LOWESWATER:

WATER QUALITY MONITORING 2011

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SUMMARY

Loweswater, one of the smaller and more picturesque lakes in the English Lake District, was once an excellent brown trout (*Salmo trutta*) fishery, but with the impact of agricultural practices and domestic input from the catchment over many years the water quality has declined and the lake now suffers seasonal blooms of potentially toxic blue-green algae, greatly diminished fish populations and a proliferation of phantom midge larvae (*Chaoborus)* in open water.

During 2011, the lake's water quality was monitored through evaluation of chemical data on water samples taken on a monthly basis and by enumeration and identification of the lake's phytoplankton populations, also on a monthly basis. The results were compared to historical data gathered from 1984 to 2010, a review of which confirmed the decline of the water quality from 1995 to 2010 when the lake's trophic status was classified as close to the mesotrophic-eutrophic boundary.

The results of the 2011 monitoring programme indicate an improvement in the lake since 2010 and that Loweswater should now be classified as mesotrophic under the OECD scheme and is close to being of good ecological status under the EU Water Framework Directive. These results also provide a baseline record against which the results of future work may be compared.

1. INTRODUCTION

Background

Loweswater is a small lake of 0.64 km^2, which lies within the north-west boundary of the Lake District National Park, 3º 21' W and 54º 35' N.

The Loweswater catchment area includes 371 ha of open fells, 273 ha of in-bye land (grassland) and 130 ha of woodland. The lake has a maximum depth of 16 metres and a volume of 5.4 million cubic metres[1] of water, a long retention time (or residence time) with a mean of 199 days, and is the thirteenth largest of the Lake District lakes (Fryer, 1991). There are several inflow streams to the lake, the four main ones being Dub Beck at the northern end of the lake, Holme Beck and Black Beck on the western side, and Crabtree Beck on the eastern side. There is one outflow, also named Dub Beck, which flows into Park Beck and then into the north end of Crummock Water close to that lake's outflow, the River Cocker.

The land surrounding Loweswater has been farmed for centuries, but by the 1950s a new age of intensive farming arrived with greater mechanisation and the introduction of government grants and subsidies to encourage higher production, with the use of chemical fertilisers, pesticides, insecticides and growth promoters, and formulated animal feeds, all of which were to have adverse effects on the local environment, including the lake (Pers. Comm., Bell, 2009).

Water quality

Loweswater has been the subject of a number of chemical surveys over the last 80 years, many of which were reviewed by Benion et al. in 2000. In addition, the Centre for Ecology

[1] One cubic metre is approximately 220 gallons.

and Hydrology (CEH) (and before them by FBA[2] and IFE[3]) have conducted surveys on a regular basis since 1984. These surveys, referred to as the ‘Lakes Tours’ and carried out in 1984, 1991, 1995, 2000, 2005 and 2010, have gathered data on 20 lakes and tarns in the English Lake District, including Loweswater (Hall et al.,1992, 1996; Parker et al., 2001; Maberly, 2006a, 2011). Maberly et al. (2006b) also monitored the lake’s water quality as part of a one year study carried out from October 2004 to September 2005 and as part of a three year community-led catchment management project (known as the Loweswater Care Project) by CEH and Lancaster University, carried out from 2007 to 2010.

The data from these surveys show that over the 20 years since 1984 concentrations of total phosphorus (TP) in Loweswater increased and that over fifteen years phytoplankton chlorophyll *a* levels (a quantitative measure of the amount of algae in the water) rose, with the result that the lake’s trophic status was classified as ‘close to the mesotrophic-eutrophic boundary’ (Maberly et al., 2006a, 2006b).

The decline in water quality has been associated with pollution from increased sources of phosphorus from greater domestic phosphorus inputs, leaking domestic septic tanks, and from farm slurry holdings and slurry and fertiliser applications to the surrounding fields. In addition, nutrient cycling following the release of phosphate from the sediments within the lake may be a contributory factor, too.

An evaluation of more recent water quality monitoring data (2007 to 2010) suggested some amelioration, possibly reflecting the initiatives of the local farmers, who in 2002 in response to the wider concerns about the effects of farming practices on the environment, and in

[2] Freshwater Biological Association
[3] Institute of Freshwater Ecology

particular on the water quality of the lake, initiated the *'Loweswater Improvement Project'* in order to explore ways of reducing pollution sources from their holdings. However, in their report of the 'Lakes Tour' of 2010 Maberly et al. (2011) again classified Loweswater as 'close to the mesotrophic-eutrophic boundary', based on TP and phytoplankton chlorophyll *a* levels.

One clear indicator of deteriorating water quality is the regular incidence of potentially toxic blue-green algal (cyanobacterial) blooms on the lake, and the decline in the lake's water quality has also brought about other changes to the aquatic community, including greatly diminished fish populations (Shaw, 2009) and a proliferation of phantom midge larvae (*Chaoborus)* in open water, possibly competing with the fish for available food (Winfield, 2008).

During 2011, the lake's water quality was monitored through evaluation of the Environment Agency's chemical data on water samples taken on a monthly basis and by enumeration and identification of the lake's phytoplankton populations, also on a monthly basis. The EU Water Framework Directive includes phytoplankton as an important element to be used in the assessment of the ecological status of a lake; its ecological significance is determined by the fact that its productivity indicators are also indicators of the trophic status of water bodies (Cheshmedjiev et al., 2010; Pasztaleniec and Poniewozik, 2010).

The purpose of this document is to:

- Report the results of the water quality monitoring programme of Loweswater in 2011.
- Compare these results with the historical data described above.
- Provide a baseline record of data against which the results of future work may be compared.

2. METHODS

2. 1 Sample collection

Using a small electrically powered dinghy, staff from Environment Agency collected five-metre integrated mid-lake water samples from Loweswater on a monthly basis. The exceptions were in January and December, when weather conditions didn't allow the use of the dinghy and samples were taken from the shore. The samples were stored in one-litre plastic containers and labelled with the sample number and date. On each occasion, one litre of water was retained by the Environment Agency for analysis at their Starcross Laboratory in Exeter, Devon and another litre given to the author for subsequent processing for algal counts.

2.2 Water quality monitoring

At the point of sampling, the Environment Agency measured water transparency with the aid of a Secchi disc. The black and white painted metal disc, 30 cm in diameter, was lowered into the water and the depth at which it disappeared from view noted from the calibrated rope. Also, using a YSI Professional Plus handheld multiparameter meter, they measured the Water temperature, pH, Oxygen concentration and Conductivity (all measurements at a depth of 25 - 30 cm). In addition, the Starcross Laboratory analysed each water sample for a wide range of variables, including: Alkalinity, Total Phosphorus, Soluble Reactive Phosphorus, Chlorophyll *a*, and Total Nitrogen.

2.3 Phytoplankton identification and enumeration

Preserving water samples

Lugol's iodine solution[4] was added to the water samples at the rate of 4 - 5ml / litre in order to preserve the algae and increase their rate of sedimentation during subsequent processing.

Concentrating samples

Sub samples of 300 ml of the iodine-preserved water samples were concentrated to 5 ml (i.e. a factor of x60) by a two-stage sedimentation procedure, in order to make counts more practicable.

Microscopy

Each concentrated 5ml sample was mixed well and a known volume transferred to a Lund counting chamber and the algae were identified and counted microscopically. The algae were viewed under phase contrast and / or darkfield illumination at magnifications of x125 or x500 and 100 random fields were evaluated for each water sample. All counts were made at x125 magnification and recorded on data sheets.

[4] A solution of potassium iodide and iodine in distilled water with the addition of acetic acid.

3. RESULTS

3.1 Water quality monitoring

Alkalinity and pH

Alkalinity (acid buffering capacity) varied between 172 μeq / L in February and 226 μeq / L in September (see Figure 1), with an annual mean of 198.5 μeq / L.

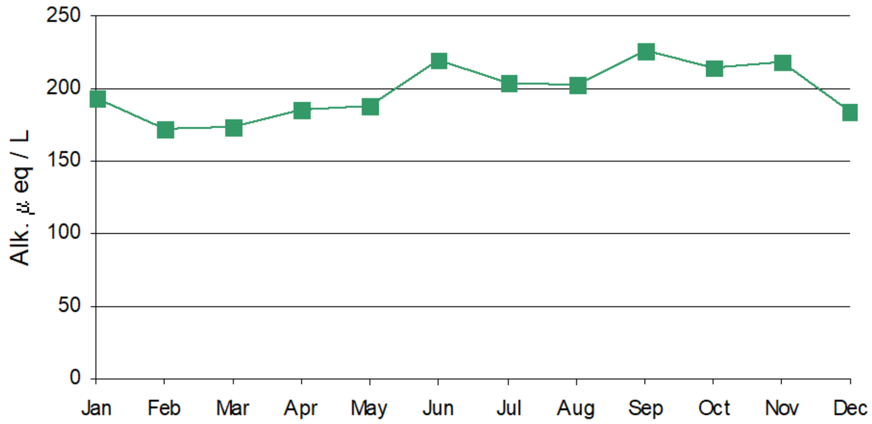

Figure 1. *Seasonal changes in Alkalinity in Loweswater, 2011.*

'Lakes Tours' and CEH data show that alkalinity in Loweswater rose from an annual mean of 152 μeq / L in 1984 to 224 μeq / L in 2005, since when it has fluctuated between 188 μeq / L and 215 μeq / L (see Figure 2); the annual mean figure for 2011 is, therefore, consistent with values of more recent years.

