Chapter 14

Global Warming Scenarios for Ireland and their Implications for Environmental Management

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ABSTRACT

Regional climate forecasts cannot yet be derived with confidence from general circulation models of the atmosphere, particularly in terms of projecting precipitation changes at middle latitude locations such as Ireland. This paper employs several large datasets relating to Irish precipitation and synoptic circulation types to examine past and present precipitation-climatic relationships. These relationships are then used to make preliminary inferences concerning likely changes in seasonal parameters in a greenhouse-warmed Irish climate. It is concluded that increases of 5-15% in winter precipitation will be accompanied by significant reductions in summer values, especially in eastern Ireland. These projections, allied to the global predictions concerning sea level rise are then used in an examination of some implications, particularly in civil engineering aspects of environmental management.

Introduction

Environmental managers, particularly in civil engineering-related fields, have, in the past, implicitly worked on the assumption that climate is a relatively conservative, stable commodity which can be characterised by a set of data derived from a long period of observations. Conventionally, a 30-year span of such observations has been used to derive the means, extremes and frequencies of the various weather elements which give a location its unique climatic ‘fingerprint’. Thus, climatologists could supply information, for example, on the likely return period of extreme wind gusts, rainfall amounts, or temperature extremes - considerations important in endeavours ranging from building design through to water resource management. It is now clear that such baselines cannot be extended into the past or more seriously into the short-term future, with any degree of certainty. That the climate of even extremely equitable temperature regions such as Ireland, as of the globe in general, changes on all scales is now an accepted fact, and that changes may be more radical over the next few years than over the last millennium is increasingly likely. It is no surprise, therefore, that the issue of climate change has been described as "potentially the greatest global environmental challenge facing mankind" (Houghton, 1990). Furthermore, arising from the investigations of the Greenland Ice Core Project, climate change appears to be on occasion a step-functional phenomenon, and not necessarily the gradual phenomenon which the results of computer modelling tend to suggest (GRIP, 1993).

In 1988 the World Meteorological Organization and the United Nations Environment Programme jointly established the Intergovernmental Panel on Climate Change (IPCC) to examine the nature, implications, and possible options for mitigation, of the anthropogenic impact on climate associated with the enhanced "greenhouse effect". The IPCC, reporting in August 1990 and 137 countries represented at the World Climate Conference in November of that year...
are about 1,000 times as fast as their predecessors of the 1970s, enabling the incorporation of more sophisticated models into numerical models and also permitting increasing resolution in their treatment of climate. Currently, seasonal and regional details are just beginning to emerge as output possibilities, as is the important question of the variability characteristics of future climate. The range of performance of GCMs has narrowed substantially in recent years. Fairly good agreement with observational data is now apparent, particularly for low latitude pressure distributions. Polewards of 60° a considerable problem still exists due to the unresolvable difficulties of the ice-albedo feedback effect detailed below. In contrast, with precipitation modelling, the greatest uncertainties lie at low latitudes, where large discrepancies with observational data continue to exist. In this case also a feedback problem is responsible, namely the failure of most models to incorporate successfully the role played by clouds.

Feedback Mechanisms Limiting the Effectiveness of GCMs

A feedback occurs when a change in a particular component of a system provokes a further series of changes in other elements, the consequence of which eventually causes a further effect on the initial component. Positive feedback reinforces change and means the system tends towards instability. Negative feedback, on the other hand, is a damping mechanism and stabilizes the system. Positive feedbacks are more difficult to appreciate since it is not clear even in which direction feedback occurs. This is a consequence of the fact that clouds are both highly reflective, thus influencing global albedo, and composed of water vapour, thus influencing the greenhouse effect. The question of whether in a warmer world more clouds mean more reflectivity, and therefore cooling, or more absorption, and therefore warming, has not yet been completely resolved. Current thinking is that midlatitude altitudes clouds may be more significant for the albedo while high clouds such as cirrus may be more important for absorption.

While increased temperatures will certainly lead to more cloud formation, global cloud cover may not increase correspondingly. Increased evaporation may manifest itself in the form of more cumulus clouds, with little change in overall albedo. An increase in stratus clouds on the other hand would imply an increase in total coverage and a cooling tendency - a negative feedback effect overall. GCMs are not currently very successful in handling cloud formation, particularly in terms of height, since it occurs at a scale much smaller than their grid size and much work needs to be done before complete confidence in their output is possible.

