WATER QUALITY STATUS OF THE CARRA-MASK SYSTEM, CO. MAYO, IRELAND.

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1. Summary

The lakes and rivers of the Carra-Mask system are of enormous ecological and economic importance and constitute an area of outstanding natural beauty. Their preservation should be of national concern.

Recent reports of an increase in algal blooms, the spread of attached weed and a decline in the quality of the trout fishery on Lough Mask have raised concern about the threat to the lakes from nutrient enrichment and eutrophication. Assessments of the condition of the lakes by the EPA, based on mid-lake sampling, suggest that Lough Mask is not significantly effected by enrichment. Evidence from more detailed local monitoring and from the observations of anglers indicate that this is misrepresentative. The EPA assessment may grossly oversimplify a complex water body and lead to local deteriorations in water quality being overlooked.

Scientists from Greenpeace Exeter Research Laboratory and Greenpeace Ireland visited the lakes in July 1994 to carry out an independent assessment of water quality and highlight the threats to the system.

Nutrient analysis of L. Mask showed nitrate to be in excess, indicating that phosphorus supply was the factor limiting, or controlling, phytoplankton production. Phytoplankton biomass (chlorophyll *a*) was higher than would be expected for an oligotrophic lake in mid-summer, even at the centre of the lake, and the species composition showed characteristics of both oligotrophic and eutrophic waters. Similar phytoplankton compositions have been recorded for lakes undergoing eutrophication in the UK. Presence of the nuisance blue-green algae *Oscillatoria*, *Anabaena* and the highly toxic *Microcystis aeruginosa* is of particular concern.

The Robe River was identified as the most significant point source of nutrients to L. Mask. High algal biomass in summer, high oxygen demand and the reported spread of bottom-dwelling weed are clear evidence of local eutrophication affecting the eastern side of the lake. Non-uniformity in the distribution of phytoplankton species suggests that the lake is not fully mixed, decreasing the dilution factor and increasing the rate of deterioration of the eastern shores. It is this side of the lake which is most frequented by anglers and other visitors. Eutrophication reduces visual amenity and may, through exclusion of insect larvae, oxygen depletion and decrease in water transparency, contribute to the decline in the game fishery.

Stretches of the Robe were in poor condition, with few characteristics of a trout fishery. Collation of EPA data indicates that, in some aspects, water quality is steadily decreasing. Nutrient enrichment was detected below Hollymount and Ballinrobe. The tertiary treatment works under construction will reduce a significant point source of phosphorus, but enrichment will continue at the same or increased levels until

then. In addition, the poor condition of the river water immediately upstream of the current outfall confirms that there are other problems which may not be addressed by the new works. The importance of other point sources of nutrients, urban and rural, and of diffuse inputs from agricultural land should also be properly investigated.

L. Carra is a special case, with highly productive fringes but low productivity in the rest of the lake. The unusual chemistry of the lake and its sediments may have prevented many of the deleterious effects of eutrophication.

Continued eutrophication of L. Mask would have serious consequences for amenity value and could lead to further decline in the trout fishery, an increased incidence of nuisance (even toxic) algal blooms and continued danger of contamination by pathogens from human and animal waste. This in turn would have serious consequences for the abstraction and chlorination treatment of drinking water.

Levels of pollution in L. Mask are currently not as severe as in other Irish lakes (e.g. L. Conn, L. Sheelin) but the threats are very real. Naturally oligotrophic lakes are particularly sensitive and changes can be rapid and take many years to reverse.

The upgrading of all sewage treatment in the catchment is a priority as communities are currently discharging sewage in to their drinking water. Legislation should be introduced to reduce phosphorus in detergents and the development of alternative technologies for the treatment of rural waste should be encouraged. Diffuse sources of enrichment should also be tackled through effective fertiliser and livestock management which, in turn, would have other environmental and economic benefits.

It is essential to raise the awareness of local communities to their impact on their environment, to highlight the status of the lakes as a national ecological and commercial asset and to work at local, national and European level to ensure their conservation for the future.

2. Introduction

The lakes of Western Ireland are a beautiful and invaluable natural resource and national asset. They represent an essential natural habitat for many species of invertebrates, fish, birds and mammals. Their commercial importance is reflected in the intensity and diversity of their use for recreation (angling, boating, bathing) by visitors and local people, and for drinking water abstraction.

Many lakes are in pristine condition, a situation almost unique in Europe, and the quality of the game and coarse fisheries and of the surrounding environment are widely renowned. However, in recent years concern has been raised at local level about the gradual deterioration in the quality of the fishing, and of water quality in general, in some rivers and lakes. Anglers have noticed an increase in the occurrence and abundance of algal scums and of weed growth on the beds of streams and shallow lakes.

These symptoms are associated with an increase in the loading of the water with plant growth nutrients, particularly nitrogen and phosphorus, a process termed eutrophication. Increased inputs can arise from distinct point sources (e.g. sewage treatment works, intensive animal rearing units, industries processing animal products) or from more diffuse sources (eg. leaching and runoff of fertilisers from agricultural land). A notable example of this process, and one which has received considerable attention, is Lough Conn, Co. Mayo. A recent study, commissioned by Mayo County Council in response to reports of algal scums by local anglers, concluded that eutrophication was a problem in L. Conn and that an increase in phosphorus loading from agricultural run-off was primarily responsible (McGarrigle *et al.* 1994). The authors recommended the implementation of an integrated nutrient management plan to overcome the problems associated with the growth in intensive farming and slurry spreading in the catchment, and the upgrading of urban and rural sewage treatment. Such developments take time to implement and to work, but their importance and effectiveness may be highlighted by the improvements recorded in the well documented case of Lough Sheelin (Co. Cavan) in response to the slurry management programme during the 1980's (see Duggan and Champ 1992 for review).

The tourist industry in Western Ireland depends, to a large extent, on the quality of the lakes. Preservation of the pristine lakes in their current state, and the restoration of waters which have been damaged by eutrophication, are clearly essential, not only on environmental grounds, but also to protect local and national economic interests.

3. The Carra/Mask system.

3.1 Lough Mask and the River Robe.

Lough Mask is the 4th largest lake in Eire (8 000 ha, Clabby *et al.* 1992) and has a complex topography and geology. The western shore lies below the granite of the Partry Mountains and the lake is fed on this side principally by a number of small streams originating from extensive peatlands. There are a number of small settlements, but overall population density is low. A deep trench runs parallel to the western shore, giving some of the greatest depths in Irish lakes.

By contrast, on the eastern side the lake is shallow, with numerous small islands and bays. The inflow is dominated by the discharge from the River Robe, which flows through productive pastureland and receives sewage effluent from the towns of Claremorris, Hollymount and Ballinrobe. Other significant inflows include water from Lough Carra, discharging to the north of the Robe, and the Aille River, entering at the far north of the lake. The principal outflow is via the Cong Canal to Lough Corrib in the south.

Lough Mask is one of the most important trout fisheries in the West of Ireland. In addition to the large numbers of regular and visiting anglers, it has hosted a number of international angling competitions (including the 1994 World Cup) which bring large revenue to the local economy. As a result an important tourist industry has developed centred on the lake and its surroundings and, more generally, the lake has served as a valuable advertisement for the environmental quality of the West of Ireland. The waters are also abstracted for treatment to drinking water standards and this role will increase over the years as towns such as Claremorris are connected to the Mask supply.

During recent years local residents and anglers have become concerned about the apparent deterioration of the River Robe and some parts of the lake. There have been a number of incidences of large surface scums over parts of the lake in summer, accumulating along the shoreline, some of which have been reported to the Fisheries Board and probably many which have not. An increase in the growth of attached weeds in shallow water has also been noted by some anglers. Although there is some disagreement, many anglers agree that the quality of the fishing has diminished over the past 5-10 years.

The Carra-Mask Angling Federation, in conjunction with other local groups associated as Water Watch, have done much in recent years to raise awareness of the apparent decrease in water quality in the Robe and L. Mask, and concern for the protection of the lake and its fishery. The Federation has been instrumental in obtaining a large database of water quality information through liaison with the Local Authority and the Fisheries Boards. In addition it has commissioned two studies of water quality, the first by James Coyle (1991) and the second, a survey of the summer phytoplankton populations in L. Mask, by Feargal Monaghan (1993). Our involvement in this issue is also at the invitation of the Federation.

3.2 Lough Carra.

Lough Carra is a very different lake, in terms of size, depth, geology and chemistry. Although the 9th largest lake in Eire (1,500 ha), it has a mean depth of only a few metres. It is a marl lake with sediment rich in calcium carbonate (calcite). The shores are fringed with emergent vegetation. The Ballintubber River is the main point inflow, although with a long shoreline the lake probably receives much of its nutrient loading from diffuse leaching and runoff from surrounding farmland. L. Carra was included in the study by James Coyle (1991) and is included in the current assessment as it is an important source of water to L. Mask. It is an important game fishery in its own right and is used locally for drinking water abstraction.

3.3 Existing data on the state of the Carra-Mask system.

Data on the water quality of lakes and rivers in Ireland are collected by several authorities.

The Environmental Protection Agency (EPA), formerly the Environment Research Unit (ERU), carries out an extensive sampling programme throughout Eire and reports on a 4 yearly basis. Each site is sampled on one or more days per year and median, maximum and minimum values are reported. Although primarily a survey of river quality, the reports include data from 172 lakes, including Carra, Mask and Corrib. Samples are analysed for dissolved oxygen, biochemical oxygen demand (BOD, a measure of the rate of depletion of oxygen by the water) and nutrient concentrations (nitrogen and phosphorus). Maximum chlorophyll concentrations are also reported and an assessment of the trophic status of the lakes (oligotrophic, mesotrophic or eutrophic) made on this basis. For rivers, a Quality Status Rating (1-5) is assigned on the basis a range of quantitative and qualitative variables. All the major inflows to L. Mask are included.

The Western Fisheries Board has been sampling Lough Mask on a monthly basis since January 1975, recording total phosphorus, chlorophyll *a* and Secchi depth for a single point near the centre of the lake.