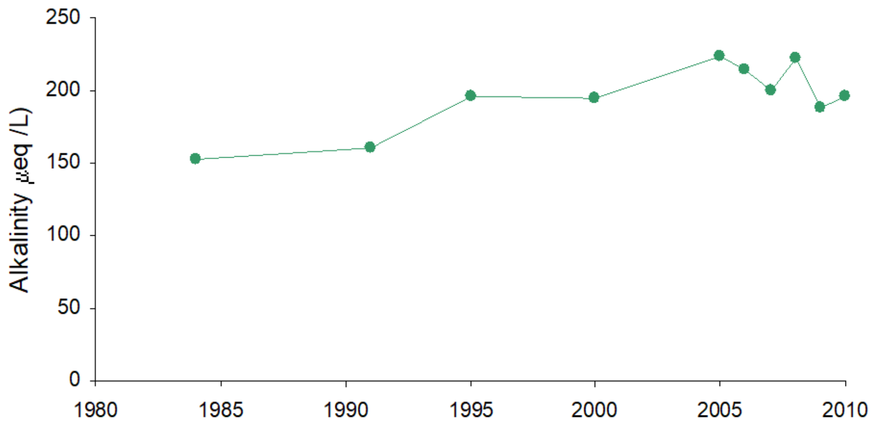

Figure 2. *Annual mean values for alkalinity in Loweswater 1984 to 2010.*
(From Lakes Tours and CEH data)

The increase in alkalinity is widespread in the Lake District lakes, largely caused by reduction in sulphate deposition from acid rain (Maberly et al., 2006; 2011) and, in Loweswater more recently, through the re-introduction of liming in the catchment (Pers. Comm., Bell, 2009).

The lowest pH recorded was in September at pH 6.86 and the highest in July at pH 8.6, see Figure 3; the annual mean value was pH 7.41. Seasonal variation in pH may be associated with phytoplankton photosynthesis during algal blooms, particularly in slow-moving water. In the more productive lakes, for example Esthwaite Water, short-term seasonal values as high as pH 10 have been recorded (Maberly et al., 2011). During May, June and July values in Loweswater were above pH 8, and these have tended to push the lake's annual mean figure higher than in previous years.

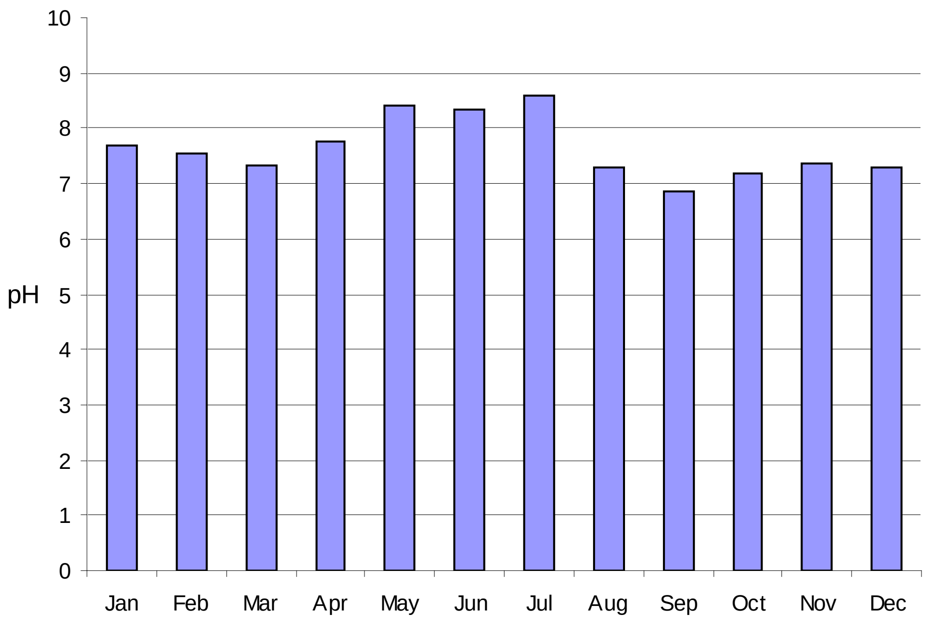

Figure 3. *Seasonal variation in pH values in Loweswater, 2011.*

Data from Carrick and Sutcliffe (1982), Lakes Tours and CEH show that over a period of 30 years the pH in Loweswater remained around or just below neutral (pH 7), but more recently, with increasing alkalinity, annual mean values have increased slightly, with Environment Agency measurements tending to be a little higher than CEH's, possibly resulting from the difference between on-site and laboratory based measurements (see Figure 4).

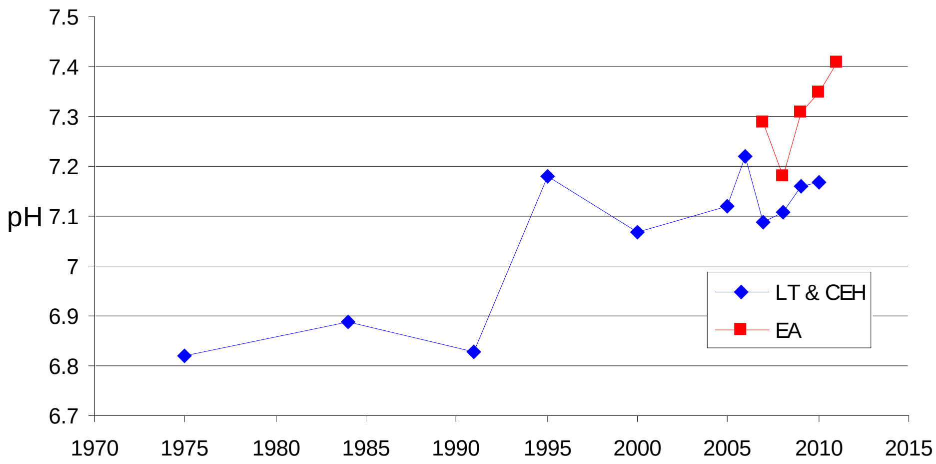

Figure 4. *Annual mean pH values in Loweswater 1975 to 2011.*
(From Carrick and Sutcliffe,1982; Lakes Tours, CEH and Environment Agency).

The results of the survey carried out by YSI Hydrodata Ltd on 01 November showed that pH values were lowest (pH 7) at the north end of the lake near the main inflow, Dub Beck, and at the south end near the outflow. The results also showed a slight difference in value from west to east, i.e. pH 7.04 to 7.1.

Water temperature

The lowest surface water temperature recorded was in January at 3.19 °C and the highest in July at 17.1 °C (see Figure 5), with an annual mean of 10.56 °C, which is comparable to the Environment Agency's annual mean figures for 2007 to 2010 of 12.5, 10.02, 10.88 and 11.3 °C, respectively.

