1 Cost implications of climate change for gardens

It is impossible, in a study of this scope, to deal in detail with the costs of climate change in each and every type of garden, and for each garden operation. However, the costs associated with managing the impacts of climate change on gardens fall into six broad categories.

Plant growth. Higher growth rates over a longer season will result in a greater mass of vegetation. The removal and disposal of surplus growth, whether lawn mowing or shrub pruning, will involve increased costs.

Plant failures. Removal and replacement of plants damaged by extreme weather events or by gradual failure over a sequence of dry summers will be very costly. Experience of past events suggests that restoring gardens after major storms or floods could mop up normal maintenance budgets of public gardens for several years.

Pest, disease and weed problems. Managing these problems will become increasingly resource intensive, particularly as environmental concerns and tougher legislative requirements are reducing the available range of approved pesticides.

Reducing negative impacts. The equipment and resources required to reduce the impacts of climate change will have significant costs. Irrigation water itself is likely to become more expensive, if it is available at all in times of severe drought.

Insuring for damage. Greater care will need to be taken to protect buildings and other garden structures against damage and decay. This may involve increased maintenance, the use of more expensive building methods, and increasingly rigorous safety inspections of trees and dams. Insurance cover against severe weather damage will be important, but may be increasingly costly or difficult to obtain. Insurers are already taking steps to withdraw protection from some flood risk locations, unless policy changes are made. Greater financial reserves may be required to cover loss.

Managing negative impacts. A major weapon against the adverse impacts of climate change will be sensitive management with long term strategies for the care and phased repair and regeneration of all components of the garden. The increasing complexity of dealing with climate change impacts will require more highly skilled staff, who may demand higher rates of pay if such staff are forthcoming.