Cloud feedbacks. Cloud feedbacks are the most difficult to understand before GCM results may be accepted with confidence. A zero value for $\lambda_{\text{clouds}}$ gives $dT=2.8^\circ \text{C}$, while a value of -0.8 $\text{W m}^{-2} \text{K}^{-1}$ for doubled CO$_2$ net radiative flux change across the tropopause, $\Delta Q^*$, the system can be simplified as follows:

$$C \left( \delta T/R_0 \right) + \lambda_T = \Delta Q$$

where $C$ is the system heat capacity, $\lambda_T$ is the net radiative change resulting from the internal characteristics of the climate system, and $R_0$ is time.

An appropriate value for $\lambda$ is $\lambda_{\text{clouds}}$ which is the value the earth would have if it was a black body with its present day albedo, so that:

$$\lambda = 4 \epsilon R_0^4 = 3.75 \text{ W m}^{-2} \text{K}^{-1}$$

The total sensitivity of the earth's climate can now be obtained by adding the internal feedback factors as follows (Henderson-Sellers and McGuffie, 1987):

$$\lambda_{\text{Total}} = \lambda_{\text{clouds}} + \lambda_{\text{water vapour}} + \lambda_{\text{albedo}} + \lambda_{\text{ice albedo}}$$

Some of these quantities are known. For doubled CO$_2$, it is known that $\Delta Q = 4.0 \text{ W m}^{-2}$, while $\lambda_{\text{ice albedo}} = -1.7 \text{ W m}^{-2} \text{K}^{-1}$ and $\lambda_{\text{albedo}} = -0.6 \text{ W m}^{-2} \text{K}^{-1}$.

Thus:

$$\lambda_{\text{Total}} = 1.45 + \lambda_{\text{clouds}}$$

Estimates for $\lambda_{\text{clouds}}$ range from 0 to -0.8 $\text{W m}^{-2} \text{K}^{-1}$ (Henderson-Sellers and McGuffie, 1987)

Substituting $\lambda_{\text{Total}}$ into the first equation above, the equilibrium temperature $[\delta T/R_0 = 0]$ for doubled CO$_2$ can be derived. A zero value for $\lambda_{\text{clouds}}$ gives $\Delta T = 2.8^\circ \text{C}$, while a value of -0.8 $\text{W m}^{-2} \text{K}^{-1}$ gives a temperature change of 6.1$^\circ \text{C}$. Clearly, cloud feedback effects must be better understood before GCM results may be accepted with confidence.
Climate Change Scenarios and Environmental Management

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Response times The response time (or equilibration time) is that time a part of the climatic system takes to accommodate itself to a perturbation. These vary enormously from a matter of days for the lower atmosphere to several centuries for the deep oceans and ice sheets. Modelling the ocean’s response to increased atmospheric CO₂ is especially important since it acts to remove CO₂ from the atmosphere and also to absorb and redistribute heat throughout its great volume. The upper three metres of the ocean store much heat as the entire atmosphere. Incorporating these slow responding components into models based on 30 minutes time steps has proven extremely difficult and successful resolution awaits the development of more powerful computers.

GCM Estimates for Irish Climate

Model predictions for global temperature change have been reduced as greater sophistication has been achieved. Whereas estimated rises of 4°C by mid-century were being suggested in the late 1980s (Hansen et al., 1988), the 1992 supplementary IPCC report suggests a best estimate for the period 1990-2100 of 1.5-3.5°C (Leggett et al., 1992). Such a declining trend has occurred also as awareness has grown concerning other near-term factors. For example, it is now believed that depletion of stratospheric ozone will have a cooling effect on the atmosphere, as will continuing increases in sulphate aerosol pollution as industrialisation proceeds in countries such as China. It is also recognised that increased atmospheric CO₂ will induce greater plant growth and carbon storage, helping to reduce the increase in atmospheric concentrations.