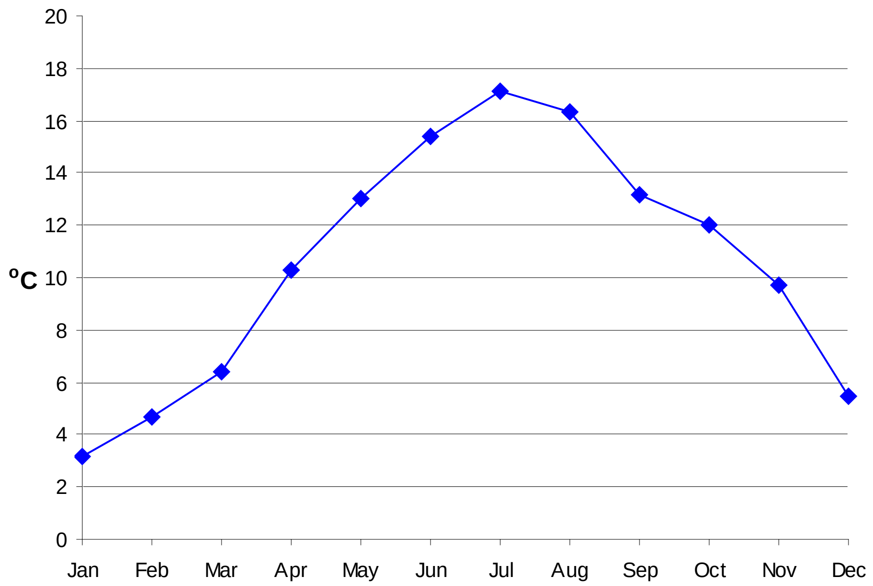

Figure 5. *Seasonal variation in surface water temperature in Loweswater, 2011.*

Conductivity

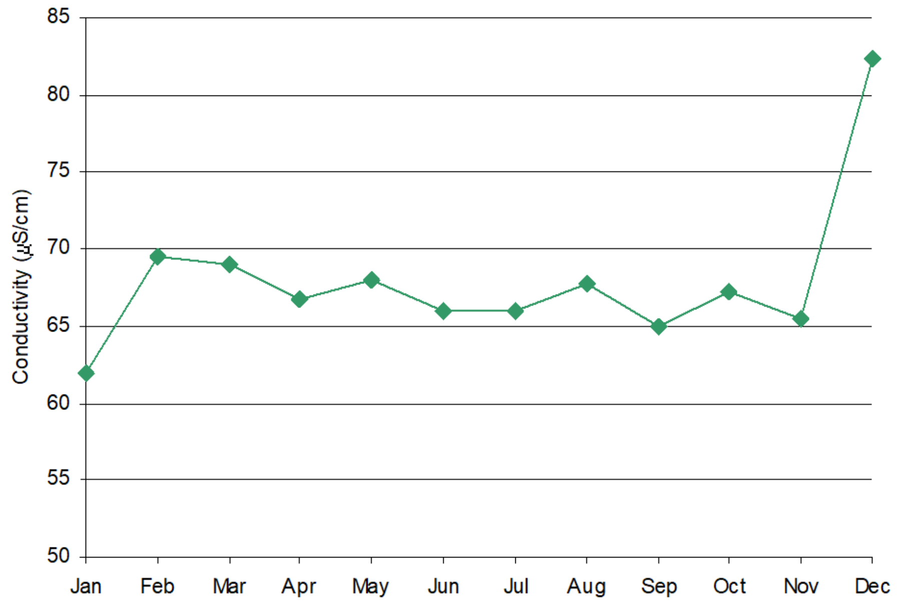

Figure 6. *Seasonal changes in conductivity in Loweswater, 2011.*

Overall, Conductivity, a measure of the water's ionic activity and content, expressed as micro Siemens per centimetre (µS / cm), ranged from 62 µS / cm in January to 82 µS / cm in December, with an annual mean of 67.9 µS / cm; however, for most of the year, February to November, the range was much smaller, i.e. between 65 and 69.5 µS / cm, see Figure 6. The reading in December, although not high in absolute terms, was high relative to those recorded in all other months. As rainfall was highest in December at 255.2 mm (see weather report, Page 22) the extra runoff at that time of the year would be expected to have had a diluting effect and, thus, lower the conductivity reading. The higher reading suggests that additional dissolved minerals were washed into the lake. The only other factor for consideration was that the December reading was from a shore-side sample; however, the only other shore-side sample was taken in January, which gave the lowest reading for the year.

Previous conductivity data available from the Environment Agency for 2007 to 2010 give annual mean values of 75.2, 76.5, 71.7 and 69 µS / cm, respectively.

The results of the survey carried out by YSI Hydrodata Ltd on 01 November showed that the lake was uniformly 68 to 69 µS / cm, except at the north end near the main inflow, Dub Beck, where the values were higher at 74 to 75 µS / cm.

Oxygen concentration

The lowest oxygen concentration recorded was in October at 93% and the highest in June at 106.1%, see Figure 7; the annual mean concentration was 98.69%. However, measurements were taken near the surface where the water would be expected to be well oxygenated. A more important consideration is the level of oxygen depletion at depth. From early to mid-summer to early autumn the lake water is thermally stratified, i.e. warmer surface water (the epilimnion) overlies, but hardly mixes with, colder bottom water (hypolimnion), the oxygen depletion at depth being caused by the decomposition of organic material produced in the upper layers of the lake.

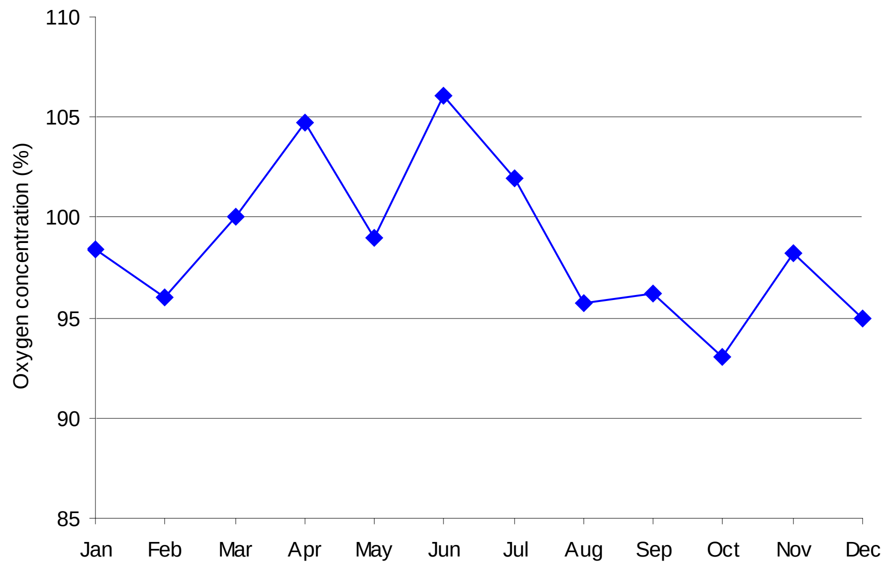

Figure 7. *Seasonal variation in surface oxygen concentrations (%) in Loweswater, 2011.*

The latest available 'Lakes Tours' data from 2010 show that oxygen levels at 10 metres were as low as 1.98 mg / L in August and that at 15 metres levels were virtually zero for June, July and August (see Figure 8). In these anoxic conditions there is potential for accumulated phosphates to be released from the sediments, leading to internal loading and further eutrophication.

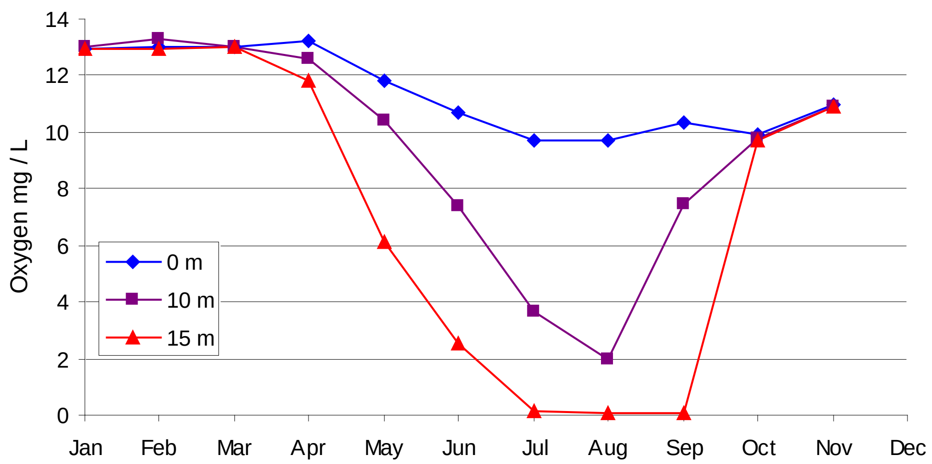

Figure 8. *Seasonal variation in oxygen levels (mg / L) at 0, 10 and 15 metres in Loweswater, 2010.* ***(from Lakes Tours data, 2010).***

Soluble Reactive Phosphorus (SRP)

The SRP concentrations given for January, February, May July and August were < 1.0 µg / L (? below detection levels) and so these have been plotted at 0.5 µg / L; the maximum concentration was in December at 2.7 µg / L, see Figure 9; the annual mean concentration was 1.2 µg / L.

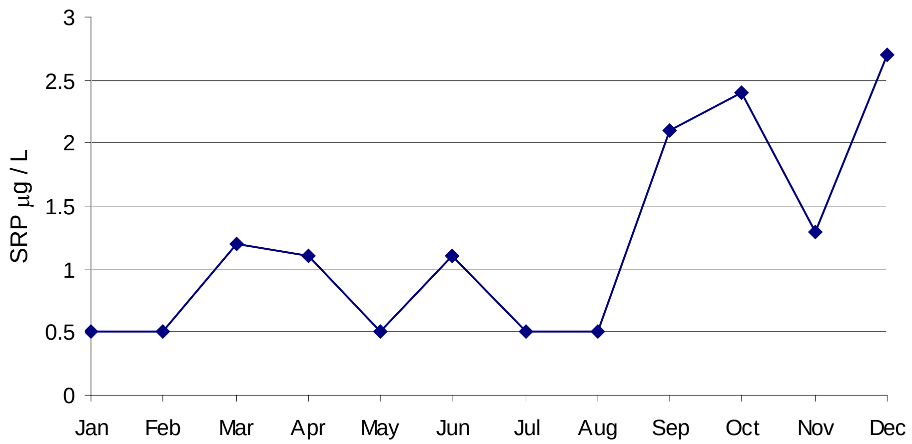

Figure 9. *Seasonal variation in concentrations of SRP in Loweswater, 2011.*

Lakes Tours and CEH data from 1984 to 2010 show that the annual mean concentrations of SRP rose from 0.5 µg / L in 1984 and 1991 to 1.76 µg / L in 1995, but by 2005 to 2009 were constant and more or less back to the 1984 level (see Figure 10).

