LAST CHANCE TO SAVE LOUGH SHEELIN

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CONTENTS **PAGE**

1. Summary 1

2. Introduction 3

   2.1 Current Water Quality Status 4
   2.2 Inputs of Nutrients to Lough Sheelin 4

3. Results of Water Quality Analyses carried out by Greenpeace. 6

   3.1 Materials and Methods 6
   3.2 Results 6
   3.3 General Discussion 13

4. Future Prospects for Water Quality and Lake Ecology 16

   4.1 Spread of Pathogens 16
   4.2 The Abstraction of Drinking Water from Lough Kinale 16
   4.3 Declining Groundwater Quality 17
   4.4 Organohalogens as By-Products of Water Chlorination 18

5. Solutions

   5.1 Source Reduction in Phosphate Loading from Ballyjamesduff Sewage Treatment Works 22
   5.2 Wetland Systems for Nutrient Reduction in Sewage Effluent 22
   5.3 Managing the Application of Slurry 23
   5.4 Slurry Digestion and Tertiary Treatment 24
   5.5 The Move towards Environmentally Sustainable Agriculture 25

6. Greenpeace Demands 27

References 28

1. Summary

Lough Sheelin is a natural resource of major ecological importance. It is a game fishery of world renown and also provides drinking water for Granard and the surrounding area.

Water quality declined and the lake was almost destroyed as a fishery in the 1960s and 70s through mismanagement of the explosive increase of intensive farming within the catchment. The introduction and enforcement of a Slurry Management Programme in the 1980s led to a marked improvement in water quality and hence the quality of the fishery.

However recent data from the Central Fisheries Board and the observations of local people indicate that lake water quality has once again deteriorated.

Concerned by such reports a Greenpeace scientist from the Greenpeace Exeter Research Laboratory and a representative of Greenpeace Ireland visited the Sheelin catchment in July 1994 in order to carry out an independent assessment of water quality through a chemical and biological survey of the lake and its main feeder streams.

Nutrient analyses from all sampling points showed significant amounts of inorganic nitrogen, indicating mesotrophic to eutrophic status. Analyses of chlorophyll a concentrations and phytoplankton species composition were indicative of eutrophic conditions. Combined with Central Fisheries Board data, the Greenpeace findings necessitate a reassessment of the status of Lough Sheelin as eutrophic.

The severely polluted condition of Lough Sheelin poses a grave threat to the lake as a fishery. With such high nutrient levels there is also a serious threat of toxic algal blooms. The high input of animal wastes to the lake also means that there is a danger of transmission of pathogens such as *Salmonella* bacteria.

The threat of algal toxins in Lough Sheelin has serious consequences for the quality of drinking water extracted further downstream from Lough Kinale. Chlorination of waters containing dissolved organic compounds (DOC) readily generates organohalogens, which can be acutely toxic to humans and animals, Eutrophic waters such as Lough Sheelin tend to have high DOC levels as a result of algal production and decay.

In order to obtain an indication of the risks posed by chlorination of water from Lough Kinale, a sample of tap water from Granard was analysed for organohalogen contamination. Three organohalogens were reliably identified - one is a confirmed carcinogen. Their presence in Granard drinking water is cause for concern.

There is an urgent need for effective control of nutrient inputs to Lough Sheelin and its catchment.

Tertiary treatment must be installed at Ballyjamesduff Sewage Treatment Works in order to reduce a major source of phosphorous to the Mountnugent river and hence to Lough Sheelin. In addition, a ban on phosphate detergents must be introduced and enforced. Alternative forms of sewage treatment, such as wetland sytems, must be explored as they could play a role in reducing nutrient loading to the catchment.

A Slurry Management Programme must be implemented immediately and given priority by local and national government. Soil and groundwater vulnerability testing must form part of this programme so that surface and groundwater can be protected.

Measures to reduce the polluting potential and bulk of slurry, such as anaerobic digestion should be given serious consideration. Furthermore the Minister of Environment must urgently implement the provision of the Ist Schedule, Section 6 of the EPA Bill 1990 for integrated pollution control of intensive agriculture.

In the long term Greenpeace advocates a move away from intensive agriculture towards sustainable farming practices. This represents the only real solution to the current degradation of water quality caused by concentrated slurry production, storage and disposal.

2. Introduction

Lough Sheelin is a beautiful and unique natural resource. Along with Loughs Mask, Corrib and Conn, it is one of the few limestone lakes in Ireland, and supports a diverse and highly specialised ecology. The lake is of world renown as a recreational game fishery and its waters (via L. Kinale) are abstracted to provide drinking water for the town of Granard and the surrounding area.

The fragile ecology of the lake was almost destroyed in the 1960's and 70's through mismanagement of the explosive increase in intensive farming, particularly pig-rearing, in the catchment during this period. Rapid deterioration of water quality resulted from greatly increased nutrient loading due to overloading of the surrounding catchment with animal wastes. Excessive growth of nuisance aquatic macrophytes was recorded in shallow water and dense blooms of phytoplankton covered much of the lake during the spring and summer. The natural community of benthic plants in deeper water (especially the charophytes), an important habitat component for the larvae of insects such as mayfly and caddis, declined because of the reduction in light penetration through the water. This in turn led to a sharp decline in the fish stocks of the Lough and consequently to the quality of the lake as a fishery.

A reversal of the devastating impacts of eutrophication resulted from the introduction and enforcement of a Slurry Management Programme, backed by effective pollution legislation, in the early 1980's. This demonstrated that agricultural production and the protection of the environment were not necessarily mutually exclusive. With sensitive planning and relatively low investment the two were integrated in an attempt to maximise the efficacy of use of all resources and minimise detrimental effects to the environment. As a result of the reduction in phosphorus inputs, water quality improved markedly and phytoplankton biomass fell over several years from levels indicative of eutrophic to mesotrophic status. The ecological balance of the lake system was gradually restored and the quality of fishing improved as key food species, such as the mayfly, began to return.

