ENVIRONMENT AGENCY

BLUE-GREEN ALGAL MONITORING 1995-1997

NATIONAL CENTRE
ECOTOXICOLOGY & HAZARDOUS SUBSTANCES

NUTRIENTS SECTION

September, 1998

CONTENTS

1. INTRODUCTION

Blue-green algae have annually been an issue for the Environment Agency and previously the National Rivers Authority (NRA), since the problems experienced at Rutland Water Reservoir, Leicestershire, and other sites during 1989. The deaths of sheep and dogs at Rutland Water were attributed to the animals drinking from the blue-green algal (cyanobacterial) scum around the water's edge and/or licking algal material from their coats after immersion. Samples of the scum were found to be hepatotoxic by mouse bioassay. The deaths of mammals, birds, amphibians and fish have been reported world-wide and attributed to cyanobacterial toxins. Moreover, the first cyanobacterial-poisoning documented event dates back to 1898 from Australia (Francis, 1898).

The hospitalisation of young soldiers who took part in canoe exercises (360^0 rolls) at Rudyard Lake, Staffordshire was also attributed to cyanobacterial poisoning during 1989, although there have been no deaths in humans which can be directly attributed to toxins produced by cyanobacteria in Europe. There have been many documented reports, however, of human illness associated with the presence of cyanobacteria (NRA, 1990a). These include skin irritation, gastrointestinal upsets, and hepatoenteritis. The potential toxic threat of cyanobacteria and their aesthetic impact has wide implications for the Agency's roles, responsibilities and activities.

There is now a greater awareness of the issue, and cyanobacterial-related problems are becoming accepted for what they are - a natural phenomena which has the potential to re-occur each year under suitable meteorological conditions in nutrient-enriched (eutrophic and mesotrophic), temperate waterbodies. There are, however, many different interactions between the biota, and between the biota and the biological/chemical/physical external/internal factors, with the nutrient regime one of the range of selective factors.

1.1 Action by the Environment Agency

A Toxic Algae Task Group (TATG) was established in 1989 under the NRA, to assess the incidence of potentially toxic freshwater algae, and later marine algae, and to make recommendations for future monitoring and control measures. Routine monitoring programmes of 1989 and 1990 effectively identified high priority waterbodies that were most likely to develop cyanobacterial problems in later years (NRA, 1990b; NRA, 1991).

In 1991, a reactive sampling strategy was adopted, in response to all external enquiries, which involved sampling waterbodies that did not contain abundant populations of cyanobacteria during the earlier routine monitoring. The reactive sampling programme reduced the repetitiveness of the previous extensive routine monitoring programme, and allowed resources to be diverted into developing methods and recommendations for resolving cyanobacterial problems in the future. The reactive monitoring programme has continued to date as it was expected that cyanobacterial problems were likely to re-occur annually (NRA, 1990a). In addition, waterbodies that were reactively sampled in previous years were re-sampled in response to increased public enquiries and specific Regional/area initiatives.

A National Centre for Toxic and Persistent Substances (TAPS) was established in Anglian Region during 1994, and co-ordinated and supported the NRA's work on toxic and persistent substances in the aquatic environment, which included eutrophication and potentially toxic algae. In 1996, the Environment Agency was created with the merger of the NRA, Her

Majesty's Inspectorate of Pollution and Waste Regulatory Authorities. Subsequently in October 1997, TAPS was subsumed into the Ecotoxicology and Hazardous Substances National Centre (EHS). The Nutrients Section of EHS now provides a focal point for the Agency on all aspects of eutrophication, its causes, problems, symptoms and remedies, including toxic and nuisance algal issues.

In the wider context, a National Eutrophication Control Strategy is being developed since the complexities of eutrophication, and cyanobacteria in particular, should not be underestimated. Visible benefits will not be achieved overnight as there is likely to be a considerable lag between the onset of controls and the observable benefits in the waterbody. In the interim, the acute problems of cyanobacteria must be managed through monitoring, and informing water users of the risks, and how to minimise them.

1.2 Purpose of this report

TAPS has routinely collated information regarding cyanobacterial monitoring and management of incidents from the Regions since 1990, and data have been summarised into annual reports (NRA, 1990b, 1991, 1992, 1993, 1994, 1995). This duty has been taken over by EHS, Nutrients Section.

Information from the monitoring programmes is collated by Regional Algal Contacts located in each of the eight Regions of the Agency, and sent to EHS for reporting *via* a completed annual questionnaire. Details of the monitoring programmes are available in the 'Monitoring and Management of Blue-green Algal Incidents Policy', available from the Algal Scientist, EHS and National Algal Contacts.

This report describes the work that has been carried out by the Agency on monitoring and management of cyanobacterial incidents between 1995-1997, and relates it to past years.

2. CYANOBACTERIAL MONITORING

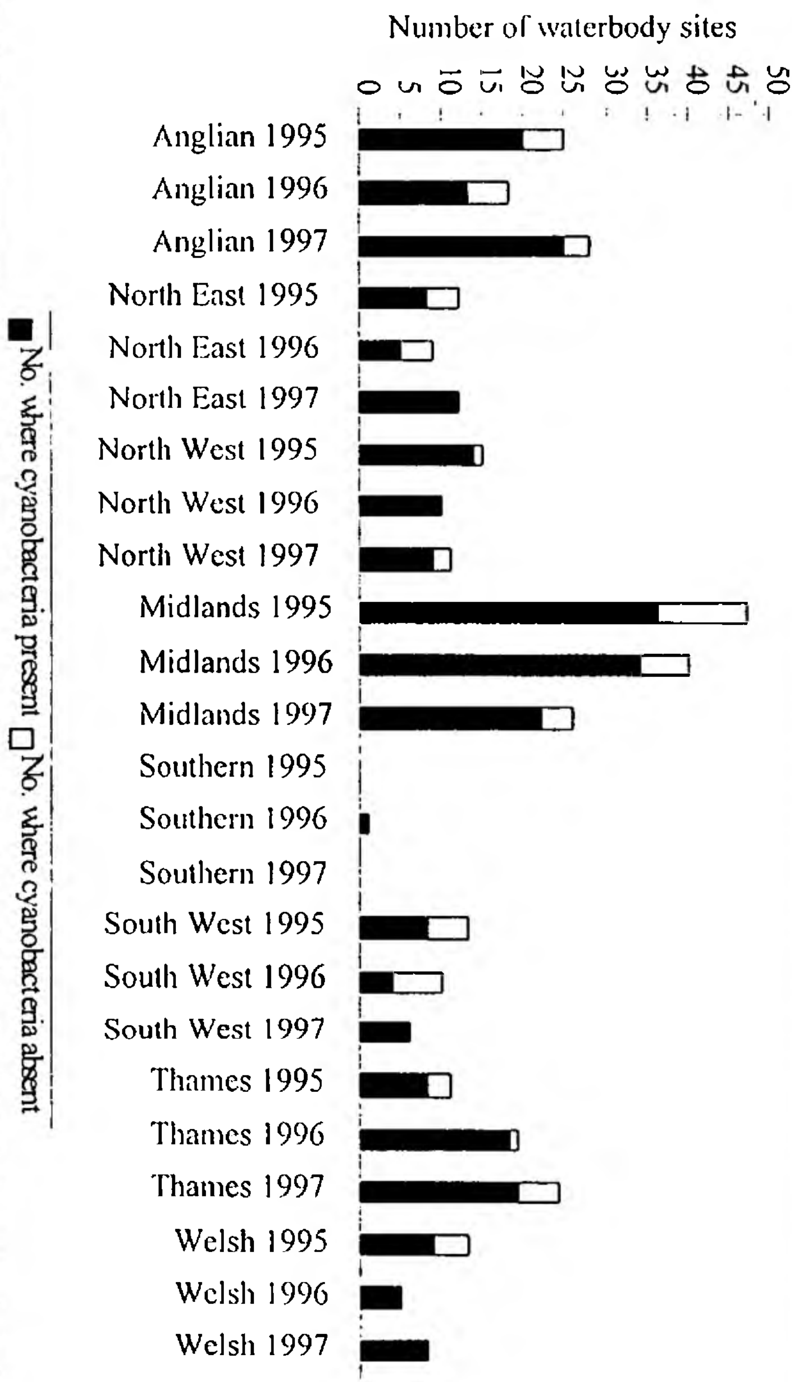
2.1 Waterbodies sampled reactively for the first time

The Regional fluctuations in the total number of waterbodies sampled reactively between 1995-1997 are shown in Figure 1. Waterbodies were sampled at the request of owners, water users and the general public, as part of the reactive monitoring programme. The total number of waterbodies are divided into those which contained cyanobacteria as the dominant group and those where cyanobacteria were absent.

Generally throughout the period, the highest numbers of waterbodies sampled reactively for the first time were evident in Anglian, Midlands, South West and Thames, whereas the lowest frequency was evident in Southern and North East. The number of sites sampled was generally highest during 1995 which was a warm year with reduced river flows, and as a result, severe algal blooms developed in running waters.

2.2 Waterbodies sampled reactively in the past which were subsequently re-sampled

The Regional fluctuations in the total of waterbodies sampled reactively in the past that were subsequently re-sampled are shown in Figure 2. This criterion indicates waterbodies that were re-sampled as part of good public relations, or as part of specific Regional/area



Number of waterbody sites
0 5 10 15 20 25 30 35 40 45 50
Anglian 1995
Anglian 1996
Anglian 1997
North East 1995
North East 1996
North East 1997
North West 1995
North West 1996
North West 1997
Midlands 1995
Midlands 1996
Midlands 1997
Southern 1995
Southern 1996
Southern 1997
South West 1995
South West 1996
South West 1997
Thames 1995
Thames 1996
Thames 1997
Welsh 1995
Welsh 1996
Welsh 1997
No. where cyanobacteria present
No. where cyanobacteria absent

Figure 1. Regional fluctuations in the total number of waterbody sites sampled reactively for the first time between 1995-1997.

