ENVIROMENTAL CHANGE RESEARCH CENTRE
University College London
RESEARCH REPORT
No. 21

Nutrient reconstructions in standing waters

H. Bennion & D.T. Monteith
A Preliminary Data Report to English Nature by ENSIS Ltd.
Contract No: F80-11-02

March 1996

Environmental Change Research Centre
University College London
26 Bedford Way
London
WC1H 0AP
INTRODUCTION

This report presents data and results for all work completed on the Nutrient Reconstructions in Standing Waters project by the end of 1995. A full description of project objectives, methods and analytical procedures plus a full interpretation of the diatom and macrophyte data will be provided in the final report in 1997.

The first part of this report describes the results of lithostratigraphic analyses (Troels-Smith sediment descriptions, percentage dry weight, and percentage loss-on-ignition), diatom analyses, the TP/and or pH reconstructions, and the radiometric dating on a site by site basis. An attempt is made to relate the findings to documented site data, where available.

The second part includes for each site, descriptions of macrophyte distribution, species lists with abundance rating, and species distribution maps.

LIST OF STUDY SITES

1. Wast Water
2. Bassenthwaite Lake
3. Esthwaite Water
4. Semer Water
5. Malham Tarn
6. Greenlee Lough
7. Martham South Broad
8. Clarepool Moss
9. Betton Pool
10. Crose Mere
11. Oak Mere
12. Upton Broad
13. Hatchet Pond
LITHOSTRATIGRAPHIES, DIATOM ANALYSES, RECONSTRUCTIONS AND RADIOMETRIC DATING RESULTS

1. Wast Water, Cumbria (NY 165 060)

Lithostratigraphy

A 38 cm sediment core (WAST1) was taken from the deepest part of the lake at a water depth of 76 m using a Glew corer on 6-6-95. The lower part of the sediment core was dark brown (10YR 3/3) lake mud with some clay and plant fragments (Ld2 Lso2 As++ Dh+). There was a slight colour change at 10 cm and the upper 10 cms were a very dark brown (10YR 2/2), organic lake mud (Ld3 Lso1 Dg+ Dh+).

The percentage dry weight (%dw) and loss on ignition (%loi) profiles (Fig 1) show that %dw has fluctuated at around 20% and %loi at around 15% for most of the period represented by the sediment core. However there was an increase in percentage organic matter in the upper 10 cm, %loi rising to 25% at the sediment surface. There was very little change in the wet density (wd) throughout the core (values range from 1.0-1.2 g cm⁻³).

Diatom stratigraphy

The percentage relative frequencies of diatom species in four levels of the sediment core were calculated and Fig 2 illustrates the results for the major taxa. Diatom preservation was good throughout the core. A total of 77 taxa was observed, 53 of which were present in the TP calibration set and 45 in the pH calibration set. Most of the common taxa were well represented in the TP calibration set, with greater than 80% of the fossil assemblage being used in the calibration procedure, except for the 10 cm sample where only 74% of the fossil data was used. This was due to the high relative abundance of an unknown species of Cyclotella, referred to as Cyclotella unknown sp. 1, which was absent from the calibration set. Similarly, over 78% of the fossil data was used in the pH reconstructions, except for the 10 cm sample.

Fig 2 illustrates that there has been little change in the diatom species composition over the period represented by the upper 15 cm of the core (1850-1995). The small, planktonic Cyclotella taxa, especially C. comensis, C. cyclopuncta and C. unknown sp. 1, species generally found in oligotrophic waters, have dominated the assemblages. Achnanthes minutissima and Brachysira vitrea, non-planktonic species typical of waters low in nutrients, were also frequent throughout the core.

Total phosphorus and pH reconstructions

The TP reconstruction shows that the lake has been oligotrophic for the whole of the period from 1850 to the present day with no marked change in TP concentrations. The model provides an estimate of 4 µg TP l⁻¹ for 1850 (15 cm), 4 µg TP l⁻¹ for 1880 (12 cm), 3 µg TP l⁻¹ for 1900 (10 cm) [although this is probably under-estimated due to the analogue problem for this sample], and 5 µg TP l⁻¹ for 1995.

Similarly, there was no change in diatom-inferred pH over the period 1850-1995 with values of c. pH 7.0 for 1850, 1880, 1900 and 1995.
Discussion

These findings are consistent with Pearsall's evolutionary series of the English Lake District lakes (1921), where Wast Water was defined as a Group 1, rocky, unproductive lake with only 5% of cultivable drainage area. The palaeolimnological data confirm that Wast Water represents a typical oligotrophic lake in a "near natural" condition.
Figure 1 Lithostratigraphic data for Wast Water
Figure 2 Summary diatom diagram and reconstructions for Wast Water
2. Bassenthwaite Lake, Cumbria (NY 214 296)

Lithostratigraphy

An 80 cm sediment core (BASS1) was taken from the deepest part of the lake at a water depth of 20 m using a Mackereth corer on 12-6-95. The lower part of the sediment core (30-70 cm) was a dark olive grey (5Y 3/2), silty lake mud with clay and plant fragments (Ag2 Ld2 As+ Lsol+ Dh+). One notable feature was a very dark greyish brown (2.5Y 3/2) layer at 26-27 cm with a high clay-silt content (Ld2 Lsol1 Ag1 As+ Dh+). The origin of this layer is uncertain (see chronology section). There was a colour change above this layer to a dark olive brown (2.5Y 3/3) although sediment composition remained largely unchanged. The upper 5 cms were a dark brown (10YR 3/3), organic lake mud (Ld3 Lsol1 Dg+ Ag+).

The %dw and %loi profiles (Fig 3) show that %dw fluctuated c.40% and %loi c.9% in the lower section of the core (35-80 cm). There was a progressive increase in percentage organic matter from 35 cm to the core top, %dw falling to 10% and %loi rising to 15% at the sediment surface. The clay layer was apparent at 26 cm with a marked increase in %dw to 43% and a corresponding decrease in %loi to 5%. The changes in wd were similar to those in %dw with values of c. 1.3 g cm\(^{-3}\) from 35-80 cm and then a decrease from 35 cm to the core top where values were only 1.1 g cm\(^{-3}\). The clay layer was not detected in the wd profile because of the low resolution of the wd measurements (every 5 cm).

Diatom stratigraphy

The percentage relative frequencies of diatom species in four levels of the sediment core were calculated and Fig 4 illustrates the results for the major taxa. Diatom preservation was good to 30 cm downcore but was poor in the more inorganic, lower core section. A total of 97 taxa was observed, 77 of which were present in the calibration set. All of the common taxa were well represented in the calibration set, with greater than 90% of the fossil assemblage being used in the calibration procedure.

Fig 4 illustrates that there has been a slight change in the diatom species composition over the period represented by the upper 40 cm of the core (c.1850-1995). The bottom sample (40cm: pre-1880) was dominated by *Achnanthes minutissima* and *Synedra nana*, species generally found in oligo-mesotrophic waters. The 30 cm sample (1880) also had a high relative abundance of *Achnanthes minutissima* (30%) and *Synedra nana* (40%), and *Asterionella formosa*, a planktonic species typical of mesotrophic waters, increased in importance. The 25 cm level (1920) was similar to the 30 cm sample except for the higher frequency of *Fragilaria crotonensis*, a planktonic diatom also associated with mesotrophic waters. Two taxa, *Aulacoseira subarctica* and *Cyclotella pseudostelligera* appeared only in the surface sample (1995) but the relative abundances of the other major taxa were similar to those in the 25 cm sample.

Total phosphorus reconstruction

The TP reconstruction shows that the lake has been mesotrophic for the whole of the post 1850 period with only a slight increase in TP concentrations. The model provided an estimate of 20 \(\mu g\) TP l\(^{-1}\) for pre-1880 (40 cm), and then stabilised with a diatom-inferred value of 31 \(\mu g\) TP l\(^{-1}\) for 1880 (30 cm), 1920 (25 cm) and 1995. This indicates that there was a slight enrichment in the late nineteenth century but that there was no evidence of any further recent
eutrophication.

Discussion

Nutrient budget data compiled by the National Rivers Authority and the Institute of Freshwater Ecology (unpublished) shows the importance of both sewage effluent and agricultural inputs as sources of P to Bassenthwaite Lake and indicates that external loading has increased in the last few decades. However, it appears that the high flushing rate has limited the impact of eutrophication on the lake. The diatom model results suggest that there has been no increase in epilimnetic TP concentrations over the last 100 years, although diatom species shifts were observed and two taxa, not found in the 25 cm sample, were present in relatively high abundances in the upper sediment, indicating that biological changes are occurring. In summary, the palaeolimnological data confirm that Bassenthwaite Lake represents a typical mesotrophic lake in a "near natural" condition, although continued monitoring of the nutrient loading to the lake and its impacts on water quality is desirable.
Figure 3 Lithostratigraphic data for Bassenthwaite Lake
Figure 4 Summary diatom diagram and reconstructions for Bassenthwaite Lake
3. Esthwaite Water, Cumbria (SD 358 969)

**Lithostratigraphy**

An 86 cm sediment core (ESTH1) was taken from the northerly basin of the lake at a water depth of 15 m using a Mackereth corer on 7-6-95. The colour and sediment composition were similar throughout the core. The bottom sediments (25-80 cm) were a very dark brown (10YR 2/2) lake mud with traces of silt and plant fragments (Ld2 Lso1 Ag1 Dg+) and the upper 25 cms were a very dark greyish brown (2.5Y 3/2).

The %dw and %loI profiles (Fig 5) show that there has been little change with %dw c. 17% and %loI c.25% in the lower section of the core (40-86 cm). There was a slight and progressive increase in percentage organic matter from 35 cm to the core top, %dw falling to 5% and %loI rising to 30% at the sediment surface. Similarly there were no marked changes in wd with values of c. 1.0-1.1 g cm$^{-3}$

**Diatom stratigraphy**

The percentage relative frequencies of diatom species in five levels of the sediment core were calculated and Fig 6 illustrates the results for the major taxa. Diatom preservation was good throughout the core. A total of 91 taxa was observed, 76 of which were present in the calibration set. All of the common taxa were well represented in the calibration set, with greater than 96% of the fossil assemblage being used in the calibration procedure.

Fig 6 illustrates that there has been a marked change in the diatom species composition since the 10 cm level, dated to 1979, following at least a 100 year period of relative stability. The four lower samples: 50 cm (pre-1850), 40 cm (c. 1850), 30 cm (c. 1870) and 10 cm (1979) were all dominated by mesotrophic taxa, particularly Asterionella formosa, Aulacoseira subarctica, Achnanthes minutissima, Cyclotella comensis and Cyclotella radiosa. However, there were slight changes in the relative abundance of these species over this period (pre-1850 to 1979). Cyclotella radiosa and Cyclotella comensis decreased in relative importance whilst the relative frequency of Asterionella formosa, a spring diatom often observed in mesotrophic to eutrophic lakes increased. Fragilaria crotonensis and Stephanodiscus hantzschii were first observed in the 10 cm sample (1979). These species changes indicate nutrient enrichment.

The surface sample was markedly different from the 10 cm sample. The mesotrophic taxa decreased in relative abundance, particularly Cyclotella radiosa and Cyclotella comensis, both of which disappeared, and Aulacoseira subarctica. Conversely, the relative abundances of Asterionella formosa, Fragilaria crotonensis and in particular Stephanodiscus hantzschii (50%) increased.

**Total phosphorus reconstruction**

The TP reconstruction indicates that the lake was mesotrophic until c. 1979 with only small though steady increases in TP concentrations since pre-1850. For example, the diatom-inferred TP concentrations were 15 µg TP l$^{-1}$ pre-1850 (50 cm), 18 µg TP l$^{-1}$ in 1850 (40 cm), 20 µg TP l$^{-1}$ in 1870 (30 cm), and 28 µg TP l$^{-1}$ in 1979 (10 cm). However, the model suggests that there has been a significant increase in TP concentration since 1979 with a diatom-inferred value for the surface sample of 150 µg TP l$^{-1}$ related to the high percentage of Stephanodiscus hantzschii, a small, centric planktonic diatom commonly observed in highly enriched lakes.
This long term stability followed by a recent increase in productivity is confirmed by the \(^{210}\)Pb profile, which suggested a rapid and sustained increase in sediment accumulation rates in recent decades following a long period of more uniform accumulation dating back to the second half of the nineteenth century.

Discussion

The significant recent eutrophication at Esthwaite Water, as inferred from the diatom model, is consistent with documented records of catchment events and water quality. The lake is considered to be the most productive of the larger lakes in the Lake District and was classed as a Group 3 silted productive lake with 45% of cultivable drainage area, large numbers of algae, and hypolimnetic anoxia in Pearsall's series (Gorham et al., 1974). Nutrient concentrations and summer phytoplankton production have increased in the last few decades (Heaney et al., 1986; Talling & Heaney, 1988; Heaney et al., 1992), largely attributed to sewage inputs from Hawkshead sewage treatment works, opened in 1973. In 1986, a P removal system was installed but no improvement in water quality has been observed, largely due to internal P loading from the lake sediments and also perhaps due to diffuse sources of P from agriculture. In addition, a trout farm was established in 1981 and this may provide a further source of nutrients.

The inferred TP concentration of 28 µg TP l\(^{-1}\) for 1979 closely matches the historical water chemistry measurements of 25 µg TP l\(^{-1}\) in 1977 and 27 µg TP l\(^{-1}\) in 1986 (Talling & Heaney, 1988). There is a mis-match, however, between the diatom-inferred TP value for 1995 and the current measured TP of c. 30 µg TP l\(^{-1}\). This is because of the dominance of *Stephanodiscus hantzschii* in the surface sample, comprising 50% of the assemblage. This taxon has a high TP optimum in the calibration set of 216 µg TP l\(^{-1}\) because it is found in the highest relative abundances in the lakes with the highest TP concentrations and the dataset includes many lakes with TP concentrations > 40 µg TP l\(^{-1}\), thus resulting in an over-estimated value for Esthwaite Water. Furthermore, the surface sample (0-0.5 cm) could over-estimate the importance of *S. hantzschii* in the annual diatom assemblage as the half centimetre slice may represent only half a year (see chronology section) and may simply represent a bloom in the species rather than an integrated annual assemblage.

In summary, Esthwaite Water has experienced eutrophication over the last two decades, resulting in a change from a naturally mesotrophic lake to a meso-eutrophic one.
Figure 5 Lithostratigraphic data for Esthwaite Water
Figure 6 Summary diatom diagram and reconstructions for Esthwaite Water
4. Semer Water, North Yorkshire (SD 918 874)

Lithostratigraphy

A 75 cm sediment core (SEME1) was taken from the deepest part of the lake at a water depth of 11.5 m using a Mackereth corer on 9-6-95. The clay-silt content of the sediment decreased up the core from a very dark grey (10YR 3/1) inorganic clay with silt and no detritus between the core base and 30 cm (As2 Ag1 Ld1), to a lake mud with some silt and clay and plant remains between 25 and 5 cm (Ld2 Ag2 Ass+ Dh+ Lso+ ). The upper 5 cms were a very dark brown (10YR 2/2), organic, silty lake mud with fragments of herbaceous plants (Ld3 Ag1 Lso+ Dh++).

The %dw and %loi profiles (Fig 7) show a clear and gradual increase in percentage organic matter from the core base to the surface, %loi rising from 10% to 18% and %dw decreasing from 52% to 20%. Wd follows the same trend decreasing from 1.45 g cm\(^{-3}\) at the core base to 1.10 g cm\(^{-3}\) at the surface.

Diatom stratigraphy

The percentage relative frequencies of diatom species in only two levels of the sediment core were calculated and Fig 8 illustrates the results for the major taxa. Diatom preservation was extremely poor throughout the core with dissolution and breakage problems, and counting was difficult due to low concentrations and interference from mineral matter. Diatom (silica) dissolution is not uncommon in lime-rich waters. Therefore, it was only possible to analyse the upper 10 cms. A total of 75 taxa was observed, 62 of which were present in the calibration set. Most of the common taxa were well represented in the calibration set, with greater than 93% of the fossil assemblage being used in the calibration procedure.

Fig 8 illustrates that there is little difference between the diatom species composition of the 10 cm sample (1971) and that of the surface sample. The results must, however, be regarded with some caution in view of the dissolution problems. For example the lower percentages of *Stephanodiscus hantzschii* relative to *Fragilaria pinnata* in the 10 cm sample compared with those in the surface sample could be explained by the fact that *S. hantzschii* is more lightly silicified than *F. pinnata* and is thus more susceptible to dissolution. The assemblages of both levels were dominated by non-planktonic taxa associated with plant or stony substrates, *S. hantzschii* being the only important planktonic species. These taxa are commonly observed in shallow, eutrophic waters.

Total phosphorus reconstructions

The TP reconstruction should be interpreted with caution due to the problems discussed above. The diatom model provides an estimate of 126 µg TP l\(^{-1}\) for 1971 (10 cm) and 93 µg TP l\(^{-1}\) for 1995.