However, as far as Ireland is concerned, many models show consistencies which give grounds for making reasonable estimates of the course of future climate. Firstly, its mid latitude position suggests that Ireland should, other things being equal, experience similar changes to the global mean. Most global warming will occur at higher latitudes due to the ice-albedo feedback effect. However, the climate of Ireland may be relatively slow to respond to greenhouse forcing due to the moderating influence of the Atlantic Ocean. The Atlantic is a particularly effective heat sink, with summer heat being dissipated each winter through a depth in excess of 200m and over a large area off the west coast of Ireland in excess of 500m (Bowen, 1990). Thus even if the European continent warms up, the existence of a cool sea surface around Ireland will inhibit warming in summer, while a poleward shift in winter isotherms will have a less positive effect on Irish winter temperatures than further east in Europe. These suggestions are partially supported by other GCMs which incorporate deep ocean mixing (Stouffer et al., 1989; Washington and Meehl, 1989) and by the work of Karoly (1987) who examined actual warming at the 700mb level between 1960-80. This study showed consistent warming almost everywhere except the north Atlantic and Pacific Oceans where considerable winter mixing depths also exist. If indeed the Atlantic around Ireland is slow to warm, the consequences for Irish climate will be determined by changes in circulation frequencies, an aspect considered in some detail below.

All GCM models predict higher annual precipitation in the high and low latitudes and higher winter precipitation in mid latitudes conditions such as Ireland. This is to be expected since the atmosphere’s capacity to hold water vapour increases by approximately 7%°C. However, little agreement is apparent from the models on where significant changes will occur and in particular what can be anticipated for summer precipitation changes. For Ireland, while there is general agreement that summer precipitation will increase, contradictory signals are in evidence when it comes to summer values.

It is thus apparent that regional climatic forecasts based on GCMs are not yet possible to make with any degree of confidence and while some credulity may be placed on temperature estimates, projected precipitation changes cannot be relied upon in any way as yet. Indeed as Wigley and Santer (1990) point out, GCMs are not able to simulate present precipitation patterns at fine scales, let alone future patterns. A great deal of work is therefore required before authoritative statements can be made. One approach to overcoming these regional inadequacies and to estimating summer precipitation changes in Ireland follows.

Sympotic Circulation Analogues for Projecting Future Irish Summer Precipitation

Examining the association between precipitation and circulation type enables the component contributions of a place’s annual precipitation regime to be disaggregated according to the circulation producing it. This is important given the growing awareness that significant circulation changes have occurred in recent times (Briffa et al., 1990) and that short term future climate changes in Ireland will be determined principally by changes in circulation frequencies. If it is possible to anticipate the nature of these, more authoritative estimation of the environmental significance of climatic change may be made.

In relation to precipitation yields to syoptic circulation types, the first requirement is for some form of daily categorisation of airflow types across Ireland. A number of approaches have been made to achieving this, ranging from early tabulations of surface wind direction frequencies (Brooks and Hunt, 1933), through more sophisticated air mass analysis (Bolascz, 1952) to perhaps the best known catalogue of airflow types devised by Lahm (1950;1972). This scheme involves seven primary types: anticyclonic, cyclonic, north-westerly, westerly, northerly, easterly and southerly. Subsequently, a further nineteen hybrid categories (together with an unclassified category) were added, incorporating more complex circulation patterns into daily classification, beginning from 1861. Updating has enabled a register of over 130 years of daily circulation types to be compiled. The categories are considered to be reasonably representative of an (50-60°N and 10°W-20°E) which includes Ireland, though problems of intra regional variation do occur (O’Hare and Sweeney, 1993; Mayes, 1994).

Circulation Types and Precipitation Yields

Anticyclonic. Pressure is typically high over Ireland and subsiding air inhibits precipitation almost everywhere. Generally daily amounts are less than 1.0mm and only in the west with Atlantic fronts the western seaboard do average falls exceed this value.

Cyclonic. A cyclonic circulation type involves the movement of an Atlantic/Biscay depression centre across Ireland. Over a long period of record the actual track taken by such lows may vary considerably, producing a fairly uniform distribution of precipitation. Only in the interior is there a hint that oceanic water vapour supplies may be diminished somewhat. With such a quite uniform distribution of rainfall by comparison with other airflow types, it could be suggested that should an increase in the frequency of cyclonic airflow occur across Ireland with global warming, the characteristic west-east contrast in rainfall receipt could be expected to diminish.