The Regional Water Laboratories at Castlebar also carry out water quality surveys on L. Mask, sampling at various times of year at a number of stations around the shoreline and in mid-lake. The data available to us indicate 2-3 samples per year, although our data set may be incomplete, including analyses of dissolved oxygen, nutrient concentrations, chlorophyll *a* and occasionally Secchi depth.

Collation of the available data highlights significant variation in, or disagreement about, the water quality of the lakes and the resulting assessment of their trophic status.

Lough Mask.

Lough Mask was described in an early report as showing some characteristics of eutrophy, but probably not very productive (Flanagan and Toner 1975). In 1983 it was assessed as oligotrophic/ mesotrophic (W.P.A.C. 1991) and this was unchanged by 1985 (Toner *et al*. 1986). From 1987-1990 the lake was assessed by the EPA (Clabby *et al*. 1992) as predominantly oligotrophic (with the exception of 1989). Phosphorus, chlorophyll and transparency data from the Fisheries Board (Champ, pers. comm.), compared against OECD definitive boundaries for waters of different trophic status (OECD 1982), suggest a mesotrophic status from 1975 until present, with little evidence of deterioration.

Recent data from the Regional Water Laboratory indicate that assessment of the water quality of the whole lake on the basis of mid-lake samples may be inaccurate. Of particular note is the occurrence of very high local chlorophyll *a* concentrations near Tourmakeady and the mouth of the Glensaul (up to 90 $\mu g\ l^{-1}$) on the western shore in June 1993. Whether this represented an algal bloom throughout the water column or a surface accumulation of buoyant algae is unclear, but this result does highlight the high biomasses which can be achieved locally in this lake. There have been eye-witness reports of similar algal accumulations in bays on the east coast and even in the open water of the southern part of the lake. Such events have been overlooked by the sampling programmes employed by the EPA (ERU) and the Fisheries Board but, unfortunately, these latter data are the more widely reported.

Lough Carra.

The status of Lough Carra is also uncertain. Flanagan (1975) classed the lake as "naturally eutrophic", but in the 1983 Review of Water Pollution in Ireland (W.P.A.C. 1991) it was assessed as oligotrophic/mesotrophic. From 1987-1991 the EPA (Clabby *et al*. 1992) reported that the lake was predominantly oligotrophic (with the exception of 1990). Local residents and anglers informed us that the lake was generally clear but that large algal blooms had occured in the past, and there is evidence that eutrophic status is still assumed by some regional authorities (de Barra, pers. comm.).

River Robe.

Data for the River Robe are more consistent and indicate a gradual but significant disimprovement in certain water quality parameters from 1977 until present. Information collated by

Coyle (1991) shows that water quality was satisfactory over the entire length of the river in 1977, although excessive enrichment, high algal growth and low oxygen concentrations were noted downstream of Ballinrobe sewage treatment works. The status was unchanged in 1980, but by 1983 significant disimprovements had been noted below Hollymount and Ballinrobe (Toner *et al*. 1986). In the most recent report from the EPA (Clabby *et al*. 1992) the Robe was classed as distinctly eutrophic in its upper and lower reaches. The stretch below Ballinrobe was noted as moderately polluted in 1989, with further deterioration in 1990.

Since 1990, yearly interim reports have suggested a slight improvement in the lower reaches of the Robe. However, the small changes in Water Quality Parameters observed from 1990 to 1991 would not seem to justify the statement in the 1991 interim results that "Overall the results indicate unpolluted conditions over most of the river length". Indeed, changes in the BOD values for the 8 sampling stations from 1991-1994 suggest increasing organic pollution and continuing deterioration of the river over the whole of its course (Fig. 1).

Other inflows to Lough Mask.

There is little evidence from published data for significant pollution of the rivers Aille, Glensaul and Finney, although the upper reaches of the Aille show some signs of lower biological quality in recent years. Few data are available for the Owenbrin, discharging to the west shore, but the abundance and diversity of organisms in the lower reaches were "severely restricted" in 1989 (Clabby *et al*. 1992). The reasons for this are not known, although a spate or acidification event (resulting from deterioration of the peatlands) could account for this observation.

The Cong Canal and Lough Corrib (North).

The canal linking L. Mask to L. Corrib was not assessed prior to 1989. In 1989 it was dry for much of its length but was assessed as satisfactory for those stretches with water (Clabby *et al*. 1992). Reports from anglers suggest that the growth of weed attached to the bed of the canal has increased rapidly over the last few years.

The Upper (north) section of L. Corrib is generally classed as mesotrophic. The lake supports a coarse fishery (as well as game) and is used locally for drinking water abstraction. The limited data available to us suggest no further deterioration in water quality.

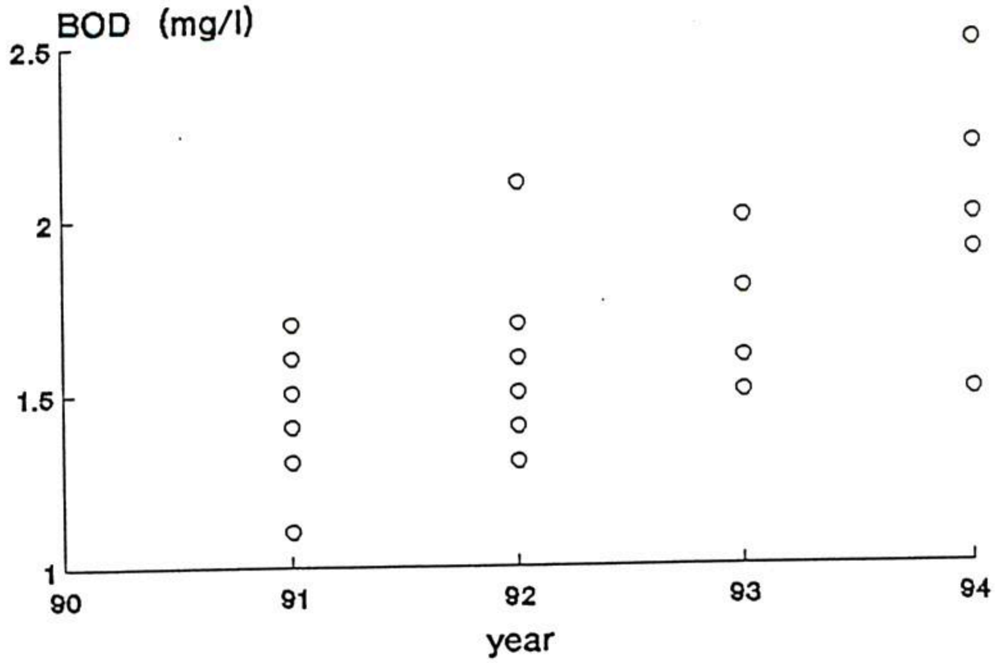


Figure 1. The increase in biochemical oxygen demand (BOD) for all stations on the River Robe over the last 4 years (data compiled from EPA interim reports, 1991-94).

Commissioned Reports on Water Quality in Lough Mask and Carra.

Coyle (1991) sampled L. Carra, L. Mask, the River Robe and other inflows in September and October 1991. BOD values and nutrient concentrations at this time of year did not indicate a significant problem in the river or lakes. No actual measurements of algal biomass were given. "Trace" quantities of chlorophyll were noted at only two stations; it is probable that chlorophyll was merely estimated by eye in this study. The author does highlight the recent appearance of attached weed growth in the shallow water on the east side of L. Mask.

The Robe River contained "a fair amount of weed and algal growth" in some stretches, but no attempt was made to identify or quantify this biomass. The other water courses entering Lough Mask appeared clean and supported fish populations. Sewage contamination was noted downstream of the septic tank sewage treatment system servicing a small housing estate on the Glensaul River. The author does not detail the nature of the contamination.

In his conclusions Coyle supported the classification of the lakes as oligotrophic/mesotrophic, but warned that a significant increase in nutrient loading would have serious long term effects. It should be remembered that his study was carried out in late summer/early autumn and relied principally on nutrient concentrations. Highest measurable nutrient concentrations would be expected in winter or early spring when algal growth is limited by low light levels and not nutrient supply, so that nutrients are in excess. During spring and summer nutrients are utilised for plant growth and are rapidly depleted to such an extent that the supply of one particular nutrient limits, or controls, further growth. Therefore nutrients are generally not detectable, or are present in very small quantities, in systems in which they control growth, and the measurement of nutrient concentrations without plant biomass can give little information.

Coyle (1991) stated that the potential for run-off of nutrients from agricultural land in to water courses was not significant in this catchment. It is difficult to see how such a conclusion could be reached and, until data on fertiliser loading are available so that diffuse inputs can be estimated, the potential importance of such a nutrient source cannot be disregarded.

Few studies of water quality address the species composition of the plankton. The quantification of algal biomass as chlorophyll *a* has led to an assumption that the phytoplankton is a uniform suspension and that in order to describe a system and predict changes it is not necessary to differentiate between species. This is a common but dangerous trend as, for example, 10 $\mu g\ l^{-1}$ chlorophyll *a* in the form of a toxic blue-green alga has very different consequences to the same amount of chlorophyll present as a diatom bloom.

Feargal Monaghan (1993) obtained a useful baseline data set of phytoplankton species composition and abundance in L. Mask in spring and summer 1993. His data indicated a fairly diverse phytoplankton community both at coastal and mid-lake stations and large differences in the composition and succession of the plankton in different parts of the lake. This suggests that mixing is not as efficient as commonly thought (the name Mask is derived from the Irish word for "mixed") and some of the bays on the east coast may effectively be isolated from the rest of the system.

Monaghan's study also confirmed the presence of certain nuisance taxa in the lake, particularly the scum-forming blue-green alga *Oscillatoria* sp. and the toxic blue-green *Microcystis aeruginosa*. On the bases of the species present and their relative abundances, Monaghan (1993) concluded that L. Mask should be classified as mesotrophic.