Discussion

A palaeolimnological interpretation of events at Semer Water is clearly limited by the diatom preservation problems. However, the results indicate that Semer Water has not experienced any major changes in TP concentrations in the last two decades. The diatom-inferred values closely match the measured TP concentrations of the lake from a survey in 1990 where mean
TP was 80 µg TP l\(^{-1}\) and maximum TP was 125 µg TP l\(^{-1}\). These values place the lake in the strongly eutrophic category.
Figure 7 Lithostratigraphic data for Semer Water
Figure 8 Summary diatom diagram and reconstructions for Semer Water
5. Malham Tarn, North Yorkshire (SD 894 668)

Lithostratigraphy

An 83 cm sediment core (MALH2) was taken from the deepest part of the lake at a water depth of 4 m using a Mackereth corer on 10-6-95. The bottom 10 cms of the core were a very dark grey (10YR 3/1) inorganic, marly mud with fine sand (Ld2 Lc1 Ag1 Ga+ Lso+ Dh++). Above this the sediment changed to a black (10YR 2/1), slightly more organic, silty lake mud with herbaceous plant fragments (Ld3 Ag1 Lso+ Lc+ Dh++). There was a sandy layer from 2-15 cm (Ld3 Ga1 Dh++ Lso+ Lc+). The upper few cms were a very dark grey (10YR 3/1), more organic lake mud (Ld3 Lso1 Dg+ Dh+ Lc+ Ga+) with traces of marl and fine sand.

The %dw and %loi profiles (Fig 9) show that the sediments of Malham Tarn are largely inorganic, although there was a progressive increase in percentage organic matter from the core base to 15 cm, with %dw decreasing from 35% to 20% and %loi rising from 12% to 30%. The sandy layer was apparent at 2-15 cm with a marked decrease in %loi to 15%. The changes in wd were similar to those in %dw with a gradual decrease from 1.25 g cm$^{-3}$ at the base to 1.05 g cm$^{-3}$ at c. 20 cm, and a slight increase again between 2 and c.15 cm marking the increase in sand content.

Diatom stratigraphy

The percentage relative frequencies of diatom species in four levels of the sediment core were calculated and Fig 10 illustrates the results for the major taxa. Diatom preservation was generally poor, owing to the calcareous nature of the lake sediments. A total of 72 taxa was observed, 54 of which were present in the calibration set. All of the common taxa were ‘1/ell represented in the calibration set, with greater than 90% of the fossil assemblage being used in the calibration procedure.

Fig 10 illustrates that there have been slight changes in the diatom species composition in terms of relative percentages over the period represented by the 80cm core (c.1700-1995). However, there has been no clear species replacement and the assemblages have been dominated by the same major, non-planktonic taxa throughout the core: Achnanthes minitissima, Amphora pediculus, and the benthic Fragilaria spp., all species commonly found attached to either the sediments, stones or macrophyte surfaces of shallow, alkaline waters. The only changes were that Fragilaria construens var. binodis and Fragilaria lapponica accounted for greater relative abundances in the 30 cm sample (c. 1900) than in the upper and lower samples, Gyrosigma acuminatum occurred in the highest frequencies in the bottom sample (c. 1700), and Achnanthes minutissima had higher frequencies in the bottom and surface sample than in either the 60 cm (c. 1800) or the 30 cm sample (c. 1900).

Total phosphorus reconstruction

The TP reconstruction shows that the lake has had high TP concentrations throughout the period represented by the sediment core (1700-1995), which would place the lake in the eutrophic category. However there was no clear trend in the reconstructed history. The model provided an estimate of 105 µg TP l$^{-1}$ for c. 1700 (80 cm), then indicated a slight increase to c. 150 µg TP l$^{-1}$ for c. 1800 (60 cm) and c.1900 (30 cm), followed by a decrease to 88 µg TP l$^{-1}$ by 1995.
Discussion

The results suggest that Malham Tarn is a naturally eutrophic lake and has not experienced any major increase in TP concentrations since 1800. However, these data must be viewed with caution in view of the unique chemistry of the tarn's water and sediments. It is a highly alkaline site, rich in calcium carbonate with frequent silica limitation, and pH is rarely below 8.0. Such conditions can only be tolerated by a small number of species thus restricting the flora, and may have more influence on the diatom assemblages than open water TP concentrations.

The lack of planktonic forms in the Malham Tarn sediments causes uncertainty over the results of the model because the relationship between non-planktonic taxa and open water nutrient concentrations is not as direct as that for planktonic forms (Bennion, 1995). The absence of such forms, particularly the centric diatoms, may be related to the need for motility on the sediments because these are non-motile taxa and would be buried in the deposits whenever there was disturbance by wave action etc and would be unlikely to survive (Round, 1953). The development of epiphytic (attached to plant substrates) and epilithic (attached to stones) communities at the expense of planktonic ones may be regarded as one of the characteristics of a calcareous, eutrophic system (Round, 1953). Furthermore, Malham Tarn’s calcareous sediments are naturally inorganic with traces of sand and a lack of organic remains. The importance of *Amphora pediculus* in the fossil assemblages is most likely explained by the nature of the sediment because it is a species commonly observed attached to sand grains.

These factors may explain why the model over-estimates TP values for Malham Tarn. In a recent survey, TP concentrations in the inflow and outflow ranged from 5-30 µg TP l\(^{-1}\) whereas the model estimates a current TP value for the lake of 88 µg TP l\(^{-1}\). An earlier study of Malham Tarn discussed the difficulty with classifying the lake within the usual freshwater trophic system because it exhibits eutrophic features, such as high nutrient status, high submerged macrophyte production and shallow water depth, and also oligotrophic features, such as low phytoplankton production and the absence of marginal reed beds (Round, 1953). This study concluded that the chemical and physical nature of the sediment, combined with the chemical composition of the water, was the governing factor in the composition of the algal floras.
Figure 9 Lithostratigraphic data for Malham Tarn
Figure 10 Summary diatom diagram and reconstructions for Malham Tarn
6. Greenlee Lough, Northumbria (NY 774 698)

Lithostratigraphy

A 73 cm sediment core (GREE1) was taken in a water depth of 1.8 m using a Mackereth corer on 11-6-95. The lower part of the sediment core (> 20 cm) was a black (10YR 2/1) silt with some fine sand and plant remains (Ld2 Ag2 Lso+ Ga+ Dh+). There was a slight colour change at 20 cm to a very dark grey (10YR 3/1) and the silt content of the sediment decreased (Ld3 Ag1 Ga++ Lso+). There was a clear layer of more minerogenic material at c. 4-8 cms. The uppermost 3 cms were a very dark brown (10YR 2/2), more organic lake mud with some silt (Ld3 Ag1 Lso+ Dg+ Ga+).

The %dw and %loI profiles (Fig 11) fluctuated considerably throughout the core. %dw generally varied between 20 and 40%, and %loI between 10 and 30%. This variability suggests that there have been periods of frequent minerogenic inwash and probably also a fair degree of sediment mixing (given that the site is wind stressed and shallow). There was a distinctive layer of much denser material between 4 and 8 cms, where %dw rose to 65% and %loI fell to 2%. Even the uppermost sediments were inorganic with a %loI value of only 5%. The wd data followed the same trend, values fluctuating between 1.10-1.25 g cm$^{-3}$ throughout the core, except for a clear layer at c. 5 cm where values reached 1.40 g cm$^{-3}$.

Diatom stratigraphy

The percentage relative frequencies of diatom species in four levels of the sediment core were calculated and Fig 12 illustrates the results for the major taxa. Diatom preservation was good to 30 cm downcore but was poor in the more inorganic, lower core section, where mineral matter also caused interference problems. A total of 80 taxa was observed, 64 of which were present in the calibration set. All of the common taxa were well represented in the calibration set, with greater than 88% of the fossil assemblage being used in the calibration procedure.

Fig 12 illustrates that there have been slight changes in the diatom species composition in terms of relative percentages over the period represented by the 70 cm core. It is not possible to estimate the time represented by the core because of the problematic radiometric dates, other than to say that 1930 lies at 5-16 cm and 1900 at 7-24 cm. There have been no clear species replacements and the assemblages have been dominated by the same major, non-planktonic taxa throughout the core: the benthic *Fragilaria* spp., *Achnanthes lanceolata*, *Amphora pediculus* and *Navicula cocconeiformis*, species commonly found attached to either the sediments or macrophyte surfaces of shallow, alkaline waters. The only changes were that *Fragilaria construens* var. *venter* and *Navicula cocconeiformis* accounted for greater relative abundances in the lower samples (50 and 70 cm) than in the upper ones (0 and 30 cm).

Total phosphorus reconstruction

The TP reconstruction shows that concentrations have remained largely unchanged throughout the period represented by the core. The model indicates that the lake has been eutrophic for the whole of this period with values of around 85-90 μg TP l$^{-1}$. 
Discussion

There are few nutrient chemistry data available for Greenlee Lough and so it is not possible to directly compare the diatom-inferred concentrations with measured values. The site has been classed as mesotrophic based on invertebrate and macrophyte survey data and on chemical data collected by the Institute of Terrestrial Ecology and reported in Palmer (1982), where summer TP concentrations were in the range 19-26 µg TP l\(^{-1}\). It is usual that TP concentrations are at their maximum in winter and therefore the annual mean TP values are probably greater than the concentrations measured in the summer survey.

It does seem, however, that the diatom model may have over-estimated the TP values for Greenlee Lough. As for Malham Tarn, this is most likely because of the lack of planktonic forms in the fossil assemblages. The dominance of non-planktonic *Fragilaria* spp. has been observed in other shallow, alkaline British waters (Bennion, 1994; Bennion, 1995). They are known to be poor indicators of lake trophic status because of their wide ecological tolerances and associations with substrates (plants, stones, mineral particles) rather than directly with epilimnetic water chemistry. Furthermore, the radiometric dating results indicate that the sediment record may be disturbed and therefore the temporal resolution is poor. These problems should be considered when interpreting the model results for Greenlee Lough.

In summary, Greenlee Lough does not appear to have experienced any major changes in water quality as inferred by the diatom model, and probably represents a mesotrophic lake in a near natural condition.
Figure 11 Lithostratigraphic data for Greenlee Lough
Figure 12 Summary diatom diagram and reconstructions for Greenlee Lough
Lithostratigraphy

A 104 cm sediment core (MART1) was taken in a water depth of 1.0 m using a piston corer on 19-9-95. The lower part of the sediment core (> 60 cm) was a very dark brown (10YR 2/2) lake mud with some silt and plant remains (Ld3 Ag1 Lso+ Lc+ Dh+). The upper 60 cm were a very dark grey (10YR 3/1) inorganic, calcareous sediment with small mollusc shells (Ld2 Lc2 Lso+ Ag+).

The %dw and %loi profiles (Fig 13) revealed a clear change at c. 60 cm from a more organic sediment with %loi values of c. 25-30% and %dw of around 20-25%, to less organic, calcareous material with %loi values of 5-10% and %dw of around 25-30% in the upper part of the core. The wd data followed the same pattern with generally higher values in the upper core section.

Diatom stratigraphy

The percentage relative frequencies of diatom species in five levels of the sediment core were calculated and Fig 14 illustrates the results for the major taxa. Diatom preservation was satisfactory throughout the core. A total of 90 taxa was observed, 64 of which were present in the calibration set. There were analogue problems throughout the core owing to the relative importance of brackish diatom species in the fossil assemblages that were not present in the calibration set. Analogue problems were particularly poor for the 30 cm sample and to a lesser extent the 100 cm sample because of the high percentage of *Mastogloia smithii*, a brackish species which is absent from the north-west European freshwater dataset. In view of these analogue problems, the TP reconstruction should be interpreted with caution.

Fig 14 illustrates that there have been marked changes in the diatom species composition over the period represented by the 100 cm core. Preliminary radiometric dating results indicate that the core represents at least the post-1800 period. The bottom sample (100 cm) was dominated by the non-planktonic *Fragilaria* spp., typical of shallow, alkaline waters, with relatively high abundances of *Cocconeis placentula* and *Rhoicosphenia curvata*, species commonly found attached to plants in high conductivity waters. There was no major difference between the 100 cm and the 50 cm sample (c.1850) except for the appearance of *Gomphonema angustatum* and disappearance of *Rhoicosphenia curvata*.

The assemblage at 30 cm (c.1900) was, however, slightly different from the lower levels with high percentages of *Achnanthes minutissima* and very low abundances of the *Fragilaria* spp. *Cymbella microcephala* increased in importance and *Mastogloia smithii*, a brackish species, constituted 20% of the diatom assemblage. There was a further change by the 15 cm sample (c.1950). This sample was dominated by *Gomphonema angustatum*, and *Achnanthes minutissima* was also important. The *Fragilaria* spp. dominated the surface sample, although brackish species, especially *Amphora coffeaeformis*, were still present.

Total phosphorus reconstruction

The TP reconstruction shows that there have been changes in the nutrient status of South Martham Broad. Given the analogue problems, however, the diatom-inferred results are not reliable and only a qualitative interpretation of the species changes can be made. The values
produced by the model are clearly erratic ranging from 150 µg l⁻¹ for the bottom sample to only 28 µg TP l⁻¹ for the 30 cm sample, increasing again to 112 µg TP l⁻¹ for the 1995 sample.

Discussion

Monitored TP data over the period 1982-1992 gives an average TP concentration of c. 40 µg TP l⁻¹ and shows that there has been no marked change in TP concentrations over the 10 year period (unpublished). Therefore, there is a clear discrepancy between the measured and modelled data. It is likely that the species shifts in the core are a response to changes in lake conductivity rather than nutrient concentrations because salinity is maintained by percolation under the coastal dunes bordering the North Sea. Hence, chloride concentrations are high, ranging from 1000 to 2000 mg l⁻¹ in the 1982-92 dataset. A number of the taxa in the fossil assemblages can tolerate highly conductive waters, e.g. *Cocconeis thumensis*, *Amphora coffeaeformis* and *Mastogloia smithii* and are therefore indicative of more saline periods in the lake's history. In contrast the *Fragilaria* spp. and *Achnanthes minutissima* are typical freshwater taxa, commonly observed in shallow waters. The lack of plankton in Martham South Broad, as for a number of the other shallow lakes sampled in this study, poses additional problems for inferring epilimnetic TP concentrations from diatoms. The dominance of such taxa may well be explained by extent of macrophyte growth or penetration of light rather than nutrient concentrations in the water column. Martham South Broad is one of the few remaining Phase 1 Broads (Kennison & Prigmore, 1994) because of its abundant macrophytes, particularly charophytes, and clear water conditions. Therefore, one would expect the diatom assemblages to be dominated by epiphytic forms, growing on the plant surfaces, and epipelic forms, living *in situ* on the sediment surface.

In summary, the diatom model cannot be used with any confidence to reconstruct the TP history of South Martham Broad, owing to species analogue problems. The diatom flora, however, does suggest that the lake has always been brackish. There have been species shifts over the period represented by the core which most likely indicate fluctuations in salinity rather than any change in nutrient status.
Figure 13 Lithostratigraphic data for Martham South Broad

[Graphs showing depth and related data]
Figure 14 Summary diatom diagram and reconstructions for Martham South Broad.
8. Clarepool Moss, Shropshire (SJ 435 343)

Lithostratigraphy

A 100 cm sediment core (CLAP1) was taken in a water depth of 2.1 m using a piston corer on 18-9-95. The sediment was a homogenous very dark brown (10YR 2/2) unconsolidated, highly humified, organic peat for the whole core length (Ld4 Ls0++).

The %dw, %loI and wd profiles (Fig 15) show very little change throughout the whole period represented by the core. The %loI values were extremely high (80-90%) and consequently the %dw and wd values very low (5-10%) because of the organic, peaty nature of the material.

Diatom stratigraphy

The percentage relative frequencies of diatom species in three levels of the sediment core were calculated and Fig 16 illustrates the results for the major taxa. Diatom preservation was poor, except in the surface sediment sample, with progressively poor preservation downcore. Analysis was not possible below 30 cm. A total of 52 taxa was observed, 35 of which were present in the TP calibration set. There were analogue problems throughout the core owing to the relative importance of acid-tolerant diatom species in the fossil assemblages that were not present in the TP calibration set. Analogues were particularly poor for the surface sample where only 40% of the data could be used in the TP calibration procedure. There were also analogue problems for the pH reconstruction with only 31 of the fossil taxa present in the pH calibration set, and only 70% and 52% of the fossil data could be used in the pH reconstructions for the surface and 10 cm sample respectively.

Furthermore, diatom dissolution was extremely bad in the 30 cm sample with presence of only very robust forms. The data may not therefore represent the true assemblage for this time and the observed changes in species composition may be more a reflection of the standard of preservation than any real species shifts. In view of these analogue problems, the reconstructions should be interpreted with caution.

Fig 16 illustrates changes in the diatom species composition over the period represented by the upper 30 cm of the core. Preliminary radiometric dating results indicate problems in determining sediment accumulation rates and thus no chronology has been obtained. Further measurements are ongoing. The bottom sample (30 cm) was dominated by *Eunotia incisa* and *Frustulia rhomboides*, taxa commonly observed in acid waters. The 20 cm sample appeared more diverse but this was a function of better preservation. The dominant species was a fine, poorly silicified form of *Aulacoseira granulata*, and those taxa that were present in the lower sample were still important. The surface sample was quite different with high frequencies of *Eunotia meisteri*, *Eunotia curvata*, *Pinnularia appendiculata* and *Pinnularia interrupta*, taxa associated with acid conditions.

Total phosphorus and pH reconstructions

The TP reconstruction shows that there have been changes in the nutrient status of Clarepool Moss. Given the analogue and dissolution problems, however, the diatom-inferred results are not reliable and only a qualitative interpretation of the species changes can be made. The values produced by the model ranged from 7 µg l⁻¹ for the bottom sample to 35 µg TP l⁻¹ for the 20 cm sample, decreasing again to 17 µg TP l⁻¹ for the 1995 sample. The lower TP
value for the bottom sample is explained by the high abundances of *Eunotia incisa* and *Frustulia rhomboides* which have very low TP optima, but the dominance of these two taxa is likely to be related to the degree of preservation, as discussed above, and the model may therefore be under-estimating the TP concentrations. The higher estimated TP value for the 20 cm sample is associated with the rise in *Aulacoseira granulata*, which can tolerate high nutrient concentrations and has a high TP optimum.