Westerly. Westerly circulations are the most frequent synoptic type in the Lamb-classification register, occurring 18.9% of the time With low pressure to the north and high pressure to the south of Ireland, there is obviously going to be a north-south as well as west-east decline in precipitation receipt. Indeed parts of the west coast receives almost three times as much precipitation with this airflow as the Leinster coast where
a very prominent rain shadow can be seen to the lee of the Wicklow mountains. Again the effects of a continued decline in the frequency of westerly circulations North westerly.

a very prominent rain shadow can be seen to the lee of north westerly airflow, causing depressions to move in annual rainfall, particularly if the replacement of Northerly.

such flows by cyclonic airflows occurred. South coast of Ireland where the driest north west coast receives the greatest amounts with this airflow which occurs about 4.7% of the time. The means that Ireland is generally drier than Britain with

precipitation when any lifting occurs such as over the mountains of Cork/Kerry and the southern Wicklows. Circulation-precipitation Scenarios for Irish Greenhouse Summers

What summer circulation frequency changes (and thus precipitation changes) can be expected to occur in Ireland as greenhouse warming proceeds? One way of addressing this is to examine what circulation types have been associated with warm summers in the past. For this, a long a temperature record as possible is desirable to avoid distortions due to anomalous blocking situations, and the long instrumental record developed by Manley (1974) and since continuously updated, for temperature conditions symptomatic of central England was chosen rather than a shorter run of data from Irish locations. Manley’s record is generally held to be fairly representative of conditions in both Britain and Ireland and represents the longest reliable instrumentally observed temperature record available globally, extending back to the mid 17th century. From this, summaries exhibiting departures of +1 (warm) and +2 (hot) standard deviation temperatures were extracted (Table 1). The latter corresponds to extra summer warmth of about 1.7°C, close to that hypothetically for the vicinity of Ireland in GCMs for approximately 2050. Analysis of the average frequency of circulation types (Table 2) shows that they are associated with substantial increases in anticyclonic situations and marked declines in westerly types.

Since at this point both the rainfall yield by circulation type (summer yields were distilled from the annual data discussed above) and the frequency of circulation types which produce warm and hot summers is known, it is possible to project the changes in summer rainfall which may accompany a switch to a greenhouse summer climate by simulating summer rainfall receipt at each location according to the circulation frequencies concerned (Figure 2(a)).

Diminutions in summer rainfall of approximately 5-19% are indicated for Ireland with greatest reductions occurring in eastern parts, particularly the north eastern regions. Along the south coast, warmer southerly circulations will carry greater water vapour loads and little change is apparent. Water availability implications from future climate change are thus most likely to occur in eastern Ireland in summer. It should of course also be remembered that these reductions may be accompanied by increases in potential evapotranspiration of approximately 8%.

The scenario suggested in Figure 2(a) appears also to have some support from recent observational data. Over most of Ireland and Britain summer rainfall has decreased over the last two decades, though increases over north western areas during the 1980s has partially offset this. Greatest reductions have occurred in southern and eastern parts and Myers (1995) has suggested these are associated with changes in anticyclonic and westerly circulation frequencies. In Ireland a crude regression on summer rainfall totals at Valentia and Dublin Airport suggest that a more marked downward trend is apparent in recent summers in eastern parts, in line with the suggested changes based on the synoptic circulation analysis above (Figure 3(a)).

Using a similar approach, projected changes in winter rainfall are seen to generally increases, particularly in western parts (Figure 3(b)). The records from Valentia and Dublin Airport (Figure 3(b)) again provide support, with a more substantive upward trend at the former in evidence, though such generalised analyses provide only a tentative first pass.
Table 2: Lamb Circulation Frequencies 1880-1996

<table>
<thead>
<tr>
<th></th>
<th>All Year</th>
<th>All Summers</th>
<th>Warm Summers</th>
<th>Hot Summers</th>
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<tr>
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<td>3.3</td>
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<td>0.9</td>
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<tr>
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<tr>
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<td>2.8</td>
<td>2.5</td>
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<tr>
<td>North East</td>
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<td>0.3</td>
</tr>
<tr>
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<td>2.1</td>
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<tr>
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<td>0.2</td>
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<td>Cy/NW</td>
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<td>Cy/N</td>
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<td>1.3</td>
<td>0.7</td>
<td>0.9</td>
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</table>

In summary, a scenario for Irish climate for 2050 might be as follows:

- Average annual temperature change (°C): 1.6
- Average annual precipitation: little change
- Average winter temperature change (°C): 0.5
- Average winter precipitation change: ±5-10%
- Average summer temperature change (°C): 1.5
- Average summer precipitation: ±5-10%

The values are not too dissimilar from those used as working assumptions by the Department of Environment report on climate change (McWilliams, 1992) though do emphasise the likelihood of larger reductions in summer rainfall. Warming in both seasons is slightly less than that suggested from averaging of five GCM results for north western Europe by Warrick and Barrow (1991).