3.4 Brief for the current study.

Greenpeace has been kept informed of the developments in the L. Mask issue over the last few years through the persistent hard work of the Carra-Mask Angling Federation. It was on their invitation that scientists from Greenpeace Ireland and Greenpeace Exeter Research Laboratory visited the lakes in July this year, in order to assess the current condition of the Carra-Mask system and to liaise more closely with local groups. Our brief was:-

to obtain an overview of the lake system and catchment, their ecological and economic importance and the current changes in water quality;

to sample L. Mask, L. Carra, the River Robe and other major inflowing streams for simple water quality parameters (nutrient concentrations, dissolved oxygen, chlorophyll *a*) and to identify the principal phytoplankton groups present;

to make contact with concerned local groups and individuals, the Regional Fisheries Board and the local Water Laboratory, in order to draw together existing data and raise, on a National level, awareness of the problems faced by these and other similar lakes.

to identify the main threats to the ecology of the Carra-Mask system, discuss future prospects for the region if current trends continue and suggest strategies and measures which could alleviate or avoid environmental degradation.

3.5 Timing of the study in relation to lake ecology.

Clearly it is not possible to obtain a detailed assessment of the trophic status of the lakes purely on the basis of one brief visit, but the data obtained should enable us to identify the major threats to the system and to comment on the validity of previous assessments.

It is essential to bear in mind, as mentioned above, that the highest nutrient concentrations would be expected in the winter, not the summer. In this regard the timing of our visit, determined by other constraints, was not ideal if we were to obtain direct estimates of inorganic nutrient loading. In addition, algal biomass in temperate lakes generally peaks in spring and declines to a lower level in summer as nutrients are depleted and phytoplankton are grazed by zooplankton or settle out of the water column as it becomes more stable through surface heating (Reynolds 1984, Harris 1986, Fogg and Thake 1987). Typical cycles of phytoplankton production in temperate lakes were discussed by Monaghan (1993) in relation to L. Mask and will not be discussed further here.

It is sufficient to point out that measured concentrations of nutrients and chlorophyll in the waters in July will not represent the maximum or the average concentrations attained in 1994. We would, in fact, expect both nutrients and biomass to be very low at this time of year, particularly in oligotrophic waters. If any nutrients are detectable then this will be clear evidence for excessive loading of those nutrients. Similarly a significant algal biomass would tend to indicate a move away from oligotrophic status.

Long term changes in the trophic status of water bodies will influence the species composition of the phytoplankton. These changes are detectable even in summer when the overall biomass may be fairly low. The appearance of certain groups of phytoplankton, particularly blue-green algae, are useful indicators of increasing nutrient inputs to a system and the assessment of species composition forms a central part of the current investigation.

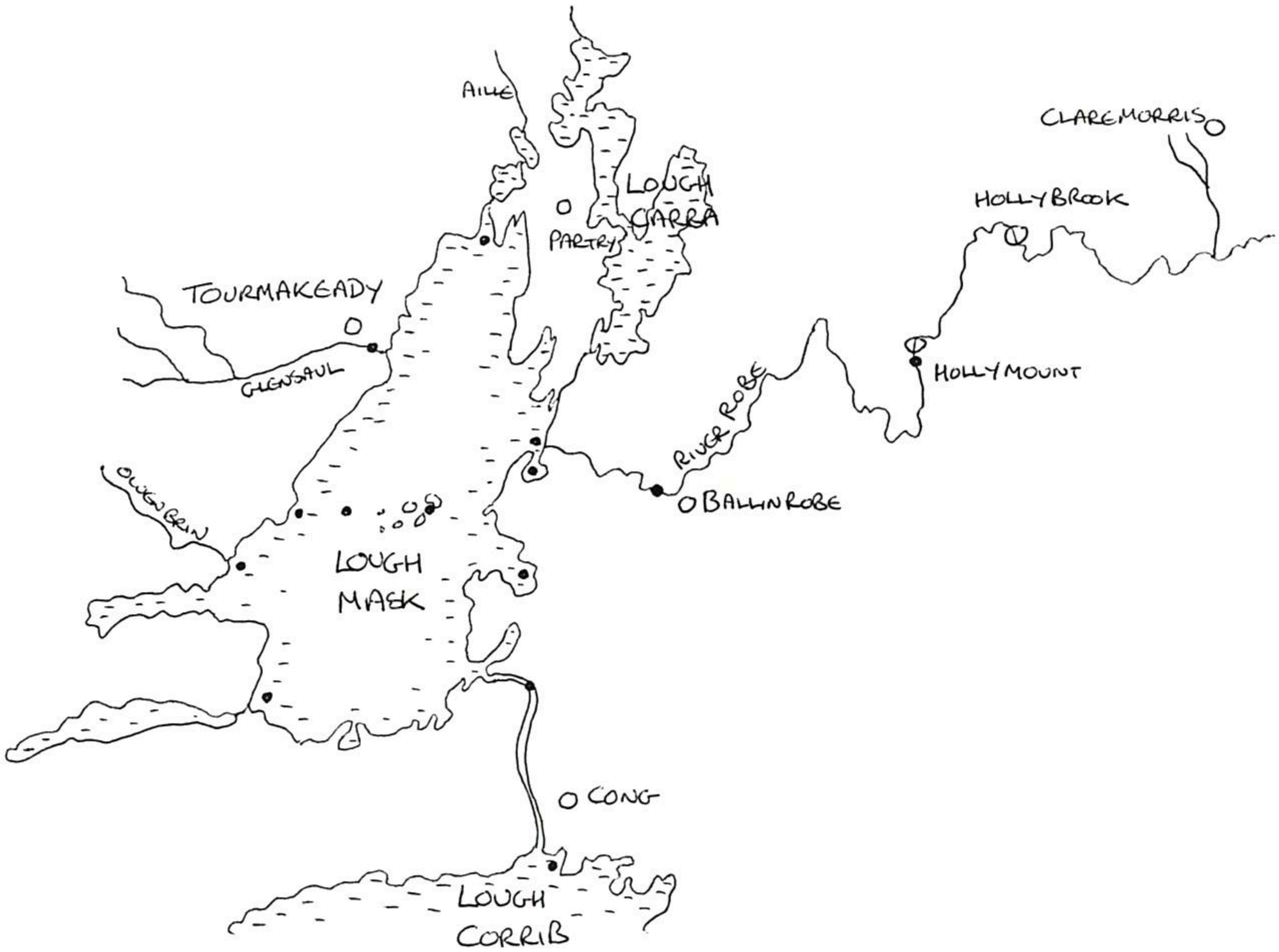
4. Materials and Methods.

Samples were taken at a number of locations on L. Mask, L. Carra, River Robe, Cong Canal and L. Corrib (North) between 20th and 23rd July 1994 (Fig. 2, Table 1).

Temperature, conductivity, pH, and dissolved oxygen concentration were measured on site using hand-held probes. Secchi depth (a measure of water transparency) was also measured on site where the water was sufficiently deep.

Duplicate 1l whole water samples were filtered through GF/C glass fibre filters and the filters retained for chlorophyll determination. These were kept cold and dark in the field and were frozen within 8 hours. Filters were returned to the Exeter Research Laboratory for extraction in 90% acetone and analysis using standard spectrophotometric techniques.

The liquid filtrates were also retained. These were transferred to clean bottles and kept cold and dark until return to our on-site laboratory in Partry, Co. Mayo. Samples were analysed for nitrate, nitrite, ammonium and phosphate concentrations according


AILLE
CLAREMORRIS
LOUGH CARRA
HOLLYBROOK
PARTRY
TOURMAKEADY
GLENSAUL
HOLLYMOUNT
RIVER ROBE
OLLINGRIN
BALLINROBE
LOUGH MASK
CONG
LOUGH CORRIB

Station	Location	Abrev.	Date	Time
Lough Mask West Side				
4001	Annagh Point	Annagh	20/7	1000
4002	midway Annagh Point-Shintilla Is.	midway	20/7	1030
4003	Shintilla Islands	S'lla	20/7	1135
4004	Ferry Bridge, mouth of Finney River	Ferry	20/7	1320
4005	mouth of the Owenbrin River	O'brin	20/7	1405
4006	Glensaul River, nr. Tourmakeady	G'saul	20/7	1610
Lough Mask East Side				
4007	Ballinchalla Bay, Bunnadober River	B'alla	21/7	1120
4008	Springvale, mouth of Robe River	Robe	21/7	1220
4009	Cuslough Bay	C'lgh	21/7	1300
4010	mouth of Aille (Cloon) River	Aille	21/7	1525
Robe River				
4017	Hollymount, d/s from sewage outfall	H'mnt	23/7	1800
4018	Ballinrobe, d/s from sewage outfall	B'robe	23/7	1925
Cong Canal and Lough Corrib				
4011	Cong Canal, 2 miles south of Mask	Canal	22/7	1150
4012	water intake, Lisloughry, L. Corrib	Corrib	22/7	1250
Lough Carra				
4013	Heneghan's Bay, Mering Drain	H'ghns	22/7	1500
4014	mouth of Ballintubber River	B'tubr	22/7	1530
4015	mouth of Annies River	Annies	22/7	1630
4016	Fannery Bay	F'nery	22/7	1715

Table 1. Location of sampling stations and times of sampling.

to standard methods, using Palintest nutrient analysis kits and a portable spectrophotometer.

A standard phytoplankton net (0.25 m diameter, 55 μm mesh) was used to collect samples of the surface phytoplankton at each station for qualitative analysis. Algae were identified to genus only and their relative abundance assessed by eye (present, common or abundant).

Submerged attached algae and higher plants represented a significant proportion of the plant biomass in some shallow areas and their presence was noted in these cases. No attempt was made to estimate their coverage or biomass.

5. Results

The lakes and their inflowing waters are a diverse system and, as such, it is difficult to discuss all the data obtained together. For this reason the results are presented in 5 sections:-

Lough Mask West Side (LMWS) - a transect from Annagh Point to the Shintilla Islands, samples near Ferry Bridge and the mouth of the Owenbrin River and a sample from the Glensaul River downstream of the Local Authority Housing Estate.

Lough Mask East Side (LMES) - samples from Ballinchalla Bay, Cuslough Bay and the mouths of the River Robe and River Aille (Cloon).