The pH reconstruction results must also be viewed in light of the analogue difficulties. The diatom-inferred pH for the three levels were very similar, ranging from 5.3 for the bottom sample to 5.8 for the 20 cm sample, and giving a current pH of 5.4.

**Discussion**

There are no water chemistry records available for Clarepool Moss and therefore it is not possible to validate the results of the reconstructions. A spot water sample taken by Gorham in 1955 gave a pH value of 5.4 and therefore the pH values produced by the model of 5.3-5.8 appear to be in the correct range (F. Rose, pers. comm.). The pool is classed as dystrophic because of the dominance of peat and the water colour is very brown with a secchi depth of only 18 cm. There are no similar dystrophic lakes in the northwest European calibration set and therefore the diatom model cannot be used with any confidence to reconstruct the TP history of Clarepool Moss. The diatom flora, however, does suggest that the lake has always been acid with dominance of acidophilous (low-pH tolerant) species throughout the core. The diatoms appear to be responding more to the low pH of the water rather than to nutrient concentrations and thus there is no clear evidence of enrichment. The results confirm that Clarepool Moss is a typical dystrophic system but it is probably not analogous to many other standing waters in the UK.
Figure 16 Summary diatom diagram and reconstructions for Clarepool Moss
9. Betton Pool, Shropshire (SJ 509 078)

Lithostratigraphy

A 90 cm sediment core (SCM27B) was taken from the deepest part of the lake in a water depth of 11 m using a Mackereth corer on 15-2-95. The sediment was a very dark greyish brown (2.5Y 3/2) from 25 cm to the core base. The lower sediments (> 60 cm) were a silty lake mud with a reasonable clay content and some plant remains. The sediment appeared to have less clay content above 60 cm. The upper 25 cms were dark yellowish brown (10YR 3/4) but sediment composition was similar to the lower part of the core.

The %dw profile (Fig 17) shows that there has been a small but steady decrease in %dw up the core from c. 20% at the base to c. 10% at the surface. The %loi values have increased from c. 20% at the core bottom, reached a maximum of c. 30% between 25-45 cm and then declined again to c. 25% in the upper 25 cms, indicating a period of more organic sediments in the central core section.

Diatom stratigraphy

The percentage relative frequencies of diatom species in six levels of the sediment core were calculated and Fig 18 illustrates the results for the major taxa. Diatom preservation was rather poor throughout the core. A total of 89 taxa was observed, 73 of which were present in the calibration set. All of the common taxa were well represented in the calibration set, with greater than 96% of the fossil assemblage being used in the calibration procedure.

Fig 18 illustrates that there have been marked changes in the diatom species composition over the period represented by the core (post-1850). The three lower samples: 88 cm (c.1850), 80 cm (c.1857), and 70 cm (c.1880) were all dominated by mesotrophic, plankttonic taxa, particularly Cyclotella ocellata, Cyclotella radiosa, Stephanodiscus alpinus and two non-planktonic forms, Achnanthes lanceolata and Fragilaria pinnata. There was a change by the 50 cm sample (c. 1927) where Cyclotella ocellata disappeared and Aulacoseira subarctica, Stephanodiscus parvus and Cyclostephanos dubius appeared for the first time, the latter two taxa being associated with enriched waters. The assemblage in the 30 cm sample (c.1963) was similar to the 50 cm level except that Fragilaria crotonensis, a planktonic species commonly found in nutrient-rich waters, was observed for the first time. The surface sample was markedly different from the 30 cm sample. The mesotrophic taxa decreased in relative abundance, particularly Cyclotella radiosa, Aulacoseira subarctica and Stephanodiscus alpinus. Conversely, the relative abundances of Fragilaria crotonensis and in particular Stephanodiscus parvus (55%) increased.

Total phosphorus reconstruction

The TP reconstruction indicates that the lake has been eutrophic in terms of TP concentrations since at least 1850. The model infers that TP concentrations increased slightly between 1880 and c.1930 but that the lake has experienced significant enrichment since 1960. For example, the diatom-inferred TP concentrations were 51 µg TP l⁻¹ in c.1850 (88 cm), 55 µg TP l⁻¹ in 1857 (80 cm), 54 µg TP l⁻¹ in 1880 (70 cm), increasing slightly to 61 µg TP l⁻¹ in 1927 (50 cm), 62 µg TP l⁻¹ in 1963 (30 cm) and then more than doubled to 147 µg TP l⁻¹ by 1995, related to the expansion of Stephanodiscus parvus, a small, centric planktonic diatom commonly observed in highly enriched lakes. This long term stability followed by a recent
increase in productivity is supported by the $^{210}\text{Pb}$ profile, which suggested an episode of rapid increase in sediment accumulation rates in the early 1970s following a long period of more or less uniform accumulation.

Discussion

The significant recent eutrophication at Betton Pool, as inferred from the diatom model, is consistent with available documented data on land use and water quality. The lake is surrounded by arable fields with ploughing near the waters edge and fields used for cattle grazing, and is also used for water ski-ing and angling. The lake also appears to have been used as a roost by a large gull population since the late 1980s, attracted by an adjacent refuse site. All of these catchment and lake uses act as potential sources of nutrients and have all either increased (e.g. agricultural intensification) or been introduced (e.g. recreation) in recent decades.

The inferred TP concentration of 147 µg TP l$^{-1}$ for 1995 closely matches recent water chemistry data collected during 1991/2, where annual mean TP was 113 µg TP l$^{-1}$ and ranged from 8-200 µg TP l$^{-1}$ over the sampling period (Moss et al., 1992). Although high, placing Betton Pool in the eutrophic category, these concentrations are modest in the context of the Cheshire and Shropshire mere's, which are renowned for their high TP levels but low nitrate values. The lake appears to be nitrogen rather than phosphorus limited because chlorophyll a concentrations are on average not high (e.g. annual mean of 11 µg l$^{-1}$).

In summary, Betton Pool has experienced eutrophication over the last few decades, resulting in a change from a naturally eutrophic lake to a hypertrophic one in terms of TP concentrations (> 100 µg TP l$^{-1}$). Moss et al. (1992) concluded that the lake did not appear to be suffering from eutrophication problems that were any greater than the probable regional change that had occurred in the post-war period, as a result of agricultural intensification. However, continued monitoring of nutrient concentrations in the lake would be desirable based on the palaeolimnological findings of the current study.
Figure 17 Lithostratigraphic data for Betton Pool
Figure 18 Summary diatom diagram and reconstructions for Betton Pool
10. Crose Mere, Shropshire (SJ 430 305)

Lithostratigraphy

A 120 cm sediment core (SCM03B) was taken from the deepest part of the lake in a water depth of 9.3 m using a piston corer on 22-6-93. The lower sediments (> 40 cm) were a very dark brown (10YR 2/2) detritus mud with some clay and silt (Ld3 Dg1 As+ Ag+ Lso+). Between 10-40 cm the sediment was a dark yellowish brown (10YR 3/4) and appeared to have a higher silt/clay content than the lower core section with some calcareous remains (Ld3 Ag1 As+ Lso+ Lc+ Dg+). The upper 10 cms were dark brown (10YR 3/3) flocculant, organic lake mud (Ld3 Lso1 Ag+).

The %dw and %looi profiles (Fig 19) show that the lower part of the core had a high organic content with %dw c. 15% and %looi c. 50%. The %looi values decreased to c.35% between 55-105 cm and decreased still further to c.20% between 10-40 cm, increasing again slightly in the upper 10 cms to c.30%. The %dw values increased slightly between 10-40 cm to c.20%. Similarly, the wd values were greater between 10-40 cm, indicating a period of denser, less organic sediments in this section of the core.

Diatom stratigraphy

The percentage relative frequencies of diatom species in 25 levels of the upper 60 cms of the sediment core were calculated and Fig 20 illustrates the results for the major taxa. Diatom preservation was progressively worse downcore but did not prevent counting above 60 cm. A total of 80 taxa was observed, 66 of which were present in the calibration set. All of the common taxa were well represented in the calibration set, with greater than 97% of the fossil assemblage being used in the calibration procedure for all except the bottom sample (91%).

Fig 20 illustrates that there have been marked changes in the diatom species composition over the period represented by the 60 cm core (post-1750). The lower samples (pre-1850) were all dominated by mesotrophic to eutrophic, planktonic taxa, particularly Cyclotella ocellata, Cyclotella radiosa, Aulacoseira granulata, Stephanodiscus parvus and two non-planktonic Fragilaria spp. (Note that this is a very similar assemblage to that in the lower samples of the Betton Pool core). There was an expansion of Stephanodiscus parvus and consequent decline in Cyclotella ocellata during the late nineteenth century. Stephanodiscus parvus was the dominant species throughout the early and mid 1900s, and a number of other eutrophic taxa increased in importance in the early 1900s, including Aulacoseira granulata, Aulacoseira ambiguа, Stephanodiscus hantzschii and Stephanodiscus neoastraea. The assemblage changed again slightly in the period 1940-1970 when Fragilaria crotonensis and Asterionella formosa were present in higher relative abundances than in previous years, taxa with lower TP optima than the Stephanodiscus spp. The assemblage has changed significantly since c.1980. Fragilaria crotonensis and Asterionella formosa have continued to expand and have replaced Stephanodiscus parvus as the dominant species.

Total phosphorus reconstruction

The TP reconstruction indicates that the lake has been eutrophic in terms of TP concentrations since at least 1750 with concentrations always in excess of 80 μg TP l⁻¹. The model infers that TP concentrations increased in the late nineteenth century and remained high throughout most of the 1900s. However, the model suggests that TP levels began to decline again c.1982 and
have continued to do so to the present day. For example, the diatom-inferred TP concentrations were 83 µg TP l^{-1} in c.1750 (58 cm), 117 µg TP l^{-1} in c.1850 (40 cm), increasing to 170 µg TP l^{-1} by c.1880 (35 cm), stabilised at c. 140-170 µg TP l^{-1} during the twentieth century (1900 and 1980), decreased to 123 µg TP l^{-1} by 1989 and declined still further to 83 µg TP l^{-1} by 1993. Thus, after a period of marked enrichment, TP levels have returned to pre-enrichment concentrations.

Discussion

The post-1850 eutrophication at Crose Mere, as inferred from the diatom model, is most likely related to changes in land-use in the lake catchment, although there are no documented data to support these conclusions. The lake is currently surrounded by open rough pasture used for cattle grazing. Parish data from 1931 indicate that the catchment saw an increase in cattle, pig and sheep numbers and an increase in arable land between 1931 and 1987 (Moss et al., 1992), but there are no earlier available data. The introduction of nitrogen-based fertilisers, increase in the production of slurry and an increase in the Canada geese population have also been suggested as possible nutrient sources to the lake. Therefore the increase may be attributed to agricultural expansion in the catchment. There are also no available data documenting any land use or management changes that might explain the reduction in TP concentrations since c.1982 as inferred by the diatom model. Moss et al. (1992), however, report the increasing importance of zooplankton grazing in the lake linked to lower fish stocks, which could reduce the crops of easily digested, small, planktonic diatoms, such as *Stephanodiscus* spp., and would favour the survival of the less digestible, long diatom forms such as *Fragilaria crotonensis* and *Asterionella formosa*, which dominate the assemblages today.

The diatom-inferred TP concentration of 83 µg TP l^{-1} for the surface sample does in fact appear to under-estimate the annual mean TP concentrations of the lake, although it falls within the seasonal range. Water chemistry data collected during 1991/2, gave an annual mean TP value of 214 µg TP l^{-1} and a range of 66-371 µg TP l^{-1} over the sampling period (Moss et al., 1992). The model under-estimates because of the importance of *Fragilaria crotonensis* and *Asterionella formosa* in the surface sample, taxa which are generally only observed at such high frequencies in lakes with lower TP concentrations than Crose Mere. This may be because of the grazing impacts (see above) or perhaps linked to the importance of nitrogen limitation in the mere's rather than phosphorus, which is generally the limiting nutrient in temperate freshwater but which is in plentiful supply in the lakes of this region. As for Betton Pool, Crose Mere would be classed as a eutrophic lake based on its high TP concentrations, although such values are typical for the Cheshire and Shropshire mere's.

In summary, Crose Mere has experienced an increase in TP concentrations since 1850. The diatom model indicates that it has always been a eutrophic lake. The model suggests that TP concentrations have been falling over the last ten years but the changes in the diatom assemblages may be related more to changes in grazing pressure or even other nutrients than to any real change in lake TP levels. Moss et al. (1992) concluded that Crose Mere did not appear to be at any greater threat from the impacts of eutrophication than one might expect for an agricultural region. Continued monitoring of nutrient concentrations in the lake would be desirable based on the palaeolimnological findings of the current study.
Figure 20 Summary diatom diagram and reconstructions for Crose Mere.
11. Oak Mere, Cheshire (SJ 509 078)

**Lithostratigraphy**

An 84 cm sediment core (OAKM1) was taken from the deepest part of the lake in a water depth of 7.7 m using a Mackereth corer on 26-1-95. The lower sediments (> 40 cm) were a very dark brown (10YR 2/2), silty lake mud with plant remains and traces of sand (Ld2 Ag1 Dh1 Dg+ Ga+). There was a distinct change at 40 cm to a dark greyish brown (10YR 4/2) silt and coarse sand layer with gravel (Ag2 Ga1 Gs1 Gg+ Ld+) between 30-40 cm. Above this layer, the sediment was very dark brown again with similar composition to the lower core section (Ld2 Ag1 Dh1 Lso++ Dg+). Diatoms were only present in the upper 30 cms. There was another sandy layer at c.8cm, above which lay a more organic layer (3-8 cm). The upper few cms were a very dark greyish brown (10YR 3/2), fine sand and silty mud (Ld1 Lso1 Ga1 Ag1 Dh++).

The %dw and %loi profiles (Fig 21) show marked changes in the organic content of the sediment. In the lower 40 cms, %dw was c.15-20% and %loi c.30-45%. There was a distinct layer of minerogenic sediments, possibly marking an inwash episode, between 30-40 cm, where %dw increased sharply to 70% and %loi decreased to only 2%. Above 30 cm, the values reverted to those similar to the lower core section. At c.8 cm, there was another marked decline in organic content with values similar to those in the 30-40 cm section, followed by a layer of higher %loi values (40%) from 3-8cm. The surface was highly inorganic with %dw of 60% and %loi of 4%.

**Diatom stratigraphy**

The percentage relative frequencies of diatom species in four levels of the sediment core were calculated and Fig 22 illustrates the results for the major taxa. Diatom preservation was very poor throughout the core, except in the surface sample, and there were no diatoms below 30 cm. A total of 64 taxa was observed, 41 of which were present in the TP calibration set and 35 of which were present in the pH calibration set. There were particularly bad analogues for the TP calibration, owing to the dominance of acidophilous taxa that were not present in the northwest European TP data set. Less than 70% of the fossil assemblage could be used in the TP calibration procedure. Analogues were slightly better for the pH reconstructions with over 85% of the fossil assemblage being used in the pH calibration procedure, except in the surface sample where only 64% could be used.

Fig 22 illustrates that there have been marked changes in the diatom species composition over the period represented by the core. The unusually dense sediment in the upper 3 cms, at c.8cm and at 30-40 cm caused difficulties for radiometric dating and there was no coherent record of fallout radionuclides, thus a chronology for the core could not be determined. The origin of these mineral layers is unknown, although fluctuations in water level, related to changes in net precipitation and addition of borehole water have been well documented (Savage et al., 1992) and sand extraction is known to occur in the catchment.

The two lower samples (30 cm and 20 cm) were almost identical, dominated by acidophilous, non-planktonic taxa, particularly Frustulia rhomboidea, Eunotia [cf. minima], Cymbella perpusilla, Eunotia incisa, Eunotia rhomboidea and Fragilaria virescens var. exigua. There was a slight change by the 10 cm sample where Eunotia rhomboidea and Fragilaria virescens var. exigua disappeared, and Navicula [cf. seminulum] and Fragilaria construens var. venter,
appeared for the first time, the latter two taxa being associated with more alkaline waters. *Pinnularia viridis* also increased in importance. The surface sample was markedly different from the 10 cm sample. The acidophilous taxa decreased in relative abundance, particularly *Eunotia* [cf. *minima*] and *Frustulia rhomboides*. Conversely, the relative abundances of the more circumneutral to alkaliphilous taxa *Fragilaria construens* var. *venter* and *Navicula* [cf. *seminulum*] increased, and *Surirella linearis* was observed for the first time.

**Total phosphorus and pH reconstructions**

The TP reconstruction shows that there have been changes in the nutrient status of Oak Mere. Given the analogue and dissolution problems, however, the diatom-inferred results are not reliable and only a qualitative interpretation of the species changes can be made. The values produced by the model ranged from 3 µg l⁻¹ for the 30 cm and 20 cm samples, to 4 µg TP l⁻¹ for the 10 cm sample, increasing to 22 µg TP l⁻¹ for the 1995 sample. The higher value for the surface sample is explained by the higher relative abundance of *Fragilaria construens* var. *venter*, which has an intermediate TP optimum, and the reduced importance of the acid-tolerant taxa that dominated the lower core levels.

The pH reconstruction results must also be viewed in light of the analogue difficulties, especially for the surface sample. The diatom-inferred pH values for the three lower levels were very similar at c. 4.9, increasing to 5.9 for the 1995 sample.