**Implications for Environmental Management**

Global change will necessitate adjustments to environmental management practices throughout the world. In Ireland, the most significant impacts are likely to relate to the management of coastal areas and water resources.

**Sea-level rise and Coastal Management in Ireland**

Various studies (Gornitz and Lebedoff, 1987; Barnett, 1983:1984) have suggested that a sea level rise of 10-15cm has occurred in the past 100 years, at least some of which may be attributable to the global warming of 0.5°C which has taken place over the same period (Wigley and Raper, 1987). Over the next century, thermal expansion of the oceans will provide about 37% of the contribution to an anticipated rise of 58cm (Watson et al, 1992), the melting of land-based glaciers in temperate latitudes a further 39%, and the thinning of the Greenland ice-cap the remaining 24%.
Figure 3(a): Summer Precipitation Trends at Dublin Airport (top) and Valentia Observatory (bottom) 1983-1997

Figure 3(b): Winter Precipitation Trends at Dublin Airport (top) and Valentia Observatory (bottom) 1983-1997
Estimates of sea level rise up to 2100 have been revised downwards consistently from figures in excess of 5 metres in the late 1970s as it has become clear that earlier fears regarding the catastrophic melting of the polar grounded/partially floating West Antarctic ice shelf were probably exaggerated. It is now believed that even a one metre rise due to melting of this ice shelf would take up to 500 years to occur (Budd et al., 1987).

Examination of the four tide gauge records in Ireland which span a full nodal tide period of 19 years show only a very slight rising trend of 0.3-0.5 mm/year though in places the rate of retreat currently exceeds 2 m/year. In some instances natural processes are exacerbated by human actions in land rebound occurring north of a line from Wicklow, Wexford and Waterford, and embayments in Kerry, Galway and Mayo (such as Clew Bay and the Mullet Peninsula) have been suggested by Carter (1991) as vulnerable.

At its most basic, two responses can be made to coping with sea level rise - retreat or protection. Retreat normally the most economic strategy though being a variant of a "do nothing" strategy it runs counter to the deeply imbued Irish cultural trait of holding on to land at all costs. Local policies often aim to minimize land losses to major political issues and produce calls for non-economic schemes for protection. About 100,000 ha of land in Ireland may be at risk from sea level rise by 2050, perhaps amounting to 100 km of the total coastline length of 6,500 km (Carter, 1991). For many of this length the cost of relocating inhabitants and infrastructure from lightly settled areas will certainly be significantly less than constructing and maintaining defences which currently cost approximately €100/m.

Undoubtedly, where a high concentration of population, industry and infrastructure exists close to the shoreline, there is little alternative to some form of protection strategy. Even here though, the costs must be carefully appraised. The recent completion of the Thames (£559 M) and East Scheldt (£1500 M) barriers, and the soon to be completed Venice barrier (£2500 M) represent investments which Ireland can never and should never contemplate. Indeed the experience of "hard engineering" solutions in arresting shoreline erosion in Ireland has been disappointing. Many of the measures have been unsuccessful and have required even more expensive remedial work, exemplifying, as Devoy (1992) has claimed, "a vicious circle of scarce resources being sunk in insoluble problems of coastal dynamics". Indeed the building of sea walls at Bray, Portnosh, Youghal and Lahinch appear to have enhanced beach erosion and left the structures themselves exposed to storm wave attack. As sea level rises other defences will become vulnerable such as the sea walls between Sandymount and Don Laoghaire in Dublin Bay,一些 parts of the Liffey estuary, and the Spanish Arch in Galway where occasional breaching presently occurs.

Engineers' responses to greenhouse led sea level rises in Ireland are probably best focused on lower cost "soft engineering" strategies. These, however, require both a good insight into how sediment transport is occurring in the area concerned, and careful modelling of what changes may ensue. Although short term levies are often considered as set back lines, beach nourishment, gabions, geotextiles, embankments and sand dune grass planting are more suitable to the financial resources of the local authority, and their political need to be seen to be doing something, although they must be seen as a long term reinsurance to coastal inhabitants that the hazard potential of living in a threatened area has been eliminated.