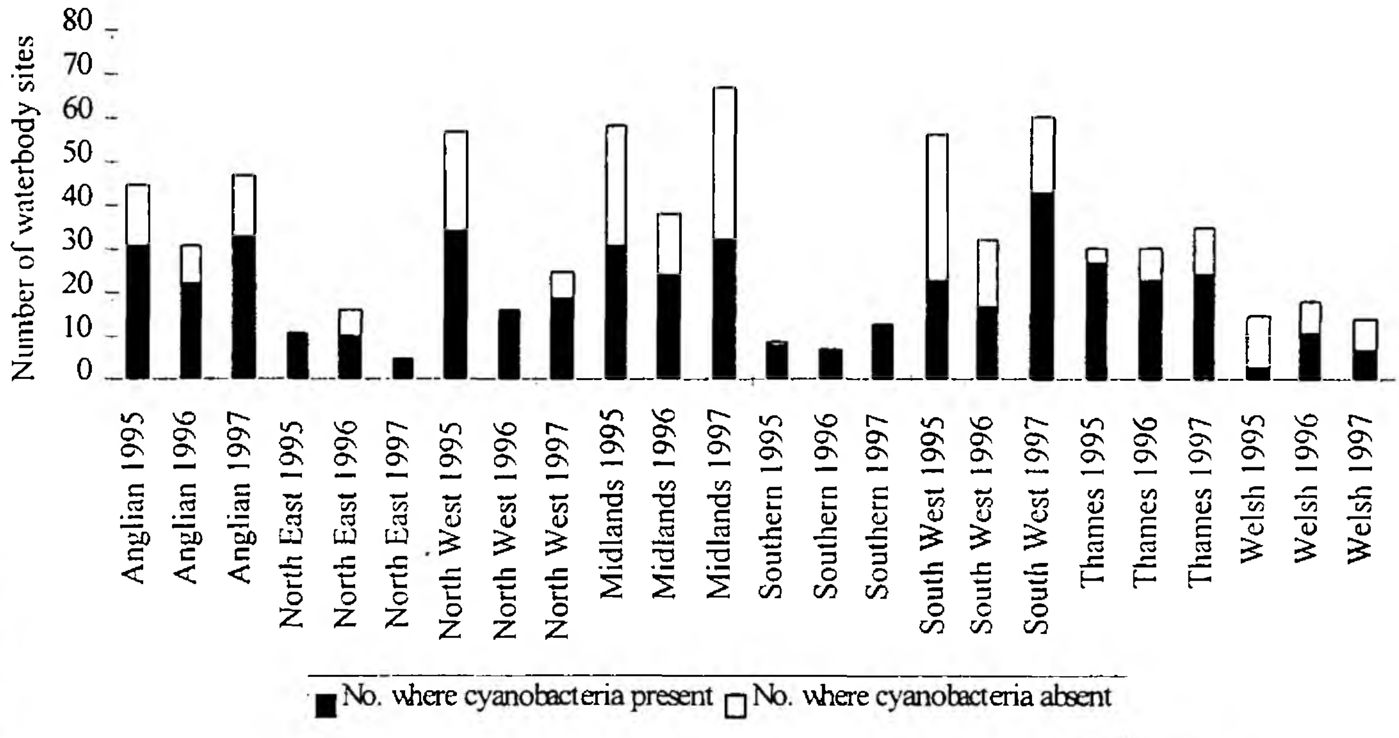


Figure 2. Regional fluctuations in the total number of waterbody sites sampled in the past that were subsequently re-sampled between 1995-1997.

incidents/initiatives. Similarly, the total number of waterbodies are divided into those which contained cyanobacteria as the dominant group and those where cyanobacteria were absent.

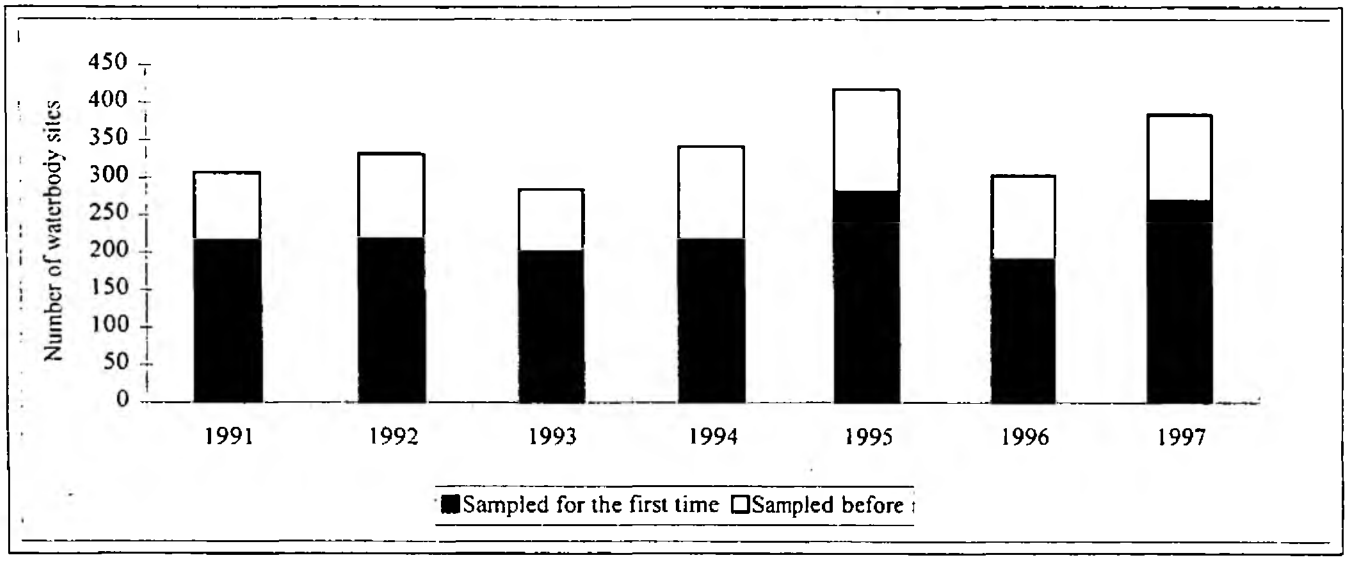
Anglian, Midlands and Thames Regions indicated the highest frequency of waterbody sites that were re-sampled, whereas Southern Region indicated the lowest frequency (in 1995 and 1997 zero waterbodies were re-sampled).

A complete list of the waterbodies sampled Regionally and their details are available from EHS on request.

2.3 Annual fluctuations

The total number of waterbodies sampled annually in all Regions between 1991-1997 is shown in Figure 3, divided into waterbodies sampled reactively for the first time and those that have been sampled reactively and re-sampled.

Figure 3. Total number of waterbody sites sampled by the Environment Agency between 1991-1997.



Reactive monitoring is a selective procedure and only sites affected with algal blooms and scums are analysed. Sites are rarely investigated which do not have algal bloom/scum present, therefore, analysis and interpretation of trends is difficult.

No distinct annual trend is evident between 1991-1997 and approximately 300-400 waterbodies are sampled annually by the Agency, although the total number of waterbodies sampled was highest in 1995 (417). This was because in 1995, severe algal problems occurred in running waters as mentioned earlier. The frequency of waterbodies sampled is related to a number of factors, but mainly the number of external enquiries received and the number of waterbody sites with algal blooms and scums. Biological, chemical, physical and meteorological factors must also not be discounted.

Nutrients are one of the range of factors and influence algal growth in standing waterbodies on a site-specific basis. Nitrogen inputs and therefore concentrations in watercourses indicate no distinct trend in the UK between 1990-1995, although there is evidence of a decline in the phosphorus inputs from point sources and hence phosphorus concentrations in watercourses between 1990-1995 (Environment Agency, 1998). Phosphorus export from diffuse sources, however, is increasing (Foy et al., 1995) and concentrations for both phosphorus and nitrogen in watercourses have remained high in the UK and fluctuate depending on dilution (Kinniburgh et al., 1997).

Moreover, although cyanobacterial problems may be becoming more common due to climate change (global warming, with milder winters and drier summers), they may also not be reported as frequently. The reasons for this may be that the public are aware of cyanobacteria and their risks, and are therefore not reporting new sites affected by algal blooms and scums. Anglian and Southern reported that many of the waters that were previously sampled for cyanobacteria might not have been reported again this year, so the number of recurrent incidents may be an underestimation. This may be for commercial/financial reasons, since, when cyanobacteria are reported above the warning threshold (see section 4), it is the owners' responsibility to take the necessary precautions that may include temporary closure of the waterbody.

The percentage, and indeed number of waterbodies sampled reactively for the first time which contained cyanobacteria was highest during the initial surveys of 1991, but as a percentage of the total number of waterbodies sampled no distinct annual trend is evident, and levels have fluctuated between 60-68% (Table 1). The dominant cyanobacteria were *Oscillatoria*, *Aphanizomenon* and *Microcystis* spp., whereas the major groups other than cyanobacteria reported as causing nuisance and aesthetic problems were diatoms (centric and pennate), cryptophytes, unicellular green and filamentous green algae.

Table 1. Summary of the incidence of the number of waterbodies containing cyanobacteria. Values in parentheses indicate percentage of the total number sampled.

Year	No. of waterbodies containing cyanobacteria sampled reactively for the first time	No. of waterbodies containing cyanobacteria sampled in past years and re-sampled during the year	No. where warning threshold was exceeded	No. where bloom and/or scum was present
1991	181 (84%)	88 (98%)	223 (83%)	182 (68%)
1992	149 (68%)	99 (88%)	197 (79%)	184 (74%)
1993	123 (61%)	72 (87%)	168 (86%)	154 (79%)
1994	141 (65%)	104 (84%)	207 (84%)	188 (77%)
1995	168 (60%)	103 (76%)	215 (79%)	205 (76%)
1996	130 (68%)	90 (80%)	155 (70%)	182 (83%)
1997	157 (65%)	92 (88%)	217 (87%)	199 (80%)

Although the number of waterbodies sampled reactively which contained cyanobacteria in the past and which were subsequently re-sampled was lower, expressed as a percentage of the total number sampled, however, the figure was higher. This indicates that once cyanobacteria develop in a waterbody they are likely to reoccur.

Moreover, out of the total waterbodies sampled which annually contain cyanobacteria, results indicate that approximately three-quarters will exceed the warning threshold and over two-thirds will have blooms and/or scums present.