**Discussion**

Oak Mere is a unique lake because of its low pH, alkalinity and conductivity and yet relatively high nutrient concentrations. Unfortunately there are no similar lakes in the northwest European TP and pH calibration sets and therefore the diatom models cannot be used with any confidence to reconstruct the lake's history. The diatom flora, however, does suggest that the lake has always been acid with dominance of acidophilous (low-pH tolerant) species throughout the core. The reconstructed pH values compare favourably with measured data for 1991/2 where mean pH was 5.1 and pH ranged from 4.5-5.7 over the sampling period (Moss *et al.*, 1992). The diatoms in Oak Mere (as in Clarepool Moss) appear to be responding more to the low pH of the water column than to nutrient concentrations.

The pH model indicates that the lake has become more base-rich in recent years. Hydrological studies of Oak Mere have reported that there are at least two separate sources of water to the lake; a base-poor surface supply entering via superficial permeable drift and a base-rich supply entering through partially or intermittently permeable lake sediments (Savage *et al.*, 1992). This study provided evidence for natural variation of the waters between acid base-poor and moderately base-rich conditions, although the latter state has also occurred following sporadic additions of borehole water. Therefore, the observed diatom species changes in the core may simply reflect this natural fluctuation between acid and alkaline conditions.

The reconstructed TP values are clearly under-estimates of the true TP concentrations of the lake because of the lack of species analogues. Measured TP data gives an annual mean of 61 µg TP l⁻¹ and a seasonal range of 30-99 µg TP l⁻¹ (Moss *et al.*, 1992) compared to a current diatom-inferred value of 22 µg TP l⁻¹. The TP concentrations of Oak Mere are higher than might be expected from a lake of comparable conductivity and alkalinity in an upland catchment. The model indicates that there has been nutrient enrichment at Oak Mere and this might be expected given the agricultural intensification in the Cheshire region. Moss *et al.*
(1992) reported that total nutrient units in the lake catchment had increased between 1931 and 1987.

In summary, Oak Mere is a unique site and it is therefore difficult to place it within the trophic classification scheme for freshwater. It is often described as an oligotrophic lake because of its low pH and alkalinity and its low algal crops but in terms of its TP concentrations, it would be classed as a eutrophic lake. This atypicalness implies it would be difficult to use Oak Mere as an example lake for providing restoration targets for other UK sites.
Figure 22 Summary diatom diagram and reconstructions for Oak Mere
12. Upton Broad, Norfolk (TG 388 134)

Lithostratigraphy

A 135 cm sediment core (UPTO1) was taken from the deepest part of the lake at a water depth of 1.6 m using a piston corer on 30-1-95. The lower part of the core (> 60 cm) was a dark olive brown (2.5Y 3/3) detrital lake mud with traces of calcareous material (Ld3 Dg1 Lc++ Dh+). Above 60 cm the sediment changed to an olive grey (5Y 4/2), although sediment composition remained largely unchanged. Diatoms were only well preserved above 40 cm. The upper few cms were a striking bright green colour, composed largely of the blue-green alga *Aphanothece stagnina*. The surface mud was a faecal pellet ooze produced by chironomids in which algal cells were preserved free from decay. Upton Broad is known for its unusual sediments (Jackson, 1978).

The %dw and %loi profiles (Fig 23) show that the sediments of Upton Broad were similar throughout the core, with %dw fluctuating at c.10-15% and %loi at 25-35%. The %loi for the surface layer was 42% reflecting the high organic content of the faecal pellet ooze.

Diatom stratigraphy

The percentage relative frequencies of diatom species in five levels of the sediment core were calculated and Fig 24 illustrates the results for the major taxa. Diatom preservation was good in the upper 20 cm and then became progressively poor downcore. Counting was not possible below 50 cm. The diatom assemblages had low diversity throughout the core and a total of only 20 taxa was observed, 16 of which were present in the calibration set. All of the common taxa were well represented in the calibration set, with greater than 94% of the fossil assemblage being used in the calibration procedure.

Fig 24 illustrates that there have been slight changes in the diatom species composition in terms of relative percentages over the period represented by the upper 50 cm of the core (c.1877-1995). However, there has been no clear species replacement and the assemblages have been dominated by the same non-planktonic *Fragilaria* taxa throughout the core, species commonly found attached to either the sediments or macrophyte surfaces of shallow, alkaline waters. The only changes were that *Fragilaria lapponica* and *Navicula graciloides* accounted for greater relative abundances in the 50 cm sample (c. 1877) than in the upper samples, *Fragilaria brevisistriata* occurred in the highest frequencies in the 40 cm sample (c. 1912) and in the surface sample, and *Fragilaria construens* had the highest frequencies in the 30 cm sample (c. 1943), declining in importance towards the top of the core.

Total phosphorus reconstruction

The TP reconstruction shows that the lake has had high TP concentrations throughout the period represented by the sediment core (1877-1995), which would place the lake in the hypertrophic category (> 100 µg TP l⁻¹). The model indicates that there has been no change in the trophic status of the lake with values always c. 150 µg TP l⁻¹. The diatom-inferred concentrations were 151 µg TP l⁻¹ for c. 1877 (50 cm), 155 µg TP l⁻¹ for c. 1912 (40 cm) and c.1943 (30 cm), 148 µg TP l⁻¹ for c.1964 (20 cm), and 153 µg TP l⁻¹ for 1995.
Discussion

The results suggest that Upton Broad is a naturally eutrophic lake and has not experienced any major increase in TP concentrations since 1877. However, these data must be viewed with caution in view of the low diversity of the diatom assemblage and the absence of planktonic taxa. The lack of planktonic forms in the sediments causes uncertainty over the results of the model because the relationship between non-planktonic taxa and open water nutrient concentrations is not as direct as that for planktonic forms (Bennion, 1995). The absence of such forms, particularly the centric diatoms, may be related to the need for motility on the sediments because these are non-motile taxa and would be buried in the deposits whenever there was disturbance by wave action etc and would be unlikely to survive (Round, 1953). The dominance of the benthic *Fragilaria* spp. could be because of the clear water conditions in Upton Broad which allow light to penetrate to the surface sediment so that benthic forms can grow there *in situ*.

These factors may explain why the model over-estimates TP values for Upton Broad. In a 13 year water chemistry survey conducted by the National Rivers Authority, annual mean TP concentrations ranged from 29-67 µg TP l\(^{-1}\) (Doarkes, pers. comm) whereas the model estimated TP values for the lake of c.150 µg TP l\(^{-1}\).

In summary, Upton Broad appears to be a typical eutrophic lake and has not experienced any marked changes in TP concentrations over the last 100 years. The diatom flora of the lake is dominated by *Fragilaria* taxa, commonly observed in shallow, alkaline, nutrient-rich waters (Bennion, 1994; 1995).
Figure 23 Lithostratigraphic data for Upton Broad
Figure 24 Summary diatom diagram and reconstructions for Upton Broad
13. Hatchet Pond, Hampshire (SU 367 016)

Lithostratigraphy

An 88 cm sediment core (HATC1) was taken from the deepest part of the lake in a water depth of 3.3 m using a Mackereth corer on 18-1-95. The lower sediments (> 50 cm) were a very dark grey (10YR 3/1), lake mud with a high clay content and plant remains, and diatoms were present to the core base (Ld2 As1 Lso1 Dg++). There was a colour change at c.50 cm to a very dark grey (10YR 2/2) and the clay content of the sediment decreased. Diatoms and detritus were more abundant (Ld2 Lso1 Dg1 Dh++). The upper 20 cms were a very dark greyish brown (10YR 3/2) lake mud with abundant diatoms and a few plant remains.

The %dw profile (Fig 25) shows that %dw decreased progressively up the core from c. 28% at the core base to c.10% at the surface, probably related to changes in clay content. However, %loi remained low throughout the core at c.16-19% and exhibited little change except for a small increase in the upper 15 cm.

Diatom stratigraphy

The percentage relative frequencies of diatom species in five levels of the sediment core were calculated and Fig 26 illustrates the results for the major taxa. Diatom preservation was good throughout the core. The diatom assemblages were very diverse. A total of 100 taxa was observed, 76 of which were present in the TP calibration set and 52 of which were present in the pH calibration set. Analogues for the TP reconstructions were generally good with more than 93% of the fossil assemblage used in the calibration procedure, except for the 70 cm sample where only 87% was used. Analogues were also good for the pH reconstructions with over 87% of the fossil assemblage being used in calibration, except for the 70 cm sample where only 82% could be used.

Fig 26 illustrates that there have been only small changes in the diatom species composition over the period represented by the core. The radiometric dating results indicated that the sediments have been subjected to focusing and vertical mixing and in view of the uncertainties with the profiles, only a mean accumulation rate of 0.93 cm yr⁻¹ was used. This dates the 80 cm level to 1909 and therefore the whole core represents the post-1900 period.

All samples contained the same major taxa, although the assemblages were very diverse and none were dominated by a single species. The most common taxa were Achnanthes minutissima, Synedra parasitica, Tabellaria flocculosa, Cyclotella stelligera, Fragilaria virescens var. exigua, Aulacoseira ambigu a, Fragilaria pinnata and Fragilaria construens var. venter. The only notable features were that Aulacoseira ambigu a, Achnanthes levanderi, Navicula jaemefeltii, Synedra acus and Achnanthes subatomoides were present in higher relative abundances in the lower samples: 88 cm (c.1900), 70 cm (c.1924) and 50 cm (c.1950); and in contrast Achnanthes minutissima, Synedra parasitica and Fragilaria construens var. venter had higher frequencies in the upper samples: 30 cm (c.1972) and the surface. The diatom assemblages of Hatchet Pond were comprised, therefore, of both planktonic forms, e.g. Aulacoseira ambigu a and Cyclotella stelligera, taxa commonly observed in mesotrophic waters, and non-planktonic forms, e.g. the benthic Fragilaria spp. and Achnanthes minutissima, taxa frequently observed across a range of lake types but commonly found in shallow, non-acid waters.
Total phosphorus and pH reconstructions

The TP reconstruction shows that there has been a slight increase in the nutrient status of Hatchet Pond since c. 1972. The values produced by the model were 23 µg l⁻¹ for c.1900 (88 cm), 18 µg TP l⁻¹ for c.1924 (70 cm) although this lower value is probably due to the poorer species analogues in this sample, 25 µg TP l⁻¹ for c.1950 (50 cm) and c.1972 (30 cm), increasing slightly to 33 µg TP l⁻¹ in the 1995 sample. The higher TP value for the surface sample is explained by the higher relative abundance of *Fragilaria construens* var. *venter*, which has an intermediate TP optimum and a wide TP tolerance.

The pH reconstruction show that these has been a slight increase in pH. The diatom-inferred pH values were 6.2 for c.1900, 6.1 for c.1924 (although there were poor analogues for this sample), increasing to 6.5 for c.1950, c.1972 and 1995. This inferred pH increase appears to be related to the increasing importance of diatom species less tolerant of acid waters in the upper samples.

Discussion

Hatchet Pond appears to have been a mesotrophic lake since at least 1900 with evidence of slight enrichment in the last two decades. Unfortunately, there are no available water chemistry data with which to compare the diatom model results, although the site is described as a mesotrophic one in the conservation literature. The pH model indicates that the lake has become more base-rich since c.1950 but there are no pH records for the lake to validate these findings.
Figure 25 Lithostratigraphic data for Hatchet Pond
Figure 26 Summary diatom diagram and reconstructions for Hatchet Pond
3. Esthwaite Water

The survey was carried out on June 7th-8th 1995. The water appeared turbid; secchi disc depth was 1.9m. A species distribution map and two transect profiles are presented in Figures 27 and 28 respectively.

The west shore was characterised by stands of Phragmites australis, often fringing Salix/Alnus scrub, and muddy littoral sediments supporting occasional Callitriche sp., Fontinalis antipyretica, Elodea canadensis and Nitella sp. (to be verified). A single specimen of Acorus calamus was observed within an area of Phragmites swamp. The more exposed areas of shoreline on this side mostly comprised cobble and boulder substrates, with lawns of Littorella uniflora occurring in more sandy reaches. A transect in a north facing, sheltered bay, (Transect 1, see Figure 28) revealed a progression from: shoreline P. australis dominated reed bed; to F. antipyretica dominant in shallow water associated with E. canadensis, L. uniflora, Callitriche sp., Nitella sp. and filamentous algae; to a mono-specific cover of L.uniflora between 0.6 - 0.9m; to occasional Potamogeton obtusifolius and P. berchtoldii in deeper water to the maximum depth of plant growth of 1.4m.

The inflow area at the north end was dominated by Phragmites reed beds, bordered by small stands of Typha latifolia and Scirpus lacustris. The open water was occupied by floating canopies of Nuphar lutea and Nymphaea alba; F.antipyretica, P.obtusifolius and Lemma trisulca being the most abundant submerged taxa.

The east shore is generally more exposed with coarse substrates ranging from sand and gravel to boulders. Few submerged or floating leaved species were evident although L.uniflora lawns were present on the finer substrates. The most common taxa were emergent/shoreline species such as Polygonum hydropiper, Eleocharis palustris and Phalaris arundinacea. However some sheltered bays contained stands of Phragmites with Carex rostrata, Nuphar lutea and Nymphaea alba, while Nitella sp., and F. antipyretica were the dominant submerged taxa and P.obtusifolius was occasional. This association also dominated the south end although no submerged plants were found in the exceptionally turbid water close to the outflow.

Esthwaite Water has been the subject of several aquatic macrophyte surveys over the last century, the most recent of which was carried out by Newbold and Palmer in 1986 for the Nature Conservancy Council. There are several taxa which have been frequently recorded in the past but were not found in our survey. Among these are certain species characteristic of oligotrophic waters, i.e. Isoetes lacustris, Myriophyllum alterniflorum and Lobelia dortmanna, which were recorded in 1986 and previously. It is possible that I.lacustris and M.alterniflorum, which usually have deeper water habitats, were overlooked, perhaps owing to the water turbidity at the time of the visit and the restricted use of the survey boat in open water due to strong winds. However, there was no evidence of shed Isoetes leaves in strand-line material. The absence of L.dortmanna is more difficult to account for given its preference for shallow water habitats. The possible loss of any of these species would be consistent with
the chemical and palaeoecological evidence for a decline in water quality in recent times, however more survey work is required to verify this.

*Najas flexilis*, a nationally scarce species, for which there are records at this site, was not found during the 1986 or 1995 surveys (despite the use of snorkel divers in the former) and it is possible that it may also have been lost as a result of a deterioration in water quality at this site. However the absence of *Potamogeton crispus*, a species characteristic of more mesotrophic to eutrophic waters cannot be similarly accounted for and is more likely to have been overlooked.

The use of the 1995 species list types Esthwaite water (after Palmer 1992) as type 5a, a mesotrophic category. The trophic ranking score is 7.3.
Species list and DAFOR abundance rating for Esthwaite Water

Submergent taxa

<table>
<thead>
<tr>
<th>Species</th>
<th>Rating</th>
<th>Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitella sp.</td>
<td>F</td>
<td>in south</td>
</tr>
<tr>
<td>Fontinalis antipyretica</td>
<td>A</td>
<td>widespread</td>
</tr>
<tr>
<td>Littorella uniflora</td>
<td>F</td>
<td>locally dominant</td>
</tr>
<tr>
<td>Potamogeton obtusifolius</td>
<td>F</td>
<td>in sheltered bays</td>
</tr>
<tr>
<td>Potamogeton berchtoldii</td>
<td>O</td>
<td>in south-east</td>
</tr>
<tr>
<td>Potamogeton pusillus</td>
<td>R</td>
<td>in north-west</td>
</tr>
<tr>
<td>Elodea canadensis</td>
<td>O</td>
<td>in west and north</td>
</tr>
<tr>
<td>Callitriche hamulata</td>
<td>O</td>
<td>widespread</td>
</tr>
<tr>
<td>Callitriche sp.</td>
<td>F</td>
<td>widespread</td>
</tr>
<tr>
<td>Sparganium minimum</td>
<td>O</td>
<td>in north and east</td>
</tr>
<tr>
<td>Lemna trisulca</td>
<td>R</td>
<td>abundant in north inflow bay</td>
</tr>
<tr>
<td>Ranunculus sp.</td>
<td>R</td>
<td>in north inflow bay</td>
</tr>
</tbody>
</table>

Floating leaved taxa

<table>
<thead>
<tr>
<th>Species</th>
<th>Rating</th>
<th>Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuphar lutea</td>
<td>O</td>
<td>locally dominant in sheltered bays</td>
</tr>
<tr>
<td>Nymphaea alba</td>
<td>O</td>
<td>locally</td>
</tr>
</tbody>
</table>

Emergent taxa

<table>
<thead>
<tr>
<th>Species</th>
<th>Rating</th>
<th>Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phragmites australis</td>
<td>A</td>
<td>dominant on south and west shores</td>
</tr>
<tr>
<td>Typha latifolia</td>
<td>R</td>
<td>locally abundant at north end</td>
</tr>
<tr>
<td>Scirpus lacustris var. lacustris</td>
<td>R</td>
<td>in north and north-west</td>
</tr>
<tr>
<td>Carex rostrata</td>
<td>F</td>
<td>locally dominant in sheltered bays</td>
</tr>
<tr>
<td>Eleocharis palustris</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>Acorus calamus</td>
<td>R</td>
<td>single specimen on west shore</td>
</tr>
<tr>
<td>Alisma plantago-aquatica</td>
<td>R</td>
<td>on east shore</td>
</tr>
<tr>
<td>Phalaris arundinacea</td>
<td>F</td>
<td>widespread</td>
</tr>
<tr>
<td>Myosotis laxa</td>
<td>O</td>
<td>widespread</td>
</tr>
<tr>
<td>Caltha palustris</td>
<td>F</td>
<td>widespread</td>
</tr>
<tr>
<td>Polygonum hydropiper</td>
<td>O</td>
<td>on east shore</td>
</tr>
<tr>
<td>Agrostis stolonifera</td>
<td>O</td>
<td>widespread</td>
</tr>
<tr>
<td>Ranunculus flammula</td>
<td>O</td>
<td>widespread</td>
</tr>
<tr>
<td>Mentha aquatica</td>
<td>O</td>
<td>in west</td>
</tr>
<tr>
<td>Juncus effusus</td>
<td>F</td>
<td>widespread</td>
</tr>
<tr>
<td>Hydrocotyle vulgaris</td>
<td>O</td>
<td>widespread</td>
</tr>
</tbody>
</table>
Figure 27 Aquatic macrophyte distribution map for Esthwaite Water 7th June 1995