River Robe - qualitative assessment of the condition of Clare Lake, Claremorris, and the stretch upstream of Ballinrobe, with samples below the sewage treatment works at Hollymount and Ballinrobe.

Cong Canal and Lough Corrib (North) - a single sample from the Cong Canal, 2 miles south of L. Mask and a sample adjacent to the drinking water intake for Cong at Lisloughry on L. Corrib.

Lough Carra - samples from Heneghan's Bay (inflow from Mering Drain), Fannery Bay and the mouths of the Ballintubber Stream and Annies River.

5.1 Lough Mask West Side.

All six stations were sampled on 20/07/94. Nutrient and chlorophyll a concentrations, oxygen saturation and Secchi depths are presented in Table 3.

On the transect from Annagh Point to the centre of the lake nitrate was the only nutrient present in high concentrations, although ammonium was also detectable. The absence of measurable phosphorus suggests that the growth of phytoplankton was limited by the supply of this element, as is the case generally in fresh

Trophic status	Secchi depth (m)		Chlorophyll *a* ($\mu g/l$)		Total P ($\mu g/l$)
	mean	min	mean	max	mean
ultra-oligotrophic	>12	>6	<1.0	<2.5	<4
oligotrophic	6-12	3-6	1.0-2.5	2.5-8.0	4-10
mesotrophic	3-6	1.5-3.0	2.5-8.0	8.0-25	10-35
eutrophic	1.5-3.0	0.7-1.5	8.0-25	25 -75	35-100
hypertrophic	<1.5	<0.7	>25	>75	>100

Table 2. Boundary value criteria (fixed boundary system) for trophic categories of freshwater bodies according to OECD (1982).

Stat.	Temp. ('C)	Cond. (µS/cm)	O_2 (%)	Secchi (m)	Chl *a* (µg/l)	NO_3^--N (µg/l)	NO_2^--N (µg/l)	NH_4^+-N (µg/l)	PO_4^{2-}-P (µg/l)
4001	15.4	251	87.5	4.4	2.8	225	<5	20	<5
Annagh					2.4	220	5	5	<5
4002	15.6	253	93.8	4.4	3.0	230	<5	20	5
midway					3.0	180	<5	30	<5
4003	16.5	251	96.3	4.1	5.3	235	<5	30	<5
S'lla					4.9	270	<5	15	<5
4004	16.6	168	92.5	4.0	2.5	115	<5	25	5
Ferry					2.4	170	<5	<5	5
4005	15.5	254	91.9	4.5	2.6	120	10	20	<5
O'brin					2.5	140	5	15	5
4006	15.4	154	98.8	n.d.	0.8	110	<5	40	20
G'saul					0.8	175	<5	45	20

Table 3. Principal water quality data for stations on Lough Mask West Side and associated feeder streams.

Genus	Station					
	Annagh	mid	S'lla	Ferry	O'brin	G'saul
	4001	4002	4003	4004	4005	4006
Diatoms						
Asterionella	**	***	**	**	***	
Cylindrotheca			*	*		
Fragilaria	**	***	***	**	**	
Gyrosigma					*	
Melosira	*	*	*	*		
Navicula	**		*	*	*	
Nitzschia	*	*	*	*	*	
Rhizosolenia	*	*	**	**	*	
Synedra	**	*	*	*	*	
Tabellaria						*
Dinoflagellates						
Ceratium	*	**	**	**	**	
Chrysophytes						
Dinobryon	***	***	***	**	**	
Blue-green algae						
Anabaena	*	*	*	**	*	
Gomphosphaeria	**	*	**	*		
Merismopedia	**		*		**	
Microcystis		*		**		
Oscillatoria	*	**	**	***	***	
Green algae						
Ankistrodesmus	*	*	*	*	*	
Chlorella		*	*	*		
Oocystis			*			
Pediastrum		**	*	*		
Spirogyra				*	*	
(Desmids)						
Spondylosium				*		
Staurastrum	*			*	*	

*	present
**	common
***	abundant

Table 4. Phytoplankton composition (by genus) and relative abundance at the six stations on Lough Mask West Side (identified using West and West 1906, West 1932, Hustedt 1930, Round and Brook 1959, Belcher and Swale 1978, Lee 1980, Dodge 1985).

waters in summer (Wollenweider 1968, Jones and Lee 1986).

Chlorophyll levels were quite low but were not insignificant, particularly at the mid-lake station off the Shintilla Islands (>5 $\mu g\ l^{-1}$). Populations were higher than may be expected for the centre of an oligotrophic lake in summer and exceeded the annual mean OECD boundary value for oligotrophic status (Table 2, OECD 1982).

Dissolved oxygen concentrations were slightly depressed below saturation (100%), but this was to be expected on an overcast morning. Higher values at the centre of the lake reflect the later sampling time and the higher algal biomass.

Despite significant algal populations and the deep brown colouration of the water (due to humic substances washed down from the peatlands), Secchi depth was consistently greater than 4 m.

Species composition and approximate relative abundances are presented in Table 4. At all stations the phytoplankton population was quite diverse, with over 14 genera represented. The diatoms *Asterionella* sp. and *Fragilaria* and the colonial chrysophyte *Dinobryon* dominated the phytoplankton, although the dinoflagellate *Ceratium hirundinella* was also common. Of particular significance is the almost complete absence of desmids, a group of green algae indicative of oligotrophy (Nygaard 1949), and the conspicuous presence of the blue-green alga *Oscillatoria* sp., commonly associated with nutrient enrichment. The blue-green genus *Anabaena* and the green algae *Pediastrum* sp. and *Ankistrodesmus* sp. are also more common to more nutrient rich waters.

The stations near Ferry Bridge and the plume of the Owenbrin River revealed similar biomass, oxygen and Secchi depths to those off Annagh Point (ca 2.5 $\mu g\ l^{-1}$ chlorophyll *a*). Concentrations of free nitrate were lower and again phosphate was barely detectable.

Species compositions were similar to those on the transect, the most important differences being the greater abundance of, and dominance by, *Oscillatoria* sp. and the presence of large colonies of the toxic genus *Microcystis* (probably *M. aeruginosa*). The green algal genera *Pediastrum*, *Ankistrodesmus*, *Chlorella* and the filamentous *Spirogyra* were also present.

The lower reaches of the Owenbrin contained high loads of suspended sediment, possibly indicative of erosion of the peatlands due to overgrazing by livestock near the headwaters.

The Glensaul River appeared very clean at the sampling point, with little suspended matter and very few phytoplankton (Table 2). Dissolved oxygen was high as the stream was quite shallow and fast moving in places and the Secchi depth was greater than the greatest depth of water (ca 1.5m).

Nitrate concentrations were similar here to other stations but ammonium and phosphate levels were significantly higher. This enrichment may have resulted from the close proximity of the septic tank serving the small housing estate nearby. The distance from the tank to the river is insufficient to allow effective soak-away and the overflow, during periods of heavy rain, discharges directly in to the river. Although relatively small, such tanks would be significant point sources of nutrient inputs to the lake.

5.2 Lough Mask East Side.

All stations were sampled on 21st July 1994. Nutrient, chlorophyll, oxygen and Secchi depth data are presented in Table 5. Species composition and abundance data are given in Table 6.

Ballinchalla Bay, at the mouth of the Bunnadober River, is a shallow bay fringed by reeds and other emergent vegetation. Phytoplankton chlorophyll levels were similar here to values on the west side but a significant coverage of the lake bed with attached weed was noted here. Photosynthesis by this weed probably accounted for the oxygen supersaturation of the water.

Nutrients were barely detectable. This is possibly a result of nutrient depletion of inflowing water by the phytoplankton and submerged algae and higher plants attached to the lake bed. Emergent plants are fairly ineffective at removing nitrogen and phosphorus directly from flowing water as they obtain nutrients exclusively from the sediment.

Nevertheless, nutrient enrichment was suggested by the composition of the plankton; the assemblage was less diverse here and was dominated by the genera *Fragilaria*, *Anabaena* and *Oscillatoria*. The fairly low abundance of phytoplankton probably reflects the lack of vertical mixing of the water in this isolated bay which would otherwise keep the plankton in suspension.

The stations in Cuslough Bay and at the mouth of the Robe showed the highest phytoplankton biomasses measured in L. Mask in this study (Table 5). These are significantly in excess of the OECD mean value boundary for oligotrophy and, at the mouth of the Robe, also exceed the OECD annual maximum value boundary for this classification. For such a biomass to be supported in July is indicative of nutrient enrichment of the east shores of the lake by the Robe.

The plankton samples concentrated in the 55 μm mesh net were distinctly mucilaginous, similar to the algal "slimes" reported covering fishing nets in Lough Conn (McGarrigle *et al.* 1994). The phytoplankton was diverse, dominated by *Dinobryon* but also containing high densities of the diatoms *Fragilaria* sp., *Rhizosolenia* sp. and *Asterionella formosa*, the blue-green genera *Anabaena* and *Oscillatoria* and the green algae *Chlorella* sp. and *Ankistrodesmus* sp.. High densities of very small, unidentified

Stat.	Temp. ('C)	Cond. (μS/cm)	O_2 (%)	Secchi (m)	Chl *a* (μg/l)	NO_3^--N (μg/l)	NO_2^--N (μg/l)	NH_4^+-N (μg/l)	PO_4^{2-}-P (μg/l)
4007	18.5	293	132.5	n.d.	3.1	15	<5	45	<5
B'alla					2.4	5	<5	30	<5
4008	18.7	280	108.8	3.4	10.7	150	<5	<5	<5
Robe					10.8	80	<5	<5	10
4009	18.6	270	113.1	2.8	7.1	45	<5	<5	<5
C'lgh					7.0	45	<5	<5	<5
4010	19.2	243	106.3	3.2	4.5	55	<5	5	<5
Aille					4.6	50	<5	5	<5

Table 5. Principal water quality data for stations on Lough Mask East Side, including the mouth of the River Robe.