The immediate phytoplankton growth response to the temporary increase in phosphorus loading in 1985 showed the sensitivity of the system to external phosphorus inputs, while the continuation of higher productivity for some time after this event demonstrated the importance of sediment dynamics and recycling of phosphorus within the lake. The hydraulic and nutrient data of Duggan and Champ (1992) confirm that Lough Sheelin is a net accumulator of both nitrogen and phosphorus as the inputs generally greatly exceed outputs. Inputs of nutrients to such a system should, therefore, be very carefully limited and controlled.

2.1 Current water quality status

We are already seeing the beginnings of a return to the high nutrient and organic loading of the Sheelin system which characterised the 1960's and 70's and caused severe damage to the ecology of the lake. Recent reports from the Central Fisheries Board (Champ 1994a,b,c,d), and the observations of local people, indicate that the quality of the lake water is again in decline. Champ (1994d) reported scums of the blue-green algae *Coelosphaerium sp.*, *Aphanizomenon sp.* and *Oscillatoria sp.* covering significant areas of the lake in November and December 1994. *Oscillatoria sp.* dominated the phytoplankton during October last year and high chlorophyll a concentrations (24-24ug/l) were maintained through November and December. The classification of the lake as mesotrophic in the Water Quality Report for 1987-1990 (Clabby *et al.* 1992) needs to be reassessed as the system drifts again towards eutrophic status.

2.2 Inputs of nutrients to L. Sheelin

Lough Sheelin currently receives inputs of nutrients and organic matter from two principal sources, the disposal of slurry from cattle and intensive pig-rearing units and sewage effluent from the Ballyjamesduff Sewage Treatment Works (STW). The Mountnugent River is the most significant point source discharge, receiving nutrient loads from Ballyjamesduff STW, from agricultural run-off from slurry-ammended ground and possibly from intensive units directly, accounting for over 70% of the phosphorus inputs to the lake itself (Champ 1994c).

i) Intensive Pig Production

As much as 10% of the national pig herd is owned by producers in the Lough Sheelin catchment. The intensive methods employed mean that the natural carrying capacity of the environment is greatly exceeded and this raises the serious problem of disposal of the vast quantities of slurry waste which are generated, equivalent in larger units to the sewage prodution of a small town. Since the breakdown of the Slurry Management Programme in the late - 1980's, neither has the production and disposal of animal slurry been effectively regulated, nor storage facilities properly inspected. This has led, inevitably, to the spreading of slurry during restricted periods and the inappropriate and inefficient application to soils already rich in nutrients. In such circumstances increased inputs of nutrients and organic matter through runoff, leaching and seepage are unavoidable.

The response from Cavan County Council, that the recent deterioration in the water quality of Lough Sheelin and its feeder streams is due to heavy precipitation (Anglo-Celt, November 1994), fails to identify and address the real problems. Heavy rain does increase the run-off and leaching of nitrogen and, possibly, phosphorus, but if it were not for the nutrient excess in the catchment because of intensive farming, the impact of rainfall would be much less significant.

ii) Sewage Treatment

The existing Sewage Treatment Works at Ballyjamesduff is capable of treatment only to secondary level (coarse screening, settlement and microbiological treatment) and is in need of replacement. The plant is currently responsible for around 25% of the phosphorus loading of L. Sheelin. It is understood that proposals for replacing and upgrading the plant to supply tertiary treatment (phosphorous stripping) are under consideration but, even if accepted, it will be many years before such a plant will be operational. Until then the sewage effluent will continue to be a major point source of nutrient inputs to the Mountnugent River and Lough Sheelin.

3. Results of Water Quality analyses carried out by Greenpeace

On 24th July 1994 a scientist from the Greenpeace Exeter Research Laboratory and a representative of Greenpeace Ireland visited Lough Sheelin. The purpose of our visit was to obtain an overview of the catchment, to discuss the recent trends in the lake with representatives of the Lough Sheelin Trout Protection Association and to carry out a very limited chemical and biological survey of the lake and its main feeder streams.

3.1 Materials and methods

Water samples were taken from five stations; three feeder streams (Mountnugent River, Ross River/Upper Inny and the mouth of the Bellsgrove River at Hollywell Bay), the main outflow to L. Kinale (entrance to the Lower Inny) and a mid lake sample (in deep water near Church Island). Duplicate samples were taken at each station. Samples were analysed for major nutrient ions (nitrate, nitrite, ammonium and phosphorus) and chlorophyll a. Water transparency was measured where applicable using a Secchi disk. Surface (0-0.5m) phytoplankton populations were collected using a net with a 55um mesh and identified to genus level only under a light microscope. Relative abundances of the different genera were estimated during identification. Surface oxygen saturation was determined using a hand-held, temperature-compensating Oxygen probe and meter.

3.2 Results

Data from nutrient and chlorophyll analyses are presented in Tables 1 and 2. OECD fixed boundary limits used for the classification of lakes according to trophic status (OECD 1982), and guideline values suggested by Harper (1992) are included in Table 1 for comparison.

At all stations, significant amounts of inorganic nitrogen (principally nitrate, see Table 2) were recorded, including values in the Ross River (Upper Inny) which were more than double the upper limit for mesotrophic status. In the lake samples (21-23) nitrogen concentrations were lower, probably resulting from uptake by phytoplankton and other aquatic plants and denitrification by bacteria. However, all data indicate mesotrophic to eutrophic status for the feeder streams and the lake itself.