Other than the dominant cyanobacteria, the Regions also recorded interesting taxa. *Hydrodictyon* sp., forming dense surface mats was detected in South West (1995), Wales and

Midlands (1997). *Prorocentrum* sp. (1995), *Woloszynskia coronata* and *Anabaenopsis* sp. (1996) were detected in Anglian (and sulphur bacteria were detected in South West (1995)).

2.4 Waterbodies sampled routinely

Routine monitoring was carried out at a specified number of sites (standing waterbodies and rivers) which required sampling in response to particular Regional and area incidents. The distinction between routine monitoring and operational investigations is that routine monitoring was carried out specifically for cyanobacteria, whereas operational investigations were carried out for other purposes with algal samples obtained at the same time. A complete list of waterbodies sampled routinely between 1991-1997 is available from EHS on request, and summarised in Table 2 below.

Table 2. Summary of waterbodies sampled routinely between 1991-1997.

Year	No. of waterbodies sampled	No. which contained cyanobacteria	No. where warning threshold exceeded	No. where bloom/scum was present
1991	124	93	64	39
1992	49	23	13	11
1993	43	29	27	24
1994	51	36	22 (+15 unknown sites)	20 (+15 unknown sites)
1995	14	11	9	9
1996	13	10	7	9
1997	10	10	7	9

In 1995, 14 waterbodies were routinely sampled throughout the Regions, including those as part of the National Lakes Classification project. In 1996, 13 waterbodies were sampled throughout the Regions, and included Farmoor Reservoir in Thames; Tamar Lake, Loe pool, R. Tamar, Bristol floating harbour and R. Sowy in South West; and Colemere, the Mere and Whitemere in Midlands. No routine monitoring took place in Anglian during 1996, whereas Southern routinely monitored Baffins Pond.

In 1997, Colemere, the Mere and Whitemere were again routinely sampled in Midlands, and South West routinely sampled Chilton Trinity Lake. Thames carried out routine monitoring at Bray Lake. The number of waterbodies sampled routinely has declined annually (Table 2); possible due to resource limitation in areas/Regions with more operational investigations carried out Regionally.

In the period 1991-1997, the percentage of waterbodies sampled routinely that contained cyanobacteria was high, between 67-100%, with the exception in 1992. The warning threshold was exceeded in over 60% of sites sampled routinely, and a high proportion of sites contained a bloom/scum (between 40-90%). These results support data from the reactive monitoring programmes where more than three-quarters of the sites sampled contained cyanobacteria, and which were above the threshold level and which had blooms and/or scums present.

2.5 Waterbodies sampled as part of on-going investigations

As distinctions between routine monitoring and operational investigations were not discrete, a degree of overlap existed. Table 3 below lists the total number of waterbodies sampled as part of operational investigations between 1991-1997. Results also indicate a similarly high percentage of sites sampled which contained cyanobacteria (generally cyanobacteria were present in two-thirds of the sites sampled), and a similarly high percentage exceeded the warning thresholds and contained a bloom/scum.

Table 3. Summary of the number of waterbodies sampled as part of on-going investigations between 1991 to 1997

Year	No. of waterbodies sampled	No. which contained cyanobacteria	No. where warning threshold exceeded	No. where bloom/scum was present
1991	13	8	7	5
1992	20	20	18	12
1993	37	32	9 (+24 unknown sites)	16
1994	19	14	9	11
1995	30	24	13	7
1996	26	16	5	11
1997	23	17	12	12

Anglian

Rutland Water, Covenham and Pitsford Reservoirs have been sampled as part of on-going investigations, monitoring the benthic invertebrates, plankton, chemical, biological and physical parameters in response to ferric sulphate dosing, and in response to their recovery following the cessation of dosing. In 1997, these three Reservoirs were reported as being sampled routinely (Rutland Water weekly, Covenham and Pitsford Reservoirs fortnightly). Whisby Nature Reserve and the Norfolk Broads are current on-going investigations.

Midlands

Crosmere and Bittel Reservoirs were on-going investigations in 1996, but only Bittel has been retained during 1997 and monitored as part of the Action Plan.

North East

In 1995, Pugneys Nature Reserve and main Lakes were sampled, but no waterbodies were sampled as part of on-going investigations in subsequent years.

North West

Stockport Environmental Health sampled Compstall Lodge at Etherow Country Park, Stockport, at the request of Stockport Borough Council and the Region agreed to analyse the algal samples as an on-going investigation. This was run in parallel with a Ph. D. research project, supervised by APEM consultants. It was reported that no blooms occurred in 1995 probably related to the reduced retention time in the Lake. Interestingly, the original NRA advice suggested reduced retention times as a means of reducing the algal problem but the Council disregarded this in 1994. In 1997, Oakmere, Betley Mere, and Marbury Big Mere were sampled three times.

Southern

Monitoring was set up at Weir Wood Reservoir specifically for the long-term monitoring programme and samples were very occasionally taken previous to 1996. In 1997 Baffins Pond was monitored as part of an on-going investigation.

South West

In 1995 only Bridgewater Docks were monitored, no sites were monitored in 1996, whereas in 1997, R. Stour, Coy Poole Lake and the Kennet & Avon Canal were sampled.

Thames

In 1996, Bray, Silverwings and Wraysbury lakes, and Horton Brook were sampled throughout 1996. The same waterbodies were sampled in 1997, apart from Bray Lake that was monitored routinely. Ongoing investigations concentrated on the freshwater R. Thames (six sites between Inglesham and Isleworth), Farmoor Reservoir and Colne Brook.

Welsh

In 1995, five lakes were sampled as part of the Anglesey Wetlands Strategy and included Llyn Coron, Penrhyn, Traffwll, Llywenan and Llygeirian. In 1996, Llyn Penrhyn, Coron, Traffwll, Llygeirian and Llywenan continued to be sampled, in addition to Rhos-ddu, as part of the Anglesey Wetlands Strategy. In 1997, the same waterbodies were again re-sampled, as in previous years, in addition to Treflesg, Llysyfran Reservoir and Syfynwy. Llyn Padarn was sampled between 1995-1997 in an investigation of trophic state change, and Llyn Tegid was sampled between 1996-1997 in response to cyanobacterial problems.

2.6 Long-term monitoring

Currently, each Region samples an unmanaged site (defined as a site with no nutrient reduction or destratification measures) where cyanobacterial blooms have previously been recorded, in order to provide 'a minimal national picture of geographical and temporal change' in terms of cyanobacterial populations. Generally, two sites were selected at each site (a fixed site e.g. jetty, fixed site from the bank, and one from the lee shore), however, when the wind is blowing in the appropriate direction only one site is effectively sampled. Water samples are routinely taken, analysed for the deteminands and phytoplankton, and if and when present, cyanobacterial blooms and scums are taken and sent to Dundee University for toxicity evaluation and analysis.

Data is routinely collected by Regional/area ecologists, and certain Regions have collated the data and produced their own annual reports. Data and reports are sent to EHS for collation and reporting.

Anglian

Filby Broad has been designated as the site for long term monitoring. The broad has been monitored (phytoplankton and water chemistry) for the past 5 years as part of the Broads project, and since 1995 specifically for cyanobacteria (sampled fortnightly from around March to October and then every 4 weeks for the rest of the year).

Midlands

Bittell Reservoirs (Upper, Lower and Millshrub) have been sampled as of February 1995, and an Action Plan has been produced.

North East

Greenlea Lough has been sampled from 1995 onwards, initially as part of the Lake Classification project.

North West

The long-term monitoring site is Pennington Flash.

Southern

Weir Wood Reservoir is sampled, and the 1996-1997 survey data has been produced and sent to EHS.

South West

The long-term monitoring site is Chilton Trinity Lake, and a 1996-1997 report has been produced.

Thames

Farmoor Reservoir I is the long-term site, monitored from 1995.

Welsh

Llyn Coron became the long-term monitoring site in 1996.

2.7 Visual inspections

Although most Regions carried out visual inspections as a matter of procedure during all biological sampling programmes, certain functions that carry out general sampling do not. The degree of inspection varied Regionally, and not all the sites were inspected by algologists/ecologists and most did not keep a record of visual inspections.

2.8 Counting methodology

In 1991, the enumeration technique was improved by the introduction of the 'warning threshold' as outlined in the 'Blue-green Algae Monitoring and Management of Incidents Policy', following the Standing Committee of Analysts methodology. All Regions, excluding Southern, reported that the warning threshold procedure was used for enumeration and reporting. In Southern, all samples received contained either a scum or a bloom, and therefore the warning threshold procedure was inappropriate since the samples were assumed to exceed the warning threshold. Moreover, most Regions also reported that when cyanobacterial scums were evident, no count was made, and the sample was only identified to species.

2.9 The extent of blooms and scums compared to previous years

Generally, a period between February/March to October/November was indicated of greatest algal incidents each year, although the majority of problems are localised, and therefore it is difficult to assess their extent and frequency nationally. In some waterbodies for example, blooms were recorded as early as March and during December. Cyanobacterial blooms may also be recorded more frequently if the waterbody is sampled with increased regularity. Moreover, estimates as to whether algal blooms were more frequent in comparison to past years would probably not be an accurate reflection of the overall number of sites affected by cyanobacteria, since a reduced public concern would have lowered the number of incidence reported. In addition, where reports of cyanobacterial blooms were received from sites that were known from past years to contain cyanobacteria, samples were not always taken.

In contrast, the long-term monitoring carried out in the Norfolk Broads showed an overall reduction in the number of waterbodies containing cyanobacteria during 1995, in comparison to previous years. It is however difficult to monitor the frequency of blooms and scums even when routine monitoring is being carried out. The reasons for this could be due to varying meteorological conditions. Generally, very warm and calm weather conditions are conducive to phytoplankton, cyanobacteria in particular, whereas strong winds and unsettled weather break up the blooms and scums.

2.10 Blooms in running waters

In 1995, Welsh, South West, Thames and Anglian reported extensive and prolonged riverine algal blooms for the first time. These generally originated from standing waterbody sources and were exacerbated by ideal conditions for phytoplankton, and cyanobacterial growth in particular; in rivers and canals - hot, dry summer, poor dilution and increased retention times. Similar problems were evident during 1996 and 1997.