- **OPEN PASTURE**
  - Abundant Ranunculus flammula & Eleocharis palustris
  - Ranunculus flammula & Eleocharis palustris frequent
  - Potamogeton obtusifolius
  - Scirpus lacustris fringe
  - Nymphaea alba

- **MIXED WOODLAND**
  - Dense Fontinalis antipyretica & Elodea canadensis in open water
  - Dense Fontinalis antipyretica & Elodea canadensis frequent
  - Potamogeton obtusifolius
  - Phalaris arundinacea, Mentha aquatica, Caltha palustris
  - no macrophytes in open water

- **KEY**
  - Phragmites australis
  - Nuphar lutea
  - Littorella uniflora
  - 250m

- **TRANSECTION 1**
  - Salix/Alnus fringe
  - Interspersed with strands of Phragmites sp. & Typha sp.
  - Typha sp.
  - Scirpus lacustris
  - Nymphaea alba

- **TRANSECTION 2**
  - Juncus effusus, Eleocharis palustris, Mentha aquatica, Carex rostrata
  - Carex rostrata
  - mixed stand with Nymphaea alba
  - Juncus effusus & Carex rostrata
  - Potamogeton berchtoldii & P. obtusifolius, Fontinalis antipyretica, Chara sp. & Elodea canadensis

- **OTHER SPECIES**
  - Polygagnum hydropiper
  - Alisma plantago-aquatica frequent
  - Salix/Alnus
  - Open pasture
  - Salix/Alnus fringe
  - Sparse Carex rostrata
  - Occasional Elodea canadensis in open water
  - Phragmites fringed in places by Carex rostrata

- **REMARKS**
  - Mixed stand with Nymphaea alba
  - Alisma plantago-aquatica
  - Salix/Alnus fringe
  - Open pasture
  - Salix/Alnus
  - Sparse Carex rostrata
  - Occasional Elodea canadensis in open water
  - Phragmites fringed in places by Carex rostrata
Phragmites australis

Phragmites australis-dominated + Littorella uniflora & Chara sp.uniflora

Littorella uniflora

Potamogeton obtusifolius

Max depth of growth 1.4m

TRANSECT 1

TRANSECT 2

Potamogeton obtusifolius

Carex rostrata

Phragmites australis

Littorella uniflora

Mud & silt

Clay
4. Semer Water

The site was surveyed on June 9th 1995. Water clarity was poor and a secchi depth of 1.3m was recorded. The level appeared to be approximately 0.3m below normal. An aquatic macrophyte distribution map is presented in Figure 29.

The east shoreline was characterised by a cobble/pebble substrate, and very few macrophytes were evident within the littoral zone except for *Fontinalis antipyretica* attached to the cobbles. *Caltha palustris* and *Myosotis scorpiodes* were occasional above the normal waterline and *Juncus effusus* was abundant at the pasture/shoreline fringe. A substantial stand of *Nuphar lutea* occupied the south-east corner of the lake, behind which the shoreline soils were severely poached by cattle.

The southern shoreline substrate consisted chiefly of sand and a significant area was covered in a lawn of *Eleocharis acicularis* to a water depth of approximately 0.2m. *Potamogeton pectinatus* was also found here in local abundance to a depth of approximately 0.3m.

The west shore supported areas of sedge fen, with several stands of *Carex rostrata*, often bordered on the open water side by *Scirpus lacustris ss. lacustris* and *Equisetum fluviatile*, and *Potamogeton pectinatus* was the most commonly occurring submerged macrophyte in shallow water. *Elodea canadensis*, *Chara* sp., *Calliergon* sp. (to be verified) and *Callitriche stagnalis* were also found here, although the deeper water benthic habitat (from approximately 0.7 - 1.4m) was largely dominated by the filamentous alga *Cladophora* sp..

Open water in the bay leading to the outflow was dominated by *P. pectinatus*, and *Chara* sp. was also present at approximately 0.2m water depth. In open water, *Cladophora* sp. generally blanketed sediments in a zone from 0.5 - 1.4m depth which represents a large proportion of the total lake surface area.
Species list and DAFOR abundance rating for Semer Water

Submerged taxa

*Cladophora* sp.  A  dominant within middle-depth zone
*Chara* sp.  O  in shallow water in west
*Calliergon* sp.  R  in shallow water in est
*Potamogeton pectinatus*  F  locally abundant in north
*Elodea canadensis*  R  in shallow water in west
*Fontinalis antipyretica*  F  on east shoreline
*Eleocharis acicularis*  O  dominant on sand by main inflow
*Callitriche stagnalis*  R  near minor inflow

Floating leaved taxa

*Nuphar lutea*  R  locally abundant in south-east

Emergent taxa

*Phalaris arundinacea*  O  in west
*Scirpus lacustris*  F  in west
*spp. lacustris*  F  in west
*Equisetum fluviatile*  O  locally abundant in north-west
*Carex rostrata*  F  locally abundant in west
*Carex sp. (vesicaria?)*  O  in west
*Caltha palustris*  F  on east shoreline
*Salix sp.*  A  dominant behind sedge fringe in west
*Eleocharis palustris*  R  in north west
*Myosotis scorpiodes*  O  on north-east shore
*Juncus effusus*  F
Figure 29 Aquatic macrophyte distribution map for Semer Water 9th June 1995

- muddy, cattle poached shoreline
- mixed stand of Carex rostrata & Scirpus lacustris
- lawn of Eleocharis acicularis to 20 cm
- Callitriche stagnalis
- Sparse Equisetum fluviatile
- Nuphar lutea
- Open water dominated by Cladophora sp. from 0.7-1.4m depth
- Scirpus lacustris
- Potamogeton pectinatus at 25cm depth
- Elodea canadensis & Chara sp. & Calliergon sp.
- COBBLES/PEBBLES
- Carex sp.
- & Equisetum fluviatile
- Eleocharis palustris abundant Potamogeton pectinatus & Chara sp. at 30cm depth
- Salix fringe, roots begin 80cm above water line
- Carex rostrata
- overhanging Salix sp.
- Carex rostrata
- Scirpus lacustris
- Carex sp.
- Nuphar lutea
- Carex sp.
- COBBLES/PEBBLES
- Scirpus lacustris
- POTAMOGETON PECTINATUS
Aquatic macrophyte transect profile  Semer Water  7th June 1995

**TRANSECT 1**

- Sparse *Chara* sp. & *Potamogeton pectinatus*
- *Chara* sp. coated in *Cladophora* sp.
- Mat of *Cladophora* sp.
- Growth limit for *Cladophora* sp.

**Diagram Details:**
- 0 - 200 metres
- 0 - 1 - 2 metres
- Cobble - Sand - Mud
5. Malham Tarn

Malham Tarn was surveyed on 10th June 1995. Water clarity was very good, the secchi disc depth being greater than the maximum depth of the lake. A species distribution map and aquatic macrophyte transect profiles are presented in Figures 30 and 31 respectively.

The north and east shorelines were characterised by a boulder/cobble substrate with *Fontinalis antipyretica* attached to cobbles above the water-line and occasional shoreline *Caltha palustris* and *Mentha aquatica*. The littoral appeared to be too exposed to allow the establishment of macrophytes. However, at the stone weir outflow *Elodea canadensis* was evident in abundance.

A stand of low growing *Chara* sp. (to be verified) was present in shallow water off the south-west shore, on a sand/silt substrate to a depth of approximately 0.6m.

The north-west shore is characterised by an overhanging peat margin, and an old "pre-weir" peat terrace, now submerged by approximately 1m, supported few plants other than occasional small stands of *E. canadensis* in sheltered hollows. A detached strand of the acidophilous species *Callitriche hamulata* was found in the lake outflow and it is likely that this would have originated in this part of the lake.

The area around the lake outflow was dominated by *Salix* scrub, flanked by *Carex rostrata*, *Menyanthes trifoliata*, *Caltha palustris*, *Iris pseudacorus* and *Mentha aquatica*.

Numerous transects across the lake employing both a double-headed rake and bathoscope revealed alternating dense stands of *Chara* sp. and *E.canadensis* in similar proportions. There was no clear pattern in the local distribution of these two species, with the exception that *E.canadensis* dominated in deeper water off the peat shoreline and the zone around the weir. *E.canadensis* clearly thrives in the Malham Tarn environment; the surveyor has never encountered such substantial cover/biomass or individual plant size of this species before.

In the deepest part of the tarn, *E.canadensis* and *Chara* sp. were dominant to a depth of approximately 3.6m, with the exception of an isolated stand of *Potamogeton lucens* which occurred to a maximum depth of 3.4m. This was the only location in which *P.lucens* was found. Balls of *Cladophora* sp., up to 7cm in diameter, were observed covering a significant area of the lake bed towards the outflow, at a water depth of approximately 2m.
### Species list and DAFOR abundance rating for Malham Tarn

#### Submerged taxa

<table>
<thead>
<tr>
<th>Species</th>
<th>Rating</th>
<th>Abundance Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cladophora sp.</td>
<td>O</td>
<td>Locally abundant in shallow water</td>
</tr>
<tr>
<td>Chara sp.</td>
<td>A</td>
<td>Locally dominant throughout</td>
</tr>
<tr>
<td>Fontinalis antipyretica</td>
<td>F</td>
<td>Shoreline rocks in north and east</td>
</tr>
<tr>
<td>Potamogeton lucens</td>
<td>R</td>
<td>Single stand in deep water</td>
</tr>
<tr>
<td>Elodea canadensis</td>
<td>A</td>
<td>Locally dominant throughout</td>
</tr>
<tr>
<td>Callitriche hamulata</td>
<td>R</td>
<td>Single detached specimen found</td>
</tr>
</tbody>
</table>

#### Emergent taxa

<table>
<thead>
<tr>
<th>Species</th>
<th>Rating</th>
<th>Habitat Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equisetum palustre</td>
<td>R</td>
<td>South-east shoreline</td>
</tr>
<tr>
<td>Carex rostrata</td>
<td>O</td>
<td>Locally abundant</td>
</tr>
<tr>
<td>Menyanthes trifoliata</td>
<td>R</td>
<td>Near outflow</td>
</tr>
<tr>
<td>Iris pseudacorus</td>
<td>R</td>
<td>Near outflow</td>
</tr>
</tbody>
</table>
Figure 30 Aquatic macrophyte distribution map for Malham Tarn 10th June 1995

- **Carex rostrata** (& Caltha palustris, Iris pseudacorus, Mentha aquatica)
- **Salix sp.**
- **Chara sp.** & Fontinalis antipyretica, to 1m, Elodea canadensis & Chara sp. co-dominant from 1.2m
- **Elodea canadensis** & Chara sp. growing on peat
- Elodea canadensis dominant
- **Fontinalis antipyretica**, on cobbles above waterline
- Lawn of Chara sp. & filamentous algae to depth of 0.6m
- **Cladophora balls**
- **Equisetum palustre**
- **WEIR**
- **BOULDER DAM**
- **Dense Elodea canadensis**
- **Mixed Woodland**
- **BOULDER/COBLES**
- **TRANSET 1**
- **TRANSET 2**
- **Submerged Peat**
- **peat**
- **Sand**
- **bare mud**
- **park of Potamogeton lucens to max depth of 3.4m**
- Elodea canadensis & Chara sp. co-dominant from 1.2m
- **Elodea canadensis & Chara sp. to max depth of 3.6m**
- **Elodea canadensis & Chara sp. co-dominant**
- **Elodea canadensis & Chara sp. growing on peat**
- **overhanging peat shoreline**
Figure 31  Aquatic macrophyte transect profiles  Malham Tarn  10th June 1995

TRANSECT 1

Chara sp.  Fontinalis antipyretica  Elodea canadensis

gravel/sand

mud

metros

0 20 40 60 80 100 120 140

TRANSECT 2

Overhanging peat shoreline

Sparse Chara sp. & Fontinalis antipyretica in sheltered peat hollows

Elodea canadensis

metros

0 20 40 60 80 100 120 140
6. Greenlee Lough

Greenlee Lough was surveyed on 11th June 1995. The site is shallow (maximum depth 1.8m) and despite poor water clarity (secchi disc depth 1.2m) submerged macrophytes were found to cover much of the lake bed. A species distribution map is presented in Figure 32.

Much of the shoreline around the western half of the site was fringed by beds of emergent macrophytes. Carex rostrata was dominant in many sheltered bays, often flanked on the open water side by stands of Equisetum fluviatile. At the outflow end these communities graded shorewards into Phragmites australis swamp. Stands of Eleocharis palustris were also observed in shallow water habitats in places.

On the north-east shoreline a wide but relatively sheltered bay contained an association of C.rostrata, Hippuris vulgaris (in very shallow water), Alisma plantago-aquatica, Sparganium erectum and Callitriche sp..

The bay at the far east end of the lake was very shallow (0.1-0.2m) with a sand substrate which supported Juncus bulbosus var. fluitans, Nitella sp. and Potamogeton gramineus.

The southern shore of the east end of the lake was characterised by an exposed, boulder dominated substrate which offered no suitable habitat for macrophyte colonisation. However Fontinalis antipyretica and Chara sp. appeared to thrive in deeper water off-shore.

Two, partly artificial, deeply cut bays contained a rich species assemblage, highlighting the importance of physical habitat for species diversity at this generally wind exposed site. Within this area the shoreline emergent community included C.rostrata, Typha angustifolia, A. plantago-aquatica, Eleocharis palustris, S. erectum, S. emersum, Menyanthes trifoliata and E. fluviatile while Potamogeton crispus, P. gramineus, P.natans, P.berchtoldii, Elodea canadensis and J.bulbosus var. fluitans were all found in shallow water.

The open water habitat throughout much of the lake was dominated by thick beds of Chara sp. and F. antipyretica, with Nitella sp. locally abundant towards the outflow end.

Greenlee Lough was surveyed for aquatic macrophytes by Palmer in 1982 for the Nature Conservancy Council. The species list from that survey is very similar to the one given below which suggests that environmental conditions have not altered much in the last decade. However, certain taxa found in 1982 were not detected during our survey. These include Myriophyllum alterniflorum, Utricularia australis/vulgaris and Potamogeton perfoliatus. The survey team were hampered by poor weather and particularly strong winds which made working from the inflatable survey boat in open water problematic. It is therefore possible that these three species were overlooked. It is interesting to note that the relatively newly introduced species E. canadensis, recorded as "dominant over much of the lough" in the 1982 survey was found in very few locations during our survey.

Greenlee Lough is typed, according to Palmer (1992), as type 5a, a mesotrophic category. The trophic ranking score is 7.5.
Species list and DAFOR abundance rating for Greenlee Lough

**Submerged taxa**

*Chara* sp. to be verified  
A  locally dominant

*Nitella* sp. to be verified  
O  locally abundant towards outflow

*Fontinalis antipyretica*  
A  widespread in deeper water

*Callitriche* sp.  
O  widespread

*Elodea canadensis*  
R  in south

*Littorella uniflora*  
O  locally abundant in north-east

*Potamogeton alpinus*  
R  in north-east

*P. berchtoldii*  
O  in west

*P. crispus*  
O  locally abundant around pier area

*P. gramineus*  
F  locally abundant in shallow water

*P. pectinatus*  
R  in inflows

*P. pusillus*  
R  in west

*Juncus bulbosus* var. *fluitans*  
O  mostly in north-east bay

**Floating leaved taxa**

*Potamogeton natans*  
O  in east

*P. polygonifolius*  
R  in north-west

*Sparganium emersum*  
O  locally abundant in east

*Nuphar lutea*  
R  in north-east

**Emergent taxa**

*Hippuris vulgaris*  
R  in north-east

*Phragmites australis*  
F  locally dominant in west

*Phalaris arundinacea*  
O

*Typha latifolia*  
O

*Typha angustifolia*  
R

*Carex rostrata*  
A  locally dominant in sheltered bays

*Carex paniculata*  
R

*Sparganium erectum*  
O  mainly in sheltered bays in south

*Eleocharis palustris*  
A

*Alisma plantago-aquatica*  
F

*Caltha palustris*  
R

*Eleocharis palustris*  
A

*Mentha aquatica*  
O

*Ranunculus flammula*  
F

*Potentilla palustris*  
O

*Scirpus lacustris* ssp. *lacustris*  
R  locally abundant in west

*Iris pseudacorus*  
O  in west
Typha latifolia, Carex rostrata & Equisetum fluviatile

Artificial bays with diverse macrophyte assemblage (see text)

Rhododendron stand

Sheltered peaty bay dominated by Equisetum fluviatile, Eleocharis palustris, Alisma plantago-aquatica & Sparganium emersum

Equisetum fluviatile, Alisma plantago-aquatica, S. erectum & Callitriche sp.