It is important to note that the measurement of inorganic nitrogen and phosphorus present in the water at any one time cannot give a full picture of nutrient loading to a system. What is measured in the water is that which has not yet been taken up by algae or higher plants. Thus we would expect to find high nutrient levels in winter when algal and higher plant growth is limited by poor light conditions, and lowest concentrations during the main growing season in the spring and summer, when light-limitation is alleviated and the plants are able to take up

Station		Parameter			
No.	Location	Ni(ug/l)	Pi(ug/l)	Chl.a(ug/l)	Secchi(m)
	Lough Sheelin				
1	Mountnugent River	327 322	55 52	3.25 3.06	n.d.
2	Ross River (Upper Inny)	1061 1205	<5 <5	8.74 8.79	n.d.
3	Bellsgrove River (Hollywell Bay)	259 197	<5 <5	10.09 10.23	2.1
4	Lower Inny (to L.Kinale)	234 227	<5 <5	3.54 3.00	>2.0
5	Sheelin mid-lake (Church Island)	60 148	47 12	15.92 16.64	1.9
	OECD fixed boundary classification				
			mean	mean	mean
	Oligotrophic		<10	<2.5	>6
	Mesotrophic		10.-35	2.5-8	3.-6
	Eutrophic		>35	>8	<3
	Classification based on Harper (1992)				
	Oligotrophic	<200	<10	<4	>3.7
	Mesotrophic	200.-500	10.-20	4.-10	3.7-2
	Eutrophic	>500	>20	>10	<2.0

Table 1. Principal water quality data for five stations in the Lough Sheelin system, including three main feeder streams, the main outflow to Lough Kinale and a mid-lake station near Church Island. Ranges for waters of different nutrient status (OECD 1982, Harper 1992) are included for comparison. (Ni - total inorganic nitrogen; Pi - total inorganic phosphorus)

and utilise the inorganic nutrients. Therefore nutrient concentrations may be a better indicator of trophic status of a lake in winter, and phytoplankton biomass (ie. chlorophyll concentration) in spring and summer.

In very nutrient rich waters, however, excess nutrients may still be detectable during summer. That we were able to measure high nitrogen and phosphorus concentrations in samples from Lough Sheelin and its feeder rivers in July is cause for concern.

Station 1: Mountnugent River

Phosphorus was detectable in consistently high concentrations at this station. Values measured in duplicate samples were higher than the OECD limit for mesotrophic waters (based on annual mean values) and in the eutrophic range (Table 1). It is likely that the secondary Sewage Treatment Works at Ballyjamesduff contributed significantly to the phosphorus loading of this stream.

There was also clear evidence of the input of material rich in organic matter directly to the Mountnugent River. Extensive areas of the gravel stream bed were covered by a thin (1-2 cm) layer of fine sediment which had a sulphurous odour. In places the river water was deep brown in colour and surface accumulations of foam were seen in slower flowing sections. According to local reports this is a fairly recent recurrence of what was observed during the 1970's before the implementation of the Slurry Management Programme. Although the gravel below the fine sediment appeared clean, this thin, organic-rich layer over the surface would rapidly exclude most stream invertebrates through asphyxiation, including the larvae of the mayfly and caddis fly on which the fish feed. These would be replaced by species capable of surviving low oxygen levels (eg. *Tubifex tubifex*) but which are of little food value to salmonid fish. Benthic invertebrates were not sampled in the current study, but should form part of any future assessment of the condition of the streams (Metcalfe-Smith 1994).

In pools and dead zones of the river large quantities of organic matter had accumulated. This represents a large latent demand for oxygen which, if resuspended by increased flow following heavy rain or by other disturbance, could rapidly deplete oxygen from the river water. A simple test was carried out in order to estimate the potential oxygen demand of the sediment (Chemical/Biochemical Oxygen Demand).

A small quantity (ca 2g wet sediment) was transfered to a sterile container. The container was filled completely with river water (30ml) and the oxygen concentration of the water was measured before, and at short intervals after, resuspension of the sediment. Within 10 minutes oxygen saturation fell from ca 93% to below 50% and continued to fall rapidly. Such a high oxygen demand would have severe consequences for river fish, particularly salmonids, which require highly oxygenated conditions.

Despite high nutrient concentrations, no phytoplankton were detected in the net samples. Low levels of chlorophyll a (Table 1) were due to the presence of debris from higher plants suspended in the water. The river was quite fast flowing at this point; the absence of a conspicuous phytoplankton community is expected under such conditions as plankton are simply washed out of the river more rapidly than they can divide. The enriched trophic status of the river was apparent from the extensive growth of submerged aquatic higher plants (*Potamogeton spp.*) which are attached to the sediment and are therefore able to maintain their position in the flow. Although these plants will remove some of the nutrients entering the system, much of the nutrient loading will be carried directly in to Lough Sheelin.

No.	Location	[N] (ug/l) NO_3^--N	NO_2^--N	NH_4^+-N	Total
1	Mountnugent River	310	5	12	327
		305	4	13	322
2	Ross River (Upper Inny)	1031	1	29	1061
		1141	<1	64	1205
3	Bellsgrove River (Hollywell Bay)	222	<1	37	259
		180	1	16	197
4	Lower Inny (to L.Kinale)	179	3	52	234
		166	2	59	227
5	Sheelin mid-lake (Church Island)	56	1	3	60
		146	<1	2	148

Table 2. Concentrations of the ions nitrate, nitrite and ammonium making up the total inorganic nitrogen concentration in water at the five stations.

Genus	Station no.			
	2	3	4	5
Diatoms				
Asterionella		***	***	***
Cylindrotheca			*	
Diatoma	*	**	*	**
Fragilaria		**	***	**
Melosira			**	*
Navicula	*			**
Nitzschia		***	**	**
Rhizosolenia		*	**	*
Tabellaria	*			
Blue-green algae				
Anabaena				**
Aphanocapsa			*	
Aphanothece				*
Gomphosphaeria		**	*	*
Merismopaedia		*	*	
Microcystis		*	*	*
Oscillatoria			*	*
Green algae				
Dictyosphaerium			*	*
Oocystis		*	**	*
Pediastrum		*		*
Chrysophytes				
Dinobryon		**		*
Dinoflagellates				
Ceratium		*		*
Desmids				
Staurastrum			*	*

Table 3. Species composition and relative abundance at four of the five stations sampled.