Anglian

Throughout 1995, significant quantities of *Anabaena* sp. were recorded in the R. Waveny downstream of a trout Lake at Otter Trust, Earsham. The R Witham/Haven at Boston contained a bloom of *Oscillatoria* sp., and *Phaeocystis* sp. from the Wash. In the Grand Union Canal at Bugbrooke and Duston Mill, a bloom of *Oscillatoria agardhii* up to 15 kms in length was reported. In Pike drain, Lincoln, *Microcystis* sp. was discharging from Grebe Lake, Whisby Nature Reserve. This was stopped immediately once identified. In Fossdyke, Lincoln, large growths of benthic *Oscillatoria* mats occurred in early summer. A bloom on the R. Great Ouse system during 1995 was reported, although no blooms were recorded during 1996. The Relief Channel contained very low flows in summer, and almost become a Lake, with conducive conditions for cyanobacterial growth. A bloom of *Oscillatoria* sp. was believed to have been discharged from Willen Lake, Milton Keynes.

In 1996, *Anabaena* and *Gomphosphaeria* spp. were detected in the Louth Canal (over the threshold) which were suspected to have been seeded from Covenham Reservoir. Thrapston and Ringstead lakes overflowed into the upper R. Nene in early July although no major impact was detected.

In 1997, the R. Bure had high levels of cyanobacteria downstream of South Walsham Broad which was dominated by *Anabaena* sp.. A major cyanobacterial bloom was again detected in the Louth Canal that was directly attributed to discharge of water from Covenham Reservoir, which contained high levels of cyanobacteria. It was also reported that the June rains resulted in an increased flow of nutrients from land into watercourses causing an increase in algae, with subsequent localised deoxygenation problems in the water as the algae died.

Midlands

In 1995, nearly all tributaries off the south side of the R. Avon were positive for cyanobacteria. The tributaries were characterised by waters low in nutrients draining the Cotswold Hills. Floating mats of *Oscillatoria* spp. were evident at the R. Stour at Halford, which had a coverage of approximately 100m x 30m, but which did not originating from standing waters. The mats were robust and buoyant for months and their frequency were more severe compared to previous years. Cyanobacteria were recorded from the R. Sow, downstream of Cap Mere, in the Staffordshire and Worcester Canal, downstream of Gailey pools, and in the R. Idle.

In 1996, more severe riverine blooms were again reported but over a shorter period of time than in previous years. These were also attributed to low river flows, still conditions, and sunny warm weather. Incidents were reported on the R. Stour, R. Dene where angling and canoeing was affected, R. Sow where farmers were notified of the bloom's progress downstream, and R. Sence. Similarly during 1997, short-lasting blooms were reported in the R. Sow and R. Sence, R. Dene and Wotton Brook in Gloucester.

North East

No incidents were reported during 1995, however in 1996, incidents were reported throughout the Regions on the R. Wansbeck, R. Morpeth where the bloom dispersed following heavy rains, and the R. Wharfe where a bloom of *Microcystis* originated from Harwood Lake. Similar blooms were repeated during 1997, and regular monitoring was carried out to assess the bloom's progress downstream.

North West

A degree of algal washout (*Aphanizomenon*) occurred from Scotsman's Flash into the R. Douglas in 1994, although this was not sufficient to form a riverine bloom. A similar event was recorded in subsequent years. In 1996, the algal bloom was self-sustaining, due to reduced river flow, and persisted for approximately 12 miles downstream to Rufford. In 1997, the algal bloom was not self-sustaining and persisted for approximately 8 miles downstream to Parbold. Rostherne Brook, which is downstream of The Mere, became sluggish and stagnant during periods of low flow, and cyanobacteria developed. A bloom of *Anabaena* and *Aphanizomenon* spp. was reported on Blackburns Brook that also overflows from Rostherne Mere. Bruntwood Hall Brook is very narrow and shallow, and a sample contained benthic *Oscillatoria-Phormidium* mats. This was a common occurrence in the Brook, although an assessment of the amount present was rather subjective. Similarly in the Trent and Mersey Canal, sluggish conditions promoted the growth of cyanobacteria.

South West

In 1995, a cyanobacterial problem on the Bridgewater Taunton was believed to be related to long retention time and increased sediment loading in the dock area. A bloom of *Aphanizomenon* in the R. Tamar during the summer originated from the Upper Tamar Lake, and persisted in the river due to the low flow conditions and the warm, sunny weather. The

Upper Tamar catchment is widely used for agriculture, and it is thought that increased leaching and run-off from the area may have also contributed to a build up of nutrients within the river. The Grand Western Canal, at Tiverton, contained low levels of *Oscillatoria* spp. and *Anabaena* spp.

In 1996 riverine blooms were also present on the R. Tamar (*Coelosphaerium*, *Microcystis aeruginosa* and *Anabaena flos-aquae*) but were less persistent than in previous year. The cyanobacteria originated from the upper and lower Tamar Lakes.

In 1997, cyanobacterial problems were less severe and localised. An *Oscillatoria* bloom was reported on the R. Lydden, at R. Till a dog illness and death was associated with a cyanobacterial mat, at R. Stour fish mortalities and a dog illness and death were attributed to a mat of *Oscillatoria* spp., and at R. Stock dead ducks and crows were possibly attributed to algal mats (reported as 'green slime on silt').

Thames

In 1995 cyanobacterial blooms extensively affected a number of running waters for the first time. West Clandon stream was seeded with cyanobacteria which originating from a series of on-line lakes in a country park. Optimum weather conditions and high retention times allowed the bloom to develop and persist in the stream until an overspill from an adjacent much larger watercourse, the R. Wey, diluted and dispersed/mixed the bloom. No cyanobacteria were detected downstream after this point. Farley Moor Lake, a small, shallow, mixed waterbody, seeded the outlet with cyanobacteria that were detected in the stream connecting it to The Cut, but not within The Cut. Dilution and mixing were likely factors preventing cyanobacteria from growing in The Cut itself. In the R. Ash, Sunbury, *Microcystis* originated from the Ashford water treatment works Reservoirs, as backwashes from the filters that were discharged into the R. Ash. Subsequently, *Microcystis* were detected in a tributary of the R. Thames and in the Thames itself. The discharge continued for 35 days despite Thames Water Utilities trying to stop it. The Cut at Maidenhead, a tributary of the R. Thames, also contained *Microcystis*, which originated from Bray Lake. The conditions were ideal for cyanobacteria, with hot, still conditions and little surface disturbance. The R. Stort and R. Lee, Hoddesdon, also contained cyanobacteria.

Similarly in 1996, cyanobacterial blooms were identified in a number of rivers, at R. Churn, Baunton Mill, Cirencester and R. Rib, Chapel End, where benthic mats of *Phormidium-Oscillatoria* were detected. *Aphanizomenon* sp. was detected in a tributary of the R. Cherwell, Farndon Hill farm, and *Oscillatoria* sp. was identified in the old R. Lee, above Ware lock. This particular stretch of the river was deep and slow flowing with no standing water sources.

In 1997, no major riverine incidents of cyanobacteria were detected, although the R. Thames developed a cyanobacterial bloom in Abingdon Marina, where the still conditions in the navigable stretches of the river provided conducive conditions for cyanobacterial growth.

Welsh

Anabaena spp. were identified in dead-zones in the R. Wye during 1995, following reports that several people had experienced blistering on their skin after wading in the river, but no algae were evident in the main stretch of the river. Warning signs were erected and considerable communication began between the local Agency office, Environmental Health Officers

(EHOs) and the health authority, in particular as the affected area was adjacent to a canoeing centre. Subsequently, canoeing ceased. Surface mats of benthic *Oscillatoria* spp. were also detected at the R. Wye near Hereford and Capler Hill, and the R. Thaw at Llandouh.

A *Gleotrichia* bloom was detected at the beginning of August in the R. Cefni, Anglesey, which originated from Cefni Reservoir. *Microcystis aeruginosa*, *Anabaena spiroides* and *Aphanizomenon* were also detected, with the *Microcystis* bloom approximately 4km in length downstream of the Reservoir which was attributed to the prolonged hot and still weather conditions. The bloom persisted until mid September, and was identified as acutely hepatotoxic. This was treated as a major incident since the area has a high public amenity value. The riverine bloom did not occur in previous years despite the annual bloom in the Lake. An extensive cyanobacterial scum was also detected in the R. Ritec that has had no previous history of cyanobacteria, and with no inputs from standing waters.

In 1996 blooms in running waters also occurred but with lower frequency, for example in the impoundment of the R. Tawe behind the barrage, and at Westfield Pill and Brandy Brook where *Oscillatoria* spp. were detected. An algal bloom at Freshwater East occurred in a pond on the beach as flow in the stream decreased with conducive conditions for algal growth. In 1997, the frequency of riverine blooms was even lower, with only a couple of reactive samples taken, one of which contained *Oscillatoria* spp..

3. TOXICITY

Many cyanobacteria are capable of producing toxins, and more than one species in each genera may be toxic. These chemicals are toxic to mammals but it is not clear whether cyanobacteria produce toxins only under certain environmental conditions and whether toxic strains become non-toxic at different times. It is best to regard all cyanobacterial blooms as being potentially able to produce toxins (NRA, 1990a).

The University of Dundee has carried out R&D work for the NRA and now Agency, on the fate and behaviour of cyanobacterial toxins. Regions have sent cyanobacterial bloom and/or scum samples for toxicity analysis as part of this research work. The samples have been used to build a library of toxins.

3.1 Incidents as a result of toxicity

Incidents of cyanobacterial toxicity are well known in many countries providing evidence of lethal and sub-lethal animal poisonings. Cyanobacteria are implicated with the death of wild animals, farm livestock, pets, fish and birds, however the events are difficult to substantiate because many are post-event accounts and descriptions of events may be incomplete. An indication of toxicity may be a contributory factor to death, although a single analysis will not always provide firm evidence of deaths. Generally, deaths may be caused by several other factors, although the rapidity of death and presence of toxins in samples may indicate that cyanobacterial poisoning was a contributory factor. In some cases, histological samples may prove useful.

Waterbodies affected with cyanobacterial toxins between 1995-1997 and degree of severity are documented below in Table 4. The number of samples received which merited cyanobacterial toxin analysis/toxicity assessment were 30 in 1995, 33 in 1996, and 32 in 1997 (Codd, 1998). In addition, a very small number of samples sent (*ca.* 5% of annual total) did not merit analysis due to insufficient sample volume sent or the deterioration of the sample and cell breakdown/decay on receipt. Incidents from past years can be found elsewhere (NRA, 1990b, 1991, 1992, 1993, 1994, 1995).