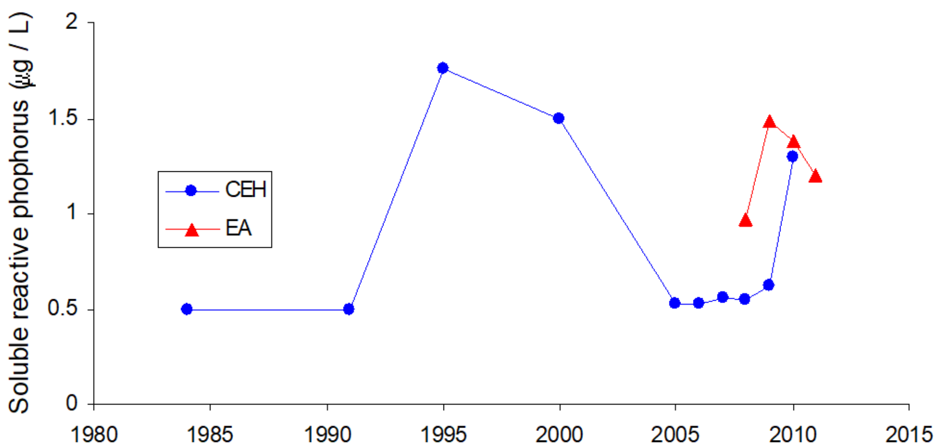

Figure 10. *Annual mean concentrations of SRP in Loweswater, 1984 to 2011.*
(From Lakes Tours, CEH and Environment Agency data).

However, there was a rise to 1.3 µg / L in 2010 and the Environment Agency's data show a rise in 2008 and 2009, with a similar value to CEH in 2010 and a slight fall in 2011. Phosphate is the main nutrient controlling phytoplankton production in Loweswater and as SRP is readily available to phytoplankton, concentrations can change rapidly in response to supply and demand and tend to be very low throughout the growing season. As a result, SRP is less reliable as an indicator of the trophic state of a lake than total phosphorus (Maberly et al., 2006).

Nitrate- nitrogen

Concentrations of nitrate-nitrogen (NO3-N) ranged from 280 µg / L in August to 670 µg / L in February, with an annual mean of 474 µg / L (see Figure 11).

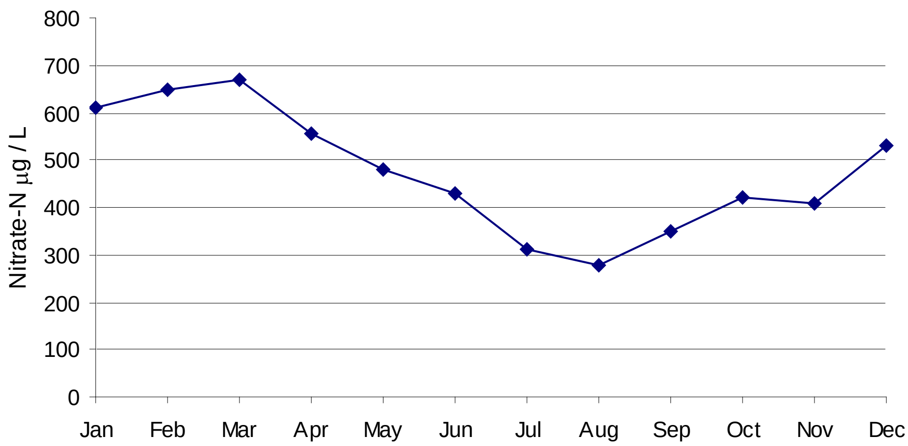

Figure 11. *Seasonal variation in concentrations of nitrate-nitrogen in Loweswater, 2011.*

Lakes Tours and CEH data from 1984 to 2010 show that the annual mean concentrations of nitrate-nitrogen fell from 553 µg / L in 1984 to 287 µg / L in 2006 due mainly to falling summer values; Maberly et al. (2006a) reported a highly significant and strong tendency for summer and autumn concentrations of nitrate to decline. This, they suggest, is caused by processes within the lake consistent with increasing productivity caused by increasing availability of phosphorus, which in turn increases the demand for nitrogen. More recent data from CEH and the Environment Agency show increases in annual mean concentrations to 2008 followed by falls in 2009 and 2010 to about the levels of 2000 (see Figure 12).

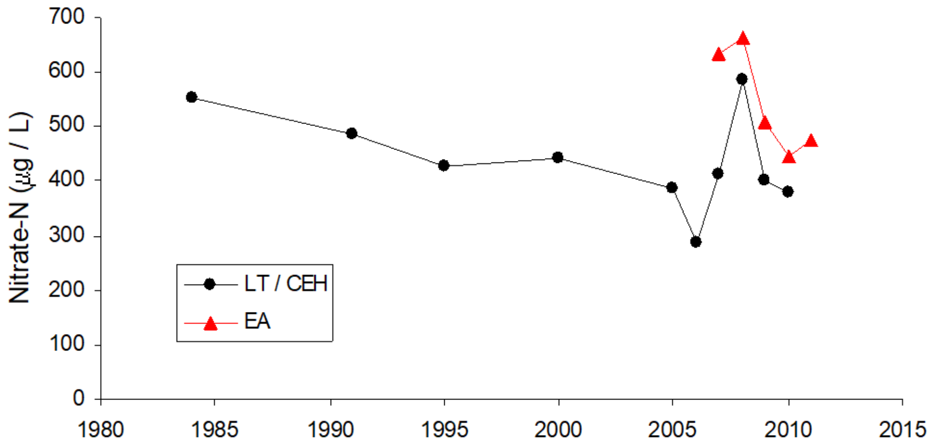

Figure 12. *Annual mean concentrations of nitrate-nitrogen in Loweswater, 1984 to 2011.* ***(From Lakes Tours, CEH and Environment Agency data).***

Total phosphorus (TP), Phytoplankton chlorophyll* a *and depth of Secchi disc

As phytoplankton production is governed by the availability of phosphorus, there is close correlation between TP and phytoplankton chlorophyll *a* concentrations; there is also an inverse correlation between phytoplankton chlorophyll *a* concentration and depth of Secchi disc readings. For these reasons these three parameters are considered together.

The minimum TP concentration was in June at 8.5 µg / L, and the maximum in December at 18.1 µg / L; the annual mean concentration was 12.44 µg /L (see Figure 13).

Phytoplankton chlorophyll *a* concentrations varied between 1.9 µg /L in February and 13.3 µg /L in May, with an annual mean concentration of 6.17 µg /L. (see Figure 14).

The minimum depth of Secchi disc was in May at 2.5 metres (when phytoplankton chlorophyll *a* was at the maximum) and the maximum in November at 4.25 metres, see Figure 1, with an annual mean of 3.44 metres (see Figure 15).

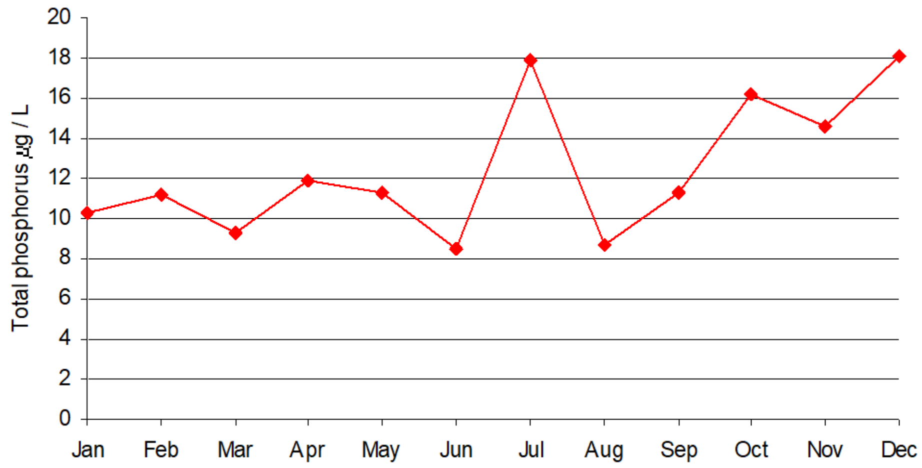

Figure 13. *Seasonal variation in concentrations of total phosphorus in Loweswater, 2011.*

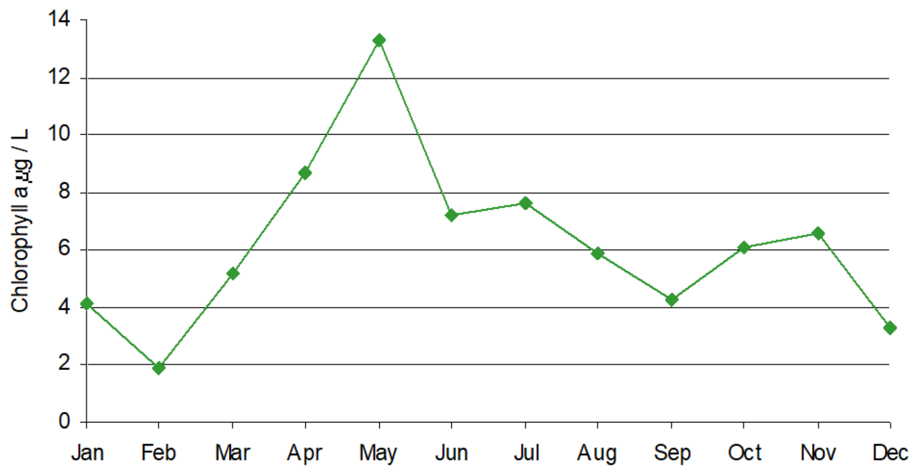

Figure 14. *Seasonal variation in concentrations of phytoplankton chlorophyll a in Loweswater, 2011.*