Genus	Station			
	B'alla 4007	Robe 4008	C'lgh 4009	Aille 4010
Diatoms				
Asterionella			**	**
Cylindrotheca		*	**	*
Fragilaria	***	**	**	**
Gyrosigma				
Melosira				
Navicula	*	*		
Nitzschia			*	*
Rhizosolenia		**	**	*
Synedra				
Tabellaria				*
Dinoflagellates				
Ceratium	**	**	*	**
Chrysophytes				
Dinobryon	*	***	***	**
microflagelates		**		***
Blue-green algae				
Anabaena	***	**		***
Gomphosphaeria				
Merismopedia				
Microcystis				
Oscillatoria	**	**	**	**
Green algae				
Ankistrodesmus		*	*	*
Chlorella		**		
Oocystis	*			
Pediastrum				
Spirogyra				
(Desmids)				
Spondylosium				
Staurastrum				

* present
** common
*** abundant

Table 6. Phytoplankton composition (by genus) and relative abundance at the four stations on Lough Mask East Side.

microflagellate phytoplankton were also conspicuous at the mouth of the Robe. Again, such an assemblage shows many characteristics common to nutrient enriched waters.

In addition there was a high abundance of attached green algae, including *Cladophora* spp., and higher plants, including the genus *Potamogeton*, in Cuslough Bay. Local sources informed us that a small amount of weed had always been present, but that the dense coverage now present was a relatively new phenomenon. Cuslough Bay undoubtedly receives water from the mouth of the Robe and appears to be eutrophying as a result.

As a supplementary investigation, an approximation was made of the oxygen demand of the water in the Robe plume. Two sample bottles were filled completely with water, the oxygen concentration measured at time zero and the bottles placed in the dark at approximately 18'C for 4 hours. The final oxygen concentration was determined and the oxygen demand of the water estimated after making a small correction for temperature change. Oxygen consumption over the four hour period lay between 0.8-1.13 mg O2/l, or approximately 10-15% of the total oxygen dissolved in the water. Over a 24 h period of darkness, such as may prevail at depth in the water column, such respiration rates could excert a demand for oxygen almost equivalent to the total oxygen content of the water.

Such oxygen demands may be symptomatic of the continued deterioration of the River Robe in its lower reaches. Phytoplankton appear to be responsible for much of the oxygen demand in the Robe plume, rather than high organic loading. Nevertheless, these estimates highlight the potential for serious oxygen depletion of the water column on a diurnal basis, and of the sediment as suspended phytoplankton and other organic matter settle out. The zone of light penetration, estimated from the Secchi depth, did not extend to the lake bed at the mouth of the Robe, indicating that the deeper part of the water column would be in oxygen deficit even during the day. Salmonid fish and many of the larvae of the invertebrates on which they feed cannot tolerate oxygen depletion. Unfortunately we could not measure sub-surface oxygen saturation.

Data for the mouth of the Aille (Cloon) River at the north of L. Mask suggest that this is less significant as a point source of nutrients, although the predominance in the plankton of *Anabaena* sp. and microflagellates is cause for concern. The diatoms *Asterionella* and *Fragilaria* were also conspicuous.

5.3 The River Robe.

Observations were made and samples taken on 23rd July 1994. Clare Lake appeared highly eutrophic, with algal scums accumulating at the lake margins. This is not surprising as the outfall of the local sewage treatment works discharges directly in to this fairly small lake. We tried to reach the end of the outfall but the emergent vegetation proved impenetrable and, without a boat, it was not possible to obtain a representative sample of the lake water.

The Robe above and at Hollymount appeared to be fairly clear with some stretches of clean gravel. However, in the region of Ballinrobe, upstream of the discharge of the existing treatment works, deterioration of the water quality was evident. The water was deep brown and contained high loads of suspended sediment and plant debris. Surface slicks and foam showed evidence of oil and detergent contamination from upstream sources. Surface oil was also noted by Coyle (1991) in this stretch of the river. This stretch did not appear to be of sufficient quality to support a trout fishery.

Samples below Hollymount and Ballinrobe sewage treatment works show elevated concentrations of ammonium and phosphate in the river compared to the lake (Table 7). This is perhaps not surprising as the river runs through productive pasture land, receives treated sewage effluent and supports a fairly low phytoplankton population typical of running waters. Note also that, while higher than measured in the lake, nutrient values did not approach mandatory or guideline limits for salmonid waters (EC 1975).

Despite low overall phytoplankton biomass, short filaments of *Oscillatoria* sp. were predominant in the Ballinrobe sample (Table 8).

5.4 The Cong Canal and Lough Corrib at Lisloughry.

Samples were taken on 22nd July 1994. The canal contained less than 1m depth of water at the time of sampling and has, in the past, been completely dry (Clabby *et al.* 1992). Attached algae (*Cladophora* and other genera - no formal identification was carried out) were abundant. Information from local sources suggested that this was a recent development and that the weed extended further down the canal year by year. This would seem to indicate increasing nutrient enrichment from L. Mask rather than from sources more local to the canal.

Free nutrient concentrations and algal biomass were relatively low (Table 7), but a diverse phytoplankton assemblage was present (Table 8). This assemblage was more similar to the plankton on the east side of the lake than the west. This would be expected if the plumes from the Robe and other inflows on the eastern shores did not mix completely with the lake water but instead were restricted to the east side of Lough Mask and flowed southwards to the canal.

A higher biomass was recorded at the station adjacent to the water intake at Lisloughry (Table 7). Here the plankton was dominated by *Dinobryon* and the blue-green genera *Oscillatoria* and *Anabaena*; the diatoms *Fragilaria* and *Nitzschia* were also common. *Oscillatoria* spp. release extracellular chemicals which impart a stale odour and taste to water and fish and the filaments

Stat.	Temp. ('C)	Cond. (µS/cm)	O_2 (%)	Secchi (m)	Chl *a* (µg/l)	NO_3^--N (µg/l)	NO_2^--N (µg/l)	NH_4^+-N (µg/l)	PO_4^{2-}-P (µg/l)
River Robe									
4017 H'mnt	18.6	552	101.3	n.d.	2.6 3.3	155 180	<5 <5	35 35	35 30
4018 B'robe	17.6	579	93.1	n.d.	2.3 2.3	160 165	<5 <5	25 25	40 30
Cong Canal and L. Corrib									
4011 Canal	17.9	248	94.4	n.d.	2.9 2.8	190 135	<5 <5	35 30	<5 5
4012 Corrib	19.5	248	88.8	2.5	4.3 4.1	60 105	<5 <5	10 15	15 10

Table 7. Principal water quality data for stations on the Cong Canal and on Lough Corrib, near the water intake at Lisloughry, Cong.

Genus	Station			
	H'mnt 4017	B'robe 4018	Canal 4011	Corrib 4012
Diatoms				
Asterionella			**	
Cylindrotheca				
Diatoma		*		
Fragilaria			**	**
Gyrosigma				
Melosira	*			
Navicula	*	*		*
Nitzschia	*	*	*	**
Rhizosolenia			**	*
Synedra				
Tabellaria				
Dinoflagellates				
Ceratium			**	
Chrysophytes				
Dinobryon			**	***
microflagelates				
Blue-green algae				
Anabaena			*	***
Gomphosphaeria			*	
Merismopedia				
Microcystis			*	
Oscillatoria	*	**	*	***
Green algae				
Ankistrodesmus				
Chlorella				**
Claophora	*			
Microspora	*	**		
Mougeotia	*			*
Oocystis				
Pediastrum				
Spirogyra				

*	present
**	common
***	abundant

Table 8. Phytoplankton composition and relative abundance at two stations on the Robe River and stations on the Cong Canal and L. Corrib.

readily block filters used in drinking water treatment. Some species of *Oscillatoria* and *Anabaena* can produce toxins but identification was not taken to species level in this case. However, small colonies of the toxic species *Microcystis aeruginosa* were identified at low abundance. The consequences for drinking water abstraction are discussed in detail later.

The close proximity (2-3m) of a rusting ship hull to the water intake at Lisloughry is cause for concern. This could act as a source of metal and oil contamination of the water, or as a refuge for vermin which could introduce pathogens (e.g. Weils disease).

5.5 Lough Carra.

Four stations on Lough Carra were sampled on 22nd July 1994. Nutrient, chlorophyll and oxygen data are presented in Table 9 and phytoplankton species composition in Table 10. Secchi depth was greater than the depth of the lake at all stations.

The fringes of this lake are dominated by reed beds and other emergent vegetation. At the time of sampling large, green aggregates of algae were present in the river plumes, both attached to the stems of the reeds and free floating. These aggregates were not seen further offshore; indeed, a few metres away from the river mouth there was no evidence of a significant phytoplankton assemblage of any sort.

Difficulty was experienced in filtering samples for pigment analysis as large amounts of fine inorganic particles, resuspended from the sediment, blocked the filters. Chlorophyll a levels were low at all four stations (Table 9), being concentrated almost exclusively in the macroscopic aggregates. No samples were taken from the middle of the lake, but it is likely that these would have shown only trace quantities. Nitrate was barely detectable at three of the four stations. Significant concentrations were measured only at the mouth of the Annies River, but even then values were a fraction of those in L. Mask (West Side, see Table 3). By contrast ammonium and phosphorus concentrations were relatively high (Table 9). Ammonium is a highly labile substrate, normally rapidly depleted by phytoplankton or converted to nitrite and nitrate by nitrifying bacteria in soils and fresh water systems. Its presence in the absence of nitrate is an unusual occurence; the reasons for this anomalous nutrient ratio are not clear. Concentrations of phosphate exceeded the OECD mean value boundary for oligotrophic status at all stations (Table 2). Elevated concentrations of both ammonium and phosphate suggest direct input of human or animal waste to the water close to the lake.

Two types of sample were taken for phytoplankton identification, the aggregates and the surrounding water excluding the aggregates. Populations associated with the clumps were very different from the unaggregated plankton (Table 10).