Changes in Hydrology and Implications for Water Resource Management

The rainfall changes suggested earlier would, if realised, have considerable implications for engineers concerned with hydrological management and water quality. Inclement of the order of 15% in winter precipitation and decreases of a similar magnitude in summer represent an unfavourable scenario for many endeavours including: Flood control, drought management, urban drainage and water quality services, and the maintenance of adequate flow of efficient discharges. In essence they centre on the problems of higher winter river flows and reduced summer flows, the latter further exacerbated by reduced soil moisture storage.

Higher winter flows When the mean of a distribution changes, the extremes change by a greater amount. Wigley (1989) suggests that a change in the mean of approximately one standard deviation produces a seven fold change in the frequency of an extreme. Irish rainfall however typically has a high standard deviation already relative to the mean and so changes of this magnitude are unlikely. Nonetheless, significant changes in river regimes can be expected. The precipitation and evaporation changes suggested in this study correspond quite closely to those of Scenario 2 in Cane and Regan's (1991) work on likely changes in the hydrological regime of the River Brosna. For winter, they suggest that the discharge currently exceeded 5% of the time would increase to 6% and that the return period for design floods would reduce by approximately 50%. Changes in the average annual maximum flow in a catchment is significant. One of the foundations of the Flood Studies Report (NERC, 1975) is that the probability of a given storm can be calculated from a long term series of such values. If these changes significantly, the need for water management in the catchment are immediately restored unsound.

Wigley's scenario for high flows in winter: significant changes in river regimes can be expected.
flows will permit greater dilution of effluent at this time of the year.

Lower summer flows Reduced summer rainfall has an enhanced effect on river flows due to accumulating depletion in soil moisture and increases in potential evapotranspiration demands. Again Cannane and Regan’s (1991) estimates on the Brosna suggest that the discharge experienced less than 5% of the time will increase in frequency to around 11% of the time and that the 10 year low flow would become the five year event. Such changes have obvious implications in terms of reservoir storage where, particularly at the end of summer, terrihial delays in recharge could occur. It will be necessary to design for increased capacity both in reservoirs for greater carryover of water from the winter period and to cater for higher summer water demands from both domestic and agricultural consumers. Irrigation economics change significantly with any reduction in summer rainfall and considerable expansion in sprays and sprinkler systems seems probable in the driest south east of the country.

Groundwater resources provide less than 25% of Irish water supplies. Drier summers would pose a threat to some shallow aquifers, particularly in karstic areas where throughput of water is quite fast. In such areas deeper wells will be required. Some coastal aquifers may also suffer more frequently from summer sea water intrusion as a consequence of falling freshwater levels and rising sea levels.

Water quality implications Increased summer temperatures and decreased summer rainfall are not conducive to the maintenance of present water quality standards. In awarding effluent licences, a common criterion for an organic effluent might be that it should be discharged in amounts not calculated to cause an increase in Biochemical Oxygen Demand of more than 1 mg/l during the time of lowest flow. But if the likely lowest flow is substantially reduced, the dilution factor for effluent is correspondingly compromised. Unleached and accidental spillages also have enhanced effects in such circumstances. A deterioration of up to 20% in average downstream B.O.D. levels is possible in Irish rivers as a result of the change in regime. Lower summer flows also have the effect of producing higher nutrient concentrations, particularly phosphates (McGarrigle, 1990). This will, together with higher temperatures, encourage eutrophication, ultimately lead to a further reduction in dissolved oxygen and pose additional stresses on salmonid fish. The problems of nutrient loading in the midland lakes has been well researched. Further warming would tend to exacerbate these difficulties by encouraging greater thermal stratification in lake waters and inhibiting oxygenation.

Conclusion

The scenario developed for greenhouse-led changes in Irish climate will have a pervasive effect on many aspects of concern to environmental managers. Only two major families of impacts are addressed in this paper although several other aspects of concern exist. It must be stressed however that greenhouse-led changes will not be so radical as to take us out of our past range of experience for the foreseeable future. Rather it is the pervasiveness of changes which we will have to come to terms with if we are to accommodate to the new environmental stage, or rather take the right decisions which will enable us to survive economically upon it. Either way the maxim of keeping a safety margin as insurance against the unforeseen will more than ever be empirically sensible.

References