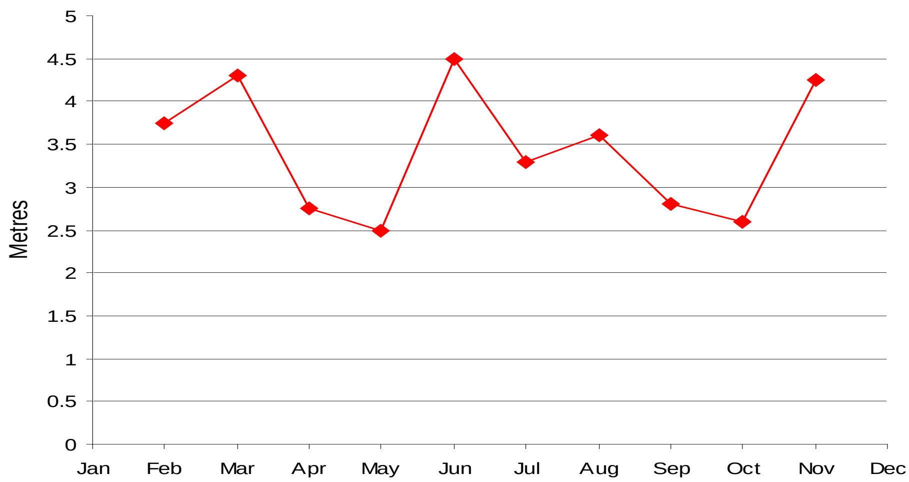

Figure 15. *Seasonal changes in depth of Secchi disc in Loweswater, 2011.*

Lakes Tours and CEH data from 1984 to 2010 show that the annual mean concentrations of TP rose steadily from 11.13 µg / L in 1984 to a peak of 16.46 µg / L in 2000, since when annual mean concentrations have fluctuated between 9.62 and 16.25 µg / L. The most recent data, however, from CEH in 2010 (12.74 µg / L) and the Environment Agency in 2011 (12.44 µg / L) show that annual mean concentrations are almost back to 1991 levels (see Figure 16).

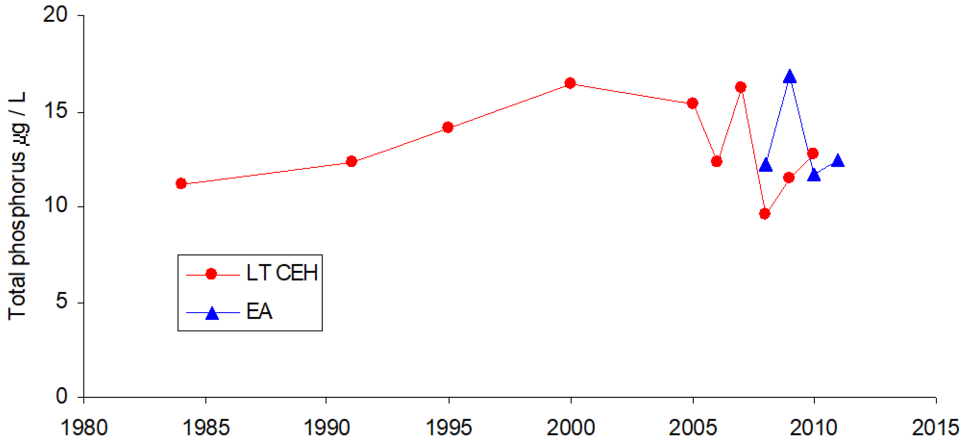

Figure 16. *Annual mean concentrations of total phosphorus in Loweswater, 1984 to 2011.* ***(From Lakes Tours, CEH and Environment Agency data).***

Lakes Tours and CEH data from 1991 to 2010 show that the annual mean concentrations of Phytoplankton chlorophyll *a* rose to a peak of 12.09 µg / L in 2005, fell steadily to 9.01 µg / L by 2008, but the most recent data from 2010 show a level of 11.01 µg / L. The Environment Agency data from 2005 (earliest available) to 2008 show a similar trend, but with lower values, i.e. from 9.59 to 6.99 µg / L and continue more or less at that value to 2011 (see Figure 17).

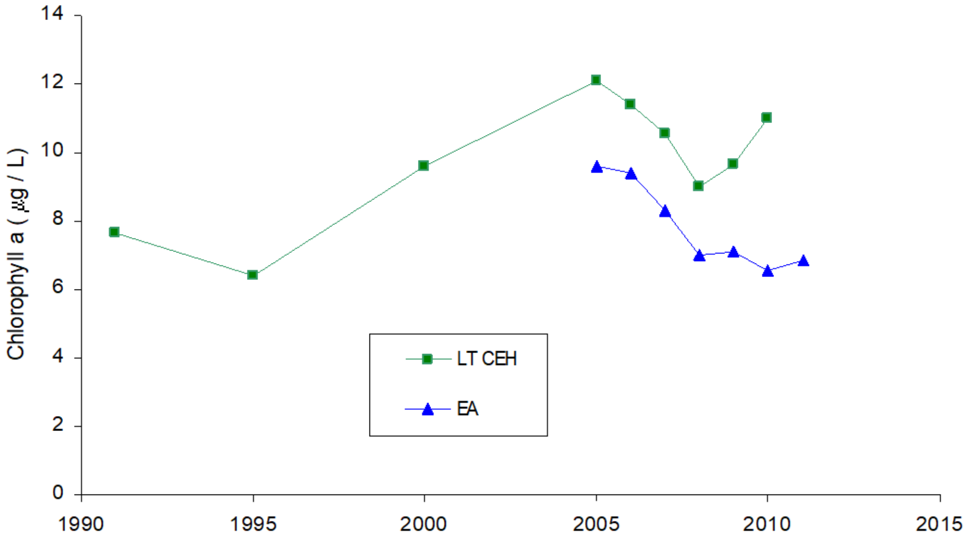

Figure 17. *Annual mean concentrations of phytoplankton chlorophyll a in Loweswater, 1990 to 2011* ***(From Lakes Tours, CEH and Environment Agency data).***

Lakes Tours and CEH data from 1990 to 2010 show that the annual mean depth of Secchi disc decreased from 5 metres (minimum 3.5 metres) in 1995 to 2.75 metres in 2005 and then slight increases in 2006 to 2008, followed by slight decreases in 2009 and 2010 to 2.76 metres (minimum 1.9 metres), see Figure 2. Thus, the result for 2011 indicates an improvement in the annual mean of 0.68 metres on 2010 and almost back to the 1991 level.

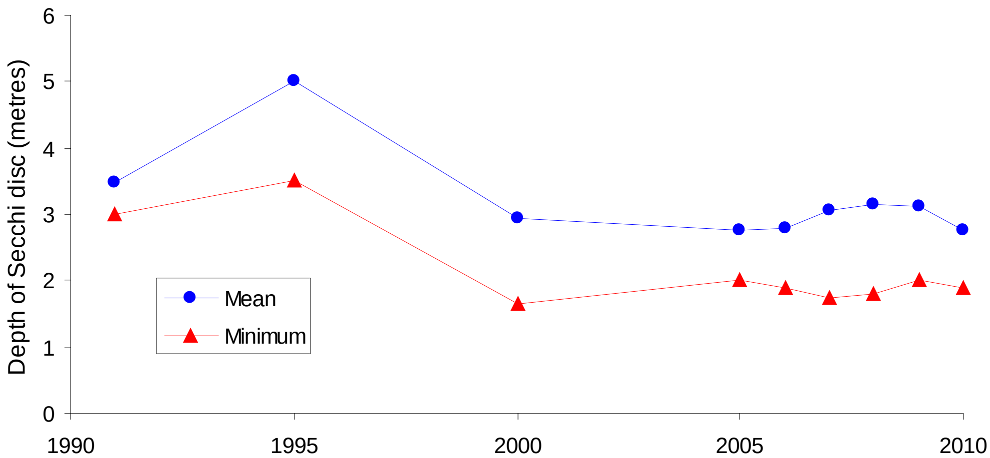

Figure 18. *Annual mean and annual minimum depth of Secchi disc in Loweswater, 1991 to 2010.* ***(CEH data).***

3.3 Microscopy and algal counts

A wide range of algae were identified and counted, falling broadly into the following phylogenetic groups: Chlorophytes (including Euglenophytes), Chrysophytes, Cryptophytes, Dinophytes, Diatoms and Cyanophytes (blue-green algae), although the latter are not true algae having features more in common with bacteria (Cyanobacteria).

Figures 19, 20 and 21 show the populations of the various Loweswater algae identified in 2011 and their patterns of seasonal variation.