Stat.	Temp. ('C)	Cond. (μS/cm)	O_2 (%)	Secchi (m)	Chl *a* (μg/l)	NO_3^--N (μg/l)	NO_2^--N (μg/l)	NH_4^+-N (μg/l)	PO_4^{2-}-P (μg/l)
4013	19.2	294	104.4	n.d.	3.3	<5	<5	30	10
H'ghns					2.7	<5	<5	30	10
4014	19.6	286	116.9	n.d.	3.1	5	<5	65	30
B'tubr					2.7	10	<5	50	30
4015	19.2	325	128.8	n.d.	2.0	20	<5	50	15
Annies					2.2	20	<5	40	15
4016	19.7	285	135.0	n.d.	2.2	<5	<5	210	25
F'nery					2.0	<5	<5	80	20

Table 9. Principal water quality data for stations on Lough Carra.

Genus	H'ghns 4013	aggr.	Station B'tubr 4014	Annies 4015	Fan'ry 4016
Diatoms					
Asterionella					
Cylindrotheca		*			
Cymbella		**		*	**
Fragilaria	**		*	*	
Melosira					
Navicula		*		*	*
Nitzschia					
Dinoflagellates					
Ceratium	**		**	***	***
Chrysophytes					
Dinobryon	***		***		
Blue-green algae					
Anabaena					
Merismopedia		*			
Microcystis					
Nostoc				**	*
Oscillatoria		**		*	
Green algae					
Ankistrodesmus					
Chlamydomonas		*			
Chlorella					
Cladophora			*		
Lobomonàs		*			
Mougeotia		**			
Oocystis			*		
Pediastrum	**		**	*	**
Spirogyra		***			
Zygnema	*	***	*		
(Desmids)					
Desmidium		*			

*	present
**	common
***	abundant
aggr.	composition of aggregates

Table 10. Phytoplankton composition (by genus) and relative abundance at the four stations on Lough Carra.

Aggregates were dominated by the filamentous green algae *Zygnema*, *Spirogyra* and *Mougeotia* and apeared to be associated with inorganic particulate matter, probably resuspended sediment. The diatoms *Navicula* spp., *Cymbella* sp. and *Cylindrotheca* sp. were also present as well as filaments of *Oscillatoria* sp. and small flagellated organisms (possibly *Chlamydomonas* sp. and *Cryptomonas* sp.). Long chains of the desmid *Desmidium* were abundant in some aggregates.

The surrounding phytoplankton was dominated by the motile forms *Dinobryon* sp. and *Ceratium hirundinella*, although *Fragilaria* sp., *Pediastrum* sp. and *Oocystis* sp. were common at the mouths of the Mering Drain and the Ballintubber. The colonial blue-green algal genus *Nostoc* was conspicuous in samples from the southern part of the lake at Annies River and Fannery Bay, but did not dominate the plankton.

The presence of these genera, the existence of significant ammonium and phosphate concentrations in summer and the high density of emergent vegetation indicates that the fringes of L. Carra are very productive, whereas the central part of the lake appears oligotrophic. Local sources informed us that algal scums can form in early summer over areas of the lake, presumably generated as blooms in river plumes and carried out by the wind.

6. Discussion.

6.1 The current situation in Lough Mask.

Algal biomass

Compared to very productive lakes (eg. L. Sheelin, Duggan and Champ 1992) the algal biomass measured in L. Mask in this and other studies has generally been low. However, given that we sampled in late July, the biomass measured at the centre of the lake in the current study was unexpectedly high for a nutrient poor lake. Note also the very high algal biomass recorded by the Regional Water Laboratory (Castlebar) near Tourmakeady Pier in June 1993, and eyewitness reports of extensive surface scums in the southern part of the lake.

We found clear evidence of nutrient enrichment of the east side of the lake; at the mouth of the Robe and in Cuslough Bay the production of phytoplankton and attached weed (algae and higher plants) were particularly high and are clearly cause for concern. It appears that the effects of this eutrophication are now spreading down the eastern shore and along the Cong Canal.

Species composition

Concern about the enrichment of L. Mask is also supported by the species composition of the phytoplankton. Although total biomass may be patchy and algal blooms sporadic and difficult to predict, continued enrichment of a lake will bring about changes in the composition of the plankton as species indicative of nutrient poor water are outcompeted by those capable of higher growth rates when nutrient supply increases.

Typical phytoplankton genera of oligo-, meso- and eutrophic waters are given in Table 11. The phytoplankton of L. Mask consists of a mixture of genera indicative of all trophic states, with the chrysophyte *Dinobryon* (oligotrophic), the diatoms *Asterionella* and *Fragilaria* (mesotrophic) and the blue-green genera *Oscillatoria* and *Anabaena* (eutrophic) being particularly common (Tables 4 and 6). Clearly the indicator species are not strictly confined to waters of a single trophic state, but the composition of the assemblage as a whole can give useful information. The phytoplankton in L. Mask is qualitatively similar to that of some lakes of the English Lake District during their transition to mesotrophic and eutrophic status (Reynolds 1984). For example, in Lake Windermere densities of the diatoms *Fragilaria* sp. and *Melosira* sp., and of *Oscillatoria* spp., increased in response to long term eutrophication (Lund 1972a). In Blelham Tarn, a smaller lake in the same catchment, *Dinobryon* and the small diatom *Cyclotella* declined in numbers while the densities of *Asterionella formosa*, *Tabellaria* sp., *Ceratium hirundinella*, *Aphanizomenon* spp. and *Oscillatoria agardhii* increased significantly (Lund 1972b, 1978). The mixed composition in L. Mask therefore appears to suggest both oligotrophic and eutrophic characteristics, perhaps indicative of a gradual shift to more nutrient rich conditions.

Nutrient concentrations and ratios.

Most stations in L. Mask showed an excess of nitrate, whereas phosphate was close to or below the limits of detection (5 $\mu g\ l^{-1}$). This does not indicate that nitrate is the primary factor responsible for the recent increase in algal growth or that phosphorus is relatively unimportant. On the contrary, an excess of nitrogen would be expected if phytoplankton growth was limited, or controlled, by the supply of phosphorus to the system. Phytoplankton require both nitrogen and phosphorus for growth, in a ratio of approximately 16:1 by atom (Redfield 1958). When nutrients are introduced to a water body the phytoplankton will take up and deplete the nutrients roughly in that ratio. If the nutrient supply is rich in nitrogen (i.e. with an N:P ratio greater than 16:1) then the phosphorus will be the first nutrient to become depleted. As this prevents further growth, any excess nitrogen remains detectable in the water.

Further enrichment with nitrogen alone would have little effect on the system. However, if the supply of phosphorus were increased, the reservoir of excess nitrogen already in the water would allow an increase in phytoplankton growth. This is of enormous importance as it is the reduction of phosphorus inputs which would have the greatest and most immediate effect in reducing algal production. Phosphorus enrichment is much more

Group	Oligotrophic	Mesotrophic	Eutrophic
diatoms	Cyclotella Melosira Rhizosolenia Tabellaria	Asterionella Cyclotella Fragilaria Stephanodiscus	Asterionella Stephanodiscus
dino- flagellates		Ceratium Peridinium	
chrysophytes	Dinobryon		
blue-green algae		Anabaena Oscillatoria	Anabaena Aphanizomenon Microcystis Oscillatoria
green algae	Sphaerocystis	Pediastrum Scenedesmus	Chlorella Eudorina Scenedesmus
(desmids)	Cosmarium Staurastrum	Closterium Staurastrum	

Table 11. Phytoplankton genera typical to waters of different trophic status (compiled from Hutchinson 1967, Reynolds 1984, Moss 1988, Anderson *et al.* 1991 and Harper 1992).

readily controlled than nitrogen enrichment (Lee and Jones 1986) since phosphorus precipitates out of solution in the presence of many ions (including calcium, iron and aluminium) and has no atmospheric component in its elemental cycle. Nitrogen, in contrast is highly soluble (as nitrate, nitrite, ammonium and organic nitrogen), is an important component of groundwater (Young 1986, CEC 1991), which may lead to diffuse and untraceable inputs, and is introduced through rainfall from nitrogen oxides in the atmosphere (Moss 1988).

Mixing regime

There appears to be no information on circulation patterns in the lake; these would be vital to any predictive estimations of phosphorus loading of the lake and its effect on trophic status. The similarity in phytoplankton species composition between samples from the mouth of the Robe and from the Cong Canal and the dissimilarities between the east and west sides of the lake suggest that L. Mask does not mix as well as is often assumed. Although it is a very large water body, both in terms of surface area and volume, exchange between the shallow eastern waters and the deep western waters appears to be poor. Current inputs, from the Robe River in particular, are therefore leading to accelerated enrichment and eutrophication along the eastern shores. Any calculations of the phosphorus loading capacity of the lake must take this in to account.

6.2 The current situation in Lough Carra

It appears that the fringes of L. Carra have always been very productive. It is probable that the unusual inorganic chemistry of L. Carra has been responsible for preventing the spread of eutrophication to the main body of the lake. Phosphorus is known to precipitate with calcium (Allen and Kramer 1972), which is clearly in excess in the sediment, and resuspended in the water column. Precipitation as calcium phosphate would effectively remove phosphorus from solution and bind it in the sediment in a form not directly available to phytoplankton. In simple terms L. Carra carries out naturally the equivalent of tertiary wastewater treatment. A similar mechanism has been proposed for the continued mesotrophic status of some lowland lakes in N.E. Poland in spite of the large increases in phosphorus loading of inflowing waters (Hillbricht-Ilkowska 1990).

As a consequence, outflow from L. Carra probably does not represent an important source of phosphorus for L. Mask.

6.3 Water Quality Monitoring Programmes.

As discussed in the introduction, there is considerable disagreement over the trophic status of L. Mask and the River Robe. The EPA (ERU) and the Fisheries Board maintain that the lake is predominantly oligotrophic. This assessment, based on maximum recorded chlorophyll in mid-lake samples, overlooks the importance of the Robe as a point source of enrichment of the eastern side of the lake, as determined in this study, and the occurence of locally high chlorophyll concentrations measured by the Regional Water Laboratory and noted by anglers. For a lake of the size and complexity of L. Mask mid-lake sampling cannot provide the basis for a representative assessment of water quality in the whole water body.