Table 4. Regional waterbodies affected with cyanobacterial toxins between 1995-1997.

Region and name of waterbody	Comments
Anglian Region	
Thrapston, 1995	No evidence of neuro- or hepatotoxicity by mouse bioassay, but low positive result for saxitoxin obtained by immunoassay
Thrapston, 1996	*Aphanizomenon* and *Microcystis* present; toxic.
R.Great Ouse, 1995	Neurotoxic, during August/September 1995 (*Oscillatoria agardhii*)
Barton Broad, 1995	No cyanobacteria detected from intestines of dead dog believed to have swum in Broad. Low number of cyanobacteria detected in sample from Broad.
Oak ford farm, 1995	Fish kills. Samples indicated presence of *Oscillatoria* above threshold.
South Holland Main Drain, Boston, 1995	*Prorocentrum*, *Prymnesium* bloom, resulted in 2 dead fish.
GUC, Duston mill, 1995	*Oscillatoria* detected, dog fell ill.
R. Witham/Haven, Boston, 1995	Large *Phaeocystis* bloom in the Wash (no cyanobacteria), dead eels and macroinvertebrates found.
Braiseworth Orchards Pond, 1996	*Synechococcus* sp. dominant. No toxicity present
Mill green park Pond, 1996	*Aphanizomenon* scum, positive toxicity
Covenham Reservoir, 1996	*Anabaena* and *Gomphosphaeria* non-toxic at very high dose, although may be presence of low levels of neurotoxins and or other unidentified toxins.
Covenham Reservoir, 1997	Two samples containing *Microcystis*, *Aphanizomenon flos-aquae*, *Anabaena* and *Gomphosphaeria* were tested at different dates from the same site. Microcystins detected at low levels from one sample but not the other.
Rutland Water, 1997	*Aphanizomenon flos-aquae* and *Anabaena* sample - no indication of hepato- or neurotoxicity, although sheep deaths were reported at the time. Separate samples analysed two months later were non toxic by HPLC method (*Anabaena*, *Aphanizomenon* and *Microcystis*), and acutely hepatotoxic attributed to microcystins (*Microcystis aeruginosa*)
Whitlingham Country Park Lake, 1997	*Aphanizomenon*, *Anabaena* and *Oscillatoria* detected in water and scum samples analysed, but no toxicity detected. Numerous reports of people getting rashes at the Park.
Midlands Region	
R. Stour, Halford bridge, 1995	Highly neurotoxic and hepatotoxic
Holme Pierrepont, 2000m rowing course, 1995	Negative, *Aphanizomenon* spp. sample
West park, Wolverhampton, 1997	No signs of hepatotoxicity

Table 4 continued

Lower Bittel Reservoir, 1997	Low levels microcystins but no indication of neuro-/hepatotoxicity. Bloom of *Aphanizomenon flos-aquae* and *Microcystis aeruginosa* but no scum
Pittville Lake, Cheltenham, 1997	Low levels microcystins, but no indication of neuro-/hepatotoxicity. Bloom of *Microcystis* and *Oscillatoria* spp, but no scum
<u>North East Region</u>	
Killingworth Lake, 1995	Non-toxic
Druridge Bay country park, 1995	Veterinary surgeon destroyed dog, suspected cause of illness was contact with cyanobacteria (on visit two weeks previously)
Motorway Pond, Newport, 1996	Dog swam in algal bloom, but no further information
<u>North West</u>	
Scotsman's Flash, Wigan 1995	No saxitoxins detected from *Aphanizomenon* sample.
Ladybridge park resident's club, Cheadle, 1995	*Oscillatoria/Phormidium* present but no signs of toxicity detected.
Hollingworth Lake, 1996	*Oscillatoria agardhii* present above threshold level. Sample was hepatotoxic.
Wyresdale fishery, 1996	*Prymnesium* present, confirmed as toxic.
Carnforth Anglers Pond,	
July 1997	*Aphanizomenon* present, non-toxic at high/medium level but does not exclude possibility of low level toxicity.
September 1997	*Microcystis* present. Microcystins present at high levels representing an acute poisoning hazard.
Lancaster Canal, 1997	*Anabaena* present, non-toxic.
<u>Southern Region</u>	
Shalmsford street Lake, Canterbury, 1995	30 dead fish. Signs of mucous around mouth, although *Oscillatoria* detected, sample was not toxic.
Baffins Pond, 1997	Dead duck stomach contents analysed. Although microcystins were a contributing cause of duck deaths, botulinum toxin (type C) was also detected. Sample analysed four days later contained *Microcystis aeruginosa forma aeruginosa*, acutely hepatotoxic.
Broadmarsh car park, Havant, 1997	Death of three/four dogs attracted attention. *Oscillatoria/Phormidium* in puddles, mildly neurotoxic but unlikely to present acute poisoning hazard. Puddles were filled in.
<u>South West Region</u>	
Poole Park Lake, 1995	*Oscillatoria*, *Anabaena*, *Merismopedia* present (blooms and scums). No microcystins were detected.
Chilton Trinity Lake, 1996	Sample indicated as non-toxic.
Coy Pond, Poole, 1997	*Oscillatoria* spp. bloom, no acute toxicity detected. Possibility of skin irritation as a result of contact with algal material.

Table 4 continued

Thames Region	
Quays Wayer sports Lake, Mytchett, 1995	*Gleotrichia* sp. Bloom/scum, not toxic
Horseshoe Lake, Sandhurst, 1995	*Anabaena* sp., *Microcystis* sp. Non-toxic bloom/scum
Thorpe Gravel Pit, 1995	*Microcystis* sp. Bloom/scum, not toxic
R. Stort above R. Lee confluence, 1995	*Microcystis* sp. Bloom/scum, not toxic.
Ashford Common WTW discharge, 1995	*Microcystis* sp. 29.8µg total microcystin-LR equivalent/litre
Marsworth Reservoir, 1996	*Anabaena* sp. present (decaying). No toxicity detected but could not be excluded.
R. Churn, Baunton mill, 1996	Benthic cyanobacterial mat not toxic
Powder mills Lake, 1996	*Microcystis* indicated low hepatotoxicity
Vale end, Albury, 1996	*Anabaena* and *Microcystis* indicated high hepatotoxicity
Broadwater Lake, Surrey, 1996	*Oscillatoria* and *Microcystis* not toxic
R. Rib, Chapel end, 1996	*Oscillatoria*, low hepatotoxicity indicated.
Farmoor Reservoir, 1997	*Microcystis* and *Coelosphaerium*, not toxic
Wittles farm, Dorchester	*Aphanizomenon*, not toxic
Abingdon Marina, R. Thames, 1997	*Oscillatoria* from four samples at different locations, no microcystins detected.
Welsh Region.	
Cefni Reservoir and river, 1995	*Microcystis aeruginosa*, *Anabaena spiroides* scum/bloom in Reservoir; scum and water samples acutely hepatotoxic, with two strains of microcystins detected (microcystin-LR and -YR). Rivers sample also acutely hepatotoxic.
Llyn Tegid, 1995	*Anabaena* spp, no toxins present in sample.
Llyn Tegid, 1996	*Anabaena flos-aquae*, *A. circinalis*, *Microcystis flos-aquae*, *Coelosphaerium kuetzingianum*, *Gomphosphaeria* sp., and *Oscillatoria/Phormidium* group present throughout summer and autumn. Toxicity varied through period; samples non-toxic and hepatotoxic.
Llyn Tegid, 1997	Sample acutely toxic by bioassay, but no indication of neurotoxicity or hepatotoxicity (decomposing sample may have been toxic due to associated bacterial factors). Another sample analysed two weeks later was also acutely toxic with low levels of neurotoxicity but no evidence of hepatotoxicity detected.
Westfield Pill, 1996	*Oscillatoria* spp, *Merismopedia* sp. and *Microcystis* sp. present. Sample not toxic at high concentration.
Wentwood Reservoir, 1996	Sample acutely hepatotoxic, typical of microcystin. Microcystin-LR dominant in sample at levels considered high in terms of cyanobacterial cell dry weight.
Llysyfran Reservoir, 1997	Three samples analysed over two month period indicated low levels of microcystins.
Syfynwy below Llysyfran Reservoir, 1997	Numerous samples tested for toxicity indicated variable toxicity at below and above a toxic hazard level.

3.2 Unsubstantiated incidents, possibly as a result of toxicity

Cyanobacterial toxicity events are difficult to substantiate and generally only circumstantial evidence is present with post-event accounts.

Anglian

In 1996, a suspected dog illness was unsubstantiated although *Nodularia* sp., *Anabaena* sp. and *Woloszynskia coronata* were present in a sample taken from a drain near Kirton village during July. No sample was taken for toxicity. In 1997 at Whitlingham Country Park, numerous reports were received of people developing rashes although samples analysed for toxicity were all negative. Similarly children had 'bites' reported following paddling in Asheldham Hall Pond. A green slimy scum was detected on the sediment and the sample contained *Oscillatoria* and *Spirulina* spp.. Sheep were reported to be ill around Rutland Water, although toxicity test on water samples at the time were all negative, whereas at Sywell Reservoir dogs were reported to be sick following drinking from the waterbody, and high levels of *Oscillatoria* sp. were detected. Moreover, spray irrigation was suspended in an orchard that abstracted water from eastern Braiseworth Reservoir, which contained cyanobacteria. Similarly, livestock watering was suspended at Felbrigg Hall Lake.

Midlands

In 1995, hearsay reports of human and livestock illness were reported, although none were related to cyanobacteria and substantiated. In 1996 two dead cygnets were reported in Chillinton Hall Lake, with no further information available as cygnets were taken away by unknown person(s).

North East

A veterinary surgeon destroyed a dog following suspected contact with cyanobacteria from Druridge Bay Country park in 1995, however no cyanobacteria were present in the ponds sampled.

North West

In 1995, at Clifton Lake, dogs swimming in the Lake were sick. A visual inspection of the Lake did not discover any obvious signs of algal accumulations, although low numbers of *Anabaena* spp. and one *Microcystis* colony were present.