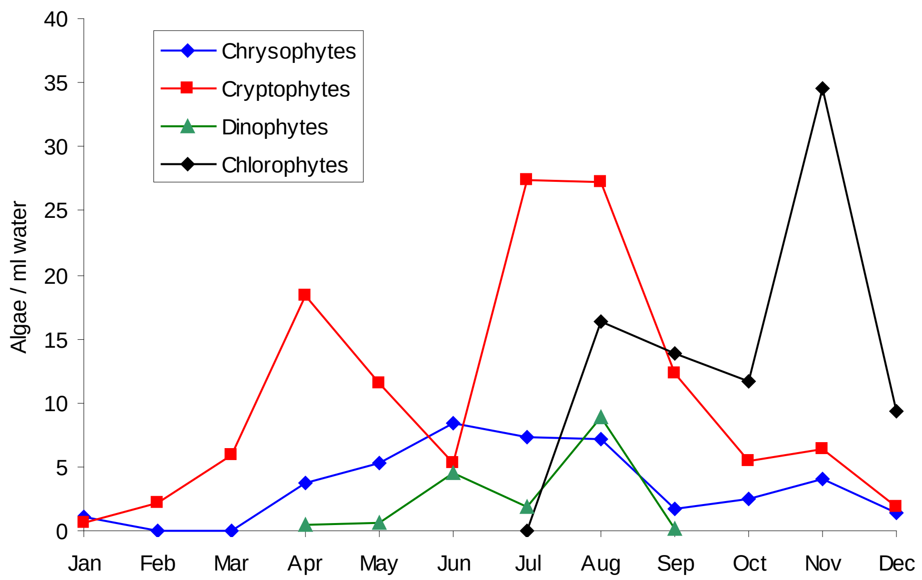

Figure 19. *Seasonal variation in Chlorophyte, Chrysophyte, Cryptophyte and Dinophyte populations observed in Loweswater – 2011.*

Cryptophytes were present all year round, with peaks in April, August and September; Dinophytes from April to September; Chrysophytes and Chlorophytes April to December and July to December, respectively.

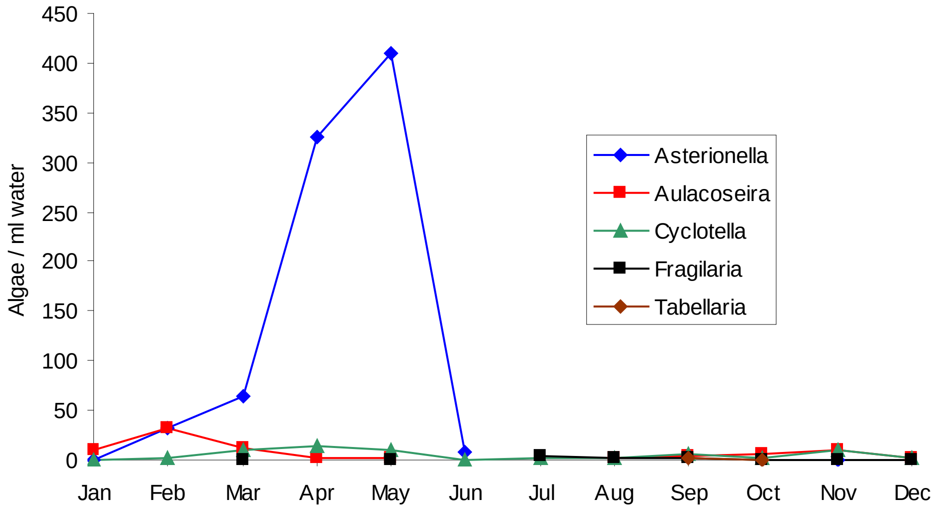

Figure 20. *Seasonal variation in diatom populations observed in Loweswater – 2011.*

Of the diatom assemblage, *Asterionella formosa* was by far the most abundant in April and May; other diatoms were present all year round, but in far fewer numbers.

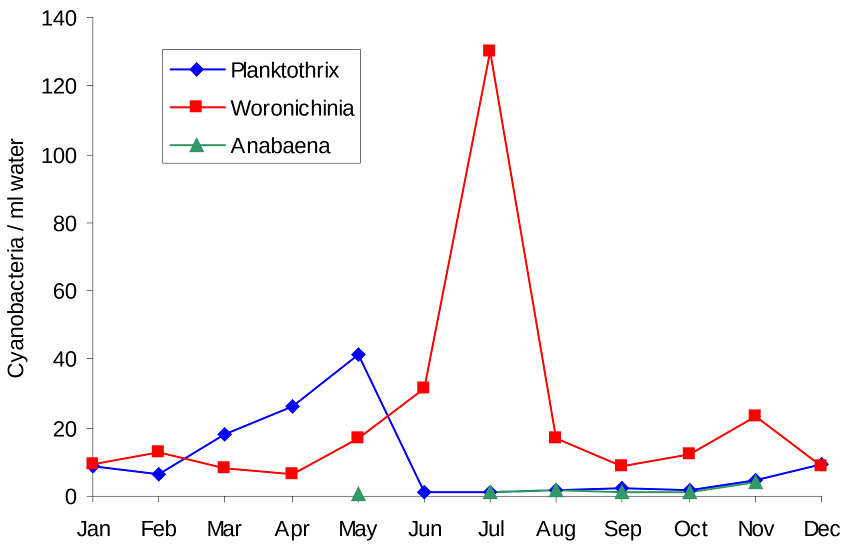

Figure 21. *Seasonal variations in cyanobacterial populations observed in Loweswater - 2011*

Two cyanobacterial species dominated the algal populations for most of the year, i.e. except in April and May, when *Asterionella formosa* was dominant. These were the filamentous *Planktothrix mougeotti*, which was most abundant in early summer and the colonial *Woronichinia naegeliana*, which was even more abundant in July and August.

CEH data available from 2007 to 2010 are plotted with the 2011 data for *Planktothrix mougeotti* and *Woronichinia naegeliana* in Figures 22 and 23, respectively. These show that all counts for *Planktothrix mougeotti* (with the exception of 2007), peaked in early summer and that the counts for 2011 were considerably lower than in 2007, 2008 and 2009, but higher than those in 2010. Counts for *Woronichinia naegeliana* tended to peak later in the year, with the exception of 2011 when the peak occurred in the summer and was much higher than in the previous four years.

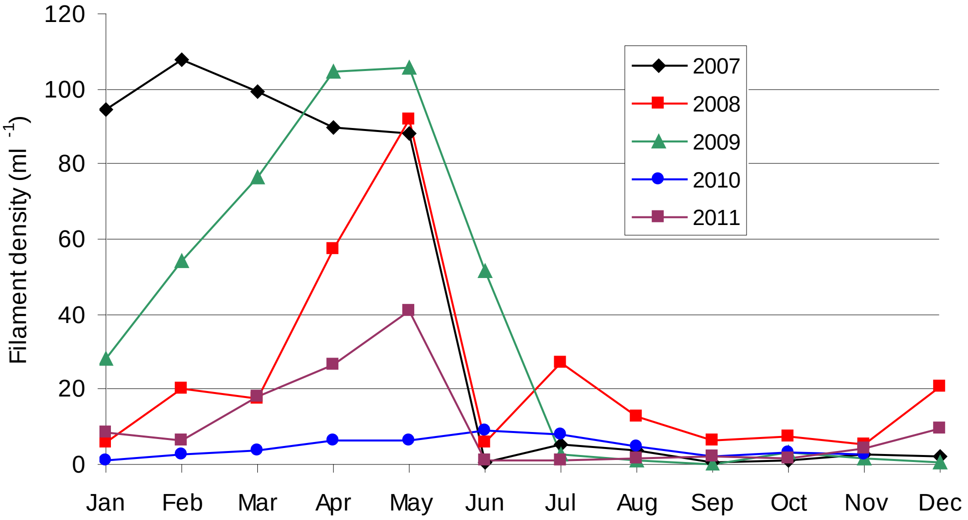

Figure 22. *Seasonal variations in Planktothrix mougeotti observed in Loweswater, 2007 to 2011.*

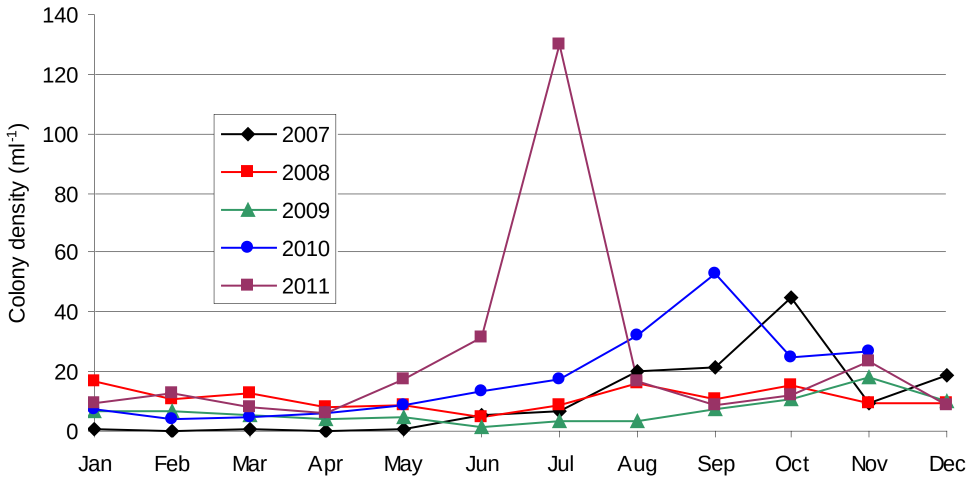

Figure 23. *Seasonal variations in Woronichinia naegeliana observed in Loweswater, 2007 to 2011.*

4. DISCUSSION

Certain correlations and patterns emerge from the results of the water quality analysis and algal counts during 2011, and these are highlighted and discussed briefly in the next paragraphs.