Simple and strict reliance on the OECD boundary values to assign trophic status leads to further insensitivity and inaccuracies. For example, a hypothetical increase in the maximum recorded chlorophyll *a* concentration from 8.0 to 8.1 $\mu g\ l^{-1}$, well within sampling and analytical error, changes the assessment of a water body from oligotrophic to mesotrophic. On the other hand an increase from 1.0 to 7.9 $\mu g\ l^{-1}$, indicative of serious enrichment of a nutrient poor lake, would not be reported as a change in trophic status and is likely to remain unnoticed.

While the task of monitoring the quality of 172 lakes across Ireland on a monthly basis is demanding, and understandably involves certain simplifications and omissions, the current level of assessment is clearly inadequate. The sampling programme currently undertaken by the Regional Water Laboratory is more sensitive to localised pollution or bloom events and long term changes, and could be of greater use in the assessment programme. It appears that these data are currently largely uninterpreted.

There were some problems with this regional sampling programme. The data available to us showed inconsistencies in the periodicity and timing of samples, of the measurements taken and the layout and units used in reporting results. Such inconsistencies make interpretation difficult and can only add to confusion for local concerned groups and individuals who exercise their right to obtain the information. Nevertheless, the sampling could provide the basis for an extensive and ongoing monitoring programme, providing consistent information to the EPA and the Fisheries Boards. If such local authority programmes operated throughout Ireland, co-ordinated through a central database and overseen by the EPA, they could replace the current insensitive and expensive national lake surveys.

The Western Regional Fisheries Board recognises the non-uniformity of production in the lake and is currently undertaking a more detailed statistical analysis on results from 17 locations on L. Mask (Kevin Rogers, pers. comm.). Such an initiative would be welcomed by local groups and by Greenpeace.

While I agree with Coyle (1991) that monitoring is not the responsibility of the anglers and local residents, their involvement could be of great value if a mechanism was set up locally to collect and collate observational data. Local involvement would also help to raise general awareness of the condition and importance of the lake.

6.4 Sources of enrichment.

It is important to remember that environmental monitoring, although essential, does not address the causes of eutrophication. Enrichment of the River Robe and L. Mask is continuing and will continue until the principal sources of elevated nutrient inputs are identified and eliminated.

Sewage disposal

A new sewage treatment plant, including tertiary treatment to remove phosphorus, is under construction in Ballinrobe and this will reduce phosphorus inputs to L. Mask. The beneficial impact of tertiary treatment was clearly demonstrated in the case of Lough Neagh in Northern Ireland (Gray 1986). However, there is disagreement about the commissioning date for the Ballinrobe plant, with estimates ranging from six months to two years from present. In the mean time Ballinrobe will continue to be an important point source of nutrient loading. The old treatment works, employing Imhoff settlement tanks without secondary (microbiological) or tertiary capability, appeared to be derelict and not fully operational at the time of our visit. The works have been in a poor state of repair for some time but still handle all the sewage from Ballinrobe (Kevin Rogers, pers. comm.). Thus, effectively untreated sewage is at present simply discharged in to the lower reaches of the Robe and thence in to L. Mask.

Sewage treatment schemes for Claremorris and Hollymount are at the planning proposal stage only and it will be many years before these are operational. Urban sewage is not the only source of phosphorus loading; rural housing developments can also act as significant point sources, particularly if planning regulations on the siting of septic tanks are not strictly adhered to.

Inputs from agriculture.

The importance of diffuse inputs from agricultural land, due to leaching and run-off following fertiliser application, is more difficult to quantify. The use of fertilisers, both organic and inorganic, is not well controlled; for example, as much as 70% of the increase in use of inorganic fertilisers in Ireland between 1980 and 1990 remains unaccounted for (Morgan and O'Toole 1992).

Over the past twenty years there has been a move towards intensive farming techniques in Ireland, particularly for the rearing of pigs and winter housing of cattle (Morgan and O'Toole 1992). The resulting excess over the natural carrying capacity of the environment necessitates mechanisms to store or disperse the manure and slurry effluent. Slurry is a rich fertiliser but the poor targeting and timing of slurry spreading in many areas has led to nutrient overloading of soils. The consequences for freshwater systems have occasionally been disastrous (cf. L.

Sheelin, Duggan and Champ 1992). Run-off from agricultural land accounted for over 80% of the elevated phosphorus inputs to L. Conn (McGarrigle *et al.* 1994).

Farming practices in the Carra-Mask catchment are less intensive, but the area is characterised by rich pasture land. In many areas cattle had access to the Robe River, with the obvious consequence of direct inputs of nutrients and BOD by defecation. In addition, we were informed by local sources that some slurry was being imported for spreading in Co. Mayo. Coyle's (1991) statement that agriculture was not a significant source of nutrient enrichment in the catchment does not appear to have been based on any quantitative analysis and must be considered invalid until the importance of these sources has been properly assessed.

7. Prospects for the future.

Much of the Carra-Mask system is still in a relatively pristine condition. The current problems faced by L. Mask are not of the same order as those facing, for example, L. Sheelin, Co. Cavan (Duggan and Champ 1992, Champ 1994) or Loch Leven in Scotland (LLAMAG 1993), but the threats to the lake must not be ignored. The eutrophication of an oligotrophic lake can be a very rapid process as such systems are sensitive to relatively small degrees of nutrient enrichment (Reynolds 1984). Effects of enrichment are already visible on the eastern shores of L. Mask and it is likely that this region of the lake will become more eutrophic over time. The operation of the tertiary treatment plant in Ballinrobe should remove this point source of phosphorus loading, but as yet the significance of other point and diffuse sources to the Robe and directly to L. Mask are unknown.

Even if all external sources of nutrient enrichment could be eliminated, an unlikely scenario, some damage has already been done to this side of the lake and it could take several years for it to return to its natural state. Phosphorus can accumulate in sediments on the lake bed as a result of inorganic precipitation or the settling out of phytoplankton and organic detritus. This can then act as a reservoir to support algal growth even after removal of external sources. This accounted for the continued high phytoplankton biomass in L. Sheelin during the first few years of operation of the Slurry Management Programme (Duggan and Champ 1992).

7.1 The decline in the quality of Lough Mask as a trout fishery.

Eutrophication of fresh water raises the productivity of all trophic levels through increased growth of the primary producers (phytoplankton, attached algae and higher plants). Inevitably this will lead to an increase in total fish biomass, but favours herbivorous and scavenging fish (eg. cyprinids) at the expense of clean-water salmonids (Lee *et al.* 1991). Therefore, although the total quantity of fish stocks increases, the quality declines.

Dense coverage of the lake bed with attached weed, as observed in some of the eastern bays of L. Mask, can lead to exclusion of the larvae of some of the food species of salmonid fish. In addition to the loss of clean gravel preferred by stonefly, mayfly and caddis larvae, high algal biomass in the water column and on the lake bed can result in deoxygenation of the water due to high respiratory demand at night. Surface algal scums can exacerbate the problem in shallow water by preventing the exchange of oxygen with the atmosphere.

The deterioration in the quality and quantity of food species will inevitably lead to a decline in the stocks of salmonid fish, including brown trout, initially locally but eventually over a wider area. Salmonids have a requirement for well oxygenated waters. Deoxygenation resulting from eutrophication led to the elimination of the cold-water cisco from Lake Mendota, Wisconsin, in the 1940's (Lee *et al.* 1991) and may well be the cause of the disappearance of the Arctic charr from L. Conn (McGarrigle 1994). Low oxygen in conjunction with elevated pH, a further consequence of high algal production, seriously impairs gill function in salmonids (Moss 1988, Lee *et al.* 1991). In addition, any decrease in the transparency of the water (by phytoplankton or suspended sediment) will reduce the feeding efficiency of fish species which are visual predators. A decrease in Secchi depth from 5m to 3m can result in significantly reduced trout catches (Moss 1988).

It is not clear whether the recent decline in the quality of the game fishing in L. Mask, reported by many anglers, is a direct effect of the enrichment of the lake but there is clearly a possibility that the two phenomena are linked. In any event, the presence of thick weed growth and algal scums greatly reduces the visual amenity to visitors and the attraction of fishing the lake.

While the mechanical clearance of weed, the reintroduction of gravel and the control of water flow can help to improve the quality of spawning rivers and potential fisheries (eg. the Robe River), such measures do not tackle the route causes of nutrient and organic enrichment and habitat deterioration.

7.2 The threat of toxic algal blooms.

Eutrophication can increase the risk of significant blooms of toxic phytoplankton, most notably the blue-green algae. *Microcystis aeruginosa*, present in the plankton of L. Mask, produces microcystin, an hepatotoxic peptide and one of the most potent algal toxins known (Santikarn *et al.* 1983, Codd and Poon 1988, Ohtake *et al.* 1989). This toxin has been implicated in the deaths of livestock, birds and fish all over Europe. Notable examples include the death of sheep and cattle following consumption of water from Lake Froylandsvatn in Norway in 1982 (Codd and Bell 1985) and the deaths of several domestic dogs and livestock in Rutland Water, UK, in 1989 (NRA 1990). The production of this toxin does not always coincide with the presence of large blooms of *Microcystis*, although of course the effects would be greater in eutrophic waters.

Some species of *Anabaena* (eg. *flos-aquae*) can generate potent neurotoxins and *Oscillatoria agardhii* has been implicated in a small number of toxic bloom events (Codd and Poon 1988).

7.3 The survival of pathogens

The input of sewage to freshwater systems not only causes nutrient and organic enrichment but can introduce important pathogens. These may remain dormant but viable for some time. Geldreich (1972) recorded viable *Salmonella typhimurum* 117 km downstream of their point of discharge to a river. Many strains of *Salmonella* have the potential for cross infectivity between different groups of vertebrates. Viruses and encysted protozoan parasites may even resist sewage sterilisation processes (Ellis 1989) and are likely to persist for even longer in the environment.

The primary treatment currently in operation at Ballinrobe does not have the capacity for removal of pathogens which, as a result, have been carried in to L. Mask. The east shore of the lough is popular with boat users and, in the summer, bathers who will therefore be exposed to an increased risk of contamination.