Includes Hydrocotyle vulgaris & Alisma plantago-aquatica

Littorella uniflora

Ranunculus flammula

Potamogeton gramineus

Potamogeton alpinus

Fontinalis & Chara sp. in deeper water

Chara sp. & Fontinalis dominant

Fontinalis & Chara sp. in open water, Nitella sp. & Potamogeton berchtoldii

Scirpus lacustris

In association with Littorella uniflora

Dense Chara sp.

Littorella uniflora in shallow water with Equisetum fluviatile

Fontinalis sp. & Nitella sp. dominant

Rhododendron stand

Eleocharis palustris

Sheltered area of shallow water includes Equisetum fluviatile, Eleocharis palustris, Polygonum natans, P. gramineus & Alisma plantago-aquatica

Detached fragments of Potamogeton pectinatus

Alisma plantago-aquatica frequent

Hippuris vulgaris, Callitriche sp. & Sparganium erectum in shallows

Nuphar lutea

SAND

BOULDERS

very shallow

SAND

KEY

Phragmites australis

Equisetum fluviatile

Carex rostrata

0 100m

Figure 32: Aquatic macrophyte distribution map for Greenlee Lough 11th June 1995
7. Martham South Broad

The broad was surveyed on 19th September 1995 with the assistance of the site warden (Mr Richard Starling). A species distribution map for the site is presented in Figure 33. Water clarity was very good and as the site is shallow (maximum depth 1.2m) it was possible to assess the zonation of the major stands of submerged macrophytes throughout the site without the use of an underwater viewing apparatus. However, an Ekman grab and double-headed rake were used to retrieve plants for identification.

The broad was mostly fringed by *Phragmites australis* and *Cladium mariscus* dominated reed-swamp, although part of the shoreline on the south side was open deciduous woodland. Open water across the south-eastern half of the broad was dominated by charophyte beds composed of several *Chara* spp. (specimens to be verified, further details to be presented in final report). The south-western end was dominated by a substantial bed of *Najas marina*, which also occurred in lesser abundance off the north shore where it was flanked by a stand of *Hippuris vulgaris*. Specimens of *Nitellopsis obtusa* (to be verified) were recovered from within the main *Najas* bed. The two bays in the north-east contained the more diverse macrophyte assemblages. A mixed stand of *Nuphar lutea* and *Nymphaea alba* occupied the arm connecting the water body to the North Broad, and *Callitriche* sp. was locally abundant under the floating leaf canopy. A single individual of *Potamogeton perfoliatus* (to be verified) was recovered from a rake trawl in the open water of the main bay. The *Chara* dominated south-eastern bay included the occasional occurrence of *Myriophyllum spicatum*, *Zannichelia palustris* and *Potamogeton pectinatus*. *P. pectinatus* was locally abundant in several locations adjacent to the eastern shoreline.

Application of the site typing scheme of Palmer (1992) to the species list, types Martham South Broad as type 10, a eutrophic category, and the trophic ranking score is 8.4.
Species list and DAFOR abundance rating for Martham South Broad

Submergent taxa

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chara spp. (species to be verified)</td>
<td>A</td>
<td>some species locally dominant</td>
</tr>
<tr>
<td>Nitellopsis obtusa (to be verified)</td>
<td>R</td>
<td>within <em>Najas</em> stand</td>
</tr>
<tr>
<td>Najas marina</td>
<td>F</td>
<td>locally abundant</td>
</tr>
<tr>
<td>Hippuris vulgaris</td>
<td>O</td>
<td>locally abundant</td>
</tr>
<tr>
<td>Potamogeton perfoliatus</td>
<td>R</td>
<td>single specimen found</td>
</tr>
<tr>
<td>Potamogeton pectinatus</td>
<td>O</td>
<td>locally abundant in east</td>
</tr>
<tr>
<td>Zannichelia palustris</td>
<td>O</td>
<td>close to east shore</td>
</tr>
<tr>
<td>Myriophyllum spicatum</td>
<td>O</td>
<td>close to east shore</td>
</tr>
<tr>
<td>Elodea canadensis</td>
<td>R</td>
<td>in north-east</td>
</tr>
</tbody>
</table>

Floating leaved taxa

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuphar lutea</td>
<td>R</td>
<td>locally abundant in north-east</td>
</tr>
<tr>
<td>Nymphaea alba</td>
<td>R</td>
<td>locally abundant in north-east</td>
</tr>
</tbody>
</table>

Emergent

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phragmites australis</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>Cladium mariscus</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>Typha sp.</td>
<td>O</td>
<td></td>
</tr>
</tbody>
</table>
Arec1 of most dense Nachtobopsis growth

Obtusa

Calitriche sp. under Nupharbed

Nuphar lutea & Nymphaea alba

Potamogeton perfoliatus & Potamogeton pectinatus

Myriophyllum spicatum, Elodea canadensis

KEY

Najas marina

Phragmites australis

Hippuris vulgaris

1991 September 1995

Figure 33 Aquatic macrophyte distribution map for South Martham Broad
Radiometric Dates for Wastwater Core WAST95/1

The Wastwater core had a relatively simple $^{210}$Pb profile with a good record spanning the past 150 years at least. Equilibrium with the supporting $^{226}$Ra was reached at a depth of c. 20 cm. There was little significant difference between dates calculated using the CRS and CIC $^{210}$Pb dating models, except at c. 10 cm where the CRS model indicated a small acceleration in sedimentation. This event was dated c. 1900, and is possibly due to a small inwash layer. A similar feature was recorded in an earlier 1985 core from this lake. The mean sedimentation rate for the past 150 years was estimated to be $0.019\pm0.003 \, g \, cm^{-2} \, y^{-1}$ ($0.10 \, cm \, y^{-1}$).

Resolution of the $^{137}$Cs profile was too coarse to determine $^{137}$Cs dates, but from comparison with the 1985 core it would appear that the high surficial value originates in Chernobyl fallout and that the value at 5.25 cm just predates the 1963 weapons fallout maximum.

The results are summarised in the following table and the attached plots.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Cum Dry Mass (g cm$^{-2}$)</th>
<th>Chronology</th>
<th>Accumulation Rate (g cm$^{-2}$ y$^{-1}$, cm y$^{-1}$, ± (%))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>1995, 0</td>
<td>0.015, 0.12, 6.6</td>
</tr>
<tr>
<td>1.00</td>
<td>0.11</td>
<td>1987, 8, 2</td>
<td>0.014, 0.11, 7.7</td>
</tr>
<tr>
<td>2.00</td>
<td>0.23</td>
<td>1978, 17, 2</td>
<td>0.013, 0.10, 8.7</td>
</tr>
<tr>
<td>3.00</td>
<td>0.35</td>
<td>1969, 26, 3</td>
<td>0.013, 0.09, 9.8</td>
</tr>
<tr>
<td>4.00</td>
<td>0.48</td>
<td>1960, 35, 3</td>
<td>0.012, 0.08, 10.9</td>
</tr>
<tr>
<td>5.00</td>
<td>0.60</td>
<td>1951, 44, 3</td>
<td>0.016, 0.09, 15.5</td>
</tr>
<tr>
<td>6.00</td>
<td>0.77</td>
<td>1941, 54, 4</td>
<td>0.020, 0.11, 21.2</td>
</tr>
<tr>
<td>7.00</td>
<td>0.95</td>
<td>1931, 64, 6</td>
<td>0.025, 0.13, 26.9</td>
</tr>
<tr>
<td>8.00</td>
<td>1.13</td>
<td>1920, 75, 7</td>
<td>0.030, 0.14, 32.6</td>
</tr>
<tr>
<td>9.00</td>
<td>1.31</td>
<td>1910, 85, 9</td>
<td>0.034, 0.16, 38.3</td>
</tr>
<tr>
<td>10.00</td>
<td>1.49</td>
<td>1899, 96, 10</td>
<td>0.033, 0.15, 44.0</td>
</tr>
<tr>
<td>11.00</td>
<td>1.72</td>
<td>1889, 106, 13</td>
<td>0.029, 0.13, 49.6</td>
</tr>
<tr>
<td>12.00</td>
<td>1.97</td>
<td>1880, 115, 16</td>
<td>0.025, 0.11, 55.3</td>
</tr>
<tr>
<td>13.00</td>
<td>2.21</td>
<td>1870, 125, 19</td>
<td>0.021, 0.09, 60.9</td>
</tr>
<tr>
<td>14.00</td>
<td>2.46</td>
<td>1861, 134, 23</td>
<td>0.017, 0.07, 66.6</td>
</tr>
<tr>
<td>15.00</td>
<td>2.70</td>
<td>1851, 144, 26</td>
<td></td>
</tr>
</tbody>
</table>
Wastewater

\( ^{210} \)Pb Activity versus Depth

Core 95/1

- Total \(^{210}\)Pb
- Unsupported \(^{210}\)Pb
- Supported \(^{210}\)Pb

Depth (cm)

\(^{210}\)Pb Activity (Bq kg\(^{-1}\))
Wastwater

$^{137}$Cs & $^{241}$Am Activity versus Depth

Radiuscaesium Activity (Bq kg$^{-1}$)

$^{137}$Cs 95/1
$^{241}$Am 95/1

Depth (cm)
Wastwater Core 95/1
Depth versus Age

Depth (cm)

Age (y)

CIC \(^{210}\)Pb Dates
CRS \(^{210}\)Pb Dates
CRS Sedimentation Rates
Radiometric Dates for Bassenthwaite Core BASS95/1

The Bassenthwaite core had a good $^{210}\text{Pb}$ record, closely matching that of a recent (1994) core from the same lake. In both cores equilibrium with the supporting $^{226}\text{Ra}$ was reached at a depth of c.32 cm. In the 1994 core the CRS model $^{210}\text{Pb}$ dates were validated by well resolved $^{137}\text{Cs}$ and $^{241}\text{Am}$ peaks defining the 1986 (Chernobyl) and 1963 (weapons test fallout) levels. Although the restricted number of measurements did not allow adequate resolution of these features in the 1995 core, the results that were obtained were sufficient to suggest the two cores also had closely matched artificial radionuclide records. The CRS model has accordingly been used to construct the chronology given in the following table. As in the 1994 core, the results indicated a significant increase in sedimentation rates during the period 1900-40 that has been more or less sustained to the present day.

The $^{210}\text{Pb}$ record terminates at 30 cm (dated c.1880), just above a characteristic clay layer marked by much higher sediment densities. The origin of this layer is not certain, but possible causes include mining, railway construction (c.1855) or construction of the Thirlmere dam (c.1890). In view of this uncertainty it would be inappropriate to extrapolate the chronology below 30 cm.

Table of Dates

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Cum Dry Mass (g cm$^{-2}$)</th>
<th>Chronology</th>
<th>Accumulation Rate (g cm$^{-2}$ y$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>1995 0</td>
<td>0.093 0.43 13.7</td>
</tr>
<tr>
<td>2.00</td>
<td>0.38</td>
<td>1991 4 2</td>
<td>0.094 0.39 14.9</td>
</tr>
<tr>
<td>4.00</td>
<td>0.78</td>
<td>1987 8 2</td>
<td>0.101 0.37 17.0</td>
</tr>
<tr>
<td>6.00</td>
<td>1.27</td>
<td>1982 13 2</td>
<td>0.117 0.38 20.6</td>
</tr>
<tr>
<td>8.00</td>
<td>1.90</td>
<td>1976 19 3</td>
<td>0.133 0.39 24.3</td>
</tr>
<tr>
<td>10.00</td>
<td>2.54</td>
<td>1970 25 4</td>
<td>0.127 0.36 27.2</td>
</tr>
<tr>
<td>12.00</td>
<td>3.26</td>
<td>1965 30 5</td>
<td>0.118 0.33 30.1</td>
</tr>
<tr>
<td>14.00</td>
<td>3.99</td>
<td>1959 36 6</td>
<td>0.111 0.30 34.3</td>
</tr>
<tr>
<td>16.00</td>
<td>4.73</td>
<td>1952 43 7</td>
<td>0.109 0.30 41.1</td>
</tr>
<tr>
<td>18.00</td>
<td>5.47</td>
<td>1946 49 9</td>
<td>0.107 0.29 47.8</td>
</tr>
<tr>
<td>20.00</td>
<td>6.21</td>
<td>1939 56 11</td>
<td>0.095 0.25 59.7</td>
</tr>
<tr>
<td>22.00</td>
<td>6.96</td>
<td>1931 64 14</td>
<td>0.081 0.21 72.2</td>
</tr>
<tr>
<td>24.00</td>
<td>7.70</td>
<td>1922 73 18</td>
<td>0.067 0.17 83.1</td>
</tr>
<tr>
<td>26.00</td>
<td>8.48</td>
<td>1912 83 21</td>
<td>0.054 0.13 91.2</td>
</tr>
<tr>
<td>28.00</td>
<td>9.29</td>
<td>1897 98 23</td>
<td>0.041 0.09 99.3</td>
</tr>
<tr>
<td>30.00</td>
<td>10.11</td>
<td>1882 113 26</td>
<td></td>
</tr>
</tbody>
</table>
Bassenthwaite

$^{210}$Pb Activity versus Depth

Core BASS95/1

- Total $^{210}$Pb
- Unsupported $^{210}$Pb
- Supported $^{210}$Pb

$^{210}$Pb Activity (Bq kg$^{-1}$)

Depth (cm)
Bassenthwaite

$^{137}\text{Cs}$ & $^{241}\text{Am}$ Activity versus Depth

Core BASS95/1

Radiocaesium Activity (Bq kg$^{-1}$)

Depth (cm)

$^{137}\text{Cs}$

$^{241}\text{Am}$
Radiometric Dates for Esthwaite Core ESTH95/1

Reduced $^{210}$Pb activities above 15 cm suggest a rapid and sustained increase in sedimentation rates in recent decades, following a long period of more uniform accumulation dating back to the second half of the 19th century. Mean accumulation rates during this earlier period were $0.035 \pm 0.005 \text{ g cm}^{-2} \text{yr}^{-1}$, compared to contemporary values 2-3 times higher. Since dating of the top 15 cm by the CIC model was impractical, and there is no ambiguity in dates of the earlier levels, the results given below have been calculated using just the CRS model.

The $^{137}$Cs measurements identified a major peak in activity at 5.25±2.5 cm depth recording fallout from the 1986 Chernobyl accident, corroborating the very recent CRS model $^{210}$Pb dates which place the 1986 level at c.6 cm. Although the deeper $^{137}$Cs measurements were insufficient to resolve the 1963 fallout peak with any accuracy, they do suggest that this feature occurs at 10.25±2.5 cm, in reasonable agreement with the $^{210}$Pb determined level of 14 cm.

### Table of Dates

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Cum Dry Mass (g cm$^{-2}$)</th>
<th>Chronology</th>
<th>Accumulation Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Date (AD) (\pm) Age (yr)</td>
<td>(\pm) cm yr$^{-1}$</td>
</tr>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>1995 0</td>
<td>0.135 1.05 8.0</td>
</tr>
<tr>
<td>2.00</td>
<td>0.24</td>
<td>1993 2 2</td>
<td>0.095 0.72 7.5</td>
</tr>
<tr>
<td>4.00</td>
<td>0.50</td>
<td>1990 5 2</td>
<td>0.071 0.51 7.5</td>
</tr>
<tr>
<td>6.00</td>
<td>0.77</td>
<td>1987 8 2</td>
<td>0.071 0.48 8.1</td>
</tr>
<tr>
<td>8.00</td>
<td>1.06</td>
<td>1983 12 2</td>
<td>0.071 0.45 8.7</td>
</tr>
<tr>
<td>10.00</td>
<td>1.36</td>
<td>1979 16 2</td>
<td>0.054 0.34 9.3</td>
</tr>
<tr>
<td>12.00</td>
<td>1.69</td>
<td>1971 24 2</td>
<td>0.035 0.22 9.9</td>
</tr>
<tr>
<td>14.00</td>
<td>2.02</td>
<td>1963 32 2</td>
<td>0.027 0.15 12.2</td>
</tr>
<tr>
<td>16.00</td>
<td>2.36</td>
<td>1954 41 3</td>
<td>0.036 0.20 17.2</td>
</tr>
<tr>
<td>18.00</td>
<td>2.71</td>
<td>1942 53 4</td>
<td>0.044 0.24 22.2</td>
</tr>
<tr>
<td>20.00</td>
<td>3.06</td>
<td>1931 64 5</td>
<td>0.043 0.23 27.1</td>
</tr>
<tr>
<td>22.00</td>
<td>3.44</td>
<td>1922 73 6</td>
<td>0.040 0.21 32.1</td>
</tr>
<tr>
<td>24.00</td>
<td>3.82</td>
<td>1913 82 8</td>
<td>0.036 0.18 36.8</td>
</tr>
<tr>
<td>26.00</td>
<td>4.22</td>
<td>1902 93 10</td>
<td>0.030 0.14 41.3</td>
</tr>
<tr>
<td>28.00</td>
<td>4.65</td>
<td>1887 108 14</td>
<td>0.023 0.11 45.8</td>
</tr>
<tr>
<td>30.00</td>
<td>5.08</td>
<td>1873 122 18</td>
<td></td>
</tr>
</tbody>
</table>

Extrapolated Date: 1850 34 cm
Esthwaite

$^{210}$Pb Activity versus Depth

Core ESTH95/1

- Total $^{210}$Pb
- Unsupported $^{210}$Pb
- Supported $^{210}$Pb

Depth (cm)
Esthwaite

$^{137}$Cs & $^{241}$Am Activity versus Depth

Core ESTH95/1

- $^{137}$Cs
- $^{241}$Am

Radiocaesium Activity (Bq kg$^{-1}$)

Depth (cm)
Esthwaite Core ESTH95/1
Depth versus Age

![Graph showing depth versus age with various data points and lines representing different dating methods: 
- $^{137}$Cs, $^{241}$Am Dates
- CIC $^{210}$Pb Dates
- CRS $^{210}$Pb Dates
- CRS Sedimentation Rates]
Radiometric Dates for Semer Water Core SEME95/1

Although the Semer Water core appeared to have a relatively simple $^{210}$Pb profile, there were significant differences between dates calculated using the CRS and CIC $^{210}$Pb dating models due to an abrupt termination of the unsupported $^{210}$Pb record at c.25 cm. Whereas the CIC model indicates a more or less constant sedimentation rate for the past 60 years of $0.12 \pm 0.03 \text{ g cm}^{-2} \text{y}^{-1}$, the CRS model suggests much lower accumulation rates prior to the past 20 years. The hiatus at 25 cm appears to be associated with a shift from less dense sediments above this level to more dense sediments in the deeper sections.