The **pH** varied between 7.2 and 8.6. The seasonal elevated values, commencing in May at pH 8.41, result from the photosynthesising action of algal blooms, which increase the water pH, particularly in slow moving waters (Loweswater has a long residence time of about 200 days). The highest **phytoplankton chlorophyll *a*** concentration of 13.3 µg /L was also in May, corresponding with the time of the highest **algal counts**, including mainly the diatom assemblage and the filamentous cyanobacteria. In general, there is an inverse correlation between **phytoplankton chlorophyll *a*** and **depth of Secchi disc** values and in May the **depth of Secchi disc** reading was the lowest for the year at 2.5 metres. However, **phytoplankton chlorophyll *a*** concentration is not the only factor determining water transparency; heavy rainfall has the potential to wash large amounts of suspended solids into a water body, which may also lower **depth of Secchi disc** readings. Local records show that in May 2011 Loweswater had the highest rainfall for at least 30 years at 227.8 mm (see weather records in Appendix 1, Page 30); the average May rainfall for Loweswater is 85.1 mm (Pers. Comm. Spencer, 2011).

The form of phosphorus that is readily available to phytoplankton is **soluble reactive phosphorus** (**SRP**) the concentration of which can change rapidly in response to supply and demand and therefore is considered to be less reliable as an indicator of the trophic state of a lake than **total phosphorus (TP)** and Maberly et al. (2006) suggest there is a clear correlation between **phytoplankton chlorophyll *a*** and **TP** concentrations (see Figure 24, where the patterns of the plots are compared, not the values).

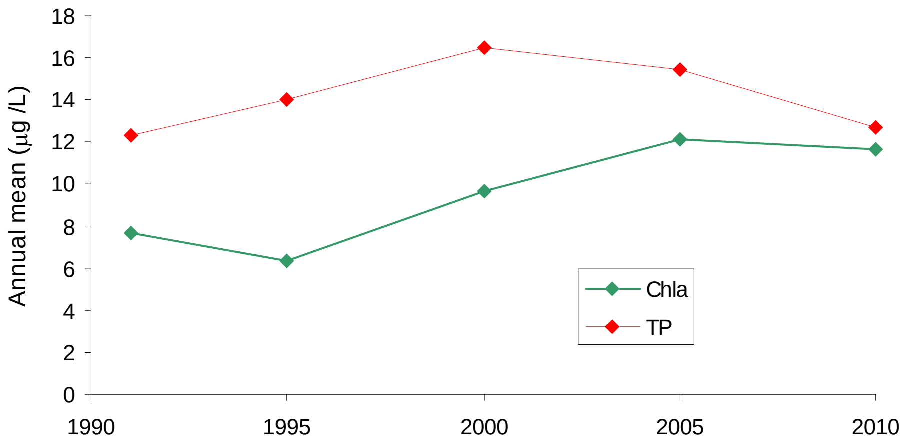

Figure 24. *Correlation of annual mean total phosphorus and phytoplankton chlorophyll a concentrations.*
(Based on data from Lakes Tours 1991 to 2010).

The summer decline in **nitrate** concentrations, Maberly et al. (2006) suggest, is caused by processes within the lake and is consistent with increased phytoplankton productivity caused by increased availability of phosphorus which, in turn, increases the demand for nitrogen. The 2011 results reflect this observation and show particularly high counts for *Woronichinia naegeliana* in July with a summer peak of 17.9 µg /L **TP,** also in July, and a decline in **nitrate** concentrations to 280 µg /L in August. Increased phytoplankton production in summer, when the lake undergoes thermal stratification, can lead to greater depletion of oxygen at depth, which leads to a reduction in the redox potential of the surface sediment resulting in trapped phosphorus (as phosphates) being released into the hypolimnion, with subsequent diffusion of dissolved phosphate into the water column (Mortimer, 1941; 1942).

Using OECD guidelines (1982), the trophic status of a water body may be classified using data on three of the variables discussed above, i.e. **TP**, **phytoplankton chlorophyll *a*** and **depth of Secchi disc**, as shown in Table 1, on the next page.

Table 1. ***Trophic categories based on five limnological variables***

Trophic category	Mean Total Phosphorus (µg / l)	Mean Choro. *a* (µg / l)	Maximum Choro. *a* (µg / l)	Mean Secchi depth (m)	Minimum Secchi depth (m)
Ultra-oligotrophic	< 4	< 1	< 2.5	> 12	> 6
Oligotrophic	4 - 10	1 - 2.5	2.5 - 8	12 - 6	6 - 3
Mesotrophic	10 - 35	2.5 - 8	8 - 25	6 - 3	3 - 1.5
Eutrophic	35 - 100	8 - 25	25 - 75	3 - 1.5	1.5 - 0.7
Hypertrophic	> 100	> 25	> 75	< 1.5	< 0.7

Using the Lakes Tours data from 1991 to 2010 and the most recent data from Environment Agency, Table 2 shows the changing trophic status of Loweswater over the last twenty years.

Table 2. ***Assessment of the trophic state of Loweswater from 1991 to 2011 using five variables.***

		Mean Total Phosphorus (µg / l)	Mean Chloro. *a* (µg / l)	Maximum Chloro. *a* (µg / l)	Mean Secchi depth (m)	Minimum Secchi depth (m)
Lake's Tour	**1991**	**12.35**	**7.65**	**9.84**	**3.48**	**3**
Lakes Tour	**1995**	**14.06**	**6.39**	**15.28**	**5**	**3.5**
Lakes Tour	**2000**	**16.46**	**9.62**	**21.69**	**2.94**	**1.65**
Lakes Tour	**2005**	**15.4**	**12.09**	**20.58**	**2.75**	**2**
Lakes Tour	**2010**	**14.75***	**11.7***	**19.2**	**2.8***	**1.9**
Environment Agency	**2011**	**12.44**	**6.17**	**13.3**	**3.44**	**2.5**

Oligotrophic Mesotrophic Eutrophic

In 1991 and 1995 the overall classification for the lake would have been mesotrophic (oligotrophic for minimum Secchi depth), but from 2000 to 2010 the data show a decline to mesotrophic / eutrophic. The 2011 figures, however, indicate an improvement and the lake's trophic state based on these data is mesotrophic. The 'Lakes Tour' data are derived from quarterly measurements (January, April, July and October), the most recent of which were published by Maberly et al. (2011) when they classified the lake as '*close to the mesotrophic / eutrophic boundary*. However, measurements taken in 2010 on a monthly basis through the Loweswater Care Project give slightly better results for mean **TP**, **phytoplankton chlorophyll *a*** and **depth of Secchi disc** (marked * in Table 2) at 12.75 μg / l, 11.01 μg / l and 3.15 metres, respectively. Although these figures don't alter the overall classification for 2010, they nonetheless give further indication of improvement similar to those for 2011.

Of particular interest from a legal standpoint is the status of the lake in terms of the EU Water Framework Directive (WFD). Water quality standards under the WFD are established in The River Basin Districts Typology, Standards and Groundwater threshold values (Water Framework Directive) (England and Wales) Directions 2010. The way that the WFD classifies water bodies is summarised in Appendix 2 (Page 32). The two WFD parameters of particular interest for the quality of Loweswater are total phosphorus and phytoplankton chlorophyll *a*. The quality levels that define status are not given in absolute terms, but are calculated from formulae given in the 2010 Directions; this calculation involves the mean depth of the lake (Loweswater is classified as shallow), its altitude and its alkalinity (Loweswater is low). The calculated boundary levels for TP and phytoplankton chlorophyll *a* for Loweswater are given in Table 3, on the next page.

Table 3. ***WFD boundary levels for total phosphorus and phytoplankton chlorophyll α for Loweswater***

WFD Status	**High**	**Good**	**Moderate**	**Poor**	**Bad**
Parameter (µg/L)					
Total phosphorus	<8.06	8.06 - 12.22	12.22 - 24.45	24.45 - 48.9	>48.9
Phytoplankton chloro. *a*	<4.5	4.5 - 7.7	7.7 - 15.5	15.5 - 46.9	>46.9

Note: *The TP level is the annual arithmetic mean, whereas the phytoplankton chlorophyll* a *level is the annual geometric mean (as required by WFD), both usually judged over 12 samples.*

The mean levels for Loweswater in 2011 were 12.44 µg/L for TP and 5.5 µg/L for phytoplankton chlorophyll *a* (lower than the level given in Table 2 as that value is the arithmetic mean). On the basis of phytoplankton chlorophyll *a*, the lake quality is thus ‘good’, but is just marginally within the ‘moderate’ quality range for TP; both these classifications agree with the 2011 Environment Agency’s assessment.

5. CONCLUSIONS

- The results of the water quality monitoring programme of Loweswater for 2011 indicate an improvement in the trophic status of the lake, when compared to the historical data, i.e. using the OECD guidelines the lake now classifies as mesotrophic, where for many years previously it was on the mesotrophic / eutrophic boundary. The lake is also close to being classified as of good ecological status under the EU Water Framework Directive.

  This improvement possibly reflects the initiatives taken by the local farmers, who in 2002 in response to the wider concerns about the effects of farming practices on the environment, and in particular on the water quality of the lake, explored ways of reducing pollution sources from their holdings.