In 1997, Maryport Aquarium had dinoflagellates in their outside tanks which killed the fish. The water was pumped from the harbour, although there were no similar specie in the harbour water sample.

Southern

In 1997, duck deaths at Baffins Pond were attributed to botulism. Moreover, in 1995, out of the six incidents reported only two involved fatalities to fish and there was no proof that the deaths were due to algal toxins, a contributory factor may have been the low dissolved oxygen concentrations in the water.

South West

In 1995 at Weston-Super-Mare, several reports of ill dogs were received, and a *Synechococcus* spp. bloom was detected in a brackish basin (Uphill Marina). A report of a very ill dog was also received from Fonthill Lake after swimming/drinking in Lake. The dog died later, and analyses indicated *Oscillatoria* sp. in the Lake. In Stourhead Gardens Lake, blooms and scums of *Microcystis*, *Anabaena*, *Aphanizomenon* and *Oscillatoria* spp. were present, and reports of an ill dog and a dead swan were received. Moreover, the man who recovered the dead swan reported a 'bad rash' on hands and arms. In 1997, a vet diagnosed hepatotoxic poisoning as the cause of a dead dog, although no autopsy was performed. Agency staff did not visit the site, and there was no recollection of any discolouration of the water when the dog's owner visited the site.

Thames

In 1997 at Abingdon Marina, dead ducks were reported. Water samples did not contain any microcystins and duck deaths were thought to be caused by botulism.

Welsh

In 1995, at Cefni Reservoir fish mortality can not definitely be attributed to *Gleotrichia* cells found on gills, since the dissolved oxygen levels in the water were exceptionally low at the time. Moreover, an angler was reported to have developed a leg-rash following immersion in the Reservoir water for 4 hours (linked to leaky waders). In Llyn Tegid there were possible reports of skin rashes from the public. Skin irritation and blistering were also reported from the R. Wye at Glasbury, while at Llangorse Lake, *Microcystis* sp. was identified in a water sample (and sediment too), but only after the sample was allowed to settle for a long time.

4. EXTERNAL COMMUNICATION

A requirement of the 'Blue-Green Algae Monitoring and Management of Incidents Policy' is that standard letters are sent out to owners of affected waters (and recently to water abstractors), Chief Environmental Health Officers (CEHO), Ministry of Agriculture, Fisheries and Food (MAFF) Regional Offices and Consultants in Communicable Disease (CCD), when waters are identified as containing cyanobacteria above warning threshold levels. These levels do not represent a risk to water users, but indicate of likely bloom and scum formation.

In 1995, a total of 702 standard letters were sent out by the eight Regions; 605 in 1996; and 647 in 1997. Highest numbers of letters were sent out during 1995, when severe algal blooms occurred in riverine sites for the first time. Moreover, Anglian, Midlands and Thames sent out greatest number of letters annually, whereas Welsh and Southern sent out the lowest. A Regional breakdown of the figures is available from EHS on request.

4.1 Liaison between the Agency, owners, water users, CEHOs, MAFF and MOEH, and feed-back received

Generally, there have been no complaints concerning the Agency's approach to dealing with cyanobacteria, and the majority of queries were successfully dealt with.

Regions, however, commented that some EHOs were still tentative or reluctant to erect notices on council owned sites, some exhibited a lack of understanding as to what their roles/responsibilities were and what advice to give on health issues, and some still required Agency advice. Moreover, some District Councils were more responsive than others.

Owners and water users were concerned, co-operative and interested in control methods, although it was noted that some may not have asked for advice, or have ignored the fact they have cyanobacteria, for possible commercial/financial reasons. Owners accept there is little they can do about such blooms and appear more aware and educated about cyanobacterial problems. The standard letters sent out to owners of affected waterbodies were accepted without complaint and in some cases generated further interest in information about algae. Generally, they wanted to know what could be done to stop the bloom, what had caused it, how long it would last, how they could prevent it recurring and if people could safely use the waterbody. Some also wanted to know who was responsible for remedial action.

There is likely to be increased awareness and numerous enquiries from water users, owners and local councils following localised events, for example at sites affected by cyanobacteria where animal illness have occurred, and at paddling pools where reports of skin rashes have been reported. In Anglian during 1995 for example, a severe *Microcystis* bloom occurred in Cadney Reservoir the day before a large water ski-ing event. Reaction by the owners was rather lax and insufficient time was given to the Agency to inform the EHO prior to the event. Similarly, the R.Great Ouse incident created some complaints from farmers about the (lack of) notification of potentially toxic cyanobacteria by MAFF, in particular in having to relocate their stock. The Agency notified MAFF as soon as it was aware of the problem, which in turn notified the farmers.

Water users were very reluctant to stop using the water for sports, despite warnings, at Holme Pierrepont, Midlands. Water-skiers were initially very reluctant to suspend their activities when so advised by EHOs, despite a very dense, visible scum during the 1995 incident.

In North East, following detection of cyanobacterial in the R. Wharfe during 1997, the Agency was questioned by Wetherby Town Council as to actions taken to prevent the re-occurrence of cyanobacteria in the future, since the problem had also occurred during 1996. No subsequent enquiries were received following an Agency response, therefore, it was assumed that the replies were satisfactory.

In Welsh, at Llyn Tegid water users were keen to see practical measures taken to remedy cyanobacterial problems, and cyanobacterial blooms were treated as toxic at all times. Warning signs were placed around the Lake (and often pulled down) throughout the season.

4.2 Queries received from external sources

All Regions commented on the number of queries that were received from sources external to the Agency. The main problem is that the Agency are not always informed, enquiries are taken by various functions within the Agency and records are rarely kept of them, therefore, it is difficult to assess the exact number.

5. WATERS CLOSED FOR RECREATIONAL ACTIVITIES

The Agency is responsible for monitoring 'controlled waters', informing owners, EHOs, CCD and MAFF officers of results of Agency analyses and of the occurrence of cyanobacteria, but it is not responsible for closing waterbodies for recreational activities, except where it is the owner. The roles and responsibilities of the Agency, owners, EHOs and MAFF officers are outlined in NRA (1990a).

Once a waterbody has been identified as having a cyanobacterial problem the matter is taken over by the EHOs, owners and local Councils. The Agency is not necessarily told what decision is made and it is therefore difficult to establish whether all or some recreational activities have been suspended, and for how long. Some Regions reported that owners and operators, who have had previous cyanobacterial problems, often have their own procedures that might not include notification of the Agency.

Table 5 below summarises the Regional sites at which recreational activities were suspended or the site closed, between 1995-1997.

Table 5. Waterbodies where recreational activities were suspended or the site closed.

Region and name of waterbody	Comments
Anglian	
Filby Broad, 1995, 1996, 1997	All watersports were suspended during the bloom including angling, dinghy boat sailing and general public access restricted upon notification of cyanobacteria above threshold levels, but uncertain of date when it was re-opened to the public, presumably at the end of the summer period.
Gt. Massingham Fishing Pit, 1995	Closed to anglers. Again no feedback concerning dates closed or re-opened
Flood relief channel in central area, 1995	Water-ski area closed by NRA, fishing continued
St Ives and Paxton Water-ski Lakes, 1995	Closed down by Huntingdon Environmental Health
Fritton Lake 1996	Boating, fishing suspended
Rollesby and Wroxham Broads, 1996	Sailing suspended
Felbrigg Hall and Holkam Hall lakes, 1996	Dog walking suspended.
Lackford Lake, 1996	Suspended for water contact sports
Whitlingham, 1997	Swimming, paddling, rowing suspended from August to the end of the season.
Tongwell Lake, 1997	Watersports suspended
Midlands	
Croft Farm leisure and water park, Tewksbury, 1996	Recommended to suspend watersports over weekend
Branston water park, 1996	Sailboarding activity suspended for two months
Pittville lakes, Cheltenham, 1996 and 1997	Boating, angling, public access suspended for most of the summer by Cheltenham Borough Council
West park, 1997	Boating suspended
Carsington Reservoir, 1997	Windsurfing cancelled by Severn Trent Water plc
Holme Pierrepont water-ski lagoon, 1997	Water-skiing suspended.

Table 5 continued

North East	
Brusselton Reservoir, 1995	The length of closure and type of activity suspended unknown.
Killingworth Lake, 1995 and 1997	All activities suspended. Windsurfing and angling suspended in 1997
Primrose valley Lake, 1995	Restricted use of waterbody
East Park Lake, 1996	Fishery closed for two months by Hull City Council's leisure services dept.
Cromwell bottom water skiing Lake, 1996	Suspended water-skiing for approximately six weeks
Raby estate Lake, 1997	All activities suspended
Rowntree park Lake, 1997	Model-boat sailing stopped until Lake had drained and refilled by local Council
Pugneys water sports, 1997	All activities suspended.
North West	
Leisure lakes, Tarleton, Southport, 1995	All activities suspended throughout summer season.
Scotsman's Flash, 1995 and 1997	Dingy sailing and canoeing was suspended throughout the season, although angling was allowed to continue.
Preston Docks, 1995	Contact water sports were suspended, due to recurring algal blooms.
Hollingworth Lake, 1996	Lake closed to public (watersports activities suspended)
Southern Region	
Baffins Pond, Portsmouth, 1996	Lake closed to public.
South West Region	
Chilton trinity Lake, 1995	Agency owned recreational site. Closed to public for approximately 3months.
Middlemoor water park, 1995	No swimming allowed
Upper Tamar Lake, 1995	Windsurfing suspended
Perry street Pond, Chard, 1995	Angling suspended for unknown period.
Bicton Lake, 1996	All activities suspended
The Mill, Avonwick, 1996	Fishing closed in large private pond.
Island Pond, Newton Abbot, 1996	Fishing suspended by local angling club.
Poole park Lake, 1997	Decision to close Lake taken by EHOs, Poole Borough Council between June-September.
Thames Region	
Bray Lake, Quays Lake Horse Lake R. Ash/ R. Thames, 1995	Once closure has occurred there is generally no feedback on duration
Maysbrook park lane, Barking, 1997	Sailing activity suspended between August-October

Table 5 continued

Bury Lake, Rickmansworth, 1997	Strong recommendation by local EHO to suspend water use in Lake during cyanobacterial scum. Some water users protested.
M. Barker memorial pit, Bishops Stortford, 1997	Angling club suspended activities for short period
Welsh Region	
Llyn Tegid, 1995	All fishing and water sports stopped for approximately 2weeks
River Cefni, 1995	Water contact sports suspended for approximately 1month
R. Wye, Glasbury, 1995	Canoeing suspended
Llangorse Lake, 1995	All activities ceased
Oxhouse farm Pond, 1995	Pond isolated from horses
Llyn Coron, Anglesey, 1995	Fishing stopped, but more likely to be due to infestation of *Argulus* sp. (fish louse) prior to algal bloom
Penbroke mill Pond, 1995	Boating activity suspended.
Wentwood Reservoir, 1996	Potable supply Reservoir closed for supply for approximately 3months, and angling suspended for a period.
Westfield Pill, 1996	Environmental health erected notices advising against canoeing, livestock watering and swimming.
Llyn Tegid, 1997	Long distance swims suspended by organiser
Llysyfran Reservoir, 1997	Warning notices erected.
Syfynwy below Llysyfran Reservoir, 1997	Walton mill fish farm closed for short period as a precautionary measure.