The $^{137}$Cs profile has a well defined peak at c.15 cm that appears to record the 1963 weapons test fallout maximum. Within the limits of the resolution of the $^{137}$Cs peak this date is in reasonable agreement with the CIC model $^{210}$Pb results, supporting the inference of an incomplete $^{210}$Pb record.

The results obtained are summarised in the following table and the attached plots. Dates above the apparent $^{210}$Pb equilibrium level have been calculated using the CIC model. Also shown are depths of the 1930, 1900 and 1850 levels calculated by extrapolation of the $^{210}$Pb results though these should be regarded with some caution in view of the possible hiatus at 25 cm.

### Table of Dates

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Cum Dry Mass (g cm$^{-2}$)</th>
<th>Chronology Date (AD)</th>
<th>Chronology Age (y)</th>
<th>Accumulation Rate ($\text{g cm}^{-2} \text{y}^{-1}$)</th>
<th>Accumulation Rate (cm y$^{-1}$)</th>
<th>Total Accumulation Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>1995</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.00</td>
<td>0.52</td>
<td>1991</td>
<td>4</td>
<td>4</td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td>4.00</td>
<td>1.07</td>
<td>1986</td>
<td>9</td>
<td>7</td>
<td>0.42</td>
<td></td>
</tr>
<tr>
<td>6.00</td>
<td>1.66</td>
<td>1981</td>
<td>14</td>
<td>10</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>8.00</td>
<td>2.33</td>
<td>1976</td>
<td>19</td>
<td>11</td>
<td>0.38</td>
<td></td>
</tr>
<tr>
<td>10.00</td>
<td>3.00</td>
<td>1971</td>
<td>24</td>
<td>12</td>
<td>0.12</td>
<td>0.36</td>
</tr>
<tr>
<td>12.00</td>
<td>3.69</td>
<td>1965</td>
<td>30</td>
<td>13</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>14.00</td>
<td>4.39</td>
<td>1959</td>
<td>36</td>
<td>14</td>
<td>0.34</td>
<td></td>
</tr>
<tr>
<td>16.00</td>
<td>5.12</td>
<td>1953</td>
<td>42</td>
<td>15</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>18.00</td>
<td>5.87</td>
<td>1947</td>
<td>48</td>
<td>15</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>20.00</td>
<td>6.63</td>
<td>1941</td>
<td>54</td>
<td>16</td>
<td>0.31</td>
<td></td>
</tr>
</tbody>
</table>

Extrapolated levels:
- 1930 23 cm
- 1900 31 cm
- 1850 41 cm
Semer Water

$^{210}$Pb Activity versus Depth

Core SEME95/1

- Total $^{210}$Pb
- Unsupported $^{210}$Pb
- Supported $^{210}$Pb
Semer Water

$^{137}$Cs Activity versus Depth

Core SEME95/1

Radiocaesium Activity (Bq kg$^{-1}$)

Depth (cm)
Radiometric Dates for Malham Tarn Core MALH2

The Malham Tarn core had a relatively simple $^{210}\text{Pb}$ profile. Calculations using the CRS and CIC $^{210}\text{Pb}$ dating models both indicate a more or less uniform sedimentation rate prior to C.1970 of 0.051±0.004 g cm$^{-2}$ y$^{-1}$. There may however have been a small increase during the past two decades.

The $^{137}\text{Cs}$ profile had two peaks that appear to record fallout from the 1986 Chernobyl accident and 1963 weapons test fallout maximum. Within the limits of the resolution of the $^{137}\text{Cs}$ peaks these dates are in reasonable agreement with the $^{210}\text{Pb}$ results.

The results are summarised in the following table and the attached plots.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Cum Dry Mass (g)</th>
<th>Chronology Date (AD)</th>
<th>Age (y) ±</th>
<th>Accumulation Rate g cm$^{-2}$ y$^{-1}$</th>
<th>Accumulation Rate cm y$^{-1}$</th>
<th>± (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>1995</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.00</td>
<td>0.29</td>
<td>1992</td>
<td>3 ± 2</td>
<td>0.100</td>
<td>0.63</td>
<td>8.0</td>
</tr>
<tr>
<td>4.00</td>
<td>0.61</td>
<td>1988</td>
<td>7 ± 2</td>
<td>0.082</td>
<td>0.50</td>
<td>7.7</td>
</tr>
<tr>
<td>6.00</td>
<td>0.94</td>
<td>1984</td>
<td>11 ± 2</td>
<td>0.070</td>
<td>0.40</td>
<td>7.4</td>
</tr>
<tr>
<td>8.00</td>
<td>1.32</td>
<td>1978</td>
<td>17 ± 2</td>
<td>0.066</td>
<td>0.37</td>
<td>7.4</td>
</tr>
<tr>
<td>10.00</td>
<td>1.69</td>
<td>1973</td>
<td>22 ± 2</td>
<td>0.062</td>
<td>0.33</td>
<td>7.4</td>
</tr>
<tr>
<td>12.00</td>
<td>2.07</td>
<td>1966</td>
<td>29 ± 2</td>
<td>0.057</td>
<td>0.31</td>
<td>9.3</td>
</tr>
<tr>
<td>14.00</td>
<td>2.44</td>
<td>1959</td>
<td>36 ± 2</td>
<td>0.053</td>
<td>0.29</td>
<td>11.4</td>
</tr>
<tr>
<td>16.00</td>
<td>2.81</td>
<td>1952</td>
<td>43 ± 3</td>
<td>0.051</td>
<td>0.27</td>
<td>13.4</td>
</tr>
<tr>
<td>18.00</td>
<td>3.16</td>
<td>1945</td>
<td>50 ± 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20.00</td>
<td>3.50</td>
<td>1937</td>
<td>58 ± 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22.00</td>
<td>3.88</td>
<td>1929</td>
<td>66 ± 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24.00</td>
<td>4.26</td>
<td>1921</td>
<td>74 ± 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26.00</td>
<td>4.65</td>
<td>1913</td>
<td>82 ± 7</td>
<td>0.051</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td>28.00</td>
<td>5.06</td>
<td>1905</td>
<td>90 ± 8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30.00</td>
<td>5.46</td>
<td>1897</td>
<td>98 ± 9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35.00</td>
<td>6.66</td>
<td>1874</td>
<td>121 ± 11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40.00</td>
<td>8.02</td>
<td>1847</td>
<td>148 ± 14</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Malham Tarn

$^{210}\text{Pb}$ Activity versus Depth

Core MALH2

- Total $^{210}\text{Pb}$
- Unsupported $^{210}\text{Pb}$
- Supported $^{210}\text{Pb}$

$^{210}\text{Pb}$ Activity (Bq kg$^{-1}$)

Depth (cm)
Malham Tarn
$^{137}$Cs & $^{241}$Am Activity versus Depth

Core MALH2

$^{137}$Cs
$^{241}$Am

Radiocaesium Activity (Bq kg$^{-1}$)

$^{241}$Am Activity (Bq kg$^{-1}$)

Depth (cm)
Malham Tarn Core MALH2
Depth versus Age

Depth (cm)

Age (y)

Sed Rate (gcm$^{-2}$ y$^{-1}$)

- $^{137}$Cs Dates
- CIC $^{210}$Pb Dates
- CRS $^{210}$Pb Dates
- CRS Sedimentation Rates
Unsupported $^{210}$Pb activities in this core were negligible except in the top 2-3 cm and were insufficient to allow dating by the $^{210}$Pb method. The $^{210}$Pb inventory of the top sections was just 438 Bq kg$^{-1}$, less than 20% of the fallout record. The reasons for this anomaly are almost certainly associated with the layer of unusually dense sediment at c.6 cm, though there was no recovery in $^{210}$Pb values in the apparently normal deeper section at 12 cm.

The $^{137}$Cs profile had a well defined maximum at 2.25 cm, though it was not clear whether this feature records the 1986 Chernobyl accident or the 1963 weapons fallout peak. Unusually, the $^{137}$Cs inventory of the core was significantly higher than the $^{210}$Pb inventory.

In view of these uncertainties it would be unsafe to make any estimate of accumulation rates beyond suggesting that they are in the region of $0.1-0.25$ cm y$^{-1}$. This would put 1930 at 5-16 cm and 1900 at 7-24 cm.
Greenlee Lough

$^{210}\text{Pb}$ Activity versus Depth

Core GREE1

- Total $^{210}\text{Pb}$
- Unsupported $^{210}\text{Pb}$
- Supported $^{210}\text{Pb}$
Greenlee Lough

$^{137}$Cs Activity versus Depth

Core GREE1

Radiocaesium Activity (Bq kg$^{-1}$) versus Depth (cm)
Radiometric Dates for Martham South Broad Core MART1

Very low unsupported $^{210}\text{Pb}$ activities in this core recorded throughout the top 20 cm do not presently allow dating by the $^{210}\text{Pb}$ method. The $^{210}\text{Pb}$ inventory in the top 20 cm was just 305 Bq kg$^{-1}$, less than 20% of the fallout record.

The $^{137}\text{Cs}$ profile has a well defined maximum at 10.25 cm, that almost certainly records the 1963 weapons fallout peak. This suggests an accumulation rate of c.0.3 cm y$^{-1}$, though further measurements are planned to determine a more precise value. The present estimate would put 1930 at c.21 cm, and 1900 at c.30 cm.
Martham South Broad

$^{210}$Pb Activity versus Depth

![Graph showing $^{210}$Pb Activity versus Depth](image)
Martham South Broad

$^{137}$Cs Activity versus Depth

![Graph showing the activity of $^{137}$Cs versus depth. The graph indicates an increase in activity to a peak at a certain depth, followed by a decrease.]
Radiometric Dates for Clarepool Moss Core CLAP1

Very low unsupported $^{210}\text{Pb}$ activities in this core recorded only in the surficial sediments do not presently allow dating by the $^{210}\text{Pb}$ method. The $^{210}\text{Pb}$ inventory is estimated to be just 120 Bq kg$^{-1}$, less than 10% of the fallout record.

Moderately high $^{137}\text{Cs}$ activities were recorded down to 20 cm, though the present measurements give no indication of the level of the 1963 weapons fallout peak.

The prospect of obtaining a reasonable estimate of recent accumulation rates appears to be low, though further measurements are planned.
Clarepool Moss

$^{210}\text{Pb}$ Activity versus Depth

$^{210}\text{Pb}$ Activity (Bq kg$^{-1}$)

Depth (cm)
Clarepool Moss

$^{137}$Cs Activity versus Depth

![Graph showing the activity of $^{137}$Cs versus depth in cm. The activity decreases linearly with depth, with error bars indicating variability at certain depths.](image-url)
Radiometric Dates for Betton Pool Core SCM27B

The $^{210}\text{Pb}$ results indicate rapid sedimentation, equilibrium with the supporting $^{226}\text{Ra}$ being reached at a depth of more than 70 cm. The non-monotonic feature at 20-25 cm indicates a major irregularity in the process of sediment accumulation and there is in consequence a significant discrepancy between CRS and CIC model $^{210}\text{Pb}$ dates for this part of the core. The 1963 level in the core is clearly marked by a well resolved $^{137}\text{Cs}$ peak at 30±5 cm depth, in good agreement with the CRS model results, and these have accordingly been used to calculate the core chronology given in the table below.

The $^{210}\text{Pb}$ results suggest that the irregularity at 20-25 cm records an episode of rapid sedimentation during the early 1970s, but that excluding this event there was a more or less uniform sedimentation rate of 0.10±0.2 g cm$^{-2}$ y$^{-1}$. Extrapolated dates below the $^{210}\text{Pb}$ dating horizon have been calculated using this value.

Table of Dates

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Cum Dry Mass (g cm$^{-2}$)</th>
<th>Chronology</th>
<th>Accumulation Rate</th>
<th>± (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Date (AD)</td>
<td>Age (y)</td>
<td>± g cm$^{-2}$ y$^{-1}$</td>
</tr>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>1995</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>5.00</td>
<td>0.76</td>
<td>1989</td>
<td>6 2</td>
<td>0.135</td>
</tr>
<tr>
<td>10.00</td>
<td>1.53</td>
<td>1983</td>
<td>12 3</td>
<td>0.163</td>
</tr>
<tr>
<td>15.00</td>
<td>2.47</td>
<td>1978</td>
<td>17 4</td>
<td>0.209</td>
</tr>
<tr>
<td>20.00</td>
<td>3.42</td>
<td>1974</td>
<td>21 5</td>
<td>0.255</td>
</tr>
<tr>
<td>25.00</td>
<td>4.29</td>
<td>1969</td>
<td>26 6</td>
<td>0.192</td>
</tr>
<tr>
<td>30.00</td>
<td>5.16</td>
<td>1963</td>
<td>32 6</td>
<td>0.116</td>
</tr>
<tr>
<td>35.00</td>
<td>6.03</td>
<td>1955</td>
<td>40 8</td>
<td>0.097</td>
</tr>
<tr>
<td>40.00</td>
<td>6.91</td>
<td>1946</td>
<td>49 10</td>
<td>0.084</td>
</tr>
<tr>
<td>50.00</td>
<td>8.80</td>
<td>1927</td>
<td>68 11</td>
<td>0.10</td>
</tr>
<tr>
<td>60.00</td>
<td>11.00</td>
<td>1905</td>
<td>90 13</td>
<td></td>
</tr>
<tr>
<td>70.00</td>
<td>13.37</td>
<td>1881</td>
<td>114 16</td>
<td></td>
</tr>
<tr>
<td>80.00</td>
<td>15.75</td>
<td>1857</td>
<td>138 20</td>
<td></td>
</tr>
</tbody>
</table>
Betton Pool

$^{210}\text{Pb}$ Activity versus Depth

Core SCM27B

$^{210}\text{Pb}$ Activity (Bq kg$^{-1}$)

Depth (cm)
Betton Pool

$^{137}$Cs Activity versus Depth

Core SCM27B

![Graph showing $^{137}$Cs activity versus depth for Betton Pool, with depth measured in cm and activity in Bq kg$^{-1}$.]
Betton Pool Core SCM27B
Depth versus Age

- \(^{137}\)Cs Dates
- CIC \(^{210}\)Pb Dates
- CRS \(^{210}\)Pb Dates
- CRS Sedimentation Rates

Age (y) vs. Depth (cm)
Radiometric Dating of Crose Mere

Sediment samples from core SCM 03B were analysed for $^{210}\text{Pb}$, $^{226}\text{Ra}$, $^{137}\text{Cs}$ and $^{241}\text{Am}$ by direct gamma assay using a well-type coaxial low background intrinsic germanium detector fitted with a sodium iodide (NaI(Tl)) escape suppression shield (Appleby et al. 1986). The $^{210}\text{Pb}$ and $^{226}\text{Ra}$ results are given in Table 1 and shown graphically in Fig. 1. The $^{137}\text{Cs}$ and $^{241}\text{Am}$ results are given in Table 2 and Fig. 2.

$^{210}\text{Pb}$ dates have been calculated using both the CRS and CIC dating models (Appleby & Oldfield 1978), and the results are shown in Fig. 3. Above 16cm (dated ca. 1956) there is little significant difference between the two models, both indicating a more or less constant sedimentation rate of $0.062\pm0.005 \text{ gcm}^{-2}\text{y}^{-1}$. Dates below 16cm are a little more problematical in view of the non-monotonic feature at ca. 20cm depth in the $^{210}\text{Pb}$ profile (Fig. 1b). Both models suggest that this feature records an episode of accelerated sedimentation in the mid 1940s, though they differ as to its duration and nature. The CRS model indicates a more prolonged event, with peak sedimentation occurring in ca. 1943. The CIC model suggests a brief but more intense event such as a sediment slump. The dilution in $^{210}\text{Pb}$ activity is an argument in favour of the CRS model, though this is not conclusive. Both models indicate that prior to this event sedimentation rates were significantly lower than those determined for the post-1950 period. In the absence of any validating evidence, dates in the deeper sections of the core have been calculated using the average sedimentation rate of $0.039\pm0.009 \text{ gcm}^{-2}\text{y}^{-1}$ determined from both models. The results of these calculations are shown in Table 3. The CRS model has been used to date the 1940s event. Using the CIC model would reduce the ages of the deeper sections by ~15 years.