- These results (together with summaries of historical data) provide a valuable base-line record against which the results of future improvement work may be measured.

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APPENDIX 1.

RAINFALL AND MEAN TEMPERATURE FIGURES

FOR LOWESWATER, 2011

APPENDIX 1.

RAINFALL AND MEAN TEMPERATURE FIGURES FOR LOWESWATER, 2011

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Rainfall (mm)	114.1	191.3	72.7	81.7	227.8	70.1	121.0	137.1	193.5	169.0	154.4	255.2
Temperature Mean max	4.67	7.33	8.68	14.31	14.34	16.53	19.27	17.07	15.10	13.40	11.47	6.32
Mean min	0.79	3.60	1.92	7.24	7.64	9.40	10.28	10.72	10.34	8.66	6.81	2.20
Mean day/night	2.73	5.47	5.30	10.78	10.99	12.97	14.78	13.90	12.72	11.03	9.14	4.26

APPENDIX 2.

WEST CUMBRIA RIVERS TRUST:
LOWESWATER CARE PROGRAMME

INFORMATION NOTE – WATER FRAMEWORK DIRECTIVE

AUTHOR: LESLIE WEBB

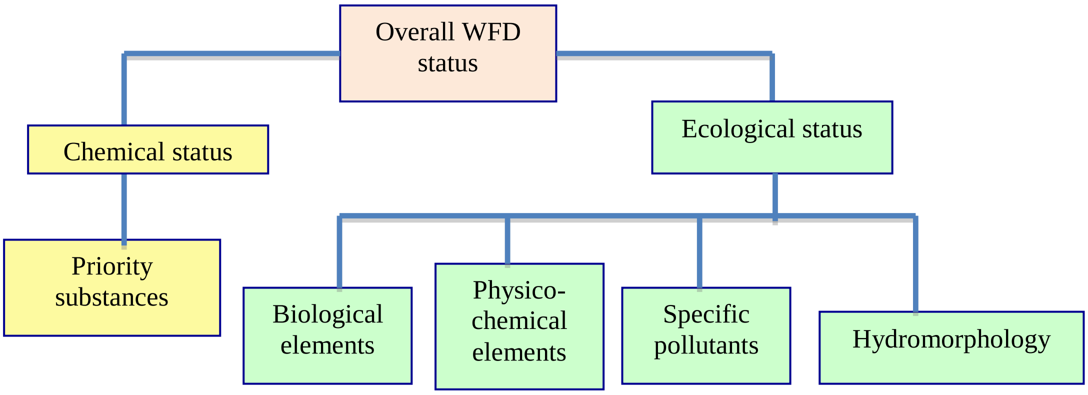
APPENDIX 2.

INFORMATION NOTE – WATER FRAMEWORK DIRECTIVE

The purpose of this note is not to summarise the whole of the Water Framework Directive (WFD), but to clarify its implications for the water quality of surface waters, notably of lakes like Loweswater.

The aim of the WFD for surface waters (and groundwaters) is to achieve "good surface (or ground) water status" by a specified date, normally by the end of 2015. The status of Loweswater was defined in the 2009 EA Report "River Basin Management Plan North West River Basin District - Annex B: Water body status objectives". Because of the scale of the improvements required for Loweswater to achieve good surface water status, the deadline to achieve this has been extended to 2027.

Figure 1 - WFD scheme for classifying water bodies



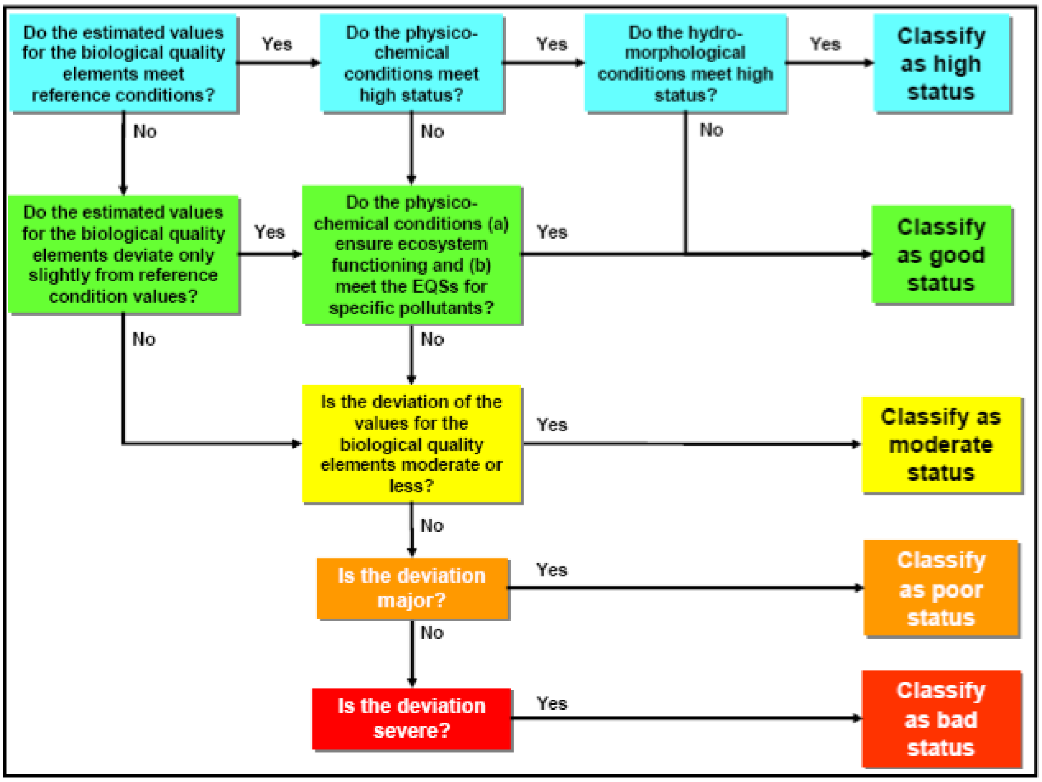
As shown above, achieving good surface water status has 2 components – achieving good chemical status and achieving good ecological status. Chemical status focuses exclusively on "priority substances", the latest list of which was published in 2008. In order to achieve good chemical status, the surface water concentration of all 33 listed priority substances must be below the defined Environmental Quality Standard (EQS) quantified as both an annual average (AA-EQS) and a maximum allowable concentration (MAC-EQS). If the concentration of any parameter exceeds the AA-EQS or MAC-EQS, the water is classified as failing to achieve good chemical status. Most of the priority substances are organic pesticides plus others such as cadmium, lead, mercury and nickel compounds. There is currently an EU proposal to extend this list with a further 15 priority substances plus tightening of standards for 4 existing substances. The chemical status of Loweswater was not assessed as there is no requirement to do this where priority substances are known not to be discharged in significant quantities to that water body.

So, the overall status of Loweswater depends solely on its ecological status. Under the WFD, the ecological status of water bodies is classified into one of five categories (high, good, moderate, poor and bad) using detailed criteria developed by the UK Technical Advisory Group (UKTAG). The overall methodology for classifying water bodies into these 5 categories is shown in Figure 2 overleaf. Reference conditions are those of undisturbed water bodies with little or no anthropological stress.

Achieving good ecological status is a much broader measure of water quality than chemical status and involves an assessment across the four elements in Figure 1:

- The lake's biological status covering phytoplankton; macrophytes and phytobenthos; benthic invertebrate fauna; and fish plus the presence of invasive species.
- Physico-chemical aspects such as pH, dissolved oxygen, nutrient levels, etc.
- Levels of specific pollutants such as metal compounds.
- In the case of high status only, hydromorphological quality elements such as depth, width, flow, structure.

Figure 2. Decision tree illustrating the criteria for determining the different ecological status classes (from EA Monitoring Strategy Briefing Note "Method statement for the classification of surface water bodies" v3, January 2013)



The lowest status for any element determines the overall ecological status. The original WFD assessment (published in 2009) is summarised in Table 1, the conclusion being that Loweswater was of moderate ecological status (despite the "bad" classification for DO, as non-biological elements can only affect classification down to the moderate level). The only predicted change by 2015 was copper being re-classified as good. The justification for not achieving good ecological status by 2015 was based on it being technically infeasible to achieve the required standards for macrophytes, phytoplankton and DO. The EA's latest re-assessment for 2012 shows deteriorations from good to moderate for total P and from high to good for ammonia and an improvement from moderate to good for phytoplankton and from good to high for littoral invertebrates..

From a eutrophication standpoint, the most relevant ecological parameters are the phytoplankton within the biological elements and the total phosphorous concentration within the physico-chemical elements. The phytoplankton comprises two specific parameters – the annual (geometric) mean chlorophyll concentration and the % by volume of cyanobacteria (compared to all phytoplankton measured from July-September). The worse of the two phytoplankton elements determines the phytoplankton classification.

Table 1. Summary of 2009 ecological classification of Loweswater

High status	Good status	Moderate status	Poor status	Bad status
Littoral invertebrates Acid neutralizing capacity Ammonia Zinc	Phytobenthos Total P	Macrophytes Phytoplankton Copper	None	Dissolved oxygen

Note that information on the standards for all types of water body are in The River Basin Districts Typology, Standards and Groundwater threshold values (Water Framework Directive) (England and Wales) Directions 2010.