*	present
**	common
***	abundant

For description of Stations see Table 1. Water from Station 19 (Mountnugent River) contained debris of higher plants but no intact phytoplankton.

Station 2: Ross River, Upper Inny

This station was on a slower flowing, canalised stretch of the Upper Inny River, close to its discharge to Lough Sheelin. Dissolved inorganic phosphorus was below detection limits here, but nitrogen concentrations (principally nitrate) were very high (Table 1). The river ran through rich pasture land upstream of the sampling point, where livestock had free access to the river channel, probably accounting for the high nitrate loading.

Chlorophyll levels were also higher, in the range of mesotrophic to eutrophic status (Table 1) and phytoplankton were present in the form of small diatom species (Table 3), although higher plant debris still formed an important component of the chlorophyll biomass. Growth of submerged aquatic plants (*Potamogeton spp.* among others) was extensive. Information from local sources suggested that this had always been a fairly productive stretch of river.

Station 3: Hollywell Bay, the mouth of the Bellsgrove River

This station was reached by boat because of the inaccessibility of the lower reaches from land. The water was fairly shallow (2-3m) and very slow flowing and the river outflow was fringed with reeds and other emergent vegetation.

Again phosphorous was below detection limits; total inorganic nitrogen was lower than in the Ross River, although absolute nitrogen concentrations were still relatively high for mid-summer. Chlorophyll concentrations were higher here, above the lower limit for eutrophic status (Table 1), and the chlorophyll biomass was dominated by a diverse assemblage of phytoplankton (Table 3). Water transparency (Secchi depth 2.1m) was lower than in July of the four previous years (Table 4, Champ 1994); light attenuation by chlorophyll was primarily responsible for the low transparency.

The phytoplankton was dominated by the diatoms *Asterionella formosa, Nitzschia sp., Diatoma sp.* and *Fragilaria sp.*. The green algae *Oocystis sp.* and *Pediastrum sp.* and blue-green algae, including the toxic species *Microcystis aeruginosa*, were also present. These species are characteristic of the more productive, meso- to eutrophic lakes in Europe and North America (Pearsall 1932, 1967, Lund (in Macan 1970),Reynolds 1978, 1984, Harper 1992, Mason 1991).

Year	Pi(ug/l)	Chl.a(ug/l)	Secchi(m)
1990	9	14	2.5
1991	8	12	3.0
1992	15	16	3.0
1993	31	18	2.3
1994	12.-47	15.9-16.6	1.9

Table 4. Changes in principal water quality parameters for July over four years (1990-1994) for mid-lake samples in Lough Sheelin. Data for 1990-1993 from Champ (1994); data for 1994 from this study.

Station 4: Entrance to Lower Inny, Outflow to Lough Kinale

Nutrient concentrations were similar here to Station 3, but chlorophyll concentrations were lower (Table 1). The Secchi depth was greater than 2m, but was impossible to determine exactly because of drift in the strong current and the shallowness of the water.

The phytoplankton community was again diverse, with many species characteristic of eutrophic waters (Table 3). In addition to the dominant diatoms, a number of blue-green genera were present, including *Oscillatoria sp.*, typical of eutrophic and hypereutrophic water bodies (Hutchinson 1967, Reynolds 1984), and *Aphanocapsa sp.*, reported in highly enriched lake systems in North America (Haffner *et al.* 1980, Sze 1980).

However, the biomass at this station was dominated by emergent vegetation and benthic plants, particularly charophytes, which appeared to cover large areas of the lake bed in the shallows. Clearly any complete assessment of the trophic status of the lake would need to take this large component of the biomass and productivity in to account. This was beyond the scope of the current investigation.

Station 5: Lough Sheelin mid-lake, off Church Island

Total inorganic nitrogen was lower at the centre of the lake than at the periphery and in feed rivers (Table 1) as may be expected through uptake by phytoplankton and other plants. Phosphorus was also detected in these samples although the replication between duplicates was not good (Table 1). This may have resulted from sample contamination, but more likely was evidence for the existence of temporal and spatial patches of nutrient supplied to surface waters from the sediments. As discussed above, Lough Sheelin is a net accumulator of phosphorus, accounting for the delayed response to reductions in external phosphorus loading (Duggan and Champ 1992). Pulses of phosphorus may reach surface waters through release following local deoxygenation or physical disturbance of the sediments, or simply the local breakdown of thermal stratification of the water by eddies and internal waves, supplying nutrients from deeper waters. The importance of these processes needs to be investigated as such pulses would be crucial to the maintenance of surface phytoplanton populations and the initiation of blooms through the year.

Inorganic phosphorus and chlorophyll concentrations and Secchi depths from our mid-lake sample (July 1994) are compared in Table 4 to equivalent values for July in 4 previous years. In general our data agree well with those of Champ (1994). Since July 1990 there has been a slight increase in July chlorophyll, an increase in phosphorus concentration and a small decrease in the Secchi depth recorded. On the basis of values of all three parameters,the status of the lake could be reassessed as eutrophic in 1994.

The mid-lake sample in deep water again showed a diverse, diatom-dominated phytoplankton assemblage (Table 3). The abundance of the green alga *Pediastrum spp.* may also be characteristic of nutrient-rich waters. Of the blue-green algae, the nitrogen-fixing genus *Anabaena* was a particularly conspicuous component of the plankton, while *Microcystis, Aphanothece* and *Oscillatoria* were present in smaller numbers. Some species of *Microcystis* and *Anabaena* can release potent toxins, particularly when growth is limited by supply of phosphorus, and all are capable of forming extensive blooms and surface scums.