The $^{137}\text{Cs}$ activity versus depth profile (Fig. 2) has a well defined peak at 14.25±2 cm that would appear to record maximum fallout from the atmospheric testing of nuclear weapons in 1963. This inference supported by the presence of traces of $^{241}\text{Am}$ at the same level (Appleby et al. 1991). Fig. 3 shows that the $^{137}\text{Cs}$ date is in excellent agreement with the $^{210}\text{Pb}$ chronology.
References


### Table 1. Crose Mere: \(^{210}\text{Pb Data}^\text{Core SCM 03B}\)

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Dry Mass (g cm(^{-2}))</th>
<th>(^{210}\text{Pb Concentration (Bq kg}(^{-1}) ± Bq kg(^{-1}))</th>
<th>(^{226}\text{Ra Concentration (Bq kg}(^{-1}) ± Bq kg(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>0.01</td>
<td>125.9 ± 7.9</td>
<td>99.7 ± 8.1</td>
</tr>
<tr>
<td>2.25</td>
<td>0.12</td>
<td>161.4 ± 10.7</td>
<td>129.8 ± 11.0</td>
</tr>
<tr>
<td>4.25</td>
<td>0.26</td>
<td>146.3 ± 8.6</td>
<td>122.3 ± 8.8</td>
</tr>
<tr>
<td>8.25</td>
<td>0.82</td>
<td>121.4 ± 7.2</td>
<td>92.3 ± 7.3</td>
</tr>
<tr>
<td>12.25</td>
<td>1.53</td>
<td>84.8 ± 5.0</td>
<td>60.3 ± 5.1</td>
</tr>
<tr>
<td>14.25</td>
<td>1.90</td>
<td>77.7 ± 6.8</td>
<td>57.6 ± 7.0</td>
</tr>
<tr>
<td>16.25</td>
<td>2.25</td>
<td>69.2 ± 5.6</td>
<td>46.7 ± 5.7</td>
</tr>
<tr>
<td>20.25</td>
<td>2.99</td>
<td>45.6 ± 5.5</td>
<td>24.2 ± 5.6</td>
</tr>
<tr>
<td>24.25</td>
<td>3.68</td>
<td>53.4 ± 5.6</td>
<td>30.4 ± 5.8</td>
</tr>
<tr>
<td>28.25</td>
<td>4.49</td>
<td>38.1 ± 5.1</td>
<td>17.9 ± 5.2</td>
</tr>
<tr>
<td>32.50</td>
<td>5.43</td>
<td>30.0 ± 4.0</td>
<td>9.7 ± 4.2</td>
</tr>
<tr>
<td>36.50</td>
<td>6.33</td>
<td>21.8 ± 5.3</td>
<td>4.4 ± 5.4</td>
</tr>
</tbody>
</table>

Unsupported \(^{210}\text{Pb inventory}: 2665±125 \text{Bq m}^2\)

\(^{210}\text{Pb flux}: 83±4 \text{Bq m}^2\text{y}^{-1}\)

### Table 2. Crose Mere: \(^{137}\text{Cs and }^{241}\text{Am Data}^\text{Core SCM 03B}\)

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>(^{137}\text{Cs Concentration (Bq kg}^{-1}) ± Bq kg(^{-1}))</th>
<th>(^{241}\text{Am Concentration (Bq kg}^{-1}) ± Bq kg(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>29.13 ± 2.33</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>2.25</td>
<td>37.94 ± 3.22</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>4.25</td>
<td>45.85 ± 2.50</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>8.25</td>
<td>48.73 ± 1.93</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>12.25</td>
<td>57.24 ± 1.74</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>14.25</td>
<td>60.39 ± 1.84</td>
<td>1.84 ± 0.83</td>
</tr>
<tr>
<td>16.25</td>
<td>52.41 ± 1.48</td>
<td>1.17 ± 0.33</td>
</tr>
<tr>
<td>20.25</td>
<td>28.81 ± 0.96</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>24.25</td>
<td>16.62 ± 1.17</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>28.25</td>
<td>8.60 ± 0.97</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>32.50</td>
<td>5.02 ± 1.24</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>36.50</td>
<td>5.88 ± 0.54</td>
<td>0.00 ± 0.00</td>
</tr>
</tbody>
</table>

Inventories: \(1825±43 \text{Bq m}^{-2}\) \(13±4 \text{Bq m}^{-2}\)
Table 3. Crose Mere: $^{210}$Pb chronology for Core SCM 03R

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Dry Mass (g/cm$^2$)</th>
<th>Date (AD)</th>
<th>Age (y)</th>
<th>Sedimentation Rate (g/cm$^2$·y$^{-1}$), (cm/y) ± (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>1993</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>0.05</td>
<td>1992</td>
<td>1</td>
<td>0.075, 1.32, 9.5</td>
</tr>
<tr>
<td>2.00</td>
<td>0.11</td>
<td>1991</td>
<td>2</td>
<td>0.063, 1.04, 9.7</td>
</tr>
<tr>
<td>3.00</td>
<td>0.18</td>
<td>1990</td>
<td>3</td>
<td>0.060, 0.80, 9.4</td>
</tr>
<tr>
<td>4.00</td>
<td>0.25</td>
<td>1989</td>
<td>4</td>
<td>0.060, 0.57, 8.9</td>
</tr>
<tr>
<td>5.00</td>
<td>0.37</td>
<td>1987</td>
<td>6</td>
<td>0.060, 0.49, 9.0</td>
</tr>
<tr>
<td>6.00</td>
<td>0.51</td>
<td>1985</td>
<td>8</td>
<td>0.060, 0.45, 9.3</td>
</tr>
<tr>
<td>7.00</td>
<td>0.65</td>
<td>1982</td>
<td>11</td>
<td>0.059, 0.42, 9.6</td>
</tr>
<tr>
<td>8.00</td>
<td>0.79</td>
<td>1980</td>
<td>13</td>
<td>0.059, 0.38, 9.9</td>
</tr>
<tr>
<td>9.00</td>
<td>0.96</td>
<td>1977</td>
<td>16</td>
<td>0.060, 0.37, 10.3</td>
</tr>
<tr>
<td>10.00</td>
<td>1.13</td>
<td>1974</td>
<td>19</td>
<td>0.061, 0.36, 10.7</td>
</tr>
<tr>
<td>11.00</td>
<td>1.31</td>
<td>1972</td>
<td>21</td>
<td>0.062, 0.36, 11.2</td>
</tr>
<tr>
<td>12.00</td>
<td>1.49</td>
<td>1969</td>
<td>24</td>
<td>0.063, 0.35, 11.6</td>
</tr>
<tr>
<td>13.00</td>
<td>1.67</td>
<td>1966</td>
<td>27</td>
<td>0.060, 0.33, 13.1</td>
</tr>
<tr>
<td>14.00</td>
<td>1.85</td>
<td>1962</td>
<td>31</td>
<td>0.055, 0.31, 14.9</td>
</tr>
<tr>
<td>15.00</td>
<td>2.03</td>
<td>1959</td>
<td>34</td>
<td>0.055, 0.30, 15.7</td>
</tr>
<tr>
<td>16.00</td>
<td>2.21</td>
<td>1956</td>
<td>37</td>
<td>0.055, 0.30, 16.3</td>
</tr>
<tr>
<td>17.00</td>
<td>2.39</td>
<td>1953</td>
<td>40</td>
<td>0.058, 0.32, 18.4</td>
</tr>
<tr>
<td>18.00</td>
<td>2.57</td>
<td>1950</td>
<td>43</td>
<td>0.063, 0.35, 21.0</td>
</tr>
<tr>
<td>19.00</td>
<td>2.76</td>
<td>1947</td>
<td>46</td>
<td>0.068, 0.38, 23.6</td>
</tr>
<tr>
<td>20.00</td>
<td>2.94</td>
<td>1944</td>
<td>49</td>
<td>0.072, 0.40, 26.3</td>
</tr>
<tr>
<td>21.00</td>
<td>3.12</td>
<td>1941</td>
<td>52</td>
<td>0.067, 0.37, 26.7</td>
</tr>
<tr>
<td>22.00</td>
<td>3.29</td>
<td>1938</td>
<td>55</td>
<td>0.058, 0.32, 26.5</td>
</tr>
<tr>
<td>23.00</td>
<td>3.46</td>
<td>1935</td>
<td>58</td>
<td>0.050, 0.27, 26.3</td>
</tr>
<tr>
<td>24.00</td>
<td>3.68</td>
<td>1931</td>
<td>62</td>
<td>0.041, 0.22, 26.0</td>
</tr>
<tr>
<td>25.00</td>
<td>3.83</td>
<td>1926</td>
<td>67</td>
<td></td>
</tr>
<tr>
<td>26.00</td>
<td>4.03</td>
<td>1921</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>27.00</td>
<td>4.24</td>
<td>1916</td>
<td>77</td>
<td></td>
</tr>
<tr>
<td>28.00</td>
<td>4.44</td>
<td>1910</td>
<td>83</td>
<td>0.039, 0.19, ~23%</td>
</tr>
<tr>
<td>29.00</td>
<td>4.66</td>
<td>1905</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td>30.00</td>
<td>4.88</td>
<td>1899</td>
<td>94</td>
<td></td>
</tr>
<tr>
<td>31.00</td>
<td>5.10</td>
<td>1893</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>32.00</td>
<td>5.32</td>
<td>1888</td>
<td>105</td>
<td></td>
</tr>
</tbody>
</table>
Crose Mere

Total $^{210}\text{Pb}$ Activity versus Depth

Core SCM 03B

$^{210}\text{Pb}$ Activity (Bq kg$^{-1}$)

Depth (cm)
Crose Mere

Unsupported $^{210}$Pb Activity versus Depth

Core SCM 03B

$^{210}$Pb Activity (Bq kg$^{-1}$) vs Depth (cm)
Crose Mere

$^{137}$Cs & $^{241}$Am Activity versus Depth

Core SCM 03B

Radiocaesium Activity (Bq kg$^{-1}$)

$^{137}$Cs
$^{241}$Am

Depth (cm)
Radiometric Dates for Oak Mere Core OAKMZ

This core does not appear to contain a coherent record of fallout radionuclides and it was not possible to make any reasonable estimate of sedimentation rates. In all samples analysed (from the top 20 cm) $^{210}\text{Pb}$ activities were essentially in equilibrium with the supporting $^{226}\text{Ra}$. Significant traces of $^{137}\text{Cs}$ were detected only in the topmost sample. The difficulties encountered with the core may be related to the events giving rise to the layers of unusually dense sediment in the top 3 cm, at 7-8 cm, and at 32-39 cm.
Oak Mere

$^{210}\text{Pb}$ Activity versus Depth

Core OAKM1

$^{210}\text{Pb}$ Activity (Bq kg$^{-1}$)

Depth (cm)

Total $^{210}\text{Pb}$

Supported $^{210}\text{Pb}$
Oak Mere

$^{137}$Cs Activity versus Depth

Core OAKM1

Radiocaesium Activity (Bq kg$^{-1}$)

Depth (cm)
Radiometric Dates for Upton Broad Core UPT01

This core appears to have a relatively simple $^{210}\text{Pb}$ profile. Sediment accumulation appears to be quite rapid, equilibrium with the supporting $^{226}\text{Ra}$ being reached at a depth of more than 50 cm. Calculations using the CRS and CIC $^{210}\text{Pb}$ dating models both indicate a more or less uniform sedimentation rate since c.1960 of $0.060\pm0.010 \, \text{g cm}^{-2}\text{y}^{-1}$ ($0.64 \, \text{cm y}^{-1}$), though there is some divergence in the deeper sections, possibly due to lower accumulation rates during the first few decades of this century.

There is however a significant contradiction between the $^{210}\text{Pb}$ and $^{137}\text{Cs}$ results. The $^{137}\text{Cs}$ measurements place the 1963 fallout peak at $10\pm 2.5 \, \text{cm}$. This suggests a mean post-1963 sedimentation rate of $\sim 0.03 \, \text{g cm}^{-2}\text{y}^{-1}$, just half the $^{210}\text{Pb}$ value. Since there is no evidence of mixing, the most likely cause of the discrepancy is post-depositional loss from the record. The inventories of both radionuclides are significantly below values expected from direct fallout, though the losses are however much greater for $^{137}\text{Cs}$ (~90%) than $^{210}\text{Pb}$ (~50%). In view of this, and the coarse resolution of $^{137}\text{Cs}$ peak, the $^{210}\text{Pb}$ dates are probably more secure. The following table gives CRS model $^{210}\text{Pb}$ dates, which are to some extent a compromise between the $^{137}\text{Cs}$ and CIC model. In light of the above discussion these should however be regarded with some caution.

### Table of Dates

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Cum Dry Mass (g cm$^{-2}$)</th>
<th>Chronology</th>
<th>Accumulation Rate (g cm$^{-2}$ y$^{-1}$, cm y$^{-1}$, ± %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>1995</td>
<td>0.060, 0.64, 19.1</td>
</tr>
<tr>
<td>5.00</td>
<td>0.47</td>
<td>1987</td>
<td>0.059, 0.63, 26.6</td>
</tr>
<tr>
<td>10.00</td>
<td>0.94</td>
<td>1979</td>
<td>0.061, 0.63, 27.8</td>
</tr>
<tr>
<td>15.00</td>
<td>1.41</td>
<td>1972</td>
<td>0.062, 0.63, 28.7</td>
</tr>
<tr>
<td>20.00</td>
<td>1.87</td>
<td>1964</td>
<td>0.052, 0.51, 30.9</td>
</tr>
<tr>
<td>25.00</td>
<td>2.40</td>
<td>1954</td>
<td>0.040, 0.38, 33.2</td>
</tr>
<tr>
<td>30.00</td>
<td>2.93</td>
<td>1943</td>
<td>0.034, 0.31, 36.7</td>
</tr>
<tr>
<td>35.00</td>
<td>3.47</td>
<td>1928</td>
<td>0.028, 0.25, 40.3</td>
</tr>
<tr>
<td>40.00</td>
<td>4.00</td>
<td>1912</td>
<td></td>
</tr>
</tbody>
</table>

Extrapolated dates:
- 45 cm: 1894
- 50 cm: 1877
- 55 cm: 1860
Upton Broad

$^{210}\text{Pb}$ Activity versus Depth

Core UPTO1

$^{210}\text{Pb}$ Activity (Bq kg$^{-1}$) vs. Depth (cm)
Upton Broad

$^{137}$Cs Activity versus Depth

Radiocaesium Activity (Bq kg$^{-1}$) vs. Depth (cm)
Upton Broad Core UPT01
Depth versus Age

- 137Cs Dates
- CIC 210Pb Dates
- CRS 210Pb Dates
- CRS Sedimentation Rates

Depth (cm) vs. Age (y)

Sed Rate (g cm⁻² yr⁻¹)
Radiometric Dates for Hatchet Pond

The radiometric results suggest that sediments at this site have been subject to extensive focussing and vertical mixing. The $^{210}\text{Pb}$ and $^{137}\text{Cs}$ inventories are more than 5 times the values expected from atmospheric fallout, their activities are more or less uniform in the top 40 cm, and the depth of the 1963 level suggested by the $^{137}\text{Cs}$ record is significantly above the depth calculated by $^{210}\text{Pb}$. In the event of mixing, the best guide to mean accumulation rates is the gradient of the $^{210}\text{Pb}$ profile beneath the mixed layer. Calculations based on this method give a value of $0.27\pm0.11 \text{g cm}^{-2}\text{y}^{-1}$, compared to the $^{137}\text{Cs}$ derived value of $0.16\pm0.07 \text{g cm}^{-2}\text{y}^{-1}$. In view of the uncertainties, the best approach would appear to use a mean accumulation rate of $0.22\pm0.09 \text{g cm}^{-2}\text{y}^{-1}$, and this has been used to calculate the dates given in the following table.

### Table of Dates

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Cum Dry Mass (g cm$^{-2}$)</th>
<th>Chronology</th>
<th>Accumulation Rate (g cm$^{-2}$ y$^{-1}$)</th>
<th>± (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Date (AD)</td>
<td>Age ± (y)</td>
<td></td>
</tr>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>1995</td>
<td>0 ± 6</td>
<td></td>
</tr>
<tr>
<td>10.00</td>
<td>1.29</td>
<td>1989</td>
<td>6 ± 9</td>
<td></td>
</tr>
<tr>
<td>20.00</td>
<td>3.15</td>
<td>1980</td>
<td>15 ± 13</td>
<td></td>
</tr>
<tr>
<td>30.00</td>
<td>5.02</td>
<td>1972</td>
<td>23 ± 18</td>
<td></td>
</tr>
<tr>
<td>40.00</td>
<td>7.12</td>
<td>1962</td>
<td>33 ± 23</td>
<td>0.22 ± 0.93 ~40%</td>
</tr>
<tr>
<td>50.00</td>
<td>9.68</td>
<td>1950</td>
<td>45 ± 35</td>
<td></td>
</tr>
<tr>
<td>60.00</td>
<td>12.26</td>
<td>1938</td>
<td>57 ± 23</td>
<td></td>
</tr>
<tr>
<td>70.00</td>
<td>15.35</td>
<td>1924</td>
<td>71 ± 29</td>
<td></td>
</tr>
<tr>
<td>80.00</td>
<td>18.46</td>
<td>1909</td>
<td>86 ± 35</td>
<td></td>
</tr>
</tbody>
</table>
Hatchet Pond

$^{210}\text{Pb}$ Activity versus Depth

Core HATC1

- **Total $^{210}\text{Pb}$**
- **Unsupported $^{210}\text{Pb}$**
- **Supported $^{210}\text{Pb}$**
Hatchet Pond

$^{137}$Cs Activity versus Depth

![Graph showing $^{137}$Cs Activity versus Depth for Hatchet Pond. The graph plots depth in cm on the x-axis and radiocaesium activity in Bq kg$^{-1}$ on the y-axis. The data point for HATC1 is marked with error bars indicating variability.]