5.1 Feedback due to the closure of a waterbody.

Public generally enquired as to the possible cause of the bloom, its potential duration and methods of control. Any queries regarding health implications were advised to contact their local EHO. Again, there is no feedback about closures because it is at the owner's discretion to close the waterbody and the Agency is not always informed when waterbodies are closed and re-opened. Moreover, closure will affect the tourist trade as highlighted by some Regions. One Region reported that a campsite owner tore-down signs as it was affecting his business in the height of the tourist season.

6. PUBLICITY

The need to raise public awareness regarding cyanobacterial issues has been recognised since 1989 (NRA, 1990a), and subsequently cyanobacterial information leaflets and posters have been produced and widely distributed. Moreover, Regions commented that additional publicity is carried out through press releases, TV and radio interviews, and at shows (e.g. County, Agricultural, world canoe slalom championships).

The effects of publicity are difficult to assess as increases in enquiries or requests for information have not been recorded, and the level of interest depends on the seriousness of the bloom and the proximity of the members of the public to this bloom.

Pro-active action on local TV, radio and newspapers was suggested, to further increase public awareness regarding cyanobacteria at sites where algal problems reoccur annually, sites which are high amenity areas, and which are routinely monitored. The information would have to be accurate and honest, and promote links and open up debates. This may for example reassure the public that cyanobacteria are only harmful if you ignore safety instructions (as with poisonous mushrooms), but also include action taken by the Agency to reduce visual eutrophication and its symptoms. The use of information boards at shows and at sites routinely monitored, and the Agency has already produced a poster for such purposes.

7. ALGAL CONTROL METHODS

Algal populations can be controlled by a wide range of methods (NRA, 1990a). The technique(s) to be used will depend on the individual waterbody, and may be used in conjunction with other algal control methods.

In Anglian region, long-term algal control methods have been used for a number of years in the Norfolk Broads in the form of nutrient stripping of sewage treatment works effluents (reducing external nutrient inputs), mud pumping and iron dosing of sediments (reducing internal nutrient inputs), and biomanipulation (changing the trophic structure of waterbodies by selective addition or removal of species with the aim to reduce phytoplankton populations). The successes of these are detailed in reports available from the region. Mixing by bubble curtains and 'Helixor' air guns has continued at a number of lowland Reservoirs, although the primary function of artificial destratification is to maintain aerobic conditions in the water column. The physical environment is strongly selective, therefore, as phytoplankton undergo mixing they alternate between periods of high (surface) and low (deeper water layers) light intensities which restricts their photosynthesis and growth through light limitation. Intermittent destratification is a more efficient method, and phytoplankton species succession may be altered from cyanobacteria to diatoms.

Ferric sulphate dosing was also carried out at a number of pumped-storage Reservoirs in Anglian. The aim was to precipitate phosphorus (P) out of solution into the sediments to reduce nuisance algal growth. Ferric sulphate dosing ceased at Covenham Reservoir in 1994, and a reduction in the dissolved inorganic phosphorus (measured as soluble reactive phosphorus) and possibly chlorophyll *a* (a measure of phytoplankton biomass) was evident in the water, however, cyanobacteria were still occurring. The results of these management plans are detailed in Agency reports.

In South West, the possibility of reducing retention time was examined in Bridgewater Docks, whereas in North East, flushing a Lake at ICI Teeside was advised to control an *Oscillatoria* spp. bloom during 1995. No further information was available.

7.1 Barley straw

Many enquiries have been received about the use of barley straw in controlling algae. Generally, enquirers have been informed of the Centre for Aquatic Plant Management (CAPM) who have carried out initial trials with barley straw, and CAPM leaflets and an Agency pamphlet have been supplied. Moreover, BASIS registered staff generally advice on use of barley straw to control algae. Reports from the Regions indicate widespread use although most is unsubstantiated with hearsay reports, with limited results or no data and feedback. The Agency has received mixed reports about the success of barley straw which may be related to the inappropriate method of application, for example some straw has simply been thrown in as tightly-bound bales, which would probably rot under anaerobic conditions, however where straw has been placed loosely, as advised, reports have generally been positive.

Anglian

A variety of owners in Norfolk and Suffolk have claimed barley straw to have a positive effect on reducing algae (for example, Christchurch Park amenity ponds). In 1996, barley straw was used to control blanket weed (*Cladophora* sp.) on the R. Welland, and the results were apparently very successful. A report has been produced, available from Anglian. Barley straw trials are taking place during 1997 in Burwell Lodge and Lackford Lake, although at Burwell Lodge the results were inconclusive due to deployment problems of the straw in relation to navigation.

Midlands

Barley straw has been used at Holme Pierrepont, Sambourne Trout pool and Earlswood lakes since 1995. Barley straw use was discontinued at Holme Pierrepont the following year, whereas at Earlswood lakes the trial was stopped by British Waterways in 1996 as it was unsuccessful, and at Sambourne Trout pools an algal bloom occurred during 1996. No trials were reported during 1997.

North East

In 1995 barley straw was used in Coney Garth and Holywell ponds and no cyanobacterial incidents were reported. This continued in 1996 and at several waterbodies throughout 1997, with mixed success. Barley straw was also used at Cromwell Bottom Water-skiing Lake during 1996 but it was unsuccessful due to incorrect application and timing.

North West

Barley straw trials were attempted at Wigan Metro and Yacht club on Scotsman's Flash with unsuccessful results. In Preston Dock, barley straw was unsuccessfully used since the dock was constantly flushed out. Moreover, barley straw was reported as going to be used at Leisure lakes, Tarleton Southport during 1996, although no data was available.

South West

The use of barley straw was proposed in Poole Park Lake in 1995, although no further information was available in subsequent years.

Thames

Thames Water Utilities added barley straw to their backwash lagoon at Ashford works on the R. Ash. This was apparently not successful in controlling algae. Barley straw was also used in gravel pits in the Colne valley, although no evidence was presented for or against its effects.

Welsh

Barley straw has been used in the past at Greenfield lakes, Holywell but it is unknown whether it was successful or whether it was used during 1995. In Cwmbran Lake, a barley straw experiment had very limited success in reducing algal blooms; the lack of suitable controls made it difficult to assess the success. In 1996, barley straw was deployed at Pembroke Mill Pond by the county council and anecdotal evidence suggested it was successful. In 1997 the Conservation team advised the use of barley straw on at least two occasions but no further information was available.

7.2 Biomanipulation

In Anglian Region biomanipulation work is continuing on the Norfolk Broads, and at Whisby Nature reserve a project has been running since 1996 examining the role of biomanipulation. Midlands region reported successful biomanipulation at Bittell Reservoirs as part of their Action Plan.

7.3 Algicides and novel algal control products

The Agency has a duty to control the discharge of polluting substances into 'controlled waters' and as such any substance which is proposed for controlling algae must be evaluated before the Agency can agree to its use. The use of algicides is not generally advised because toxins can be released into the water when cyanobacterial cells break down. The EHS should be notified if any Region is approached to use and/or recommend an algicide or a novel algal control product.

A number of novel treatments available for algal control are being marketed as controlling nutrients and algae in waterbodies. The majority of these treatments appear to be chalk based and can be associated with bacteria that are supposed to reduce bottom sediments. The products claim to act by flocculating nutrients and/or algae from the water column and thereby creating clear water conditions. The TATG, under TAPS, developed a series of evaluating criteria designed to assess the potential environmental impact of such products.

Under the Control of Pesticides Regulation (COPR), the Pesticides Safety Directorate (PSD) approves several home garden pond/aquaria pesticides. Any organisation seeking approval for new home garden pond/aquaria pesticidal products should be referred to the PSD. COPR however exclude pesticides which act solely by 'physical means' and which no longer need approval for sale, storage, supply, advertisement or use. A Biocidal Products Directive (BPD) will come into effect in the year 2000 and any new active substances will have to be authorised under the BPD, which will include reference to microbiological active substances and products. Any UK manufacturer, formulator, supplier or user of biocides in product types not presently covered by COPR should register with the Pesticide Registration Section. It is anticipated that this Directive will take away the need of the Agency to further evaluate similar products for algal control.

8. RESEARCH AND DEVELOPMENT

Regions commented that they are informed of non Agency-run projects only when information is requested externally.

Anglian

Operational investigations are continuing in the Norfolk Broads and lowland pumped-storage Reservoirs, and a project is proceeding evaluating the benefits and effects of phosphate removal at sewage treatment works on the R. Great Ouse and R. Nene. There are, however, no R&D projects related to cyanobacterial toxins or cyanobacteria specifically.

Midlands

The R&D project on the UK Algal Flora key is due for completion by late 1998.

North West

APEM consultancy (Martin Andrews) and Manchester University jointly funded research on Compstall Lodge, Etherow, and an algal Action Plan has been produced for Pennington Flash in 1996. The Institute of Freshwater Ecology (IFE) are continuing work initially commissioned by the NRA on a number of the Lakes in the Lake District to determine more fully their ecology; for example the restoration of Windermere is continuing, while at Bassesnthwaite a baseline against which the impact of P stripping may be assessed is being determined using palaelimnology.