2.3 General discussion

The value of single, or even duplicate samples taken from widely spaced stations as an assessment of the water quality status of the Sheelin system is questionable. The current study was severely constrained by the time available, but was never intended to be an extensive survey. Nevertheless, the sampling programme carried out was equivalent to that used monthly by the ERU on which official classifications of lakes are based (eg. Clabby *et al.* 1992).

Fig. 1 plots the changes in maximum recorded chlorophyll a concentration year-by-year from 1987 to present for mid-lake samples, irrespective of when the maximum occurred. It is this parameter which is tabulated in the quality assessment report for 1987-1990 (Clabby *et al.* 1992), and on which much of the classification of trophic status depends. Using the same criterion, data from 1990 onwards highlight a worrying trend of increasing phytoplankton biomass. Exceptional heavy rains in 1993-1994 may account for part of the increase in nutrient loading and phytoplankton biomass, but could not be the only factor responsible for such a sharp increase in recent years.

Figure 1. Maximum recorded mid-lake chlorophyll a levels for Lough Sheelin from 1976 to present. Data from 1976-1990, Clabby *et al.*(1992); from 1991-1994, Champ (1994a,b,c,d). Dashed lines show upper boundary limits for oligotrophic and mesotrophic status based on annual maximum chlorophyll a levels, as defined by OECD (1982).

The species composition and relative abundances of the phytoplankton can be a powerful indicator of trophic status and were also examined in the current study. Whereas nutrient concentrations and chlorophyll biomass may be highly variable in space and time, the composition of the plankton takes a greater time to respond to changes in conditions. The makeup of the phytoplankton can therefore be used as a time-integrated indicator of nutrient status of a water body.

Future monitoring programmes should include at least identification and relative abundance determination of broad phytoplankton groups and certain key species (indicators of trophic status, toxic species, etc.). This can be done with the aid of a simple key (eg. Belcher and Swale 1973) and would give a better understanding of the dynamics of the system than measurement of nutrient concentrations and biomass alone. In addition, the importance of benthic plant production to shallow areas and to the lake as a whole is currently being overlooked; our observations indicate that this is a serious ommission.

4. Future prospects for water quality and lake ecology

Lough Sheelin is naturally more nutrient-rich than many of the Western lakes and has always supported very high fish populations. However the process of artificial (or cultural) eutrophication is extremely damaging to the lake and to the local economy, as was clear from the experiences of the 1970's. If the current trends in nutrient loading and production of phytoplankton and higher plants continue, further decline of the water quality and overall ecology, and the complete destruction of the lake as a fishery, are inevitable. Without effective inspections and pollution control legislation this is a highly likely scenario. Lough Sheelin is clearly capable of accumulating large reserves of nitrogen and phosphorus as organic matter and in the sediments. These reserves could sustain high spring and summer phytoplankton populations for many years, even after cessation of further inputs, with the possibilty of extensive algal blooms and surface scums, local deoxygenation in shallow bays and the generation of potent toxins, particularly by blue-green algae. Although not dominant in July, the scum forming blue-green alga *Oscillatoria sp.* and the toxin-producing genera *Microcystis* and *Anabaena* were present in the lake in numbers which could readily initiate a bloom, particularly during prolonged periods of warm, sunny weather. Such genera do not need to dominate the plankton in order to pose a serious threat from the toxins they produce. For example, the toxicity of waters of L. Caragh, Co. Kerry, in summer 1994, although suspected to have been due to toxic phytoplankton, did not correspond to large blooms or dominance of the toxin-producing forms (The Kerryman, June 10th 1994).

4.1. Spread of pathogens

While freshwater inflows to the lake continue to be exposed to the input of animal wastes, either directly or through runoff, the danger of pathogen transmission remains very real. The bacterium *Salmonella sp.*, of which over 200 types are known (some of which are capable of cross infection), can survive for great times and distances in freshwater, eg. Goldreich (1972) recorded viable *Salmonella typhimurum* 117 km downstream of their point of discharge. Data on survival of viruses and encysted protozoan parasites is poor, but it is likely that these would be even more robust than bacteria (Ellis 1989).

4.2. The abstraction of drinking water from Lough Kinale

The deterioration of water quality in Lough Sheelin has consequences also for the abstraction of drinking water further downstream.

i) High algal biomass

Blockage of sand filters, particularly with filamentous and chain forming species (Collingwood 1977), is sometime unavoidable if water is abstracted from eutrophic sources. Other species which are small enough to penetrate the filters may then decay, leading to increased undesirable microbial activity.

ii) Algal products

The presence of large algal populations, particularly *Oscillatoria spp.* and certain diatoms, can impart to water a stale odour and taste. There is also the more serious human health risk from algal toxins. For example *Microcystis aeruginosa* produces a potent neurotoxin, microcystin, which is effective at very low concentrations and has been implicated in the deaths of pets and livestock in many European countries (see Codd and Bell 1985 for a review). Similar toxins may be linked to skin and eye irritations and gastroenteritis in humans.

A recent report by the Drinking Water Inspectorate in the UK suggested that algal toxins do not present a human health risk in treated water supplies (ENDS 236, 1994). However, although concentrations in tap water may be well below levels which are acutely toxic to animals, little is known about the health risks associated with long term exposure to low concentrations. For example, there have been no studies of the carcinogenicity of these toxins.

Other algal products also have implications for water abstraction, e.g. mucopolysaccharides, secreted by many species, chelate heavy metals and may render them more bio-available (Ellis 1989). Iron or aluminium-based coagulants, used in phosphate stripping, may also end up in the drinking water system (Hayes and Greene 1984). Also, in water rich in organic matter (endogenous or otherwise), chlorination can yield a range of organochlorine compounds, including chloroform (see below).

iii) Nitrates

Concentrations of nitrate were higher than expected for this system, but were a long way below the drinking water limit of 11.3 mg l^{-1} NO_3^{-}-N; similarly for nitrite and ammonium. It would be interesting to measure the seasonality of nitrate concentrations entering Lough Kinale from Lough Sheelin as these are likely to be much higher during the winter when heavy rain may increase leaching and run-off and uptake by phytoplankton would be low.