The new treatment works at Ballinrobe will greatly reduce the risk from sewage organisms, but pathogens are introduced to the river and lake from other sources, noteably rural sewage systems, livestock access to the river channel, and via birds as vectors carrying pathogens from contaminated sites. An important site in this regard is the open tip at Claremorris, supporting a huge population of gulls. These are known vectors of *Salmonella* bacteria (Meybeck *et al*. 1989).

7.4 Destruction of peatlands in the Partry Mountains.

The rivers feeding the western shores of L. Mask are under threat from the erosion of the peatlands in their headwaters. Deterioration results from the cutting of turf for fuel and, perhaps more significantly, from overgrazing and mechanical damage by sheep. Turf is a living wetland in which a thin layer of slow-growing material at the surface is supported on decaying plant matter which may have accumulated over many hundreds, even thousands, of years. Its dense matrix acts as a sponge, holding rainwater and releasing it gradually in to the streams.

Damage to the surface layer effectively destroys the wetland as it removes the only source of new material and exposes the decaying matter below which is easily eroded. This increases the loading of streams with particulate matter and humic acids and removes the sponge capacity. Heavy rain simply runs off the surface of the bare peat, forming deep gullies and flooding the river. A single such spate event can eliminate the fish population of a river, wash gravel out of the channel or bury it with sediment. The peatland ecosystem itself may never recover.

7.5 Consequences for drinking water abstraction.

Loughs Carra, Mask and Corrib are all currently used for water abstraction and this use will increase in the future. For example, Claremorris is soon to be connected to the L. Mask supply.

Phytoplankton and dissolved organic material (eg. phyto- plankton secretions, humic acids) can cause significant problems for the abstraction and treatment of drinking water. Many diatoms and blue-green algae can block filters used to remove particulates (Collingwood 1977). Others, including the diatoms *Nitzschia* and *Synedra*, *Microcystis aeruginosa* and small flagellates can pass through primary filters and provide substrates for bacterial growth in the distribution system (Ellis 1989).

Phytoplankton extracellular secretions and the products of algal decay can cause further problems. Mucopolysaccharides, components of algal mucilages, can increase the solubility of metal ions and enhance their concentrations in the supply of potable water. This may be particularly important at the Lisloughry intake on L. Corrib because of the close proximity of a rusting ship hull to the intake. *Oscillatoria* spp. and certain diatoms synthesise compounds which impart an undesirable taste and odour to water and which are impossible to remove using conventional treatments. The presence of *Oscillatoria* spp. can also effect the flavour and odour of trout (Persson 1980).

Water treatment for town supplies often involves coarse screening, chlorination (using sodium hypochlorite) and settling only. Chlorination of water containing a significant level of organic matter (eg. phytoplankton and their extracellular products, humic and fulvic acids from peatland and soil run-off) can lead to the production of a range of organochlorine compounds. Of these, chloroform, dichloromethane, bis(2-chloroethyl) ether, tri- and tetrachloroethylene and chlorophenols are known carcinogens (Lawuyi 1992). Trihalomethanes have both chronic and acute toxicities, the main target organs being the liver and kidneys (Fawell and Hunt 1988). The toxicities of chlorination products, including chlorinated organic acids, aldehydes and ketones, and chlorobenzenes, are still under investigation.

These compounds are present in finished tapwater and may be ingested or inhaled, the latter being the primary route for exposure to the volatile trihalomethanes (McKone 1987). The generation of these products can be reduced through the use of chlorine dioxide or chloramine as disinfectants, but these are more toxic than residual chlorine.

Ozonation, in conjunction with ultraviolet radiation treatment, may be the most viable alternative, as advanced microfiltration technology may be prohibitively expensive for use in small treatment works. Ozone is an effective bactericide and virucide and may help to reduce organochlorine contaminants and other mutagens arising from other sources (Lewis *et al.* 1990, Monarca *et al.* 1992). It can generate low levels of toxic aldehydes and post-chlorination is required to maintain the sterility in the supply lines. This technology is used for many supplies throughout Europe, including a major treatment plant in London (Wolfe 1990).

8. Proposals for the protection of Lough Mask.

The doctrine that "the solution to pollution is dilution" is still all too frequently adopted. Freshwater lakes clearly have a finite volume and, with the added complexity of incomplete mixing, even small inputs can cause significant local damage.

8.1 The inadequacy of treating the symptoms.

The clean-up of polluted waters is an expensive and unsatisfactory option, particularly when the maintenance of a pristine environment is a prime economic and ecological concern. Such is the case with the Western Lakes. It would be feasible to tackle the problems associated with eutrophication by treating the symptoms eg. mechanical removal of phytoplankton and weed, precipitation of phosphorus by dosing with aluminium or iron salts, use of herbicides, mixing of deeper waters to destratify the lake and thereby reduce light availability to the plankton, introduction of herbivorous fish species (Moss 1988, Mason 1991, Harper 1992). Such remedial measures do not remove the causes of enrichment and deterioration of water quality and may, in turn, cause more problems than they solve by further upsetting the ecological balance of the system. It is essential to tackle the sources of nutrient enrichment.

8.2 The need for effective sewage treatment.

The introduction of sewage treatment works with phosphorus removal capability should be a priority for all the major urban centres in the Carra-Mask catchment. The use of iron salts or lime in place of aluminium precipitants would be preferable because the toxicity of aluminium to terrestrial and aquatic organisms makes disposal of the residue more difficult.

The cost of tertiary treatment is primarily in consumables ie. the precipitants themselves. The dosing required depends on the phosphate concentrations in the waste water. Phosphate inputs to treatment works could be greatly reduced by the wider use of phosphate free detergents. Household detergents contribute 40-50% of the total phosphorus load (Moss 1988). A wide range of alternative biodegradable detergents are now available but are more expensive. Legislation is required to reduce or eliminate the use of phosphate in household and industrial detergents; such legislation has been particularly effective in Denmark.

Rural developments often escape strict sewage treatment regulations but where small estates or even single houses are built near rivers or on lake shores they can constitute an important point source of nutrients. Planning regulations should be strictly adhered to, backed up by detailed inspections and corrective measures introduced when necessary.

8.3 The use of wetland technology for wastewater treatment.

It is obviously not possible to introduce conventional tertiary treatment facilities for small rural communities, but the use of wetland technology may be possible. Experiments in the USA have demonstrated the feasibility of the use of natural wetlands for bacteriological treatment and nutrient reduction in wastewaters. Nitrogen and phosphorus removal efficiencies by freshwater marshes and peatlands can be as high as 99 and 98% respectively (Hantzsche 1985). In fact, peat wetlands, such as those on the slopes of the Partry Mountains, are particularly effective for dealing with low volumes of wastewater because of the slow flow rates, long contact times and high nutrient absorption capacity. There is a danger that such applications could alter the ecology of the peatland locally, but such perturbations would probably be minimal compared to the destruction through turf cutting and grazing.

The marshes fringing the banks of rivers and shores of lakes may also be effective in the removal of organics and nutrients (Hantzshe 1985), although the removal of nitrogen is generally more efficient than phosphorus (Hook 1993) and artificial measures may have to be introduced to prevent deoxygenation of interstitial waters. It is possible, and ironic, that the eutrophication of Clare Lake may have been avoided if the outfall had discharged in to the fringing reed beds rather than directly in to the lake.

The use of artificial wetlands, constructed according to local needs (Wile *et al.* 1985), is still in experimental stages. Research in this field will be monitored by Greenpeace with a view to its application in Ireland.

8.4 The need for effective fertiliser management programmes.

The benefits of effective control of fertiliser use are clear from the example of L. Sheelin. A detailed, field-by-field survey of soil nutrient status, with particular attention to phosphorus availability, would allow effective targeting of fertiliser applications. This would not be a costly exercise (a single analysis of nitrate and phosphate concentrations costs approximately 50 p and could be carried out by individual farmers) and would bring savings through the reduction in wasteful fertiliser and slurry spreading.

There are regulations governing the timing and location of slurry applications and these must be followed, with prosecutions brought for serious or repeated contraventions. Recent research indicates that phosphorus may be much more mobile in soils than previously thought (Phil Brookes, pers. comm.) and in light of this the minimum distance for fertiliser application from water courses and boreholes may need to be reassessed.

8.5 Changes in grazing management.

The restriction of access of livestock to rivers is a relatively simple measure which could eliminate point sources of nutrient, organic and pathogenic contaminants.

Sheep grazing on uplands has been actively encouraged by the EC through grants to farmers in Ireland. Such subsidised destruction of an ancient ecosystem which is so important to the hydrography and ecology of the rivers and lakes is unnecessary and must be stopped. The grant money should instead be made available to farmers for improvements in animal husbandry on pastureland and for developments which reduce the impact of agriculture on the environment (eg. improved fencing and animal housing, effective slurry management and fertiliser targeting).

8.6 Upgrading and integration of water quality monitoring.

Current monitoring programmes could be improved and recent initiatives taken by the Western Regional Fisheries Board and the Regional Water Laboratory (Michael Flanagan, pers. comm.) are encouraging in this respect. There is a need to move away from the simple assessment of trophic status of a whole lake based on a small number of measurements on mid-lake samples and strict interpretation using OECD boundaries, in favour of more detailed continuous monitoring and interpretation programmes designed according to the topography, hydrography, ecology and amenity of individual lakes. The vigilance of anglers and other lake users is a valuable resource and should be encouraged and used to back up scientific monitoring.

L. Corrib is a designated salmonid water and as such is subject to intensive monitoring and must meet strict quality standards (Clabby *et al*. 1992). Given the importance of L. Mask as a game fishery, its should also receive salmonid water designation.

8.7 Long-term policy for the protection of Irish Lakes

Greenpeace Ireland aims to promote greater awareness of ecological issues and the dangers of eutrophication and other forms of environmental degradation at both local and national level. Local interest groups, like the Carra-Mask Angling Federation, have done much in the past to raise awareness and debate and it is only by working with these groups that our campaigns will be successful. We must also liaise closely with the Local Authorities, the Regional and National Fisheries Boards and the EPA if the real problems are to be identified and the causes rectified. This is essential if pressure is to be brought to bear on National Government and the EC to recognise the importance of the lakes to Irelands natural heritage and economy, and actively to promote and ensure their conservation.

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