South West

Work by the Natural History Museum (Dr. John) on Loe Pool, Helston, has been carried out involving *Hydrodictyon* interaction with cyanobacterial populations.

Welsh

Work on Llyn Tegid (Bala Lake), and its catchment, is continuing, and cyanobacterial blooms have been reported annually since the summer of 1995. An Action Plan is currently being produced. As part of the Anglesey Wetlands Strategy, a partnership approach was instigated including the Agency, Countryside Council for Wales and the Royal Society for the Protection of Birds, examining the management and trophic status of several Anglesey lakes between 1995-1997. The IFE is developing conservation plans for a number of Anglesey lakes, Llyn Coron, Penrhyn and Dinam.

9. BLUE-GREEN ALGAE ACTION PLANS AND THE EUTROPHICATION STRATEGY

The TATG recommended the development of management strategies for each waterbody affected by cyanobacteria (NRA, 1990a). These have taken the form of Action Plans, and since their conception in 1990, have been continually promoted by the Agency. A number of aids for Action Plans have been developed and produced, for example computer models 'PACGAP' (Prediction of Algal Community Growth And Production) and PROTECH (Phytoplankton Response to Environmental Change).

PROTECH is a powerful computer model that quantifies algal blooms in relation to environmental variables, and is used to move from the PACGAP response statement to a technically effective solution to algal control. Some PACGAP responses are clear in describing the control measures that could be carried out, for example, destratification. Others are more general and recommend reducing external and internal P loads. PROTECH is highly sensitive if P is the controlling factor and can therefore be used to model the impact of P reduction. For the PACGAP responses describing reducing the P load, PROTECH will be used to model the impact of P reduction and to assess what changes occur. Furthermore, cost-benefit analysis will be performed to assess, for example, the benefits of alleviating cyanobacterial problems on conservation and angling.

A number of Action Plans are currently running, and have been developed along these lines, in Anglian, Midlands, North East, South West, and Welsh Regions.

9.1 Eutrophication-control strategy

The main work areas of the Nutrients Section, EHS are eutrophication, its impact, its symptoms including toxic and nuisance algae, and its effects on water uses and water users. Nutrients section is currently developing a national eutrophication control strategy, which provides a preliminary assessment of the extent of problems and recommends a way forward through a more co-ordinated and integrated approach, increased management, communication and R&D. Remedial action will be pursued through catchment-based action plans using best available tools, techniques and procedures. It is intended that the final Eutrophication Strategy document will be published in May 1999 following a consultation in late 1998.

It is envisaged that a partnership approach at national and local level will occur aimed at site-specific areas, which will be refined through experience. Sites not already selected will become apparent from Local Environment Agency Plans (LEAPs). The development of Action Plans for prioritised waters will ideally involve community groups, advocating communication/liaison with other Regulators, water-users and industry. The process will require the setting of chemical and/or biological water quality targets to protect the uses of the specific water, monitoring, computer modelling to investigate the efficacy of different control methods, and cost-benefit analysis to determine the most cost-effective control option for consideration by the waterbody owner.

The complexities of eutrophication and cyanobacteria should not be underestimated. There may be a considerable lag between the onset of controls, and the observable benefits in the waterbody will not be achieved overnight. In the interim, the acute problems of potentially toxic cyanobacteria must be managed through monitoring, and informing water users of the risks, and how to minimise them. The Agency, therefore, continues to develop policy, drive research and give advice relating to algae, cyanobacteria in particular, and their control.

10. DISCUSSION AND CONCLUSIONS

The Agency receives enquiries from waterbody sites affected by algal blooms/scums, and responds mainly on a reactive basis. This is a selective procedure and only sites affected by algal blooms and scums are analysed, therefore, the analysis of national and regional trends is difficult. Nevertheless, the results of cyanobacterial monitoring carried out by the Environment Agency indicated between 300-400 waterbodies were sampled annually, with no distinct annual trend. Two-thirds of the waterbodies sampled had cyanobacteria as the dominant group. Results also indicated that cyanobacterial floating mats in running water may be becoming more frequent if climate change (global warming), and reduced river flows, continue.

The warning threshold, which indicates that there is a likely risk of bloom and scum formation, was exceeded in three-quarter of the total number of waterbodies sampled which contained cyanobacteria.

The majority of sites were sampled in Anglian, Midlands and Thames Regions (between 40-105 sites/Region/yr), and may be related to a higher number of external enquiries received and waterbody sites. Biological, chemical, physical and meteorological factors must also not be discounted.

Algal problems attributed to species other than cyanobacteria were also reported, and Regions reported that enquirers were still unsure about the type of algae in a waterbody, therefore, expert advice from the Agency is required.

Past research indicated a high incidence of cyanobacterial toxicity world-wide, between 56-75% (Lawton and Codd, 1991). Moreover, toxicity analysis as demonstrated at Llyn Tegid, Welsh during 1997, indicated fluctuations in toxicity levels over a period of weeks, and the results from sites with blooms/scums tested between 1995-1997 indicated a similar trend. These recent findings confirm the need to regard all cyanobacterial species and strains as capable of producing toxins (Codd, 1998).

Cyanobacterial monitoring carried out by the Agency is therefore indispensable. Work carried out since 1989, initially by the NRA, has supplied bloom and scum material to the University of Dundee for immediate analysis. The material is also used for future reference and research, consequently three novel microcystins have been isolated from a bloom dominated by *Nodularia* at Barrow Ski Club Lake, Anglian initially taken during 1989 (Codd, 1998). More research is required and is continuing at the University of Dundee on cyanobacterial toxicity.

The Agency should continue to ensure that *ad hoc* cyanobacterial bloom and scum samples are taken and sent to University of Dundee for toxicity evaluation from reactively sampled sites, as necessary, and routinely from long-term monitoring sites when they are encountered.

Long-term monitoring is continuing at a designated site in each Region, in addition to what are termed operational investigations and routine monitoring that are carried out in response to area/Regional incidents/initiatives. Such results provide extensive regular data on phytoplankton and factors affecting their distribution and abundance, and should therefore continue. EHS suggest simplifying the terminology used during the cyanobacterial-monitoring programme. Sites will remain to be referred to as sampled reactively for the first time, sampled in the past and subsequently re-sampled, and sampled as part of the long-term monitoring. EHS propose to refer to sites that in the past were termed as routine or on-going investigations simply as routine monitoring sites (with the duration and sampling frequency indicated). EHS will review long-term monitoring needs with the Environmental Monitoring and Assessment Group, and review this extensive data to maximise its potential.

It is recommended that Regions continue with visual inspections from monitored sites and keep notes, in particular from specific incidents. It is likely this will be carried out in the field and transferred onto a database at a later time.

All Regions continued using the standard counting methodologies as outlined in the 'Monitoring and Management of Blue-green Algal Incidents Policy', and it is recommended that this is maintained to ensure a consistent approach throughout the Regions. In addition, it is recommended that an assessment of the relative abundance of taxa present in scum samples, when no counts are made, be carried out.

Currently, there is no formal system for recording the number of enquiries received regarding algal problems since most are handled by public relations, catchment officers, algologists/ecologists, and by EHS. Although a number of databases are available Regionally for recording results of analyses, a national database is required to promote a consistent coherent approach, and such a database could also be expanded to include external enquiries.

An information pack for use by Agency staff at presentations/workshops, outlining roles and responsibilities of Agency, local EHOs, owners, MAFF officers, vets etc has been proposed. This was expressed as an issue nationally, to improve Regional contacts/links between the Agency and the relevant organisations. Seminars to discuss the roles of Agency, EHOs and other relevant bodies, and to discuss recent specific issues have been carried out in Thames, South West and Anglian Regions with success. Moreover, good working relations are encouraged within the Agency, and between the Agency and external bodies, such that notification letters are quickly dispatched, and external organisations are fully aware of their roles and responsibilities.

Is there a need for increased publicity? Regions commented there were no problems noted in answering all external and internal enquiries. Moreover, leaflets and relevant information are sent out, if required. A 'blue-green algae' poster is now available for dissemination and display at affected sites. Suggested methods for increasing publicity were proposed targeted at specific user groups, anglers, windsurfers, conservation groups, informing people of responsibilities and outlining possible actions and management options. This may take place at local or county shows, if required.

The way forward. Cyanobacteria are the visible symptoms of eutrophication, therefore, a national eutrophication control strategy is being developed (published in spring 1999) aimed at delivering a more co-ordinated and integrated approach through increased management, communication and R&D. An overnight solution (improvement in water quality) will not be achieved, therefore, biological and chemical monitoring, algal and cyanobacterial in particular, must continue, and water users and managers must continue to be informed of the risks and how to minimise them.

11. REFERENCES

Codd, G. A. (1998) Summary report on blue-green algae toxicity testing, assessment and reporting to the Environment Agency, 1995-1997, Internal Agency report.

Environment Agency (1998) The State of the Environment of England and Wales: Fresh Waters, The Stationary Office, London.

Foy, R. H., Smith, R. V., Jordan, C. and Lennox S. D. (1995) Upward trend in soluble phosphorus loadings to Lough Neagh despite phosphorus reduction at sewage treatment works, Water Research, 29, 1051-1063.

Francis, G. (1898) Poisonous Australian Lake, Nature (London), 18, 11-12.

Kinniburgh, J. H., Tinsley, M. R. and Bennett, J. (1997) Orthophosphate concentrations in the river Thames, Journal of Water Environmental Management, 11, 178-185.

Lawton, L. A. and Codd, G. A. (1991) Cyanobacterial (Blue-green algal) toxins and their significance in UK and European waters, Journal of the Institution of Water and Environmental Management, 5, 460-465.

NRA (1990a) Toxic blue-green algae, A report by the National Rivers Authority, Water Quality Series No. 2, September 1990.

NRA (1990b, 1991, 1992, 1993, 1994, 1995) Blue-green algal monitoring, Toxic Algae Task Group. Annual reports

REPORT AVAILABLE FROM:

ENVIRONMENT AGENCY
ECOTOXICOLOGY & HAZARDOUS SUBSTANCES NATIONAL CENTRE
NUTRIENTS SECTION[1]
EVENLODE HOUSE
HOWBERY PARK
WALLINGFORD
OXON.
OX10 8BD

[1] Jan Krokowski, Algal Scientist, EHS National Centre