4.3 Declining Groundwater Quality

Although hydrogeological data for county Cavan is poor the most recent groundwater assessment of the area (Friel & Quinn 1994) reports that groundwater quality has deteriorated since 1979, with the majority of wells showing an increase in nitrate and potassium levels. Water samples from and close to the Lough Sheelin Lower Limestones aquifer have shown coliform contamination and high nitrates. Although these are only preliminary results they may be indicative of widespread aquifer pollution considered attributable to high rates of slurry spreading. These results are cause for concern in those areas where groundwater supplies domestic water needs.

4.4. Organohalogens as by-products of water chlorination

The use of chlorine for the disinfection of drinking water was originally introduced in municipal systems early this century to combat typhoid (IARC Monographs 1991). Since then it has become the most widely used form of water treatment, in both urban and rural supplies all over the world.

All natural waters contain dissolved organic carbon (DOC) compounds. The types and abundances of such compounds depend on the nature of the water and of any perturbations to its quality. Humic and fulvic acids from soils commonly form a significant part of the total DOC composition, but algal secretions, decaying algal and higher plant material and exogenous organic matter from sewage and animal wastes also contribute. Eutrophic waters contain more DOC than waters of lower trophic status (Thurman 1986) as a result of algal production and decay.

Addition of reactive chlorine to waters containing dissolved organic carbon compounds readily generates organohalogens as by-products (Ram 1986). The presence of chloroform in chlorinated drinking water was first noted in 1974 (IARC 1991). Although this is normally the most abundant organohalogen formed, many other compounds may be generated in similar reactions from the complex mixtures of substances in the DOC fraction (including chlorinated acetic acids, acetonitriles, ketones and phenol derivatives). Humic and fulvic acids are important precursors. Clearly, the higher the concentration of dissolved organic carbon, the greater the concentrations of organohalogens generated during chlorination (Menzer and Nelson 1986). Many of these compounds are mutagenic to bacteria and, if present in high enough concentrations, can be acutely toxic to humans and other animals (Fawell and Hunt 1988, Lawuyi 1991). For example, chloroform can cause liver and kidney damage and suppress central nervous system function, and is a confirmed carcinogen (Ward 1976).

Epidemiological studies in the US indicate a link between the chlorination of drinking water, the concentration of DOC in that water and the incidence of certain forms of cancer, particularly of the kidney, bladder, stomach, intestine and lung (IARC 1991). It is difficult to define specific causes and effects in such studies as 80-90% of the DOC in finished waters is still uncharacterised (Bull 1986).

In recognition of the vast range of organohalogens detected and the paucity of ecotoxicological and epidemiological data, US Safe Drinking Water legislation requires monitoring and regulation of all substances which may have an adverse effect on human health (Ram 1986). Similarly, EC Directive 76/464/EEC aims to set strict limits on all "organohalogen compounds and substances which may form such compounds in the aquatic environment" and on substances which have been proven to "possess carcinogenic properties in or via the aquatic environment" (EEC 1976).

To obtain an indication of the risks posed by chlorine - disinfection of water from L. Kinale, a sample of tap water from a household in Granard was analysed for organohalogen contamination as part of the current study.

i) Methods

The sample was collected on 9/11/94 in an analytically clean glass bottle which had been pre-rinsed with pentane to remove any organic residues. The bottle was filled to exclude air bubbles (so that volatile organics would remain in solution), chilled and dispatched immediately by air courier to the Greenpeace Exeter Research Laboratory.

Immediately on receipt, the sample was analysed by gas chromatography/mass spectrometry (GC/MS), according to the methodology laid down in EC Directive 80/778/EEC (Annex III C) (EEC 1980b). Volatile organic contaminants were purged from the sample using analytical grade helium, separated using gas chromatography and detected and identified using a mass selective detector.

ii) Results

Organohalogens detected in the sample are listed in Table 5, along with the degree of certainty in the identification. The chromatograph trace (Fig.2) shows the detector response peaks corresponding to these compounds in the sample. Reliable identifications were obtained for trichloromethane (chloroform - confirmed carcinogen; Ward 1976), bromodichloromethane (suspected carcinogen; Menzer and Nelson 1986, Merck 1989, Sittig 1994) and dibromochloromethane (no carcinogenicity studies). All these haloforms are hazardous substances. They are quite commonly found in chlorinated tap water, but the concentrations depend on the amount and nature of DOC in the raw water.

Figure 2 Gas chromatogram for Granard tap water sample, showing peaks of compounds which were identified by mass spectrometry (see Table 5)

Compound	**Match quality**	**Carcinogen?**
trichloromethane	96%	confirmed
bromodichloromethane	91%	suspected
dibromochloromethane	87%	no data
dichloroacetonitrile	52%	no data

Table 5. List of organohalogen contaminants isolated from Granard tap water (sampled 9/11/94) using GC/MS linked to a purge and trap volatile organic carbon system. Match quality is a measure of the reliability of the identification process for each compound.

iii) **Discussion**

The analyses described above are non-quantitative, so it is not possible from these data to assess the extent of the health risk from the presence of these compounds. However, their presence in itself, in quantities which are readily detectable without extraction and concentration, is cause for concern. Without routine monitoring of these compounds, the potential health risk from consumption of chlorinated water abstracted from L. Kinale remains unknown.

EC Directive 80/778/EEC on the quality of water for human consumption requires that "haloform concentrations must be as low as possible", with a guideline upper limit of 1ug l-1 (EEC 1980b). As the generation of such compounds is strongly related to the concentration of DOC, this Directive implies that all reasonable steps should be taken to limit DOC levels in waters for abstraction, including tackling the causes of eutrophication and minimising inputs of exogenous organic matter.

There are a number of alternative mechanisms for the disinfection of drinking water which reduce or eliminate the generation of organohalogens (Lykins et al. 1994). Perhaps the most promising is the use of ozone, which is very effective against bacteria and viruses (Lewis *et al.* 1990) and may even neutralise most algal toxins (ENDS 236, 1994). Ozonation is particularly widely employed in France (IARC 1991). Although ozonation does not generate chlorinated residues, it can produce aldehydes and organic acids, which may also be toxic and undesirable (IARC 1991), if used to treat water with high DOC content. Therefore, ozonation, although beneficial and applicable for small- and large-scale water treatment (Wolfe 1990), should not be seen as a solution to the problems of drinking water disinfection from eutrophying water bodies such as L. Kinale but rather immediate steps must be taken to limit DOC levels in waters for abstraction by tackling the causes of eutrophication and minimising inputs of exogenous organic matter.

5. Solutions

Given the naturally nutrient-rich soils and the high concentration of intensive animal rearing units in this area this is hardly surprising that 70% of Irish lakes classified as eutrophic in the 1987-90 ERU assessment (Clabby et al. 1992) are in Co. Cavan. This highlights the special need for effective control of nutrient loading from animal wastes and artificial fertilisers, in this county, although this should form part of an integrated programme for the whole of the Shannon catchment.

5.1. Source reduction in phosphorus loading from Ballyjamesduff sewage treatment works

The introduction of tertiary treatment facilities at the Ballyjamesduff STW is a clear priority as this will effectively eliminate a major point source of phosphorus inputs to the Mountnugent River and so to Lough Sheelin. The cost of phosphorus removal increases proportionally to phosphorus loading of the STW; measures to reduce such loading would, therefore, be highly desirable.

Between 20% and 60% of the phosphorus load to STW in Europe arises from the use of phosphate-based detergents (Moss 1988, Dwyer *et al.* 1990, Mason 1991). Clearly this is equivalent to, or greater than, the contribution from human waste (Morris and Bird 1984). Voluntary restrictions on the use of phosphates in detergent formulations have now been adopted by France, Italy, Germany, Belgium, Sweden and the Netherlands. A total ban has been in operation in Switzerland since 1986 (Morris and Bird 1994). While such legislation alone is unlikely to alleviate the problems of eutrophication (Lund and Moss 1990), it would help to reduce total phosphate loading and should therefore be implemented as a matter of urgency.

5.2. Wetland systems for nutrient reduction in sewage effluent

Natural wetlands are generally recognised as highly effective systems for the degradation of organic matter and the cycling of nutrients (Hodson *et al.* 1985, Guntenspergen and Stearns 1985). In recent years considerable research effort has been invested in studies of the use of both natural and constructed wetlands for the polishing of municipal and industrial wastewaters prior to discharge into water courses. In addition to the reduction of biochemical oxygen demand (BOD) and suspended solids (Cooper *et al.* 1994, Conley *et al.* 1991), wetlands can be very effective in the removal of nutrients (Hantzsche 1985). Removal efficiencies for nitrogen are almost invariably much higher than for phosphorus (Green and Upton 1994, Weissner *et al.* 1994), as the complex mosaic of oxidised and anaerobic zones favours a combination of nitrification and denitrification. Up to 98% phosphorus reduction may be achieved by slow filtration through a dense soil matrix eg. peat (Hantzsche 1985), but this appears to be a largely physical, surface-binding process which ultimately will become saturated and ineffective.

There are a number of other problems with the use of wetlands for wastewater nutrient reduction. Use of natural wetlands for wastewater treatment undoubtedly changes the ecology of the system (eg. Brennan 1985, Day and Kemp 1985), which may be undesirable, and the construction and management of artificial wetlands can be an extremely intensive and delicate process (Wile *et al.* 1985, Crites 1994, Hammer and Knight 1994). Nevertheless, wetland technology has been used effectively for nutrient removal in many countries (Gosselink and Gosselink 1985, Fleischer *et al.* 1994, White *et al.* 1994), including Ireland (O'Hogain and McCabe 1994). The potential for extensive application of wetlands for rural and small urban wastewater treatment systems in Ireland should be explored in more detail. It could possibly play a significant role in reducing the burden on centralised STW plants and thus help decrease nutrient loading in a vulnerable catchment such as Lough Sheelin.

5.3. Managing the application of slurry

The Slurry Management Programme was instrumental in the recovery of the lake and its fishery in the early 1980's and, over the four year period of operation, cost less than 0.1% of the total income from pig-farming in the area (Duggan and Champ 1992). Local farmers, represented by the influential Sheelin Farmers Association, recognised the value of the programme and were willing to operate within its framework. A revised Slurry Management Scheme must be implemented immediately and given priority by both local and national government.

EC Council Directive 86/278/EEC, on the use of sewage sludge in agriculture, requires that "account is taken of the nutrient needs of the plants and that the quality of the soil and of the surface and groundwater is not impaired" (EEC 1986). The same precautions should be extended to the application of animal slurry.

Therefore soil testing should form a central part of the management strategy to ensure that slurry is directed to land deficient in phosphorus and/or nitrogen in response to crop needs, thereby avoiding wasteful and damaging overloading of nutrient-rich grounds. The direct cost of carrying out a single nitrate and phosphate analysis of soil is less than 50 pence, given current costs of commercial testing kits and accessories. Whether this cost was borne by individual producers or receivers of slurry, or by local authorities, a detailed field-by-field map of soil nutrient status should be drawn up for the spreading grounds and used to direct slurry applications.

Under the definition given in EC Directive 91/271/EEC, L. Sheelin should be designated as a "sensitive area", ie. a natural freshwater lake "found to be eutrophic or which in the near future may become eutrophic if protective action is not taken" (EEC 1991a). Although this directive relates specifically to urban wastewater, its implementation could be extended to equivalent discharges from agricultural point and diffuse sources, particularly in areas such as the Sheelin catchment where waste production by the many intensive units equates to that produced by several small towns. Ireland could follow the lead of Germany in designating the whole of the country as a sensitive area.

In order to comply with the obligation referred to in article 3(b) of Directive 80/68/EEC on groundwater protection, "Member states shall make subject to prior investigation all direct discharges of substances in List II...[including phosphorus compounds and elemental phosphorus]...which may lead to indirect discharge" (EEC 1980), with a view to minimising all such discharges. Foster and Thorn (1993) identify the predominance of point sources of nitrate discharge and the high mobility of groundwater in Ireland as two reasons for the difficulty in specifying nitrate sensitive zones and, therefore, implementing Directive 91/676/EEC on the pollution of waters caused by nitrates from agricultural sources (EEC 1991b). It is therefore imperative that a groundwater vulnerability map be drawn up, so that the Slurry Management Programme can effectively eliminate the threat of groundwater pollution.

5.4 Slurry digestion and tertiary treatment

Even an effective distribution and spreading programme could not overcome the problem of the massive overproduction of slurry in this area. Measures to reduce the polluting potential and bulk of the slurry are also essential. The larger intensive units are significant point sources of nutrients and organic matter. It is relatively simple, and economically more sensible, to control the release of nutrients from a point source than from diffuse sources (eg. following slurry spreading) or to install remedial measures to limit damage to the environment resulting from poorly controlled slurry disposal. Treatment of algal blooms by surface water and scum removal, microstraining or water column mixing by aeration are expensive and need to be repeated regularly as they do not address the route cause of the problem, nutrient enrichment. Likewise the use of herbicides and algicides (eg. copper sulphate), are also undesireable as incorrect dosing and deoxygenation of decaying dense blooms following killing can worsen problems (Mason 1991, Harper 1992). Biological control mechanisms always affect the dynamics of an ecosystem and in this case, could further risk the Lough Sheelin fishery.

Technology exists to treat animal slurry on site to reduce both organic and nutrient contents. Perhaps the most effective and economically feasible method is anaerobic digestion (Polprasert 1989, Mason 1992) in which waste is digested over 10-20 days in tanks heated using methane generated during the process. Excess methane can be used for heating of the animal houses or for power generation so that, after the initial capital cost of installation, such a digester would be self sustaining and would allow significant savings to be made by the producer in energy costs. Digestion greatly reduces the organic content and, therefore, the bulk of raw slurry. Malodours are also greatly reduced.

The digester has the added advantage that solid and liquid waste can be separated at the end of the process. The solid waste is greatly reduced in volume, is readily transported and can be used as high quality, slow release compost (Mason 1992). Liquid waste is also easily handled and is amenable to tertiary treatment processes eg. phosphate stripping with iron sulphate (in the range 3-6 mg Fe l^{-1}, Hayes *et al.* 1984, Ellis 1989). This treatment could be included as part of individual units, but it would perhaps be more feasible to build the capacity to treat this liquid slurry effluent at a central facility. Such central facilities for pig slurry effluent treatment are currently in operation or under development in other major pig-producing areas, eg. the Netherlands and the Brittany coast of France (Brionne *et al.* 1994). In the case of the Sheelin catchment, where over 70% of the pig herd is owned by just 4 producers, anaerobic digestion should be seriously considered as a means of reducing the organic and nutrient content of slurry. The potential for wetland treatment (see above) of such agricultural wastes should also be explored.

5.5. The move towards environmentally sustainable agriculture

The installation of tertiary treatment at Ballyjamesduff Sewage Treatment Works, the banning of phosphate detergents and the implementation of a Slurry Management Programme would lead to significant improvements in water quality. Another major step must be the control of intensive agriculture within the catchment. The provision in the 1st Schedule, Section 6 of the Environmental Protection Agency Bill 1990 (EPA 1990) for integrated pollution control of intensive agriculture must be implemented with urgency by the Minister of Environment.

However, the longer term goal must not simply be the control of intensive agriculture but a move towards sustainable agricultural practices. By its very nature, ecological agriculture avoids many of the pollution problems such as damaging levels of nutrients caused by intensive agriculture. For instance Danish research has shown that nitrogen loss per hectare of land on organic cattle farms was 75% less than on conventional farms (Greenpeace International 1992).

The economic viability of ecological agriculture is often questioned but studies of total farm income on ecological farms in Europe indicate that agricultural incomes are similar to those from conventional systems (reviewed in Lampkin 1990). Sustainable livestock farming does not rely on the huge expenditure on imported feeds, feed supplements, veterinary care and disinfection which is necessary for intensive production but instead capitalises on the inherent qualities of natural biological processes.

In particular it is likely that increasing numbers of pig producers in Europe will move towards extensive methods in the next few years (Varley 1994), encouraged by studies showing that such practices can be as, or more, ecomomically viable than intensive units, while at the same time having enormous benefits for animal welfare (Vermeer et al. 1991). Returning to a lower intensity of animals per unit land area would bring manure production closer to the scale of natural nutrient assimilation capacity of the soil, reducing the problems associated with mass slurry accumulation and disposal.

5. Greenpeace Demands

Data from the Central Fisheries Board and the analyses carried out by Greenpeace, as described above, confirm that Lough Sheelin should be classifiied as eutrophic according to OECD limits.

Greenpeace demand that ACTION be taken immediately to restore Lough Sheelin.

Greenpeace demand

* A ban on phosphate detergents in the Lough Sheelin catchment

* Tertiary treatment at Ballyjamesduff Sewage Treatment Works

* Immediate introduction of a Slurry Management Programme in the Lough Sheelin catchment

* Implementation of Schedule 1, Section 6 of the EPA Bill 1990 for integrated pollution control of intensive agriculture

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